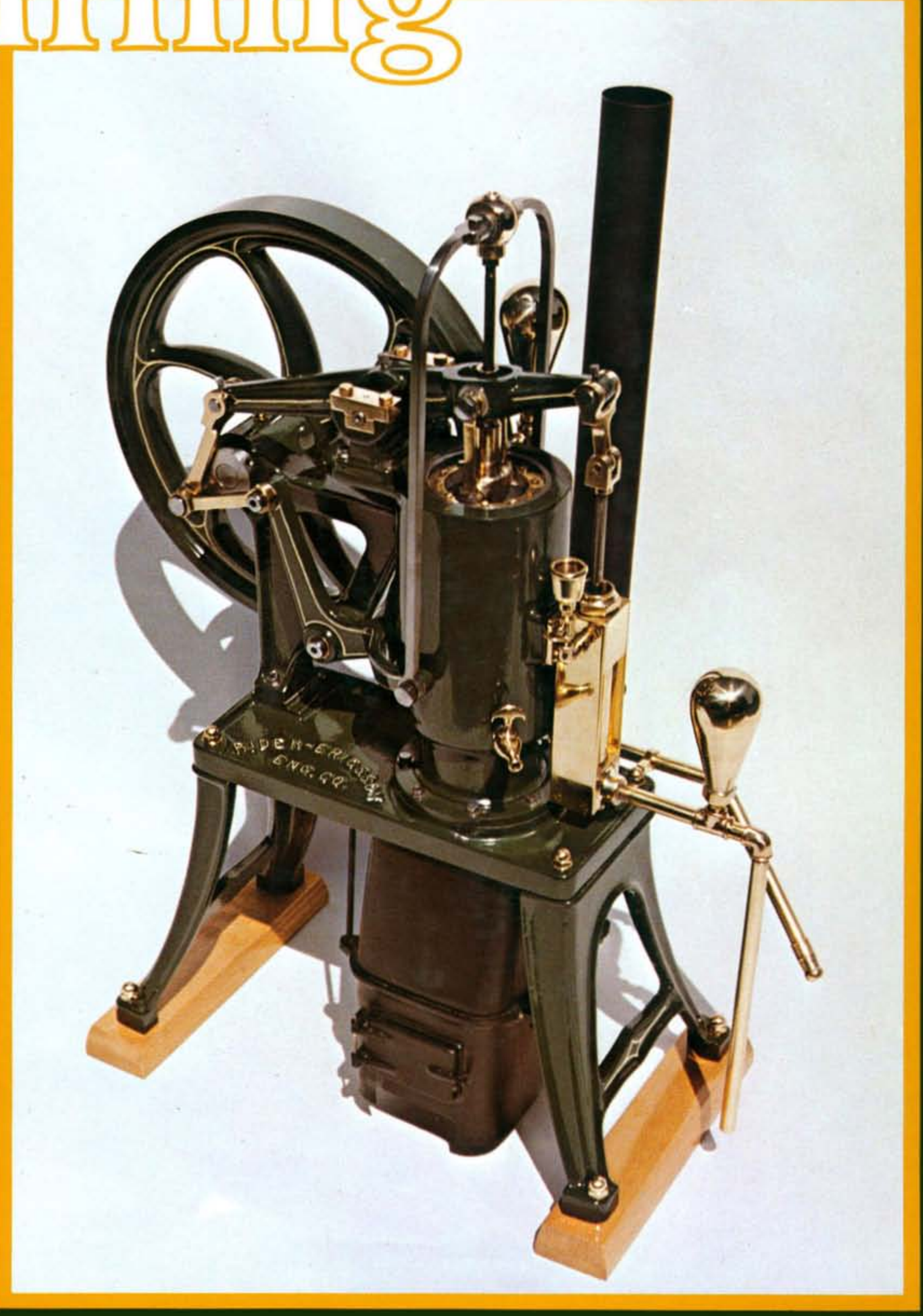
Steam and Stirling

Engines You Can Build



Edited by
William C. Fitt

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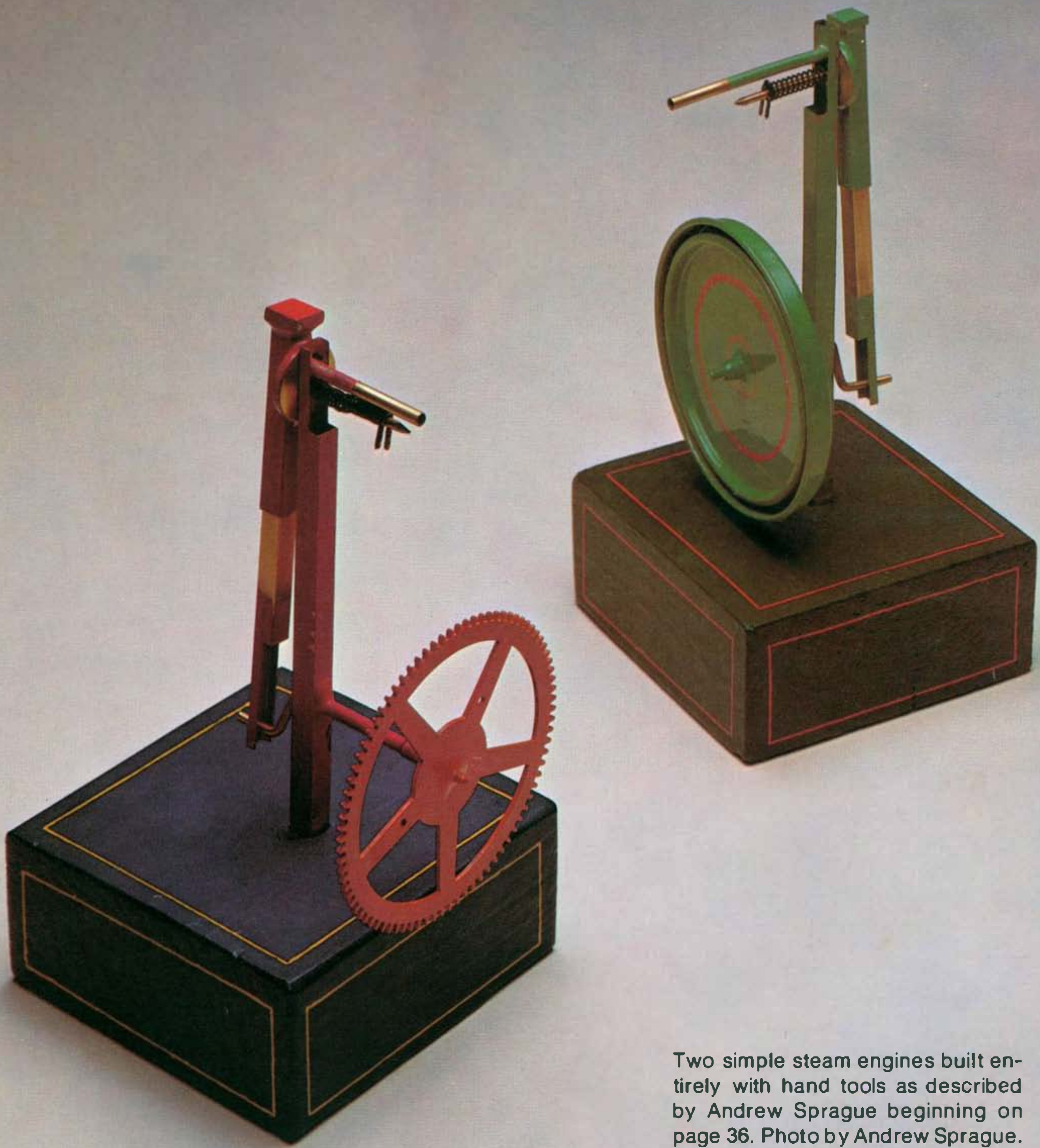
Relaxation is found in many forms. While some find it in the wide open spaces of the great outdoors, others are discovering it measured in thousandths and tens of thousandths of an inch in cozy home workshops.

To this latter group, **Steam and Stirling - Engines You Can Build** provides direction for the experienced and instruction for the novice in the fast-growing ranks of Amateur Machinists.

The projects presented have been built by men from all walks of life and were designed by hobbyists from an equally broad span of devotees who enjoy model engineering as a fascinating and extremely satisfying past time.

If you presently do not have a home workshop, you can start off with Andrew Sprague's *Hand-Tool Steam Engines* which can be built with the inexpensive hand tools found in almost any home or apartment. Many Live Steam projects have been built using a small electric hand drill as a lathe. Even if space precludes a separate room for a workshop, small-capacity metal-working machinery is available that can be set upon a kitchen table and stored away in a closet or cabinet when not in use. If you want to include some of the larger projects, consider enrolling in a night-school class where adequate facilities are available.

The two main requirements necessary to get you into the Live Steam Hobby are (1) decide and (2) begin!



Two simple steam engines built entirely with hand tools as described by Andrew Sprague beginning on page 36. Photo by Andrew Sprague.

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JACKET

This quarter-size model of a
Rider-Ericsson Hot-Air Pumping Engine
was built by Larry Kazyak after scaling
down an 8" engine which is at the
Ford Museum in Dearborn, Michigan.
Photo by Larry Kazyak.

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Dedicated to
Good Wife Doris

Foreword

At no time in history has participation in metal-working as a hobby grown as fast in America as it has in the past fifteen years. It is a safe assumption that as many metal-turning lathes have been purchased in the past five years for home workshops as were in such use prior to that time. Because of that growth, the need for "how-to" information has increased and Steam and Stirling—Engines You Can Build provides some of those details.

During this fifteen-year period, **LIVE STEAM** Magazine has been providing Amateur Machinists with projects of varying degrees of complexity but, as The Hobby grew and The Magazine's circulation increased, most of the earlier copies were no longer available. To close this information gap, several of those out-of-print projects are included in this volume so that the many newcomers to the Live Steam Hobby can have available the instruction and design information that they need.

Knowing that only time will produce a home workshop scrap bin filled with the little odds and ends of materials needed to build these engines, arrangements have been made to have all the materials required for the projects in this book to be supplied in kit form. In this way, all those newly-purchased lathes (and many of the existing ones that are being dusted off and put back into use) can be put to work by their owners to make more than a few elementary metal turnings and some experimental threaded rods!

So here is the beginning ... the thrill of building something that actually works is yours by just following the directions. If you are a complete novice in this field, pick one of the simpler projects for your first attempt and gradually work your way through the others as your skill and abilities (and confidence) increase.

The Hobby is enjoyed by persons in all walks of life and we are sure that you will find many pleasurable hours in your workshop with the projects in this book.

William C. Fitt
Editor

Traverse City, Michigan
March 6th, 1980

Contents

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It looks like an expensive antique but it's easy to build this

Stationary Steam Plant

by W. Marshall Black

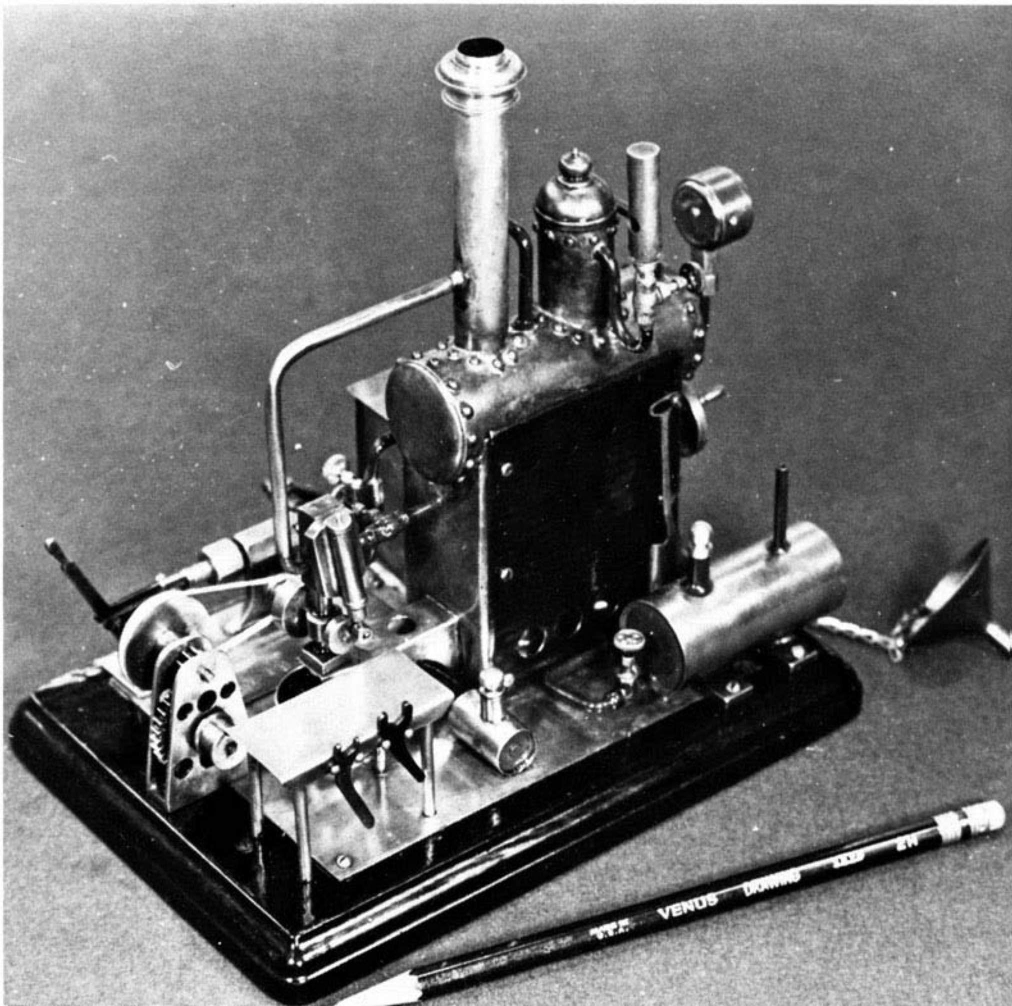
Photos and Drawings by the Author

Here's a project for all you "tinkers" like me who like to get out in the shop now and again and "make-up" as you go. The original plant will raise 40 pounds of steam in two or three minutes, and steam a 9/64" x 5/16" double acting engine at a steady 2,500 rpm on 20 psi with remarkable power. The work is within range of a beginner and his Unimat.

Instead of exact drawings, we'll provide only some sketches and photos with blow by blow instructions. The original was made from some freehand "idea" sketches. Most of the materials will be in your scrap box or at the local hardware store, but you may want to get off an order for some 1/8" OD pipe fittings, an ounce of 1/16" x ¼" copper rivets, a Stuart pressure gauge, and perhaps a small pop valve. Your local hobby store will have some sheet brass and small brass tubing in concentric sizes.

Let's begin with the boiler. Get a piece of 1¼" OD, thin wall, brass tube from the hardware store — the kind used for plumbing under sinks. File off the chrome plate. Check the end for square, and hacksaw off a piece about 3½" long for the boiler shell. Deburr the ID and set aside. Now for the boiler drum-ends. Chuck up a brass bar slightly larger in OD than the shell ID or, better, scribe a circle on a scrap of ¼" brass plate, hacksaw out, and soft solder to a chucking mandrel. Either way, turn two disks to be a tight push fit into the ends of the shell. Dig out a cavity about 3/16" smaller than the OD of the disk. This should be about 1/8" deep. Cut off the disks or melt loose from the mandrel. Push one into the shell with the cavity facing inside. If you've made the disk a snug push fit, it will be square with store-bought end of the tube. Leave a scant 1/8" sticking out. Get out the propane torch, flux the joint, and soft solder *one* drum end to the tube. Flow in a little excess solder. Use silver solder if you have the stuff, but this isn't worth the extra bother.

Scribe a centerline down the shell. Locate the center of the steam dome and clear (body) drill through the top of the drum for a 2—56 or up to a 4—40 bolt. This steel bolt is a stay that will screw into the top of the steam dome, so we had best make the dome next. I used a scrap of ¾" copper flue tube from the barrel of the dome. Lightly chuck and cut to approximate length. Then concave file one end to fit the boiler barrel saddlewise. Finish fit by wrapping a piece of emery cloth around the boiler shell stock and drawing the dome saddle across it till you've got a good square fit. Now turn up a dome top. It's easiest to have the inside end facing the tail stock. A nubbin of 1" OD brass is about right for a ¾" OD dome barrel. The inside should be drilled out to ½" diameter by about 3/8" deep to make it thimble-like. Now relieve the OD back about 1/8" lengthwise to be a very light push fit in the dome barrel. Then drill and tap about 3/16" beyond



Spirit tank appears at extreme right. Forward of this is the lube oil storage and workbench. Engine bolts to mounting bracket at front of boiler. Speed reduction is 11 to 1 at the cathead Funnel is handy for filling fuel and feed water tanks the depth of the ½" hole to receive the stay bolt. Reverse the piece in the chuck, and contour the outside to be old-timey looking or to suit your fancy.

Now take some long-nosed pliers and insert the longest bolt you can get in from the inside of the boiler shell up through the dome stay bolt hole. Run a nut down from the outside. Place the dome barrel over the stay bolt and hold your dome top in a side-view position so you can see where to cut off the stay bolt (and possibly dress off the square end of the dome barrel) so that the stay can screw into the dome top. Shortly we will fasten the dome to the barrel by simply screwing down the dome top.

But first put the boiler shell in the vise, hold the dome barrel concentric with the stay bolt, and with a long, slim scribe, mark the ID of the dome barrel on the boiler shell. Now center punch a mark for the steam outlet between the stay and the scribed location of the inner edge of the dome barrel and on the centerline of the boiler barrel. Also pop two marks just inside the scribed dome circle at the low points of the saddle — one on each flank of the stay bolt. Square up the boiler barrel in a drill vise or vee block (if you are that rich) and drill the steam port, 1/8" right through top and bottom of the boiler barrel. Then open out the *top* hole with a #29 drill. Next drill the other two center pops on the top about #51. (These two ports may not be needed — I envisioned them as drain holes for water that might get into the dome — priming is the undoing of very small boilers.)

Remove the dome stay and chuck up the boiler shell to run true. Put the soldered end into the chuck so you won't crush the tube. Polish the barrel in the stay bolt area with emery, install the stay bolt with nut, then bump in the other drum end. Flux and soft solder without removing from the chuck. Then, using very light cuts and with a file, contour the drum end and square up the shell ends. (Watch out for the spinning stay bolt.) You should have about 1/8" of drum end outside the shell, and the bottom of the inner recess in the drum end should be even with the end of the shell as seen in side view. Reverse the shell and complete the other end the same way. Polish each end of the shell up to the stay bolt area, but don't lose your centerline scribe.

Remove the shell from the chuck. Lightly rescribe the centerline on top the shell. Assemble the steam dome and soft solder in place. Now for the rivets — they do a lot for appearance and serve to pin the drum ends safely in place. Take a pair of small dividers and, using the end of the boiler shell as a guide, scribe a line right around about 1/16" back. This line should be in the center of the depth of the inner recess in the drum ends when viewed from the side. Subdivide this line for as many rivets as you want — about 3/16" to ¼" centers look good, but get the spacing even. Center pop and drill all these through with a 1/16" bit. Do the same around the dome top. Insert the rivets, flux and reheat the shell. The excess solder around the drum ends and dome top will usually grasp the rivets, but you may touch up some using small-diameter solder.

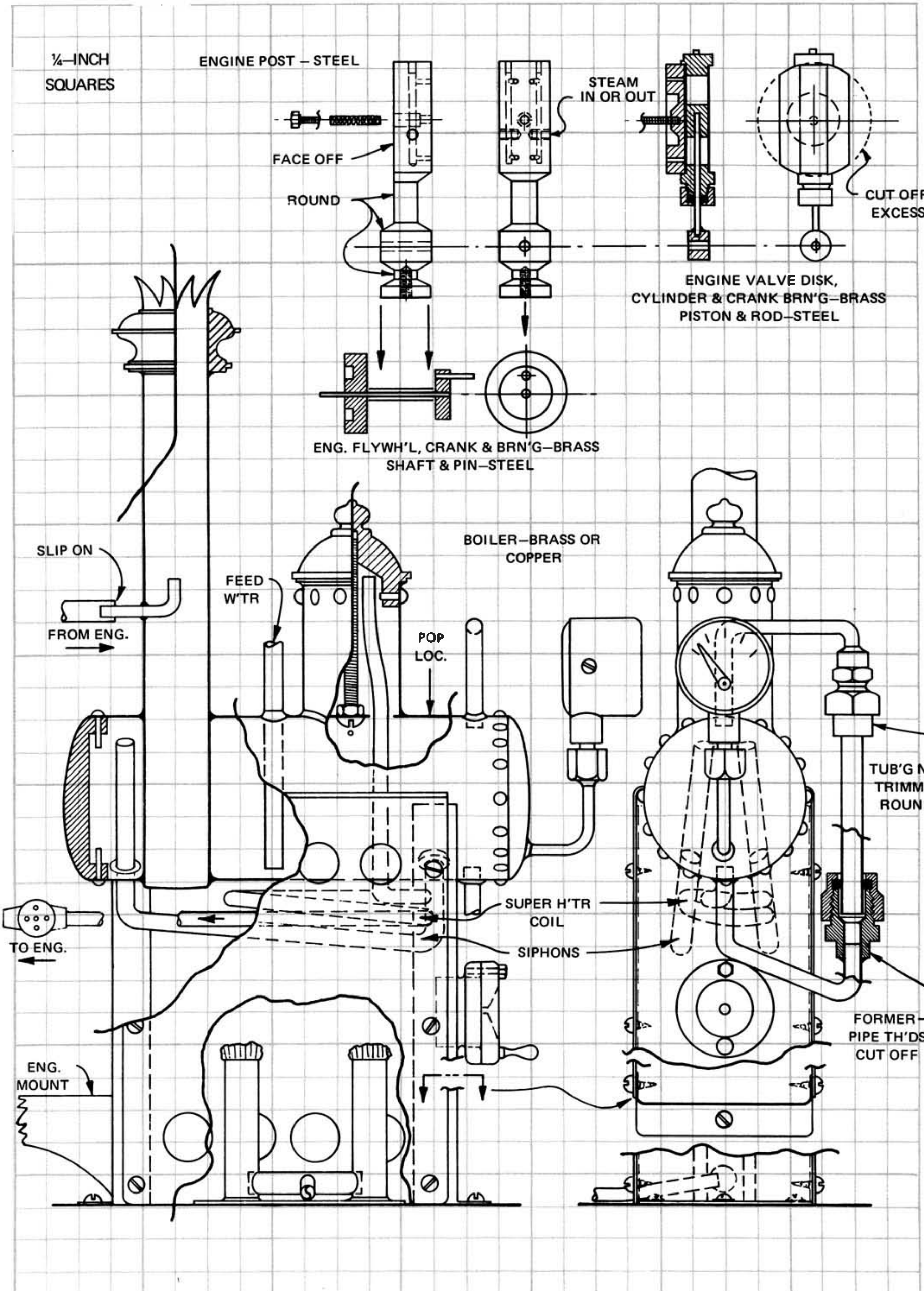
Get in the stack next. A length of the thin-wall hobby tubing will serve for the stack. Center pop its location on the drum centerline. We want a good, true ½" hole right through top and bottom of the shell for this. Drilling a true hole from the convex side of the shell is all but impossible, so scribe a ½" circle around the top center pop. True up the shell in the drill vise and go right through top and bottom with about a 1/8" bit. Open out the top with a 3/8" bit, then rat-tail file out to final OD, using frequent fitups. Once the stack tube pushes in nicely, you can remount in the drill vise and open out the bottom hole, from the top down, with one pass of a ½" bit. Insert the stack, leaving about 1/16" protruding from the bottom and soft solder in place. Now turn up a chimney top and drill through ½" so as to slip over the stack tube. For a real fancy job, soft solder the chimney top on leaving about ¼" of stack tube protruding. Then swiss-file vee notches into this portion and flare out to make a crown-like appearance.

You are now ready for the siphons and superheater. These features distinguish the little boiler from its toy counterparts. Use ordinary 1/8" copper tube for the superheater. Straighten a length, anneal if necessary, and insert through the hole previously drilled through the shell under the steam dome. Make sure it goes as high up into the dome as possible. Then begin an elongate coil abruptly where the tube exits the bottom of the shell. Begin the coil toward the rear; make 1¾ loops ending straight out toward the front, just under the stack. The coil width should be about ½" to 5/8" to allow some flame to reach the shell. Use 3/16" OD copper tube for the two siphons. The important thing is that these should extend just inside the shell at the back end, and well up into the shell on the front (stack) end, and should slope upward about ¼" from back to front. Note also on the sketch that the rear ends are located further from the end of the boiler than on the front end. Soft solder the siphons and the superheater line into the boiler shell. Now clean up the whole job, removing excess solder with a knife and emery strips, then burnish all over with a wire wheel, or go bum a sandblast job. Notice that at no time did we do any soldering on the boiler without there being an air outlet. Had we done so, the heated air (or pickle drops) inside would expand and cause blowouts of melted solder.

Now you are ready for the fire end of the thing. One cannot overestimate the importance of adequate fire space and ventilation. A good rule to follow is to provide at least one inch of clear space between the top of a spirit burner and the lowest point of the water works. First make up an alcohol fuel tank whose height should be slightly less than the height of the wick or burner tubes. A horizontal shell of 1" diameter brass tube about 2" long (25±cc) will fire the two burners for about 20 minutes. This little tank is made just like the boiler drum was made, but no rivets are necessary. A filler plug and vent are located on top, and a 1/8" copper line leads to the burner. Add a valve if you want to. The burner is a simple soft soldered assembly of brass tubes and a bit of sheet from the hobby store assortment. The burner tubes should be ¼" ID and slightly taller than the fuel tank — so that when the tank is full, alcohol cannot overflow the burner tubes. Wicks are ¼" cotton clothesline or, better, asbestos about 1/8" longer than the tubes — i.e., no more than 1/8" should protrude. You can control the steaming rate by adjusting the amount of wick protrusion, or lighting one or two burners. The fuel line valve is not good for firing control, but will reduce evaporation during shutdown.

The firebox ends are cut out of brass sheet — the important thing is that these should hold the boiler shell high enough to clear the burner tube tops by about 1¼ inches. These sheets require a simple flanging job; the flanges are made along scribed lines in a vise after the rounded recess is rotary filed out to fit the boiler shell. A neat fire door can be made from sheet or turnings with a pin or bolt at the top so as to rotate upward to open. It should be located so that the bottom of the hole is about even with the top of the burner tubes. This way you can use a pick to adjust the wick height and, of course, light off and blow out (not up). A hole must be made to let the superheater or steam line out the front sheet. Assemble these flanged sheets to the boiler as follows: Take a small piece of wood about 1¼" wide and 4" long. Stand the sheets up on this, and lower the boiler into place. Any small chain hoist will do. Wrap a piece of wire around the boiler and the wood block to hold everything in place. Square up the sheets, taking care to leave about 5/16" of boiler drum extending outside the rear sheet. When all is in good alignment, soft solder the sheets to the drum but turn the whole works upside down first to avoid "overhead" soldering. The firebox sides can be made from brass or blued stovepipe metal. They are held to the flanged pieces by tiny sheet metal screws. Drill the ventilation holes before clamping and drilling the screw holes. The upper row of ventilation holes may not be needed — but I've seen too many antique toy plants that have them to ignore their probable wor-

Free-hand sketches on grid paper serve to "gel" the design for construction. Frequently, on subminiature work, ¼" on the grid is used to represent 1/64" on the model. This drawing is a tracing of the original construction sketch which was made full size. Critical dimensions such as valve porting are determined by timely scribing on the parts as work progresses. This boiler was No. 3 in a series of experimental models and incorporates several desirable features learned the hard way.


¼-INCH
SQUARES
ENGINE POST – STEEL
FACE OFF
ROUND
STEAM
IN OR OUT
CUT OFF
EXCESS
ENGINE VALVE DISK,
CYLINDER & CRANK BRN'G–BRASS
PISTON & ROD–STEEL
ENG. FLYWH'L, CRANK & BRN'G–BRASS
SHAFT & PIN–STEEL
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thy function. The stack produces no natural draft but does add effective heating surface. Make a notch at the base of one of the side plates to admit the fuel line. It would have been more efficient to enclose the boiler in a casing, with the stack fastened to the casing and not through the boiler. I just don't care for the resulting "black box" appearance.

A gauge glass can be made in jig time from two brass fittings for copper tubing, 1/8" pipe to 1/8" tube, compression type. Turn off the pipe threads, shorten up a bit, and run through with a #38 drill, then tap 5—40 for the steam connection. Reverse the piece, shorten up the tubing fitting threaded section a bit and bore ¼" deep to be about 1/32" larger diameter than your gauge glass. (I used 5/32" OD glass tube. This is too small; 3/16" would be better.) Remove the piece and chuck the tubing nut. Run through with a drill bit about 1/32" over the glass size as before. Shorten up the skirt a bit. Do the same to the second fitting except drill through 1/8" to accept a water leg pipe of thin wall, 1/8" brass tube. Cut your gauge glass to be about 1½" long; fuse the ends with your torch. Slip on the nuts, then slip on two gaskets cut from a soft rubber tube. Then screw on the fittings. Drill a 1/8" hole at the extreme back of the boiler shell — drill right through top and bottom, but locate this hole so as to miss the drum ends and still be outside the rear firebox sheet.

Now you have a piping job — use 1/8" copper tube for the top or steam leg; thread 5—40 and screw on to the gauge glass fitting. The water leg pipe should be made from 1/8" OD brass tube (the hole in 1/8" copper tube is too small for a good water leg). Anneal the tube and fill with solder before bending, then melt and flip out the solder. When the two legs and the glass look about right, trim off the legs and solder into the boiler shell. Remove the glass and solder the pipe connections to the gauge glass fittings. A little extra bending will now let the glass be slipped back in and bonneted down. Install a small 0—80 psi Stuart gauge on the back drum so as to connect into water space.

I did not initially install a pop valve on the experimental original (Number 3 of a series). I have an aversion to very small pops that usually just weep continuously. I found that a few successive strokes of the feed pump would control pressure, or a good puff will put out the fire if pressure gets too high (40 psi is a good working pressure) while not working steam. Later, after the photos and drawings were made, one of Cole's smallest safety valves was mounted on the dome with an "L" shaped piece of tubing. This is on the side opposite the whistle. I would not recommend its location as indicated on the drawing.

Cole's also has a 3/16" plunger feed pump, although I made mine up using two store-bought 1/8" check valves that happened to be on hand. Or you can buy the balls and do it the hard way. Any sort of tank will do for the feed water supply, but the capacity should be somewhat greater than the boiler capacity which is about 40 cc at working level. This will about match the fuel capacity for a 20 to 25 minute run. A feed water heater coil can be run around the firebox, out of the direct flame. If so, put in a union in such a way that the boiler—engine assembly alone can be dismounted. Put a valve in the feed line — otherwise the boiler will over-fill itself as it cools down.

Next we'll tackle the engine.

The engine on the original plant is a double-acting oscillator, 9/64" bore by 5/16" stroke. It has a surprisingly strong torque and never gets water logged on the superheated steam provided. It seems well matched to the boiler. It's no more than an 8 hour project including lost time looking for that tool you just put down.

Start with the flywheel-crank assembly. Find a piece of steel rod about 1/16" diameter that is a good running fit in a piece of brass hobby tubing. Turn up and center drill the crank and flywheel to be a press fit on this shaft. Drill the crank to accept the crank pin for a 5/16" stroke. Press in the pin and shaft (use the drill press or lathe tail stock) but don't press on the flywheel yet. Incidentally, the flywheel is only 5/8" OD by 3/16" thick. I had apprehension that this would be too light — but it's just right for this lively double actor.

The cylinder is also made from hobby tube. The piston is turned up from steel and lapped to the cylinder tube before either are cut to length. Square off the lapped piston stock and very carefully center drill for a press fit to the piston rod, then cut off the piston so as to be about 5/16" long. The cylinder head is a simple plug, the crank end head has a 5—40 thread packing gland. Both have about 1/16" of press fit intrusion into the cylinder tube, but note we have not yet cut the cylinder tube to final length. The original turned out right at 7/8" determined at the job site as follows:

Cylinder Tube Length = Piston Length + Stroke + 2 Head Intrusions + 2 Clearances
= 5/16 + 5/16 + 2/16 + 2/16
= 14/16 = 7/8 inch

The valve disk is got out next from 1" brass bar stock. Chuck up and square off the end with a finish cut. Before tap drilling the cylinder pivot hole for a 1—72 thread and also before turning out the recess, do this: with the lathe tool, make a tiny dimple in the exact center; set a pair of sharp dividers to a radius upon which the cylinder ports will be drilled and scribe this circle on the face. Save this same divider setting to scribe the post when we will be ready to work on it. The radius should be about 11/32", determined as follows:

Port Radius = (Cyl. Tube Length/2) — 1 Head Intrusion — (1 Clearance/2)
= (14/16)/2 — 1/16 — (1/16)/2
= 7/16 — 1/16 — 1/32
= 11/32 inch

Now turn out the recess in the valve disk but don't come within 1/8" or a shade less of the port radius. Now turn the valve disk to proper OD, by again keeping at least ¼" (1/8" on radius) out from the ports. This will assure an adequate surface for good steam seal. Center drill and tap 1—72. Cut off to a thickness equal to the crank disk thickness.

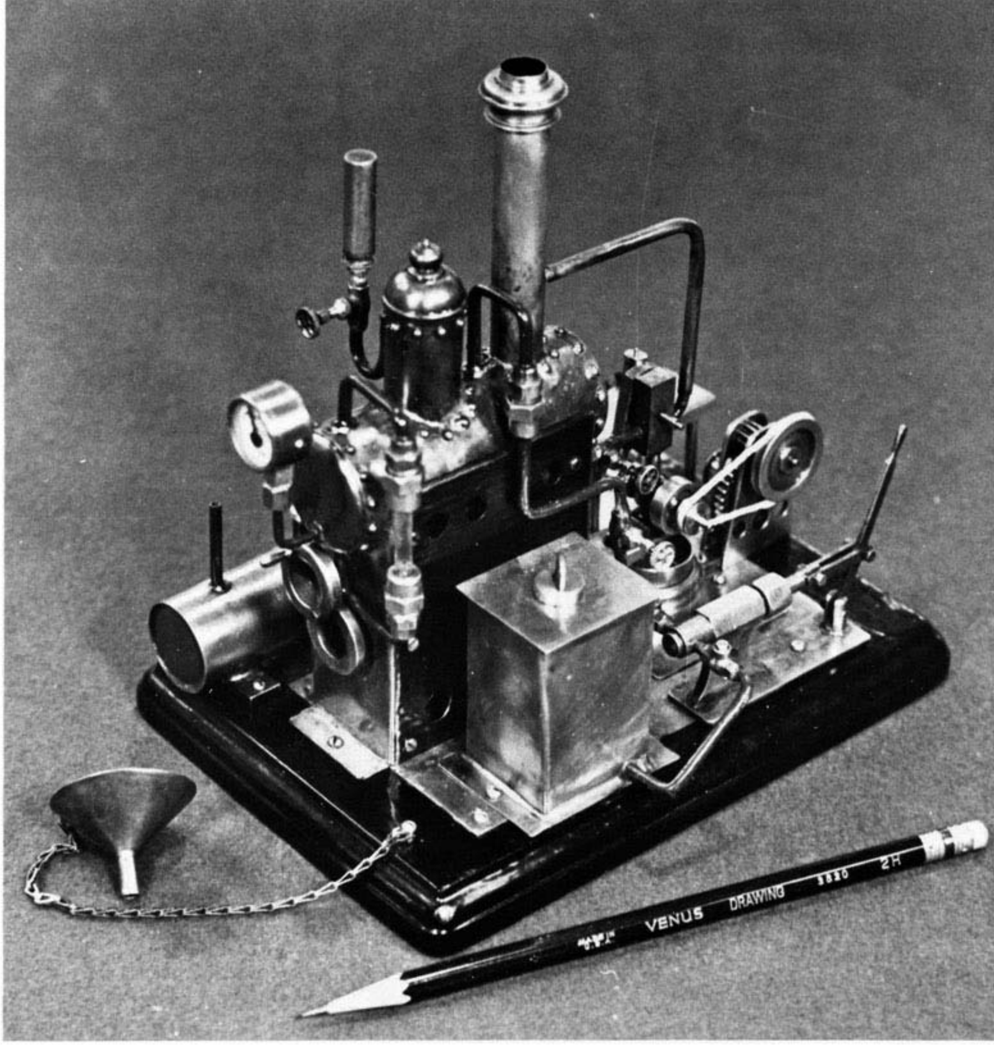
Now comes a tricky part. You must soft solder the cylinder to the valve disk, making absolutely certain that the centerline of the cylinder and an imaginary diameter line on the port disk coincide when viewed face on as seen at upper-left on the sketch. I did this with luck and a 6" scale, but if you've got a depth mike, use it to measure in equal distances from the right and left sides of the valve disk to the cylinder tube. The cylinder is held to the disk during this fit-up by a light steel spring clamp. Solder in the heads at the same time. I also soldered the piston to the rod beforehand (leaving the rod about two inches long at this time), removed all excess solder, and coated the piston with oil before assembly — no use to have the piston soldered to the cylinder. Needless to say, the center of the piston clearances on each end should coincide with the port radius scribed earlier. The amount of clearance isn't critical for superheated steam, but about 1/16" on each end seems about right.

Finally we come to the engine post. Scrounge a piece of 3/8" square steel stock and scribe a centerline on the side that will face the cylinder. Center pop on this line for the crankshaft hole. Drill the crankshaft hole to be a running fit to *shaft*, not the bushing. Drop in the crankshaft and crank. Position with crank pin at top dead center. Now lay the cylinder assembly with its 1—72 retaining bolt in place across the post stock so that the end of the stuffing box touches the top of the crank pin. Then move the cylinder assembly upward (or away) from the pin about 5/32" to 3/16". The 1—72 bolt is now where the cylinder pivot hole will be drilled on the post centerline. Mark and center pop. This was right at one inch from the crankshaft on the original. The 5/32" back-off is to provide external clearance between the crank pin journal and the stuffing box. Also mark the post at the position of the top and bottom of the valve disk. These marks will allow you to fancy up the post with a bit of turning and facing in the lathe. Trim the post to length, making sure the flywheel will clear the ground. Now find those dividers that we left set at the port radius and scribe the post around the pivot hole center pop.

Next open out the crankshaft hole and press the crank bushing into the post and press on the flywheel, leaving a modicum of end play. Clear drill the cylinder pivot hole for a 1—72 bolt and open it out partway from the back side to a diameter very slightly larger than the spring. Tighten the pivot bolt, clip off the head, and substitute a nut to retain the spring. Assemble the cylinder to the post. Now by trial, determine the proper length of the piston rod — so that the piston will have equal clearance at top and bottom dead centers. Cut off the rod and solder on a tiny brass crank journal. If everything turns freely, you are ready to do the porting.

Remove the cylinder but leave the 1—72 pivot stud in its hole in the post. Place the post in a vise with the cylinder side face up and so that the crank can be turned. Lay a thin scale against the crank pin *and* the pivot bolt. Rotate the crank on one side of the crank throw until the

Feed water tank and plunger pump occupy right side of boiler. A feedsystem is essential in very small boilers for more than a few minutes running time. The large steam dome separator evolved to reduce priming, a major problem in subminiature systems. Good superheat and large well ventilated firebox are very important.



scale reaches its maximum angle and scribe a line on the post. Place the scale against the other side of the crank pin and pivot bolt on the same side of the crank throw and scribe another line. One set of the post port holes will lie midway between these two lines and on the radius scribed earlier. Repeat the process, but on the other side of the crank throw. Lightly center pop the four port locations. Next, two long holes must be drilled down the post from the top end. These holes must be in a compromise location, as nearly as possible directly behind the ports, but they must not hit the cylinder pivot hole. Locate and drill these #52, then angle in the port holes #57 to connect. Finally, on each side of the post, drill the steam inlet and on the other side the exhaust so as to intersect the two long holes. Tap 5—40 or to suit the new-fangled tapered pipe threads. Clean out all passages and plug the long holes at the top of the post.

Finally we must drill the cylinder ports. These must be on the centerline of the cylinder and on the port radius scribed earlier. Locating the centerline is a problem — I scribed it by laying a thin scale on each edge of the pivot hole and eyeballing to align along the corresponding edges of the fully extended piston rod and spliting the difference. Drill #57, at head and crank end. Assemble the engine, oil, and run-in by holding the flywheel against the running vee belt drive for your lathe. Test on air. If there is much blowby between the post and port disk, put in a little lapping compound and run-in again — then clean thoroughly. Proper spring tension for your working pressure can be set later when on steam.

The engine on the original was mounted on a bracket soldered to the front firebox sheet. A 1/8" globe valve serves as a throttle. The coupling is very close to avoid heat loss in the steam line. The exhaust is led into the stack. This is not so much to increase the draft as to evaporate an occasional spewing water drop that would be messy. A small removable pan under the engine will catch oil and water drip, but the plant runs remarkably free from this annoyance. All except the whistle which is definitely not house broken.

The various components of the original plant are test bedded on a 5" x 7" decoupage board. The boiler—engine assembly can be removed to get at the wicks by loosening three wood screws and breaking the feedwater line at a union. The engine, in turn, can be removed via loosening the bottom mounting bolt, slipping the 1/8" copper exhaust line out of the brass 1/8" ID connection to the stack, and then unscrewing the inlet connection to the engine post. Reverse engine direction can be obtained by switching the inlet and exhaust connections on the post (though the engine will then face the other way).

No claims of originality are made for this design. It just works so well I though I'd tell you about it. The two predecessors, despite repeated readings of Evan's book, were perfectly extinct little volcanoes. It is a pilot model for one to be half this size. It looks like an expensive antique, and curiously, the useless little workbench and shovel cause more comment than my one-inch scale Mallet locomotive. Even so, here are a few points I think are important in design of extremely small boilers:

1. Provide good vapor—water separation. This dictates a well baffled dome — vertical center flue jobs are out. See also pointer 4 below.
2. Provide good circulation via water tube siphons. Definitely have the siphon exhaust high up in the shell.
3. Provide as much ventilation and fire space as your application will permit. A famous locomotive designer once said that the limiting factor governing performance was, simply, "the ability to burn coal."
4. If you must use live or exhaust steam blowers in the stack, then the stack must not be over a burner. One drop of water can extinguish a wick or bunsen burner.
5. Always superheat.

Be a good water tender — if the boiler runs dry it won't blow up — it simply falls apart.

Build an

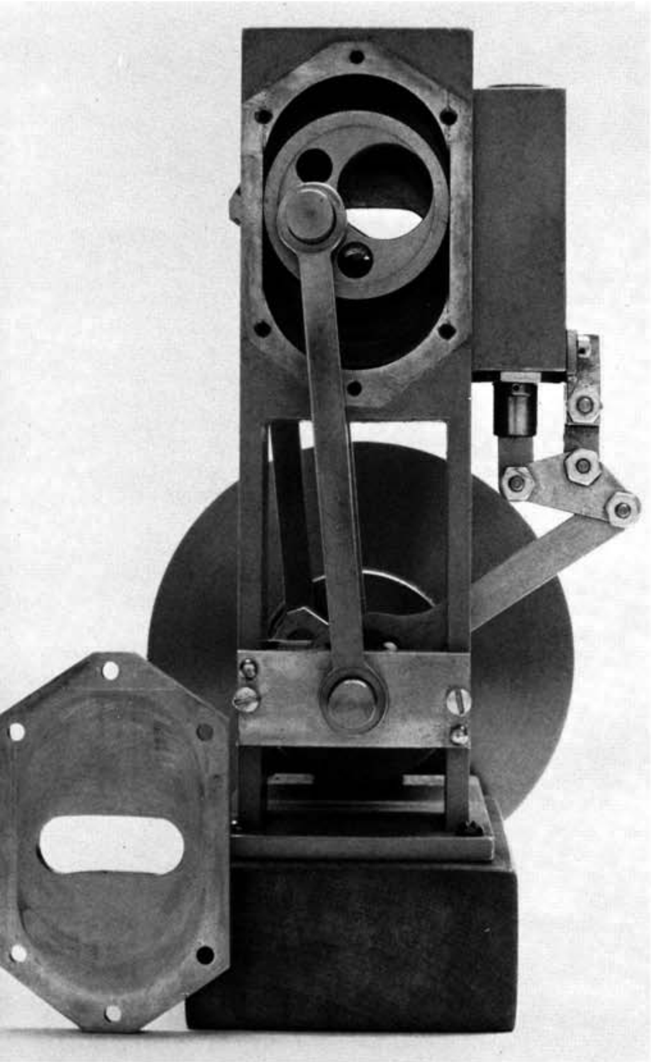
Unusual Steam Engine

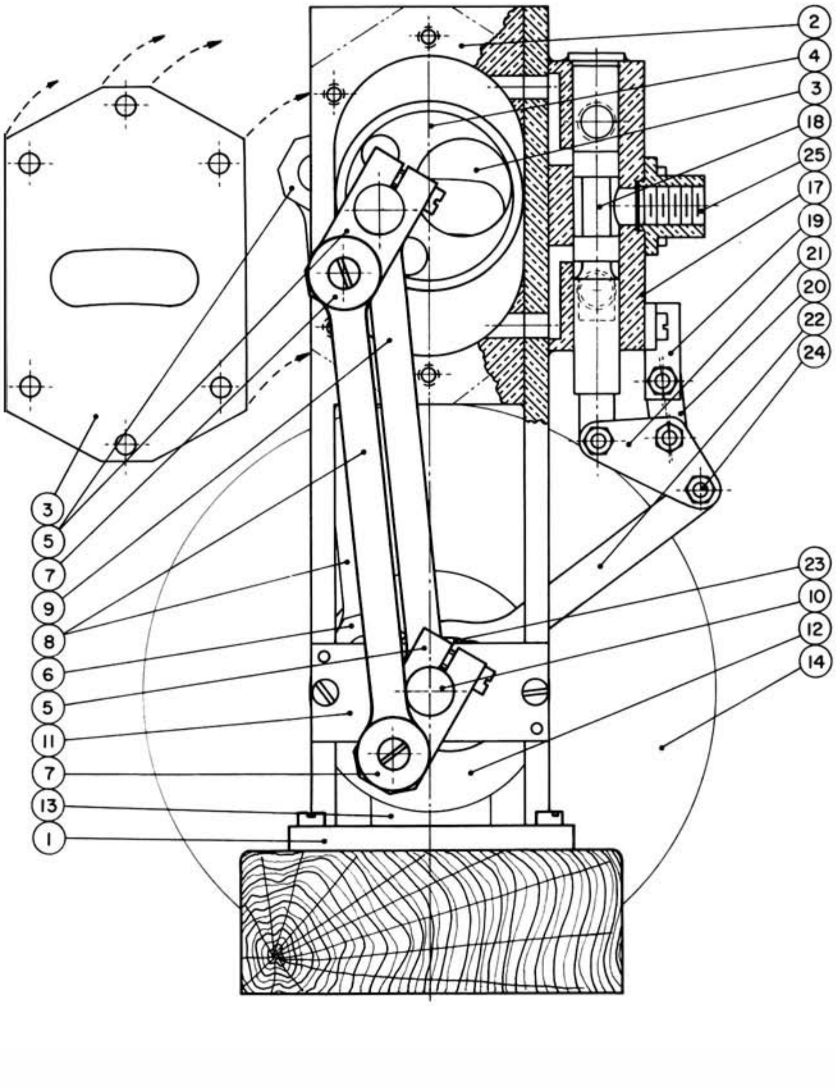
by Robert S. Hedin

Photos by the Author

This steam engine model is based on drawings shown in an old book, *The Steam Engine*, by Robert Scott Burn, published in London in 1854. Because the mechanism is unusual, I decided to build a model. The piston both rotates and oscillates in a rectangular cylinder. It is supported and guided by a pair of arms that pivot on the crank shaft. The piston is rotated by a pair of cranks and arms on either side of the cylinder, mounted on the piston shaft which extends through both cylinder side plates. These cranks are clamped to the piston shaft 90° apart and 45° to the eccentricity of the piston, as shown. This avoids dead centers and counter balances the piston eccentricity with the connecting rods.

The cranks are clamped to the piston shaft and crankshaft by split clamps. The hole in the crank must be a snug fit to make the clamp hold. I have had no problem with



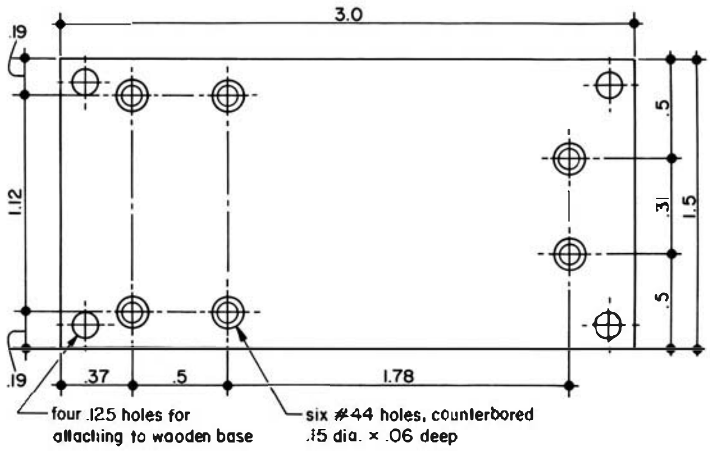


this. The cranks could be pinned in place after line up.

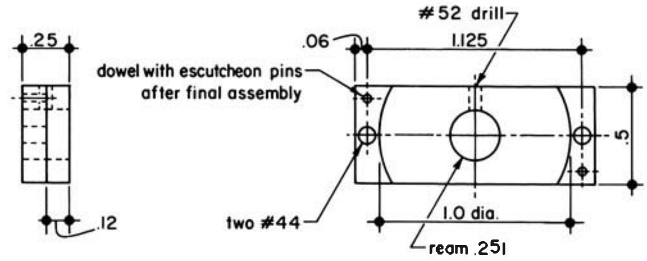
The piston is fitted with about .001" clearance on the diameter. Notethatan alloy steel is specified. It need not be stressproof but something harder than low carbon. I tried screw stock but it is too soft and scuffs in the cylinder. I also tried Teflon which is great if only air is used to run the engine. The coefficient of expansion is too high for steam and it swells up like a balloon.

The long crank pin extends into the coupling on the fly wheel shaft. The holeis a loose fit to take up misalignment. Dowel the crankshaft bearings in place with escutcheon pins — tight in the bearings and loose in the frame. Put spacers along both sides of the connecting rods at the crank pins and crankshaft.

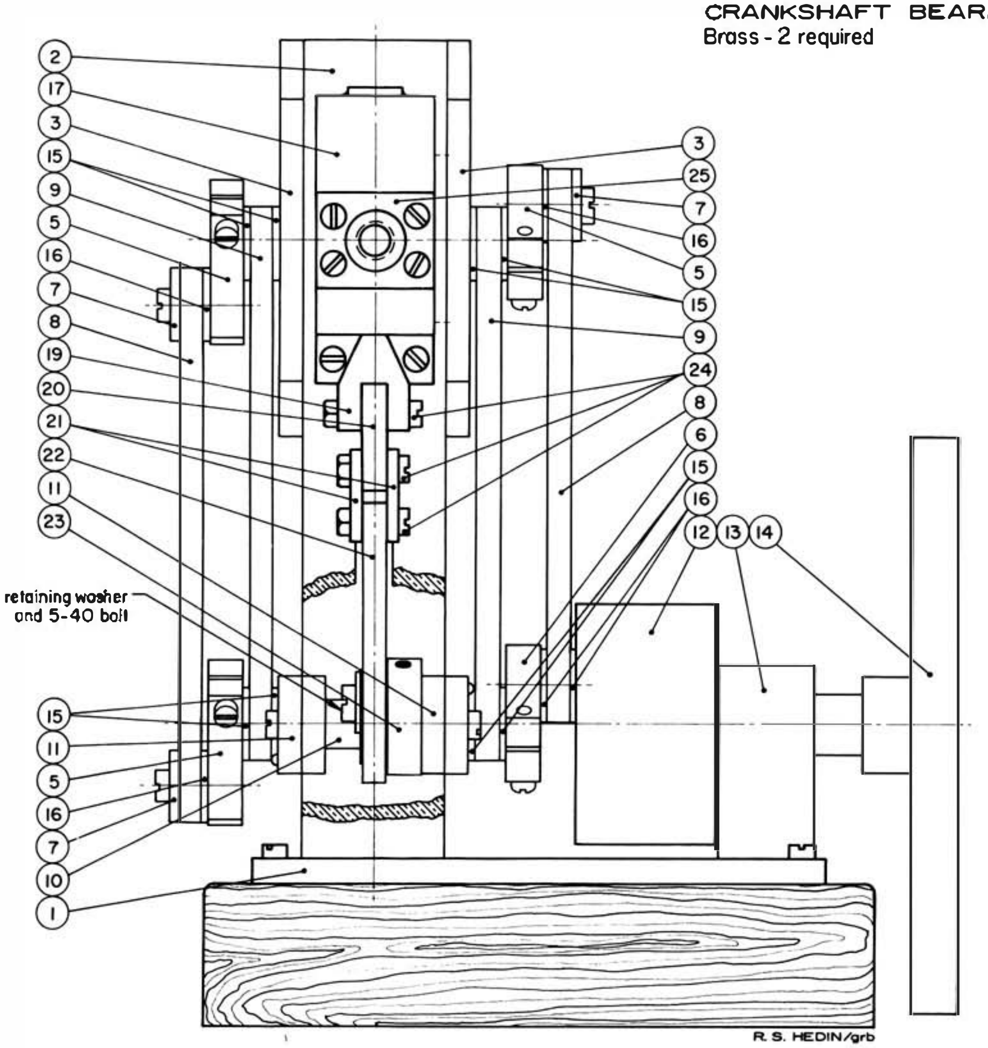
The model is designed soit can be made using a lathe, drill press and file. Although I used brass for the major portion of my model, steel can be used for many parts.

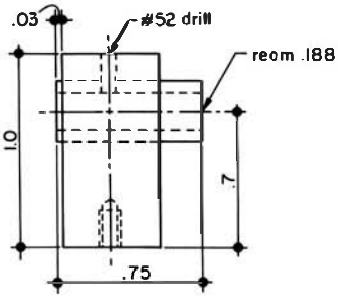


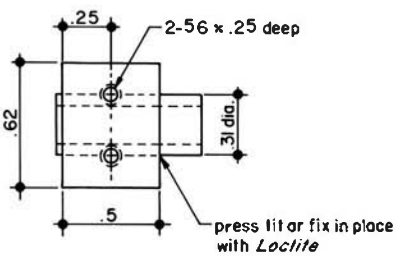
BASEPLATE (1)
.125 Brass - 1 required



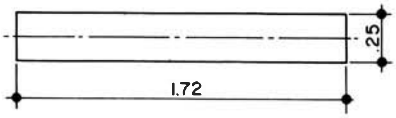
CRANKSHAFT BEARING (11)
Brass - 2 required



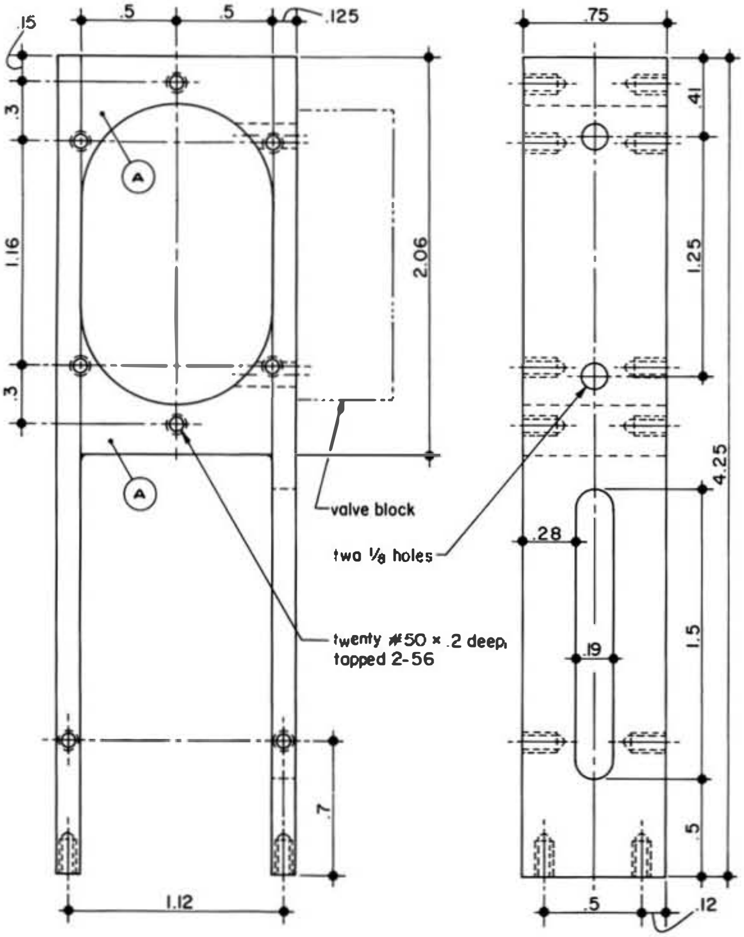




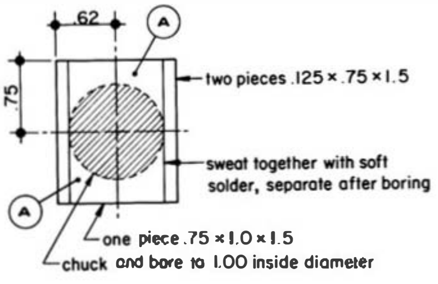
FLYWHEEL BEARING (13)
Brass - 1 required



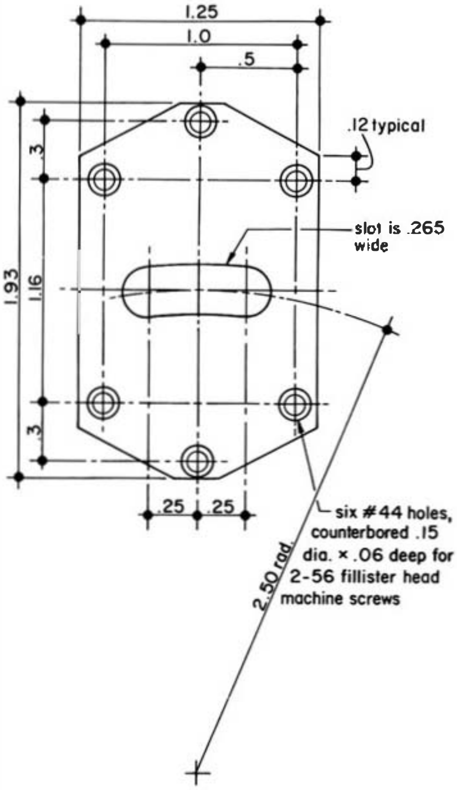
CRANKSHAFT (10)
Drill Rod - 1 required



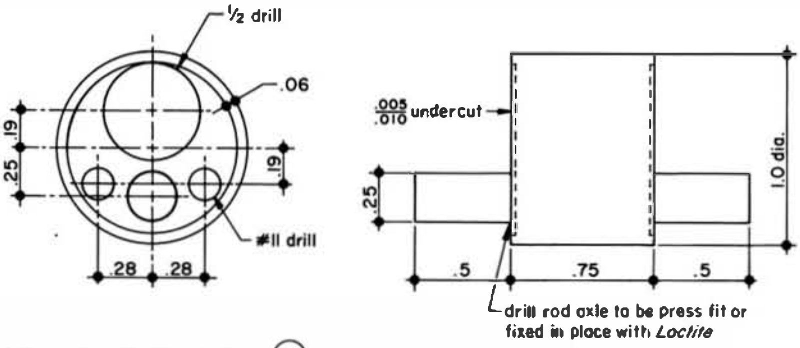
CYLINDER FRAME ASSEMBLY (2)
1 required



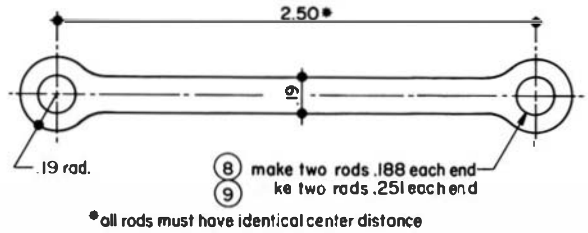
HOW TO MAKE PART A OF CYLINDER FRAME



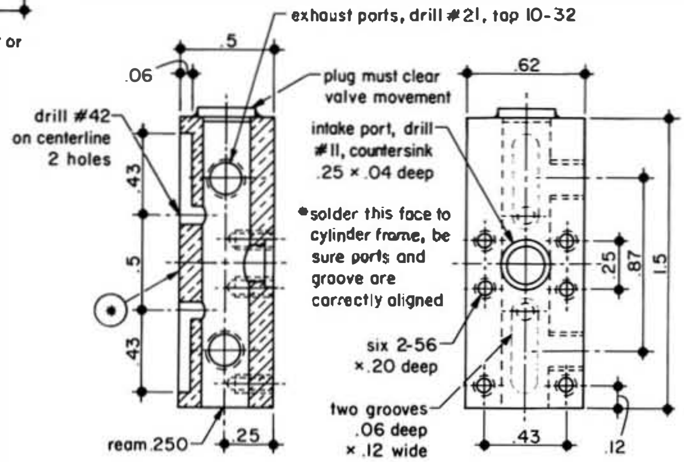
CYLINDER COVER (3)
.125 Brass - 2 required



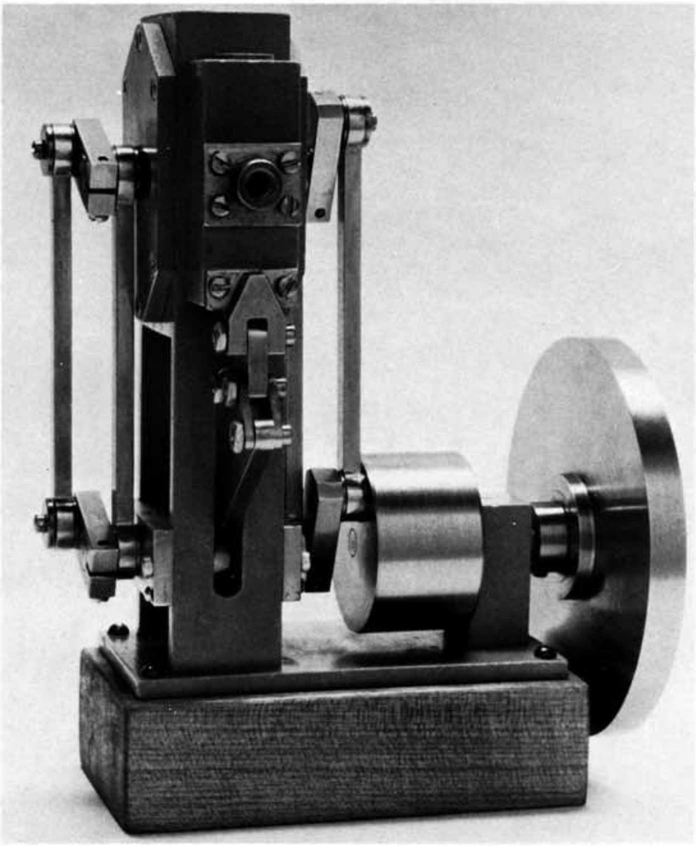
PISTON ASSEMBLY (4)
Stressproof Steel - 1 required

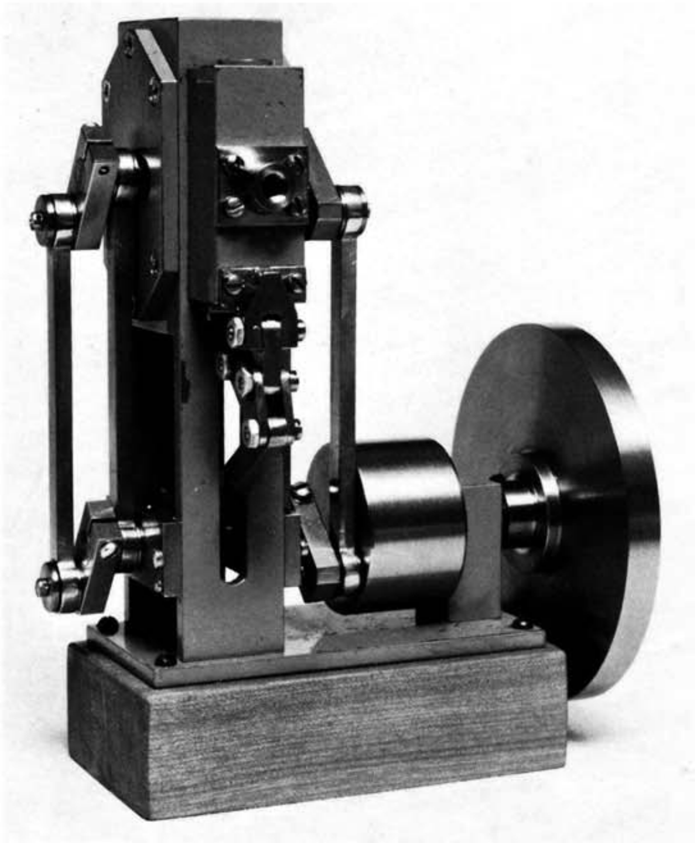


CONNECTING ROD (8)(9)
.125 Brass - 4 required

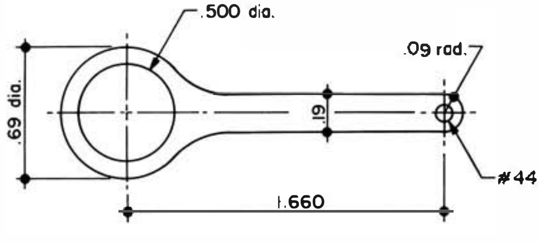


VALVE BLOCK (17)
Brass - 1 required

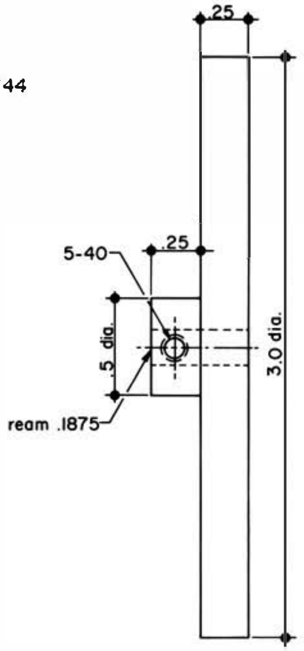




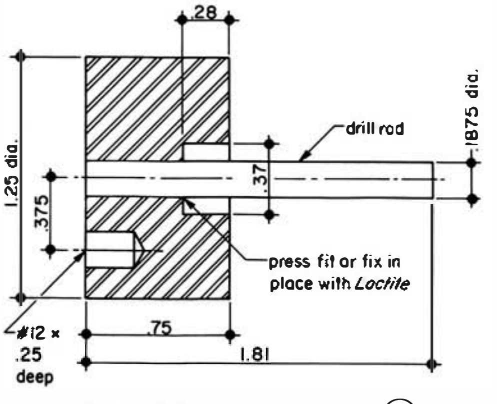
These two photographs show the manner in which the cranks and connecting rods work as the engine's eccentric piston both rotates and oscillates in the cylinder. At left, the crank nearest the flywheel coupling is in an upper position and the connecting rod and piston axle are at the back of the curved slot. At right, the piston has rotated about 90°, bringing the cranks down and the axle and connecting rod have shifted to the center. Another 90° rotation will bring the connecting rod to the front where it will reverse its direction for the other half of the piston's rotation. There's a lot of action in this little package!



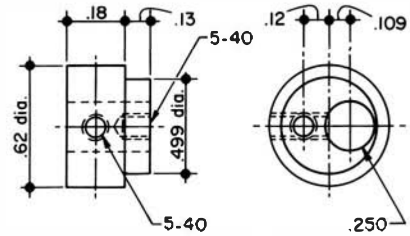
ECCENTRIC STRAP (22)
.125 Brass - I required



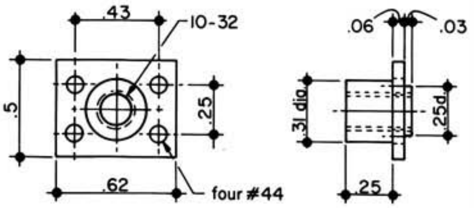
FLYWHEEL (14)
Steel - I required



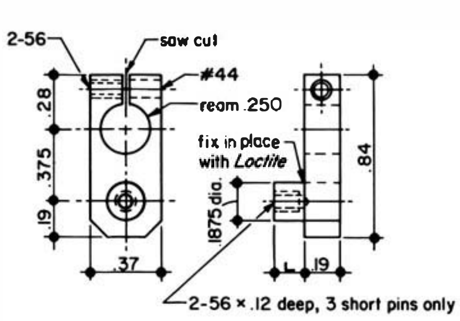
COUPLING ASSEMBLY (12)
I required



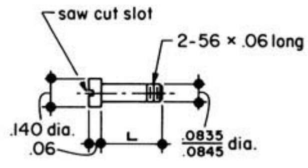
ECCENTRIC (23)
Steel - I required



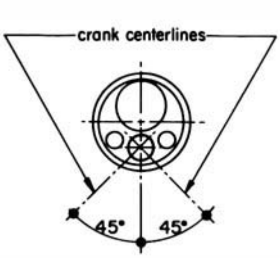
STEAM CONNECTION (25)
Brass - I required



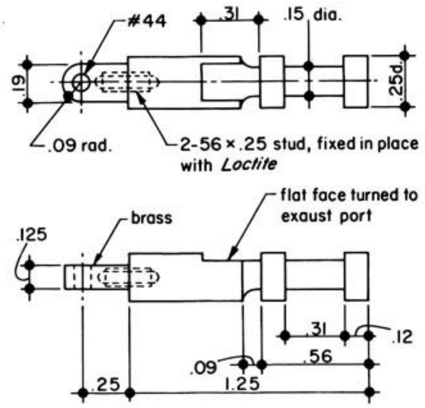
CRANK ASSEMBLY (5)(6)
3 required, L = .150 (5)
1 required, L = .31 (6)



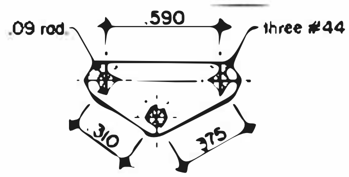
VALVE LINKAGE PIVOT PIN (24)
Steel - 3 required, L = .31
1 required, L = .44



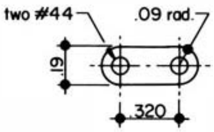
CRANK SETTING



SPOOL VALVE (19)
Drill Rod - 1 required

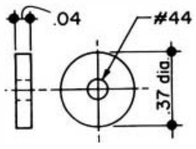


LEVER (21)
.06 Brass - 2 required
make in pairs

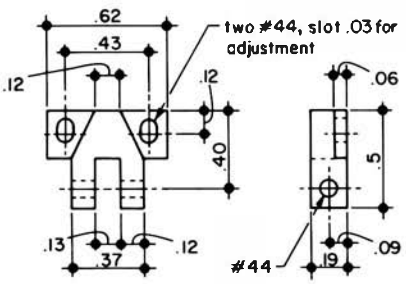


LINK (20)
.125 Brass - 1 required

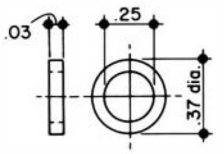
Drawings by George R. Broad, Jr.



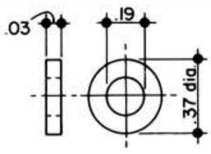
CRANKPIN COVER (7)
Brass - 3 required



VALVE BRACKET (19)
Brass - 1 required



SPACER (19)
Brass - 8 required

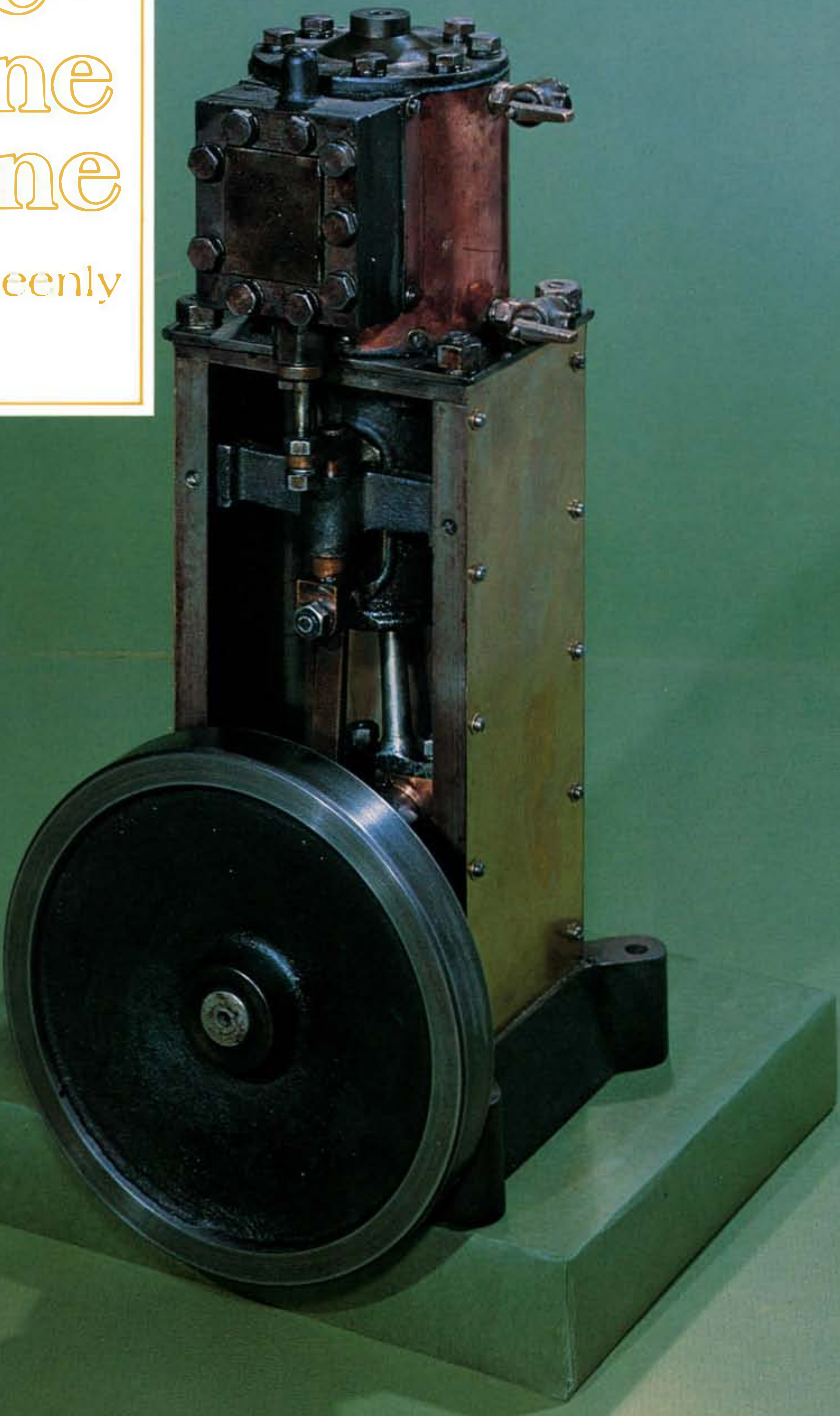


SPACER (16)
Brass - 4 required

Half-Horse Marine Engine

by Henry Greenly

from the collection of
Weston Farmer



A Brief Prelude

Having had the good fortune to be born one month before the Wright brothers flew at Kitty Hawk, my boyhood fun was nurtured by the romance of plentiful steam engines all about me; by the development of the airplane; the gas engine; the "wireless," as it was called, and by all the wonderful power boats to be seen. As were so many young Americans, I was a monkey-wrench mechanic. I was educated by building model airplanes from split bamboo and toilet paper; by jazzing up a Model T Ford with Rajo heads, Hassler shock absorbers, Rickstell axles and something called a "distributor," invented by a guy named Atwater Kent. I built and flew my own airplane and built my own power boats. We were all Rover Boys or Tom Swifts.

In 1928, at the age of 25, I lucked out again in being chosen as the editor to start Fawcett's *Modern Mechanics and Inventions Magazine*. This evolved into *Modern Mechanix* and eventually to *Mechanix Illustrated*. I seemed to have a sure touch as to the fare wanted by readers and consequently, the magazine continued to prosper.

One publishing adventure as an offshoot by Fawcett was the *Mechanical Package Magazine*. This was the first magazine-in-a-box and carried kits for hobby building. The first kit was a small oscillating steam engine, the parts for which were assembled on a bent steel strap, soldered to a copper tube which was poked through a cork which, in turn, was jammed into the proper-sized opening just under the lid of a Carnation milk can. Of course, the engine did run merrily!

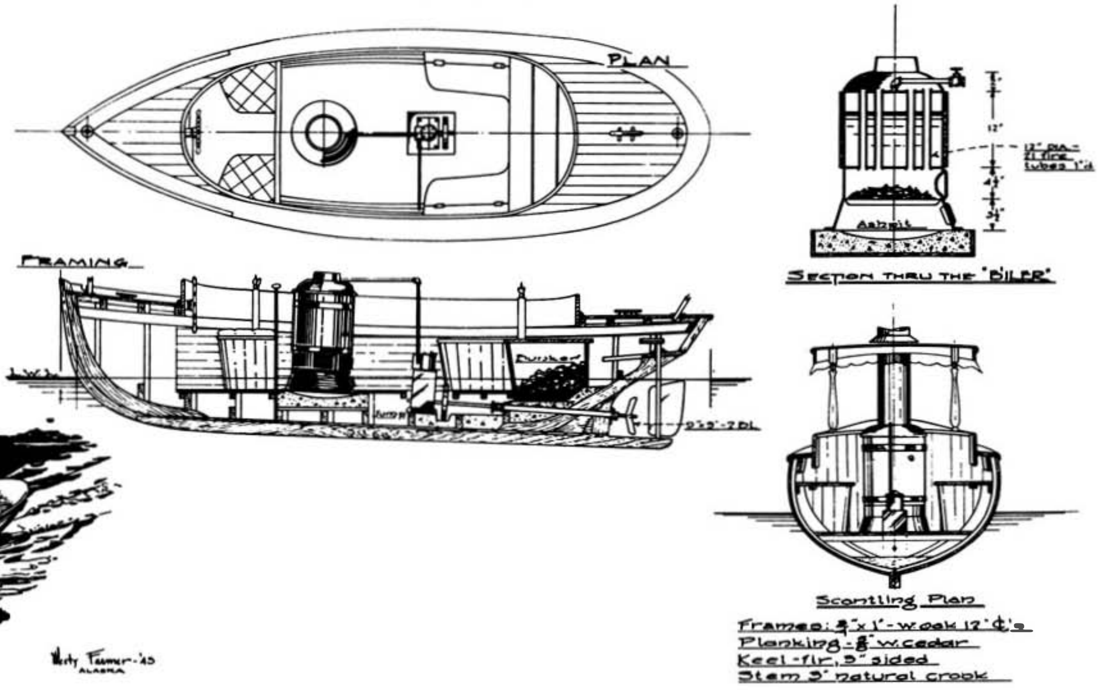
One hundred thousand steam engine kits were produced at a cost of 1½¢ each for *Mechanical Package Magazine* by the Acme Machine Company, of Minneapolis. There must have been panic among the contented cows of Carnation when there was a sudden public demand for 100,000 cans of condensed milk!

After four issues, the "packmag" was killed as being too cost-intensive. Though it sold fabulously, it cost 14¢ per copy and sold wholesale for 16¢. *Modern Mechanix* also sold wholesale for 16¢ and only cost 9¢ per copy. This was a standard spread for a 25¢ newsstand price. The break-even cost of the packmag was just too high.

Before the *Mechanical Package Magazine* died, I had ordered a steam engine design from Henry Greenly, the great English engine designer. Greenly delivered the drawings and copy just before the packmag demise and Acme Machine built his engine. The plans and manuscript were never published — but Greenly was paid the $15 he demanded for the drawings and story.

In 1943, while I was in Alaska, I designed a small, two-Rover-Boy-sized boat for the Greenly engine to power. The sketches were originally printed in an edition of *Rudder* magazine and are reproduced on these pages, also.

The other day, Greenly's letter of transmittal and his story about how to build the engine popped out of a niche in my files, long forgotten. The engine had been tested under steam, treasured, hauled from domicile



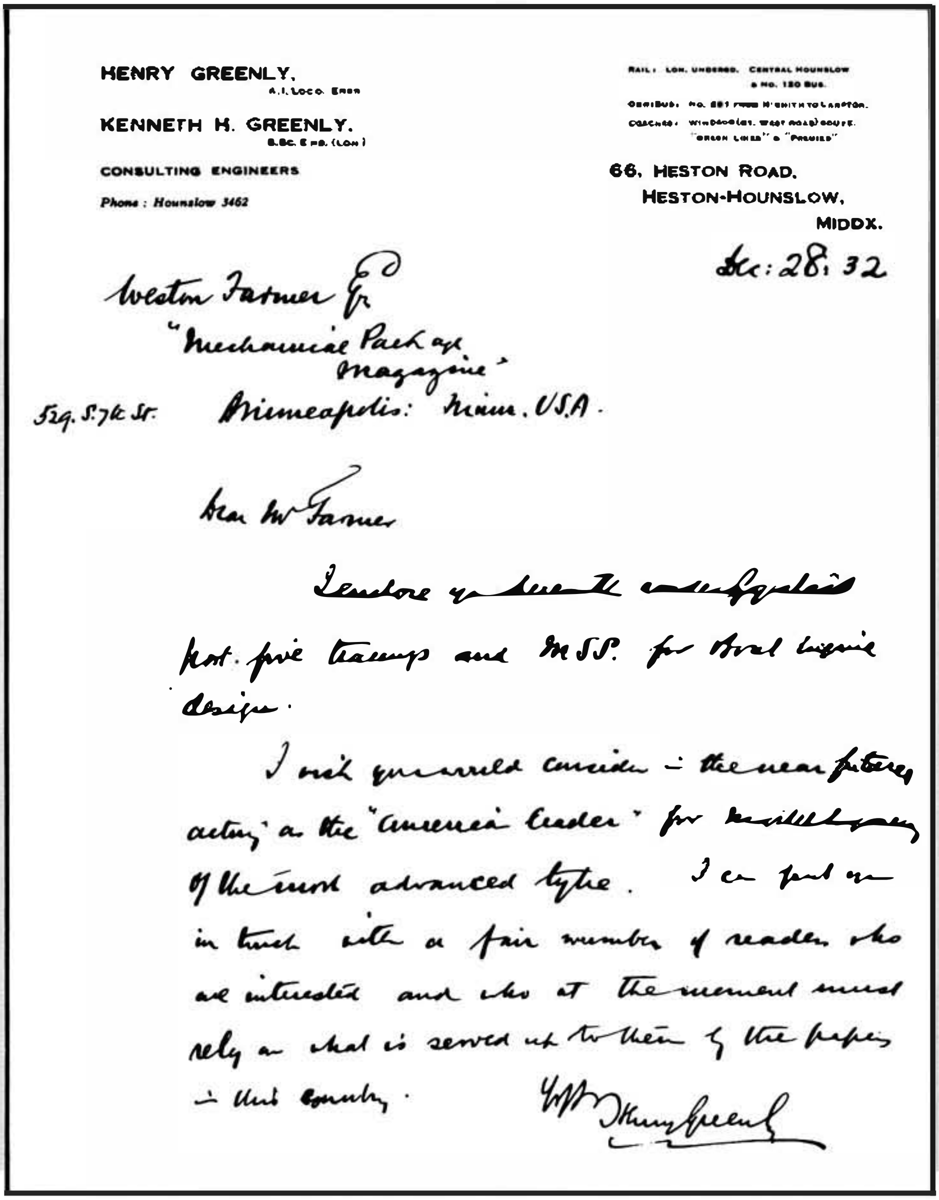
to domicile and finally had been given to my son, David K. Farmer, who became a better engineer than his Dad.

When I discovered Greenly's unpublished 46-year-old manuscript, I thought of all the grown-up Rover Boys who read **LIVE STEAM** and mailed the script to Bill Fitt. Readers of **LIVE STEAM** will savor this discovery. It relates to the fun to be had by involvement with the velvety power of steam, that unforgettable satisfaction to be had only by men who know it.

Today's kids have it too easy. For $2.98, they buy a scale model of an atomic submarine. No need to tinker or think! That, boys, is where the kick is. Take it from your old Uncle Westy who "was there, Charley" and knows.

Posthumously, then, here are fresh words of steam engine wisdom and construction by Henry Greenly, who was nonpariel in his day as a designer of British steam engines.

by Weston Farmer



HENRY GREENLY, A.I.LOCO. ENGR.
KENNETH H. GREENLY, B.SC. E.NG. (LON.)
CONSULTING ENGINEERS
Phone: Hounslow 3462

RAIL: LON. UNDERGD. CENTRAL HOUNSLOW & NO. 120 BUS.
OMNIBUS: NO. 81 FROM H'SMITH TO LAMPTON.
COACHES: WINDSOR (GT. WEST ROAD) ROUTE. "GREEN LINES" & "PREMIER"

66, HESTON ROAD,
HESTON-HOUNSLOW,
MIDDX.

Dec: 28: 32

Weston Farmer Esq
"Mechanical Package Magazine"
529. S. 7th St. Minneapolis: Minn. USA.

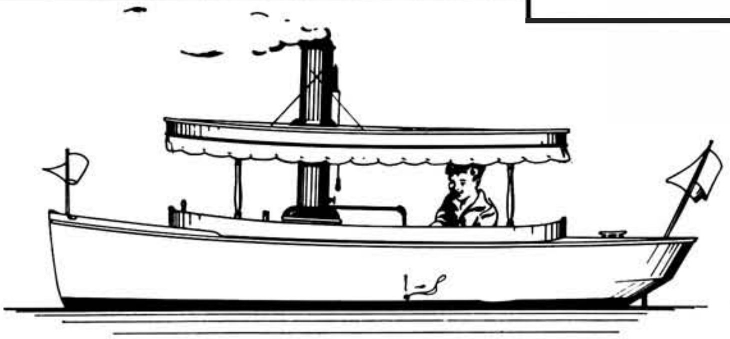
Dear Mr Farmer

I enclose [illegible] post. five tracings and MSS. for Boat Engine design.

I wish you would consider in the near future acting as the "American Leader" for [illegible] of the most advanced type. I can put you in touch with a fair number of readers who are interested and who at the moment must rely on what is served up to them by the papers in this country.

[illegible] Henry Greenly

Henry Greenly's original tetter of transmittal, which accompanied the plans and instructions for this article prepared back in 1932.

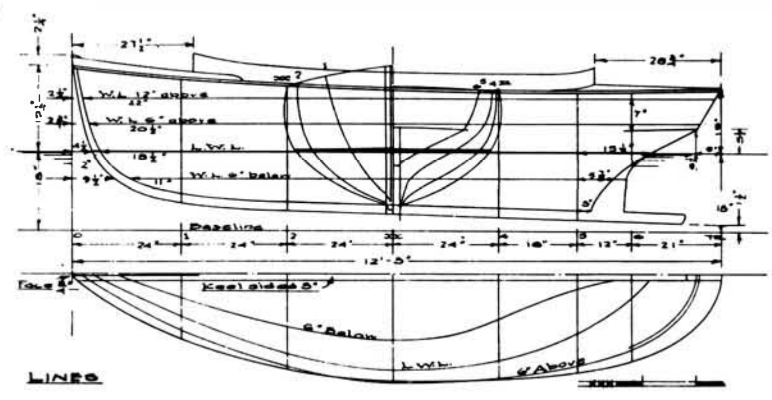


OUTBOARD PROFILE

TABLE OF OFFSETS
Feet, inches & eighths to plank face

Sta.	Sheer	Keel	Rab't	Sta.	Sheer	W 12"	W 6"	LWL	6" B	Rab't	Keel
	HEIGHTS				HALF-BREADTHS						
0	3·1·4			0	0·0·6						
1	2·10·1	0·6·0	0·8·4	1	1·5·2	1·2·1	1·0·7	0·9·2	0·6·0	1·0·4	1·0·4
2	2·8·6	0·4·4	0·6·4	2	1·9·4	1·9·6	1·8·5	1·5·6	0·11·7	1·0·4	1·0·4
XX	2·7·7	0·3·5	0·6·0	XX	2·0·0	2·0·4	2·0·4	1·9·7	1·2·6	1·0·4	1·0·4
4	2·7·2	0·3·0	0·5·2	4	1·11·2	2·0·0	1·10·5	1·6·0	0·9·7	1·0·4	1·0·4
5	2·7·3	0·7·4	0·4·5	5	1·10·4	1·10·5	1·8·4	1·1·0	0·3·7	1·0·4	1·0·4
6	2·7·4	0·2·0		6	1·7·4	1·7·0	1·4·6	0·5·5		1·0·4	1·0·4
TR	2·8·0			TR	[illegible]						

DATA:
Displacement 1005# L.O.A 12'-3"; Beam 48"
Moment to change trim: nothing flat.
Speed: 4·5 maybe-knots



LINES

To propel a steamboat which carries its own skipper, an engine of at least a half horsepower is essential. This power must not be nominal; it must be capable of development with a full head of steam, continuously, but without draining the boiler.

It is surprising how small a cylinder is really necessary, so long as it is built in a truly scientific manner. Over-cylindering must, at all times, be avoided as the real source of power is the boiler. The engine is only the medium by which the heat energy is converted into mechanical energy. (It would be no good to put a 10 HP electric motor onto a wireless battery and expect it to go.) Also, so long as the bearings are of ample area and the framing of sufficient stiffness, the lightest construction may be adopted.

The revolutions should be high enough to make the engine more or less efficient as a heat engine. All small engines have only a minute amount of calories in the cylinder at each stroke and to keep the walls at the proper steam temperature, the number of strokes per minute should be as high as the components of the machinery will stand. By this means, the cylinder walls will be maintained at proper temperature and condensation losses will be reduced to the minimum. For the present purpose, I am recommending 300 to 400 RPM as the normal rate and a pressure of at least 60 psi at the boiler stop-valve. Allowing this, we can reckon on an average or mean pressure in the cylinder of 35 psi. The Indicated Horsepower should be:

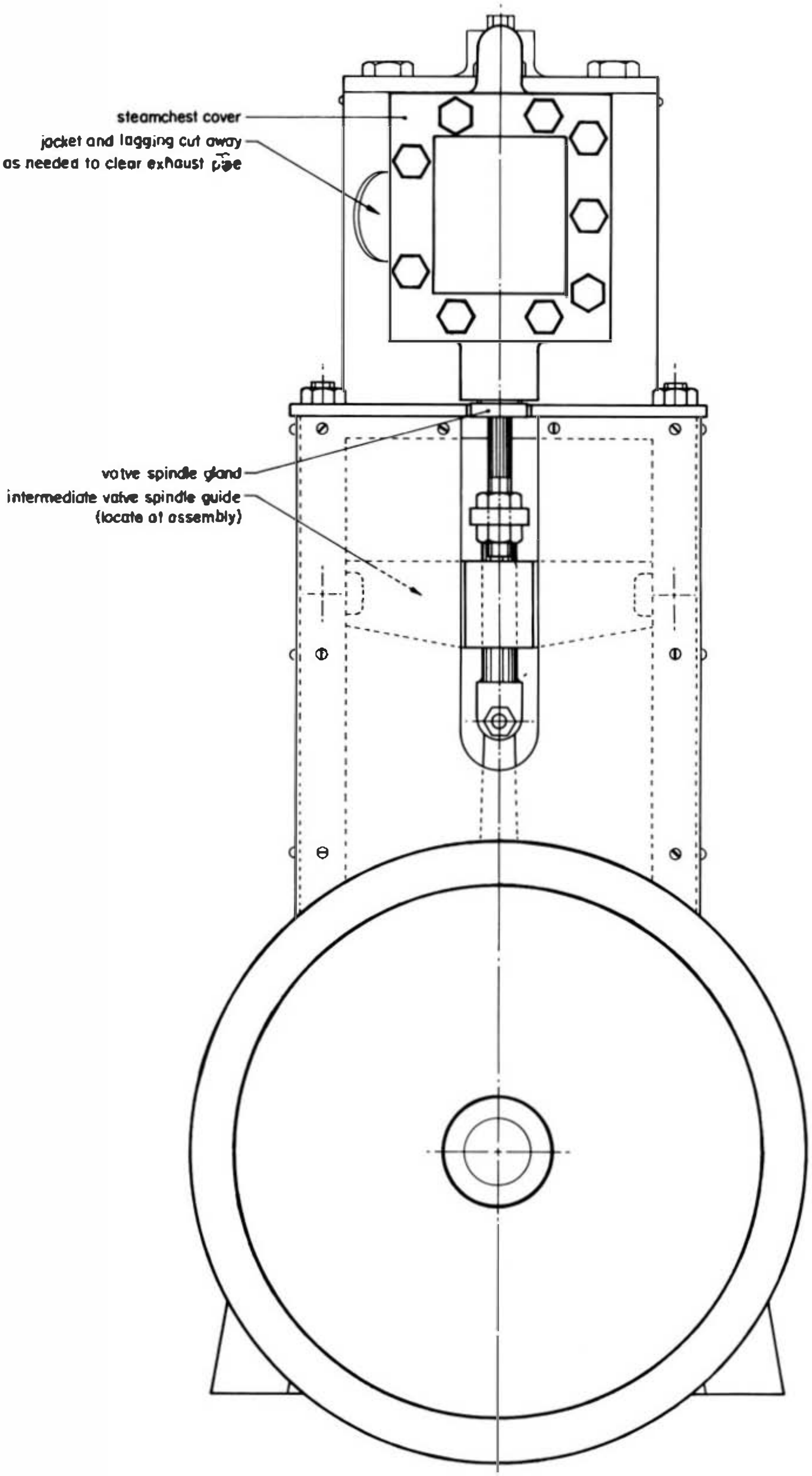
$$\frac{\text{pressure x area x length x number of strokes}}{33{,}000}$$

or, in the case of this particular engine,

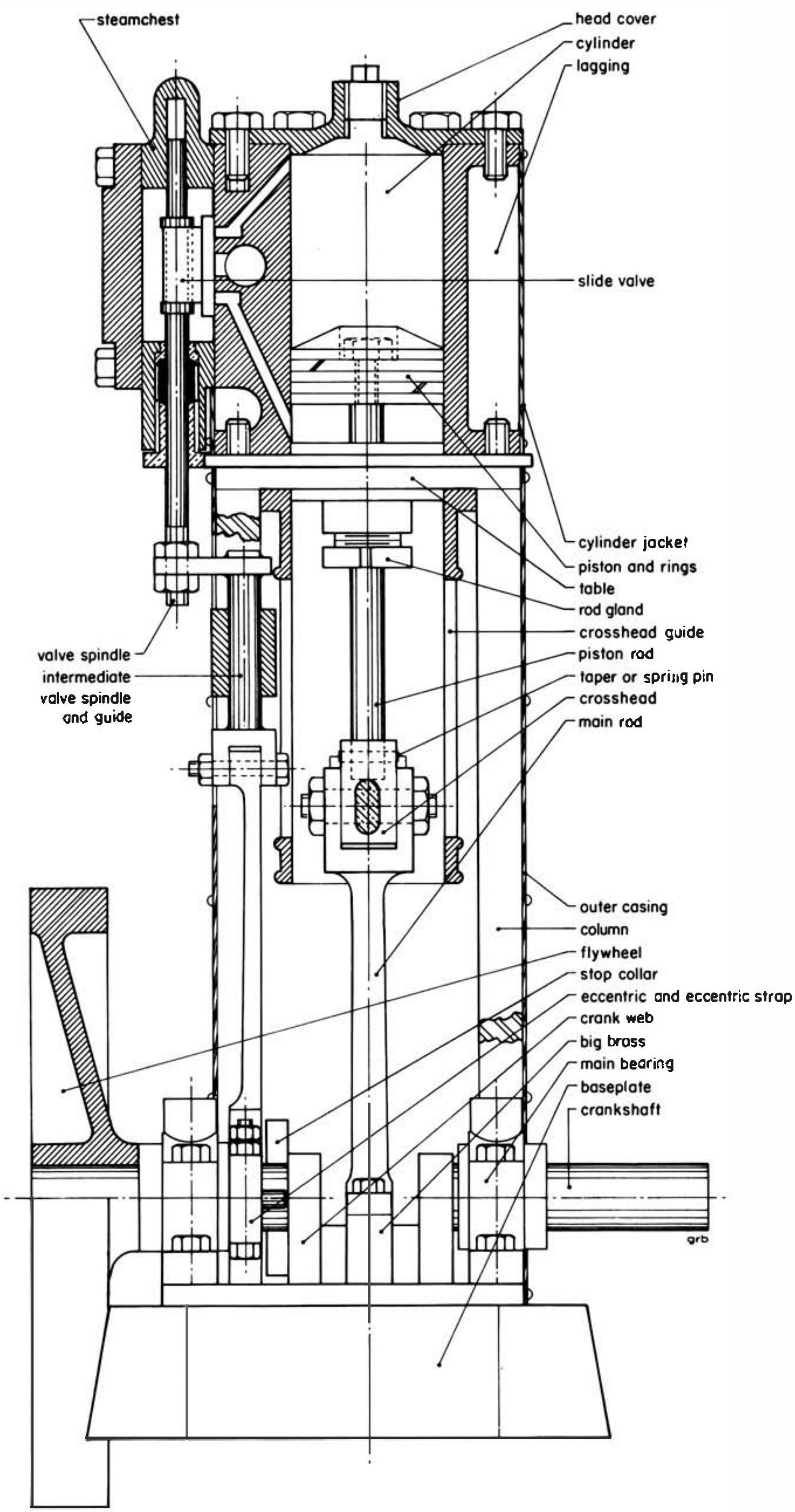
$$\frac{35 \times 2.4 \times 2.5 \times 400 \times 2}{12 \times 33{,}000} = 0.424 \text{ IHP.}$$

If the pressure can be pushed up a little, the half horsepower designed as a maximum can be obtained easily, as the speed will go up quite a lot with a small increase in mean pressure.

Another point about the job is that the engine should be simple to make. There must be no castings bigger than can be machined in the lathes usually found in the average Amateur Machinist's home work-



FLYWHEEL END



SIDE SECTION

shop. The crankcase should be enclosed so that oil may be confined to the bed of the engine and not splash about all over your boots, but at the same time, it is highly desirable that the casing be removable readily in case any adjustments to the normally-hidden machinery are necessary.

Further, it is essential that the reversing gear be as simple as possible. Nothing is as likely to go wrong or to wear so quickly that it is in danger of falling to pieces as a finnicky link motion, full of small pins and innumerable highly-stressed joints. Therefore, I have proposed for this small engine a robust slip eccentric reverse gear, the sort that will outlast all others and at the same time, give a perfect steam distribution in both directions of rotation. To reverse the engine, all that is necessary for the engineer to do is to shut off the main stop-valve and on the engine coming to rest, grab the flywheel and spin it in the opposite direction of rotation. Turning on the steam again will make the engine continue to operate in the reversed way, until the reversing process is repeated.

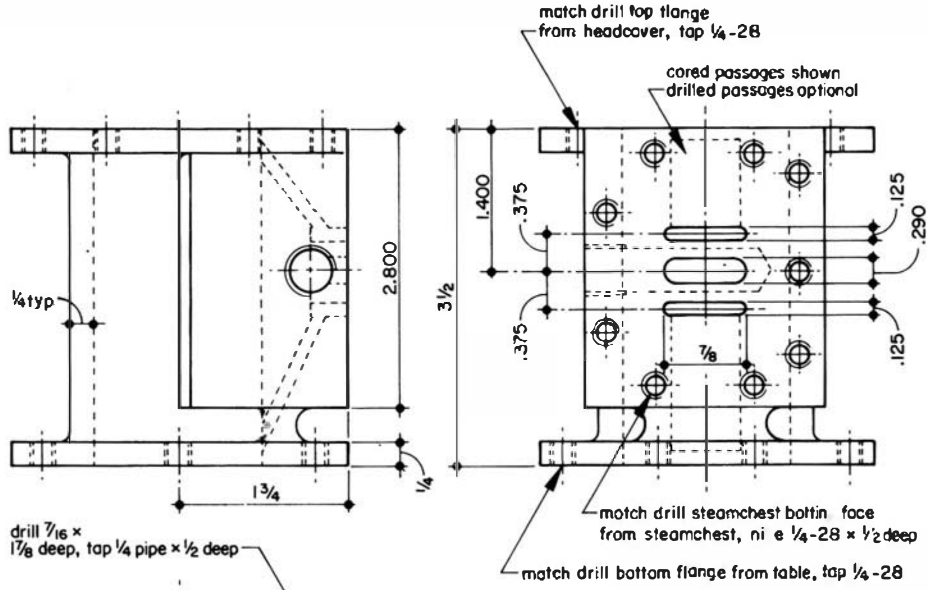
The following is a brief set of specifications and an outline which will assist you in construction of your engine.

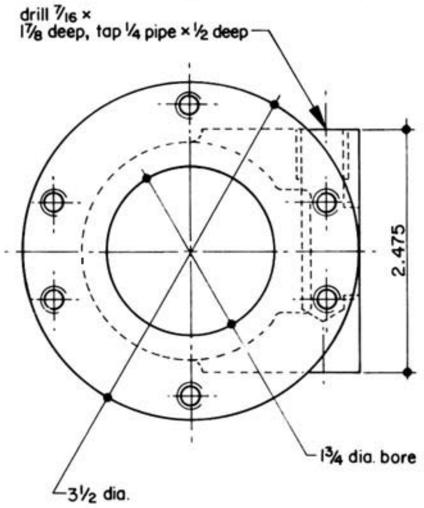
The **CYLINDER** is of cast iron, 1¾" bore x 2½" stroke. When finished, it is complete in itself with the added steam chests and bored crosshead guide standing on the four columns.

The **STEAMCHEST** is a separate casting (or fabrication) studded onto the cylinder, the studs being extended to attach the steamchest cover. This makes the valve facing and ports in the cylinder plain, straightforward jobs. There is no endmilling into recesses. Castings or component parts are relatively small. Thus, if you should happen to "muck up" any drilling, surfacing or boring operation with this cylinder and steamchest, there is not much work scrapped.

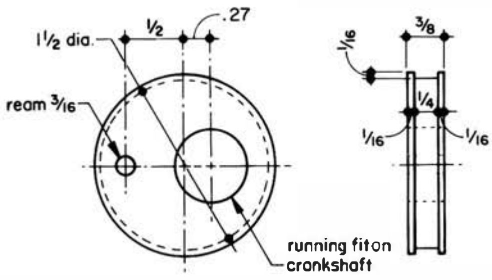
All passages are drilled in the cylinder casting and if an endmilling attachment to the lathe is not available, the ports may be formed by drilling and chipping.

The **SLIDE VALVE** and **VALVE SPINDLE** are simple jobs. A plain D-valve is used in gunmetal or hard bronze. It is slotted at the back and driven by the spindle, which has two collars turned on it out of the solid. To enable this spindle to be entered into the steam chest, the stuffing box is drilled and tapped with a ½" dia-

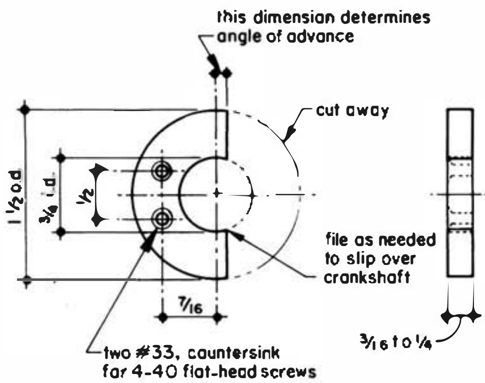




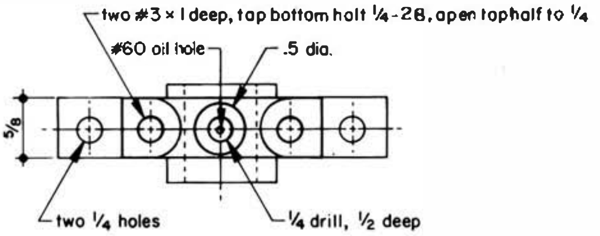
CYLINDER
Cast Iron, 1 required

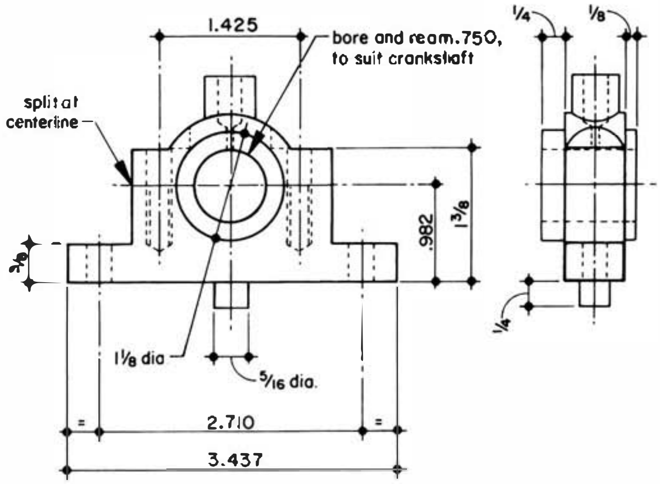


ECCENTRIC
Steel, 1 required

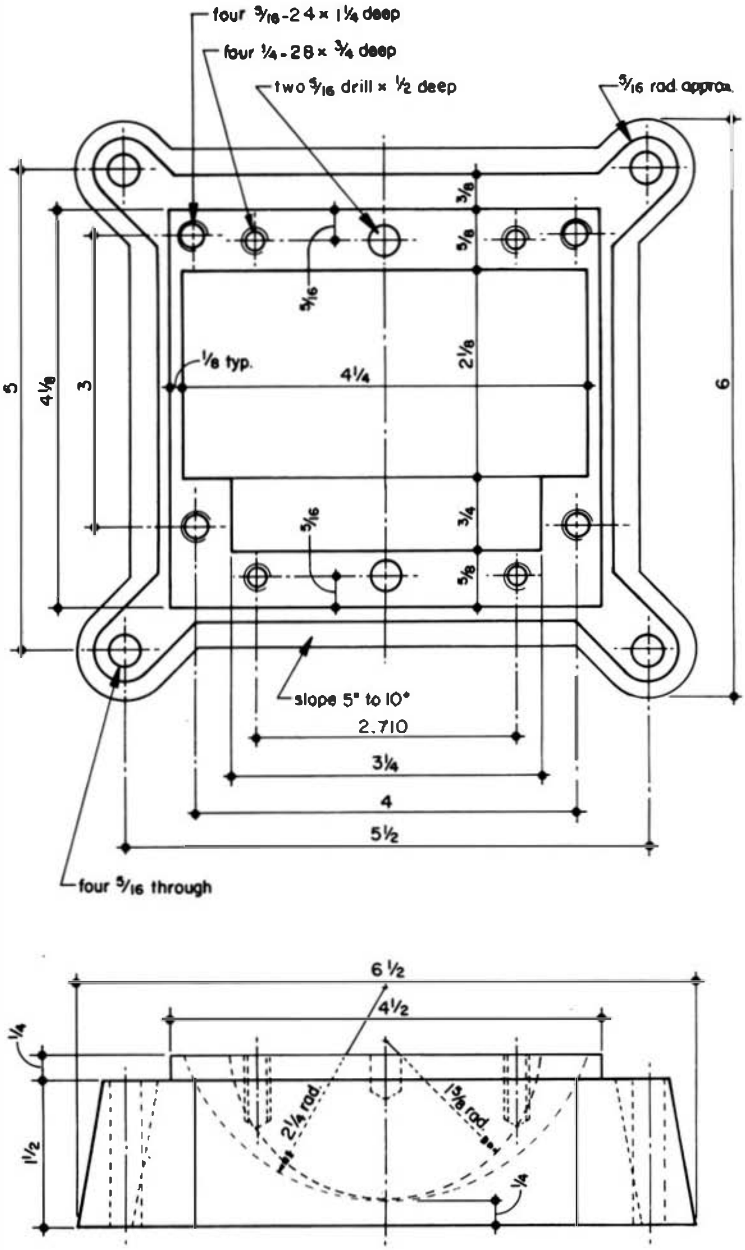


STOP COLLAR
Steel, 1 required

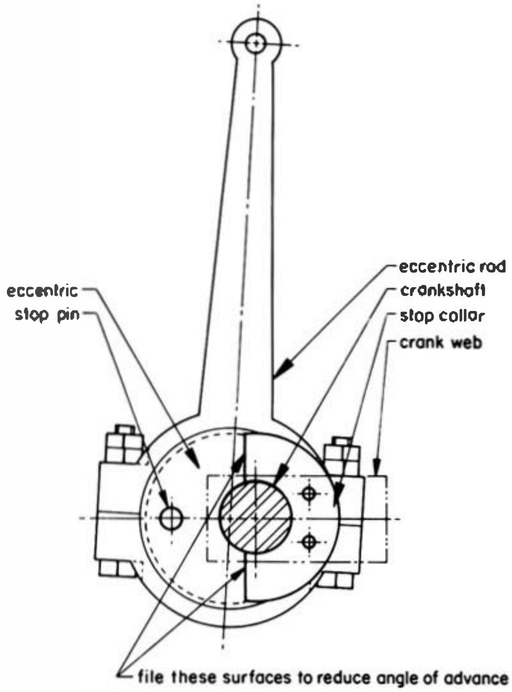




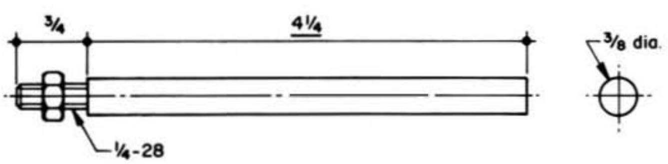
MAIN BEARING
Bronze, 2 required



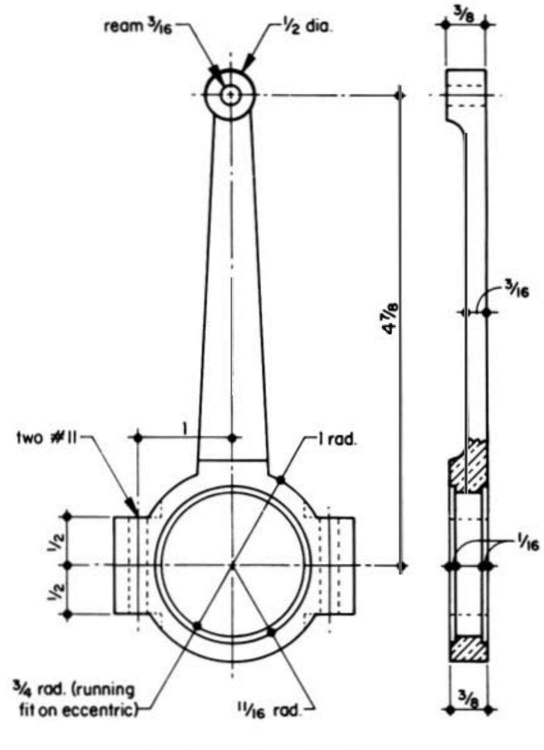
BASEPLATE
Cast iron, 1 required



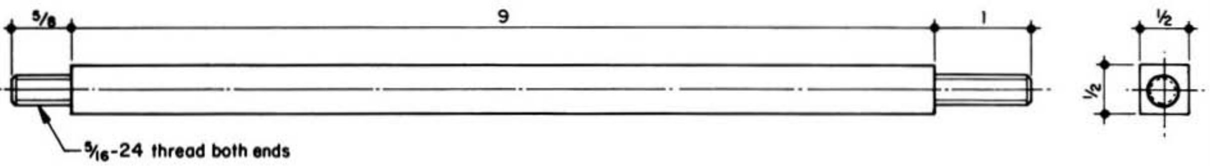
REVERSE GEAR ARRANGEMENT



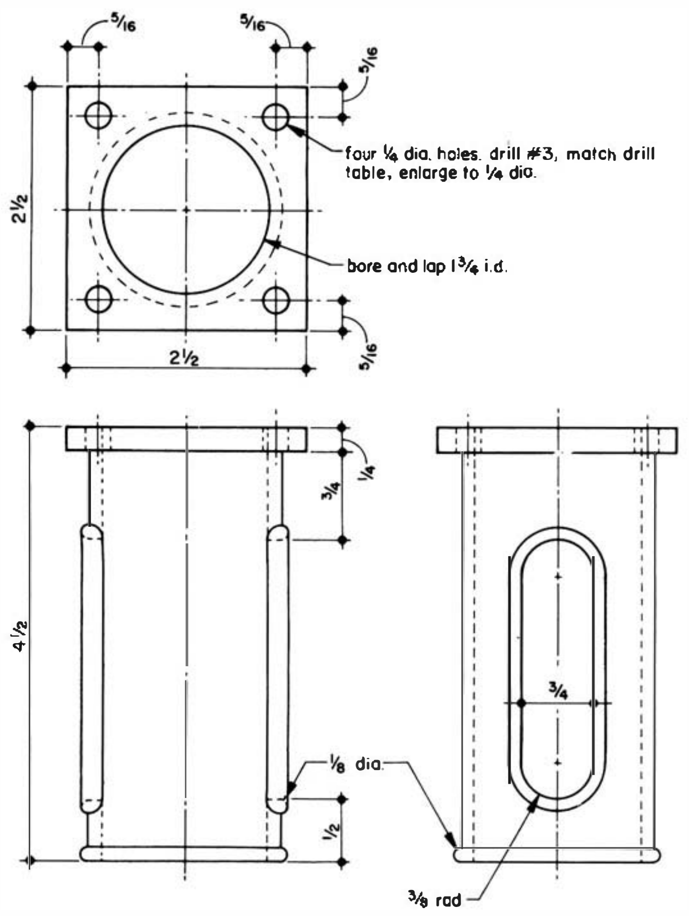
PISTON ROD
Drill Rod, 1 required



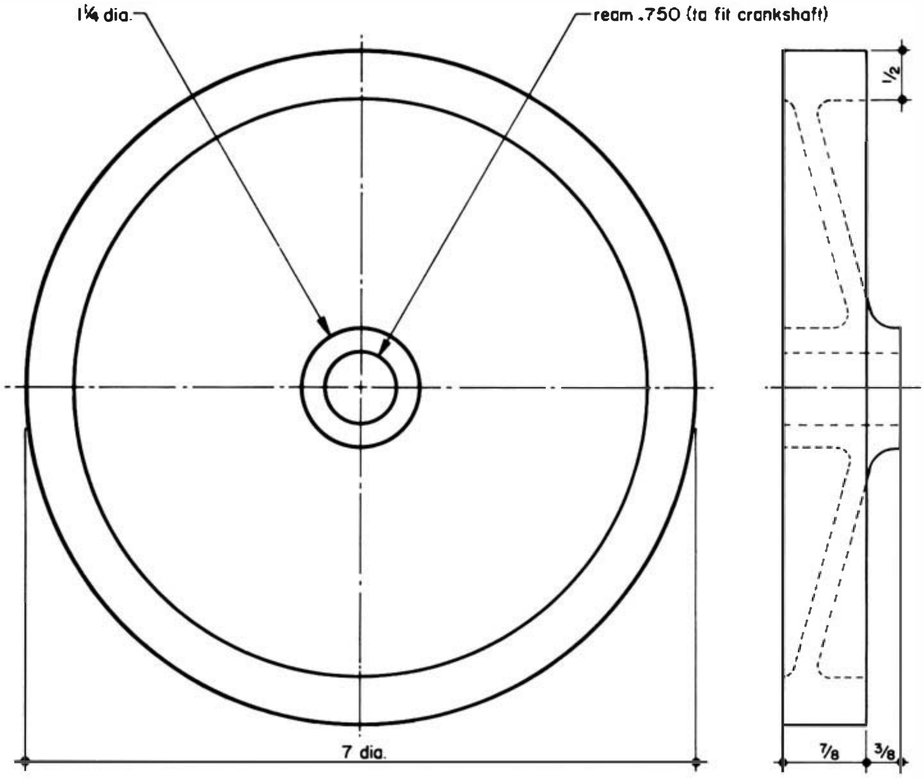
ECCENTRIC STRAP AND ROD
Bronze, 1 required



COLUMN
Steel, 4 required



CROSSHEAD GUIDE
Cast Iron, 1 required



FLYWHEEL
Cast Iron, 1 required

meter fine thread and a brass gland plug small enough to clear the threads is driven into the bottom of the box after the spindle has been entered. The gland plug seats in a 3/8" diameter hole.

The **PISTON** is lightened out as much as possible to reduce out-of-balance effects at high speed. The rings should be obtainable from commercial suppliers or any dealer handling small internal combustion engine rings.

The **PISTON ROD** should be marked off to the correct length on the job, after preliminary erecting.

Threaded **GLANDS** are recommended for the valve spindle and piston rod, but they must be machined and screw-cut true to their respective bores.

The **CROSSHEAD GUIDE** is circular and bored for the crosshead. It fits on a spigot formed on the underside of the lower cylinder cover, or table.

The **TABLE** is a square casting or fabrication, spigoted on the top for the cylinder bore and on the bottom for the crosshead bore. It should be noted that the bottom cylinder flange will have to be drilled differently from the top, in order to take the countersunk screws which attach the cover to the cylinder. Holes are also required in the corners of the table for the columns.

These four **COLUMNS** are 1/2" square steel rods, turned down at each end. There is no real objection to round rods, except that square rods make the sheet steel outer casing easier to fit up.

The **BASEPLATE** looks like an intricate casting from the drawing, but once the pattern is made, it is an easy job to face and drill for the columns and main bearings. The facing can be done in the lathe. A fabricated baseplate would also be practical.

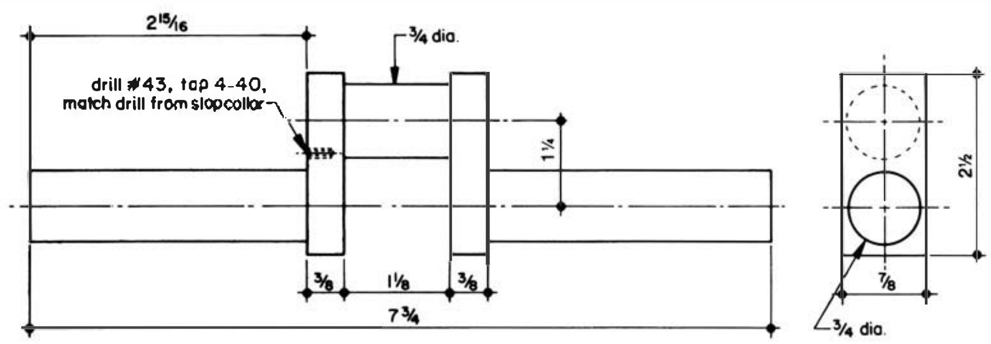
Cast gunmetal is used for the **MAIN BEARINGS**, which can be machined all over in the lathe. There is a little locating spigot on the bottom which is formed during the facing operation and fits into a drilled hole in the base casting.

Turn the **CRANKSHAFT** from 2 1/4" x 1" bar steel. Machine it all over after first removing the superfluous material by drilling and a hacksaw. Be sure to leave some lugs in the end of the crankshaft, so you will have a place to drill center holes for turning the crankpin. These will be removed when the shaft itself is turned.

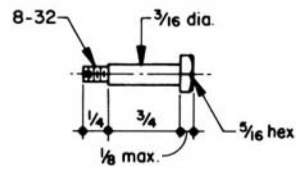
The eccentric has a short, carbon-steel pin fixed in one side. This will be driven by a washer-like **STOP COLLAR** which is fixed to the outside of the crank web by one or two small countersunk screws. This washer should be completely circular at the outset and have nearly half sawn off. The fixing of the collar should be such that the eccentric moves equally on each side of the crankpin centerline. This accuracy can be insured by leaving plenty of metal on the flatted edge of the washer and removing this contact face by filing or scraping when making the final adjustments to the valve gear.

The **MAIN ROD** is made in two pieces, a steel rod and a split gunmetal **BIG BRASS**. The bearing bolts, being necessarily small, should be of good stuff. They are kept small to reduce out-of-balance effects and to clear the crankcase.

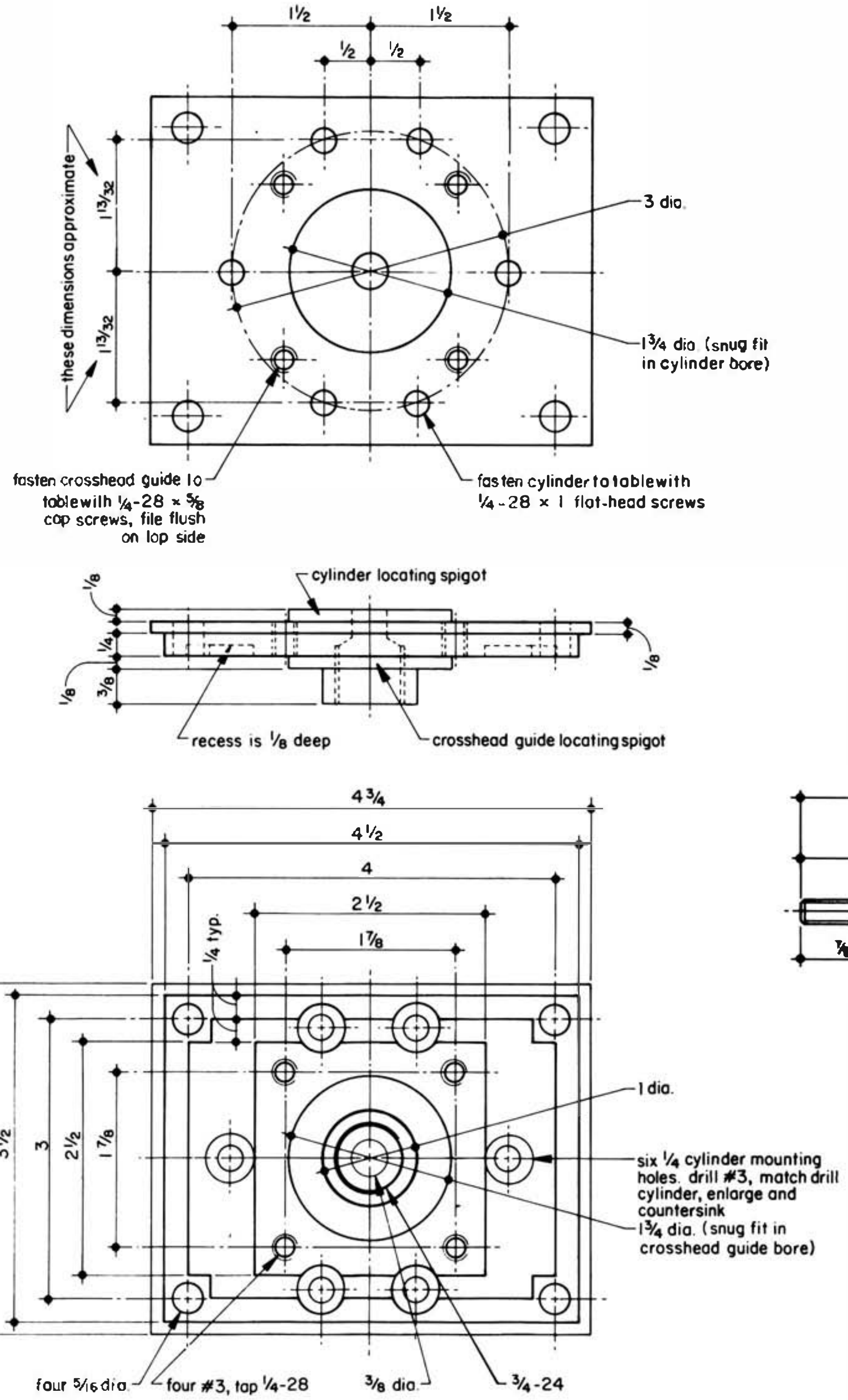
The **CROSSHEAD** may be made of cast gunmetal and if more than one engine is being made, they can be cast and machined in pairs.

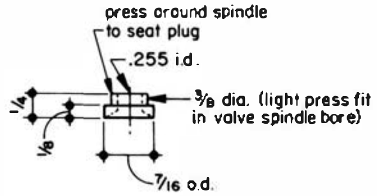


CRANKSHAFT
Steel, 1 required

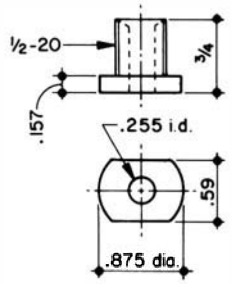


ECCENTRIC ROD PIN
Steel, 1 required

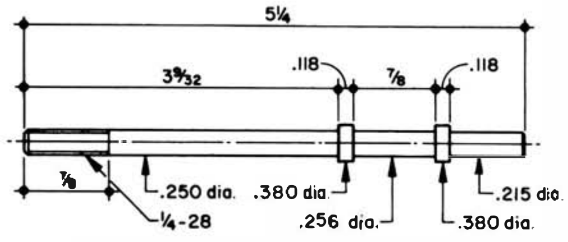




GLAND PLUG
Bronze, 1 required



VALVE GLAND
Bronze, 1 required



VALVE SPINDLE
Steel, 1 required

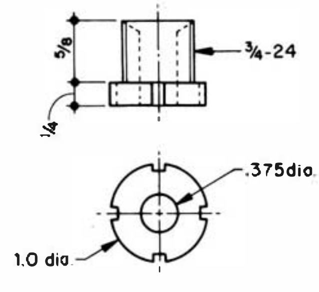
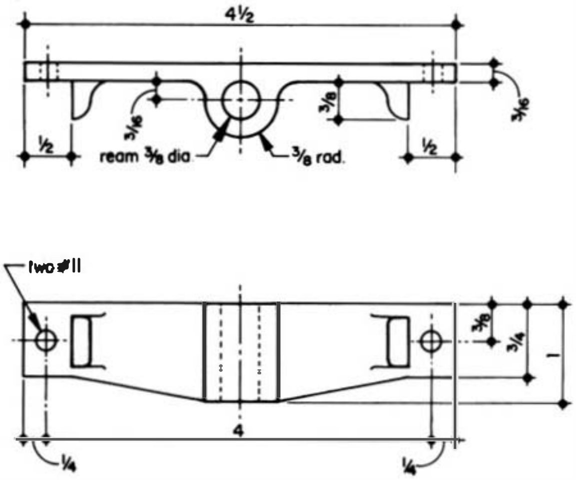
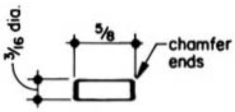


TABLE
Cast Iron, 1 required

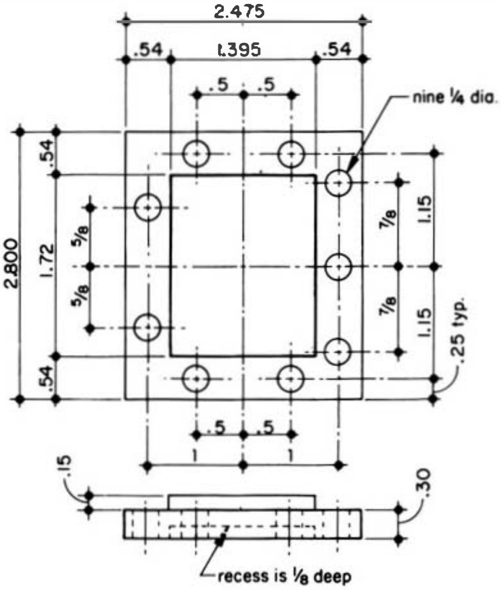
ROD GLAND
Bronze, 1 required



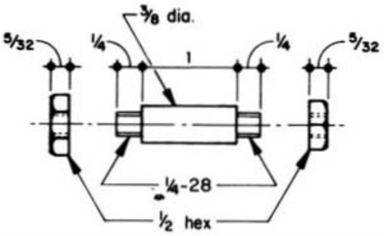
INTERMEDIATE VALVE SPINDLE GUIDE
Cast Iron or Bronze, 1 required



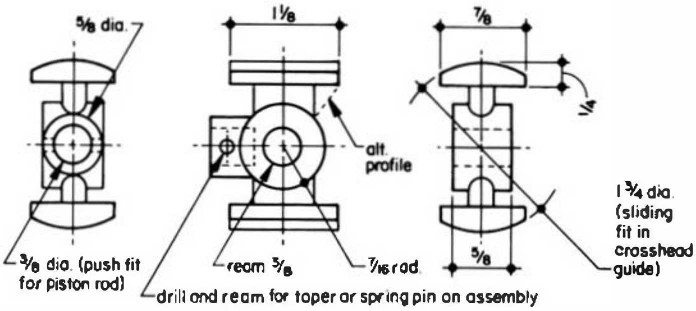
STOP PIN
Steel, 1 required



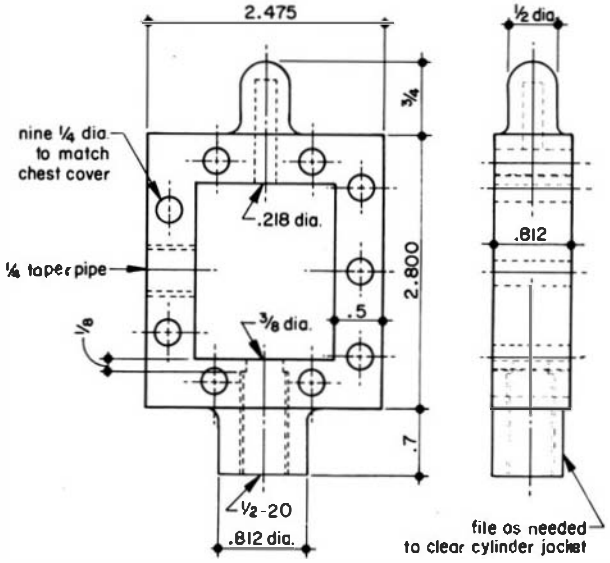
STEAMCHEST COVER
Cast Iron, 1 required



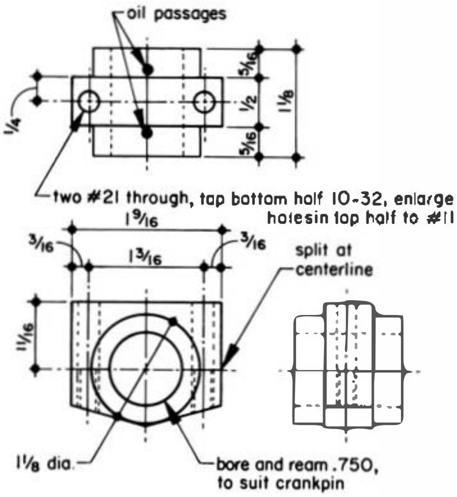
CROSSHEAD PIN AND NUTS
Steel, 1 Pin and 2 Nuts required



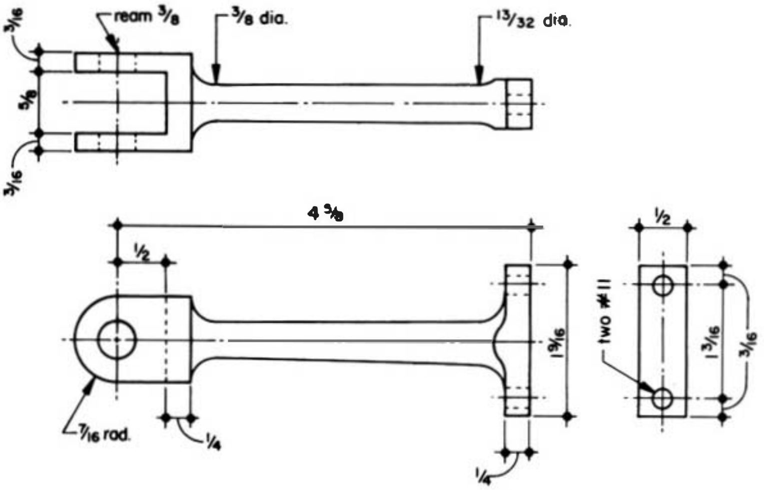
CROSSHEAD
Bronze, 1 required



STEAMCHEST
Cast Iron, 1 required



BIG BRASS
Bronze, 1 required



MAIN ROD
Steel, 1 required

The **ECCENTRIC** is of steel, loose on the shaft, and the **ECCENTRIC STRAP** is cast or fabricated integral with the eccentric rod. The sheaves themselves are split and jointed up again during the machining operations. Gunmetal or a hard bronze would be suitable.

The top end of the eccentric rod engages the forked **INTERMEDIATE VALVE SPINDLE**, which has a lug riveted or brazed on it to bracket the motion out to the valve spindle. This intermediate valve spindle is carried by the cast **INTERMEDIATE VALVE SPINDLE GUIDE**, which is attached to the columns by small screws.

The **FLYWHEEL** is of cast iron and should be turned up quite true to 7" diameter. To balance the piston, several blind holes may be drilled in the rim. The exact number is a matter of experiment.

If the drive is taken off at the back of the engine, the flywheel need not be drilled and tapped for any coupling bolts. The shaft extends far enough at the back end to allow the fixing of a flexible coupling. This can be made from a pair of flanged fittings with a disk of ¼" boot-sole leather between the lugs of the couplings, these being crossed on each other at a 90° angle to provide the necessary flexibility.

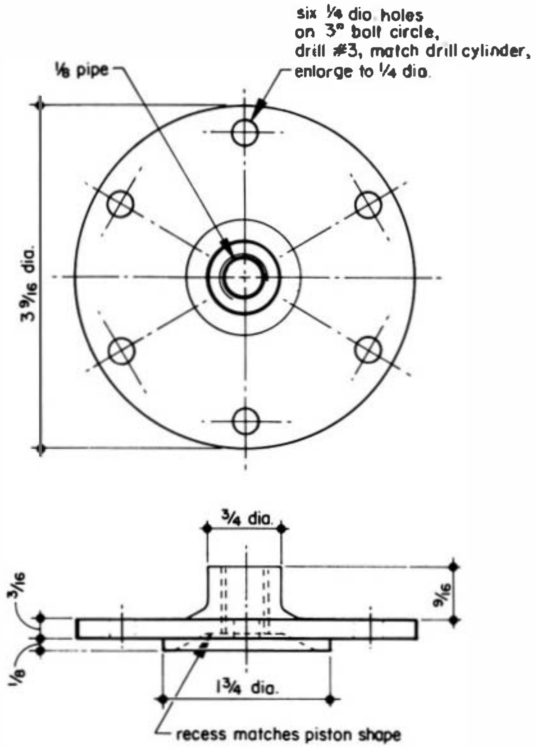
The outer casing enclosing the crank and machinery is not detailed as a separate drawing, since it must be fitted carefully to place. Make it from 16-gauge Brown and Sharpe or 18-gauge American Standard (.05") sheet steel, screwed onto the columns with round-headed screws. The casing must be cut away where necessary to allow the intermediate valve spindle and guide to poke through. On the eccentric end of the engine, the sides of the casing may be bent to enclose the bearings, if desired, and the back sheet bent to conform with the outline of the sides. The casing sheets also can carry oil boxes for the main bearings, big brasses, crosshead guides and crosshead. As many as the engineer finds convenient may be added.

The cylinder should be lagged with asbestos yarn and jacketed with sheet steel.

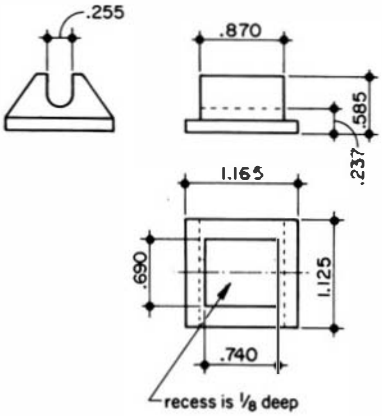
A Roscoe lubricator is advised on the main steam pipe, but give the engine a gulp of cylinder oil at the start. The top cover can be bored for an easily removable plug. In a Roscoe displacement lubricator, the oil outlet to the steam pipe is at the top of the chamber and should be a quite small hole, about 1/32" maximum. Right on top of the oiler is a large filling plug and at the bottom, a drain cock is required. The steam condenses in the lubricator and displaces an atom of oil until it becomes full of water. This can be drained off and the lubricator replenished with oil. (Steam must be off for this operation.) A suitable lubricator for this engine is one that can hold about 3 cubic inches of oil. Thick cylinder oil should be used for this accessory, not the engine oil used for the running bearings.

Cylinder drains should be provided on the front or side of the cylinder, as desired. In the best-made engines, the outlets from the cocks are generally led down the sides to the bilges.

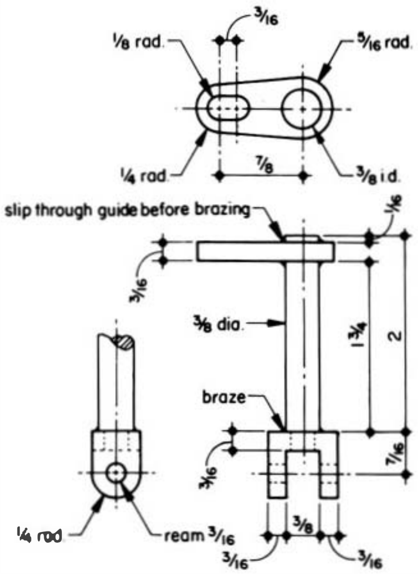
One final comment, for pipes and glands, where 26 threads per inch is specified, 28, 32 or 40 threads may be used, depending on which is the most convenient to thread or tap with the tools available in the Amateur Machinist's workshop.



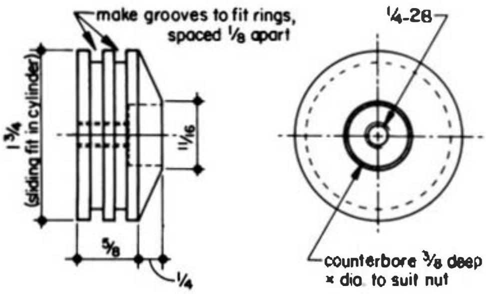
HEAD COVER
Cast Iron, 1 required



SLIDE VALVE
Bronze, 1 required



INTERMEDIATE VALVE SPINDLE
Steel, 1 required

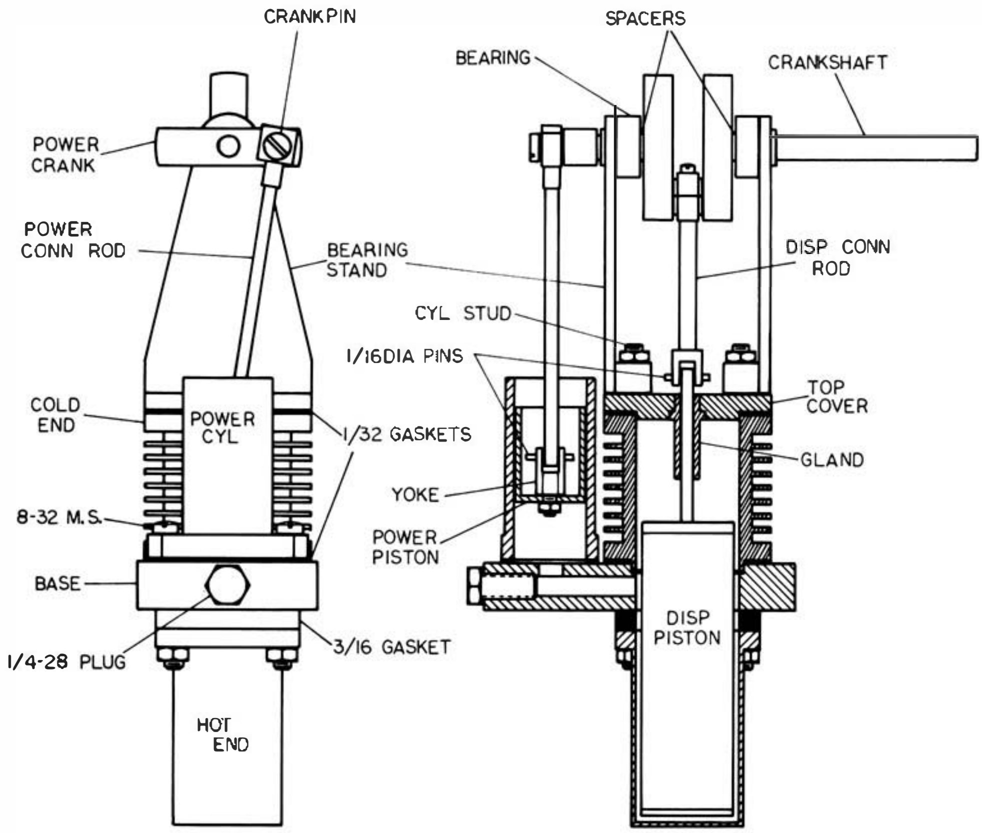


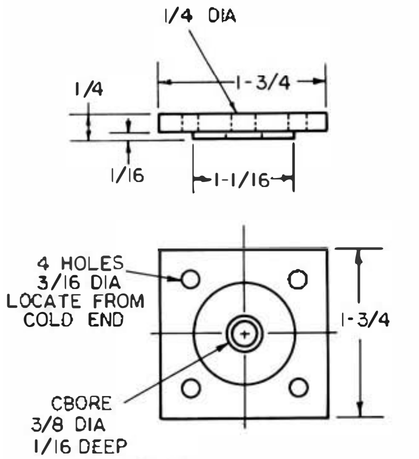
PISTON
Cast Iron, 1 required

A 10-inch Stirling Engine Powered Fan . . . Moriya

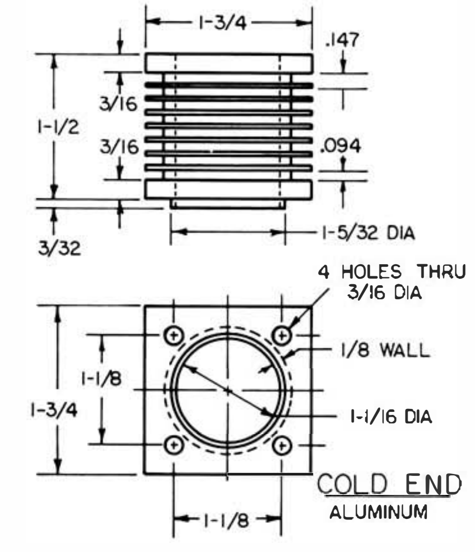
by Dr. James R. Senft

Photos and Drawings by the Author

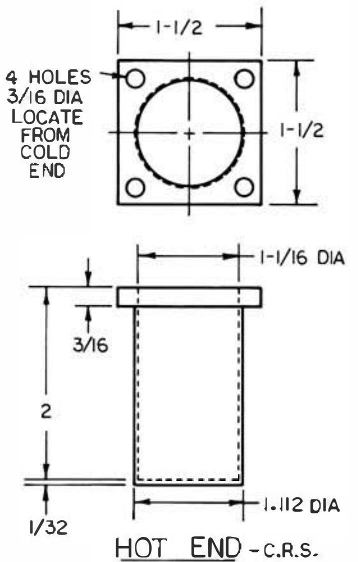




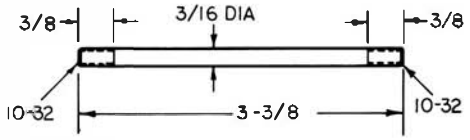
TOP COVER - ALUMINUM



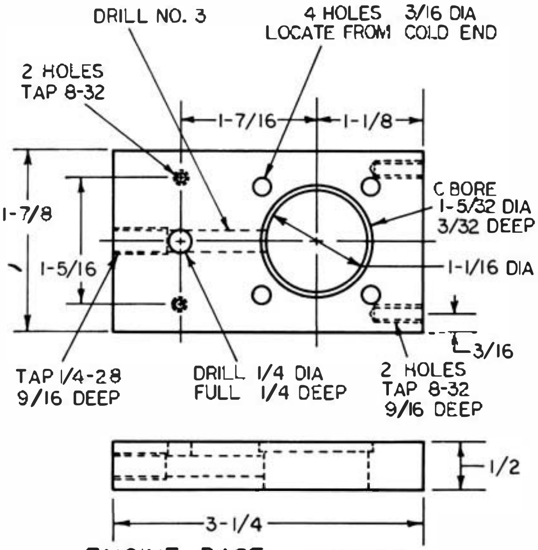
COLD END
ALUMINUM



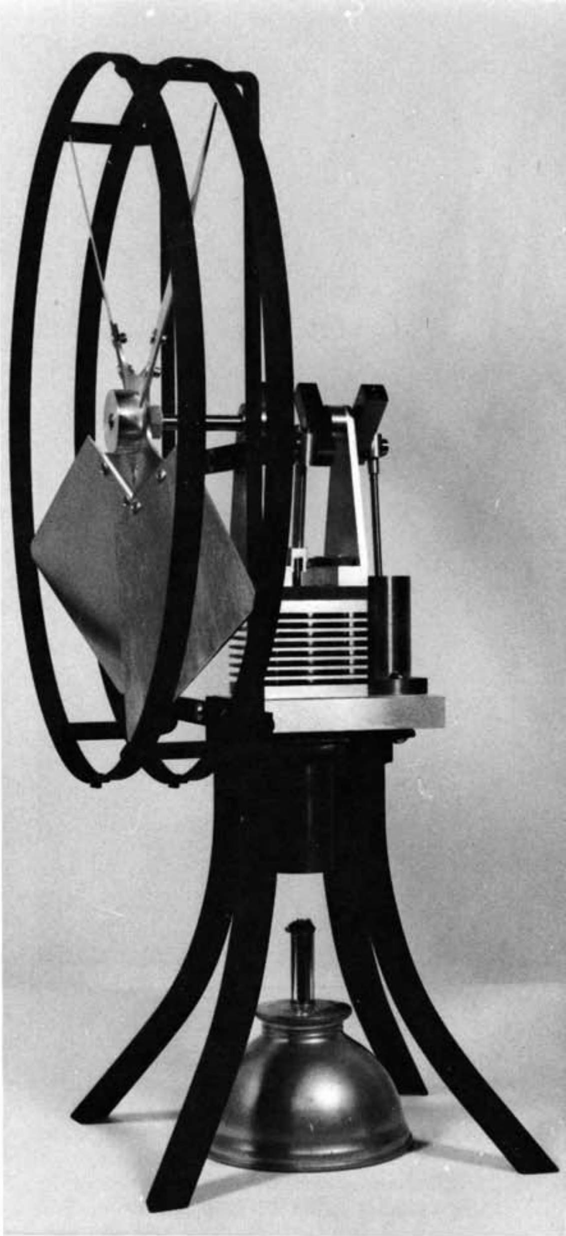
HOT END - C.R.S.

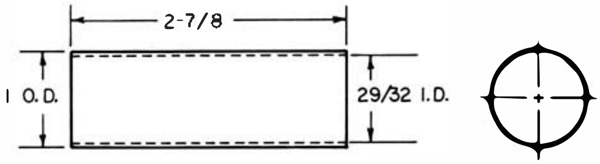


CYLINDER STUD - ALUMINUM
4 REQ

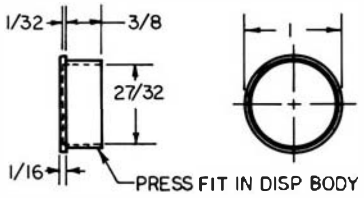


ENGINE BASE - ALUMINUM

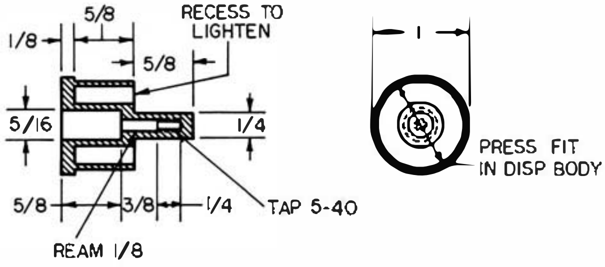




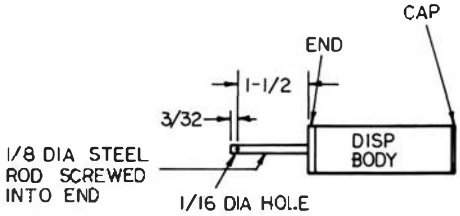
DISPLACER PISTON BODY - ALUMINUM



DISPLACER PISTON CAP
ALUMINUM



DISPLACER PISTON END - ALUMINUM

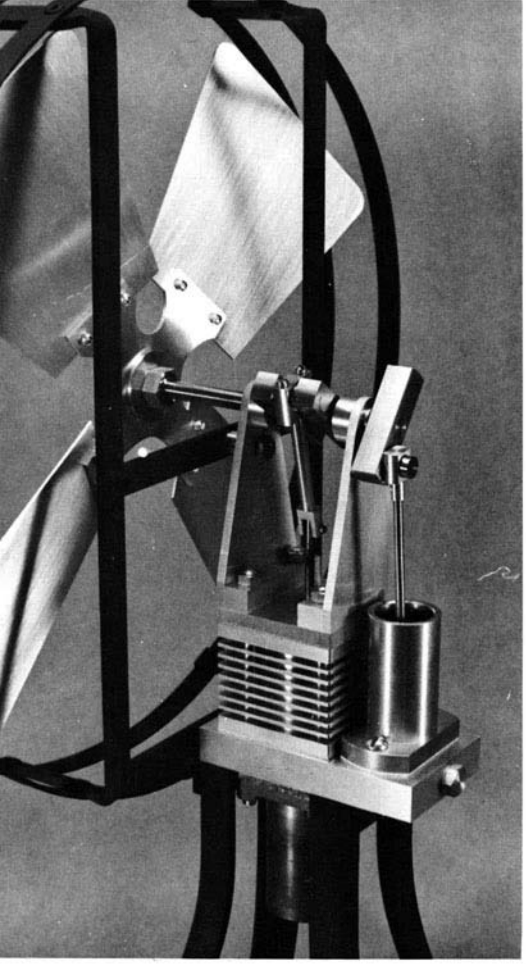


DISPLACER PISTON ASSEMBLY

Moriya is a project that can make you more comfortable. And, because of its novelty, provide perhaps more than the usual measure of satisfaction which accompanies the construction of any precision machine.

Until at least 35 years ago, hot air fans were produced commercially and were to be found in widely scattered parts of the globe. Despite the fact that the power output of the rudimentary stirling cycle engine is extremely low, it was ideally suited to the task of driving these fans because of its quiet, reliable, and maintenance free nature. These fans were very popular among farmers and missionaries in remote torrid regions.

Although hot air powered fans are no match, size for size, for electric fans, Moriya spins its 10 inch fan blade in excess of 500 rpm to provide a gentle



soothing breeze at a distance of two or three feet. Not having an electric table fan, Moriya has on several occasions done faithful and commendable duty alongside my drafting table or atop my desk. The project requires no castings and the machining can easily be handles on a 6 inch lathe.

Begin construction with the COLD END. Although it doesn't have to be a critically accurate job, it would be well to be a bit fussy about it since many parts stack above and below it and their relative alignment is important. The machining is straightforward with the possible exception of cutting the fairly deep fins in square stock. If you have never done it before, it might be well to experiment on a few pieces of scrap first.

Firmly chuck an ample length of 1¾" square aluminum bar to run true in the 4-jaw chuck, face the end, centerdrill, and bring up the tailstock center. Set up a parting tool to cut the fins. Setting the topslide parallel to the lathe axis will allow the use of its micrometer feed to precisely space the cuts. Use a good sharp (and sufficiently long!) 3/32" wide parting tool and set it dead square to the work. Set the topslide to zero, bring the side of the tool against the faced end of the bar, and lock the carriage. Back the tool clear and feed the topslide toward the chuck exactly 3/16" plus the width of the tool for the first cut.

The square shape of the work affords an ideal opportunity for devilish little chips to position themselves across the cut and jam the tool. To minimize the chance of catastrophy, loosen the drive belt as much as possible. Set the machine in lowest backgear and the finest automatic crossfeed rate. It is surprising how little belt tension is required to drive the workpiece in backgear.

Thus prepared, commence the first cut. Use a lubricant! Kerosene is usually recommended, but it might pay to try a fluid especially compounded for aluminum. I have found that lacquer thinner works extremely well, but it cannot really be recommended for machine operations because of the terrific fire hazard involved. Note the cross slide reading at the instant that the cut becomes continuous, and then continue the cut for another .218". Back the tool out, feed the topslide over exactly .147" and make the second cut. Repeat until all eight cuts have been made.

Remove from the chuck and saw off a little long. Chuck the finned block truly in the 4-jaw again with the sawn end out; best lay some flat strips between the jaws and the work to avoid marring those beautiful fins! Face the end to length and turn the 1-5/32" dia. spigot. Now drill and bore through the block to exactly 1-1/16" dia. Out of the chuck, check with a mike to be sure that the two mounting surfaces are exactly parallel; if not, wring the block onto a stub mandrel and take a skim cut across the plain end.

All that remains is the drilling of the four 3/16" dia. stud holes through the entire piece. It is important that these holes be parallel to the bore so use brand new or accurately resharpened drills. The employment of the milling attachment to locate and carry out the drilling would probably be best.

For the TOP COVER, chuck a short length of 1¾" square aluminum, face, and turn the spigot to a close fit in the bore of the cold end. Centerdrill and drill undersize for the gland; finish the stepped bore with a tiny boring tool. Chamfer the step to ensure that the gland will seat squarely when pressed in. Saw or part off a bit long. The top surface of the cover must be parallel to the spigoted surface and must be flat to ensure that the bearing stands will align nicely. Hold the cover against the faceplate with a drawbolt through the spindle or mount on a stub mandrel fitted with a nut. You can now face the top to correct width up to the drawbolt nut; the unfinished portion under the nut will not matter at all so long as it is not high enough to foul the displacer connecting rod at B D C. Use the cold end to spot the four 3/16" dia. holes and move on to the engine base.

Cut a piece of ½" thick aluminum to the outside dimensions shown in the drawing and mark out the location of the cold end. Position in the 4-jaw and bore through 1-1/16" dia.; then form the counterbore to fit the spigot on the cold end. You can now carry the ENGINE BASE over to the drill press for the remaining work. The stud holes are spotted through the cold end.

The HOT END is probably best made from solid 1½" square cold drawn steel bar even though most must be cut away! It could be fabricated from tubing and flat stock by sliver soldering but it would still need some truing on the lathe afterward — about the same amount of work either way. Do the lathe work at a single chucking. Firmly grip the stock in the 4-jaw, face, centerdrill and engage the tailstock center. Turn the outside to shape but about 1/8" oversize with the flange at the tailstock end. Follow by boring the interior to exactly 1-1/16" dia. Support the end with a large center or a stepped centerdrilled plug prepared in advance and turn the outside to size, taking lighter cuts as the wall becomes thinner. Part off to exact length.

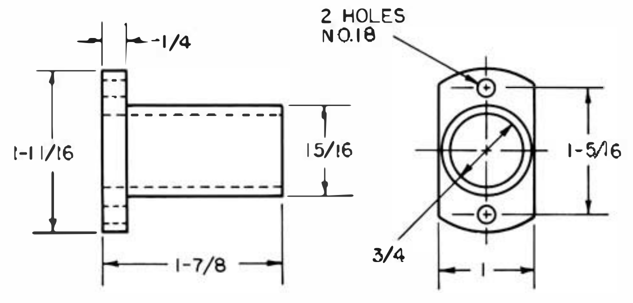
To locate the four holes in the flange, place a length of 1-1/16" dia. bar half in the cold end and half in the hot end and spot through the cold end. Be careful if you clamp the hot end in the drillpress vise not to permanently distort the thin-walled section; best fit a snug-fitting plug or clamp by the flange. If you feel a bit uneasy about the thin wall, it can be made a little thicker but engine efficiency will suffer due to heat loss to the cold end by conduction, although the thick insulating washers will assist matters.

Aluminum is used for the DISPLACER PISTON in the interest of light weight and ease of construction. Thermodynamically, a thin walled stainless steel piston would be much better. With the body cut to length and the ends lightly chamfered, the cap and the end can be made up. The cap is a simple turning, but the end must be a careful job to ensure that the piston rod will be sufficiently concentric with the piston to prevent it from making contact with the cylinder walls. Chuck a length of 1" dia. aluminum bar in the 3-jaw and turn the ¼" dia. portion, the lightening recess, and the stepped portion to a nice press fit in the body. Saw off and chuck truly — using the 4-jaw and dial indicator if necessary — and drill and tap as shown in the drawing. Press fit the pieces together carefully and make up the rod. The hollow piston must be airtight; test by immersing the piston in near boiling water. No bubbles should be seen emerging from the joints.

Now is a good time to make the GASKETS for the displacer cylinder stack. The 3/16" thick compressed asbestos gasket is best made in two or more thinner pieces. The large hole in the two 1/32" thick gaskets can be cut freehand with a penknife; the thick gasket can be treated trepan style by mounting a stout knife blade in the tool holder and tacking the material to a piece of wood secured to the faceplate. Cut the hole a little on the large side since the material will rise at the edge of the hole when cut causing the hole to close in under compression. The holes for the studs can be punched by means of a simple tool taking only a few minutes to make. Chuck a 2" lehgth of 3/16" drill rod truly, face, and centerdrill clear to the edge; harden and temper. Use a light hammer for the punching with hardwood or masonite for backing. Once again the cold end can be used for spacing the holes.

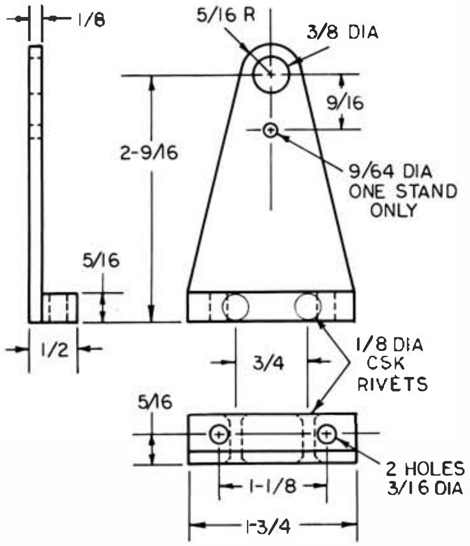
Make the four CYLINDER STUDS to the dimensions in the drawing. If necessary, you can open out the holes a bit, say to .191" dia., in the cold end, top cover, and engine base so that the studs will pass through easily and permit the pieces to bed down properly.

To make the GLAND, chuck a length of 7/16" dia. bronze in the 3-jaw and turn down to ¼" for a distance of 5/8". Saw off a little long and reverse in the chuck, gripping the piece by the ¼" dia. portion. Face to length, drill through and ream 1/8" dia. for a nice close fit around the displacer piston rod. This hole must be concentric with the portion to be turned; since twist drills often wander — especially when they mustn't — it is worthwhile to make up a .120" dia. D-bit and follow with the reamer.

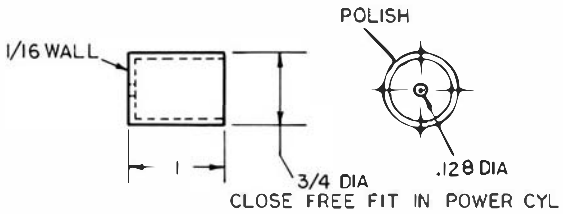


POLISH BORE TO REMOVE TOOL MARKS

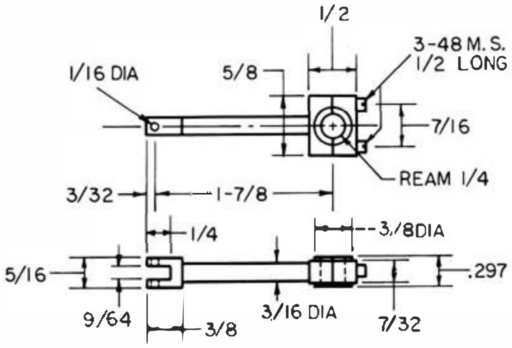
POWER CYLINDER
BRONZE



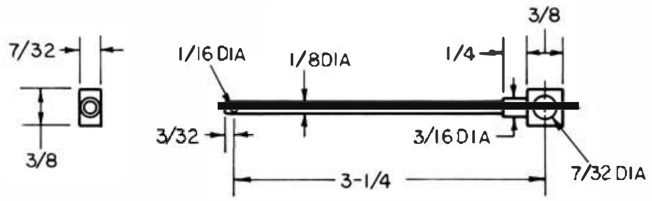
BEARING STAND - ALUMINUM
2 REQ



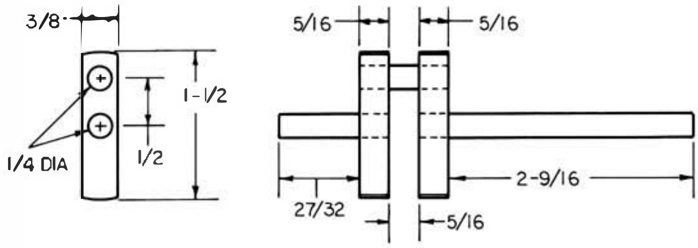
POWER PISTON
STEEL



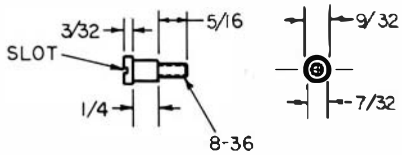
DISPLACER CONN ROD
ALUMINUM



POWER CONN ROD
STEEL ROD
ALUMINUM END

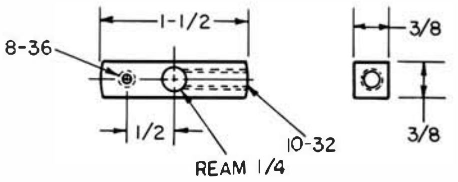


CRANKSHAFT - STEEL

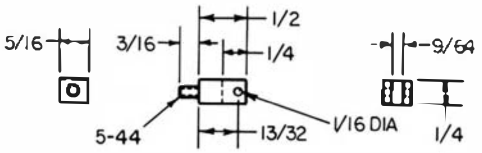


CRANKPIN - STEEL

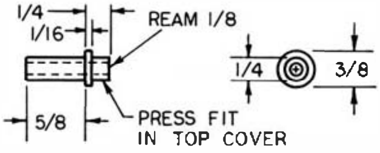
Now turn the end to 3/8" dia., a snug fit in the top cover recess. Further reduce the end to ¼" dia. for a length of 3/16"; this portion should be a good press fit in the cover. If your press fit turns out too loose to be fully trusted, you can save the job by using Loctite retaining compound. To check that all is well thus far, assemble the displacer cylinder stack with some spacers on the top cover to fill in for the absent bearing stands. The displacer piston must stay clear of the cylinder walls for its entire stroke.



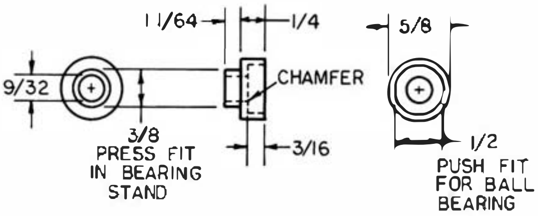
POWER CRANK - STEEL



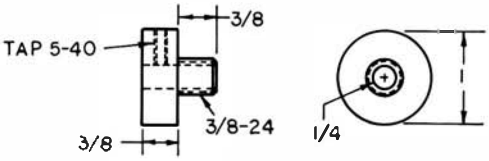
PISTON YOKE - ALUMINUM



GLAND - BRONZE



BEARING MOUNT - ALUMINUM - 2 REQ



FAN HUB - ALUMINUM

The BEARING STANDS are interesting jobs. The requirements are that they both be the same height, that they stand at true right angles to the top cover and that the holes in the base of the stands are correctly positioned for alignment of the bearing holes. Face two pieces of 3/8" aquare aluminum to a length of exactly 1¾". Drill the two 1/8" dia. rivet holes on ¾" centers equidistant from the ends and 5/32" from one edge and countersink on one side. Drill one of the mating holes in a 3" length of 1/8" thick aluminum plate about 1-7/8" wide and countersink. The wider portion of the square leg should be approximately flush with the edge of the plate which will be cut to final shape after machining. Slip a piece of 1/8" dia. rod through both pieces, rivet over to fill the countersinks, and file flush. Now drill the second hole through the plate and treat likewise.

Clamp a thick wide bar — say ½" by 2" — to the carriage with its edge parallel to the faceplate and its wide top surface square to the faceplate; if you have a milling attachment, hold the bar in the vise. Lay the bearing stand on the bar with the square leg hanging over the edge and, holding the leg against the edge, clamp securely. Use a flycutter to machine the width of the leg to the required 5/16". The result is a perfect right angle leg with a flat mounting surface. By bringing the stands to proper height, you can locate and drill the two 3/16" dia. mounting holes with micrometer precision to mate the holes in the top cover at the same setup. Carefully lay out the position of the 3/8" dia. hole, clamp the two stands back to back, and drill and ream; the holes must be square to the plate surface. Now the outline can be cut and filed as in the drawing. Don't forget the 9/64" dia. hole for holding the fan guard in the front stand.

Turn the BEARING MOUNTS to nicely take the ball bearings. Be sure to chamfer the stepped bore so the inner race of the bearing does not make contact. The mounts should press fit into the stands, but the 3/8" dia. spigot is long enough to permit rivetting over if desired.

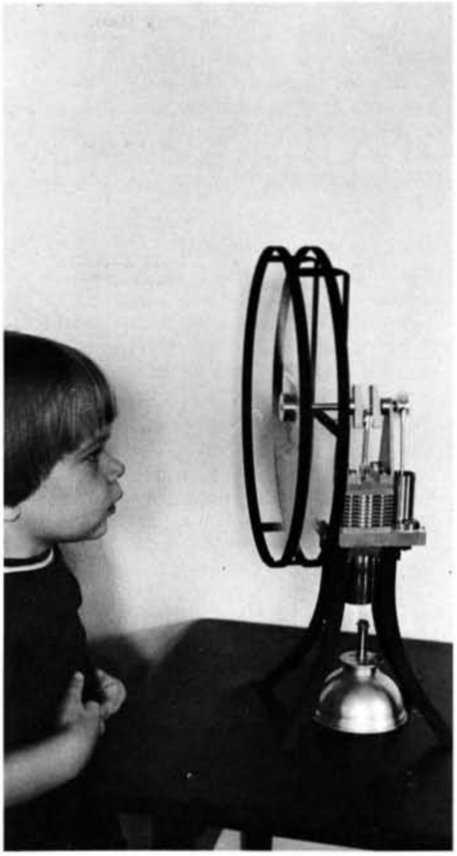
The CRANKSHAFT is built up from drill rod and bar stock. Cut the webs a bit longer than finished size from 3/8" square steel bar and reduce one dimension to 5/16" by facing or milling. Clamp the two and drill and ream the two ¼" dia. holes exactly ½" apart. You may as well make the POWER CRANK now also. If desired, the curved ends on the webs can be machined by mounting them on a stub mandrel fitted with a securing nut. Cut a piece of straight ¼" dia. drill rod 4-11/32" long for the main shaft and another piece 15/16" long for the throw. Countersink the holes in the webs slightly, slip the pieces together and soft solder. Then saw out the portion of main shaft between the webs. Cut two spacers from ¼" I.D. thinwall tubing to center the crankshaft between the bearings. The bearing stands with the shaft between can now be bolted atop the displacer cylinder; it must turn absolutely free.

Begin work on the DISPLACER CONNECTING ROD by squaring off the ends of a 5/8" by 5/16" or 3/8" rectangular aluminum bar about 2½" long. Drill and tap one end for the two 3—48 cap screws and, with a slitting saw, saw off a ¼" length. Bolt back together, drill and ream the ¼" dia. hole centered on the split line, and drill the 1/16" dia. hole through the other end; best determine the distance between these holes from your model. Chuck by the big end, centerdrill the other, bring up the tailstock center and turn the rod to shape. Saw the rod to length and file or mill the little end to shape, including the slot. Clamp the big end around a turned stub mandrel for reducing the end to proper width and turning the bosses. You can now add the rod to the engine assembly; teat for free working, shimming the cap if necessary. The 1/16" dia. pin through the little end and piston rod should be prevented from turning in the aluminum fork; otherwise, wear would be rapid. The pin ends could be threaded 0—80 and nuts fitted to hold it from rotating. A good lubricant for the big end and the piston rod is graphite or graphite grease.

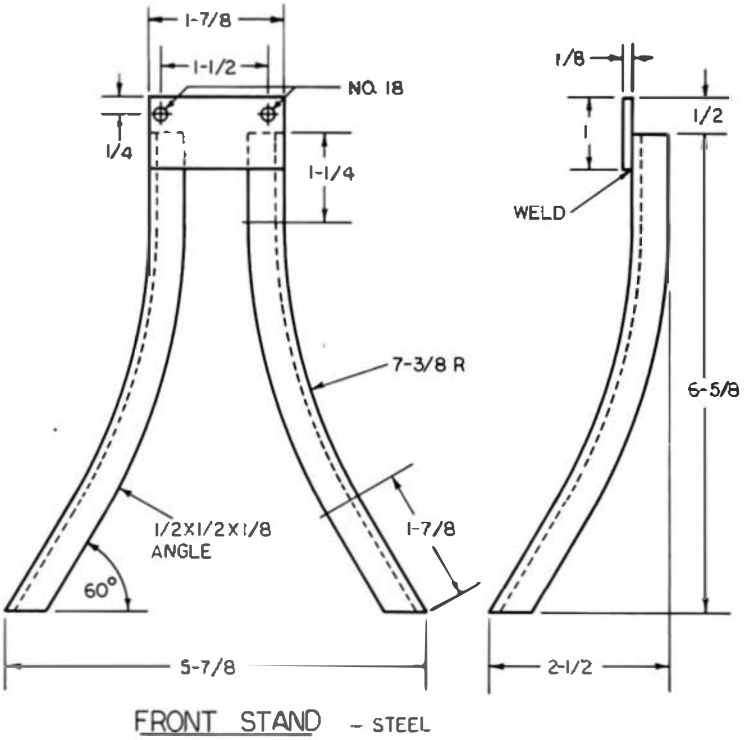
The POWER CYLINDER is an easy turning job, but care should be taken to obtain an accurate bore. A brake cylinder hone does a reasonably good job of removing the tool marks but resist the temptation to overdo it. A bronze cylinder was made for my model with a steel piston, but cast iron for both items would be better yet. Turn the piston and polish away the tool marks to a close but smooth fit in the cylinder. With the piston and cylinder surfaces clean and dry, the piston should fall through the bore when tilted, yet with the cylinder capped at one end and the hole in the piston plugged, the piston should lively snap back when pulled outward or pushed inward. Do your best here.

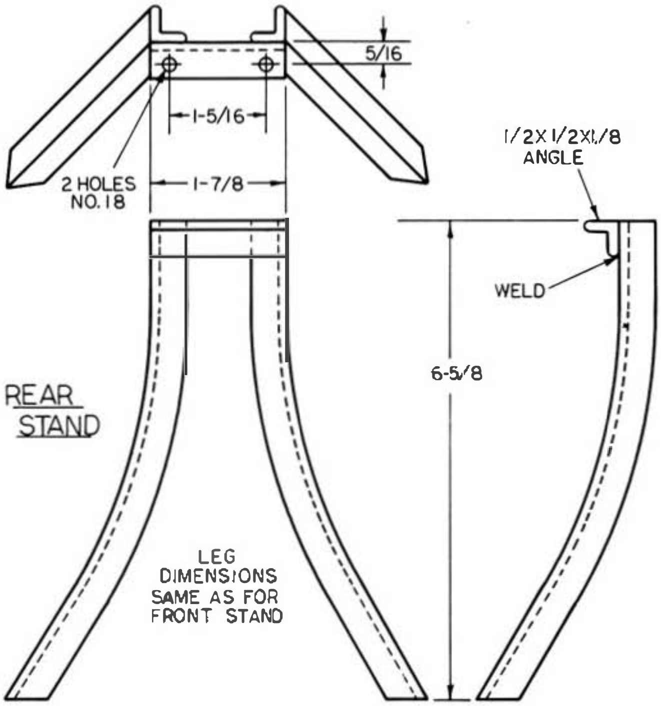
The POWER CONNECTING ROD is made in two pieces, a steel rod screwed into an aluminum end. If desired, the end can be bushed with bronze or teflon. Make the power CRANKPIN and the PISTON YOKE now. Use a small nut to secure the yoke to the piston — small enough to clear the ¼" hole leading to the passageway in the engine base. Make sure that the yoke seals the piston; apply gasket cement if necessary. Cut a 1/32" thick gasket for the cylinder and mount it on the base with 3/8" long 8—32 machine screws. Lubricate the power cylinder with dry graphite or dry molybdenum disulfide; oil would eventually find its way to the hot end and inhibit heat transfer. Set the cranks at about 90°. Check that the shaft turns absolutely free — no tight spots allowed here! Plug the end of the passage with a ¼—28 bolt and soft washer and make sure the engine is airtight. Moriya's engine is ready to come to life!

Secure a temporary flywheel to the shaft, apply a good size flame to the bottom of the hot end, wait about 30 seconds, and give the shaft an easy spin; the displacer piston leads the power piston 90° in the direction of rotation. Direction can be reversed by turning the power crank 180°.



The author's son (above) enjoys Moriya's gentle breeze on a summer day. The "Ky-Ko" hot air fan, depicted in the 1938 advertisement below, was about four feet high and well-known for its trouble-free performance. Reproduction of the ad is by David Swann.



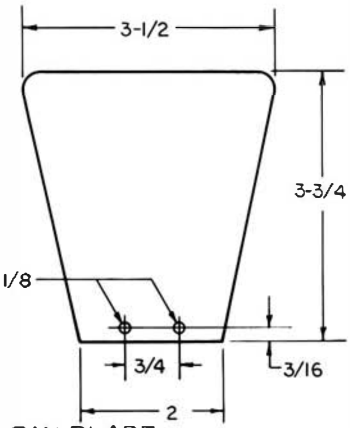


If Moriya is the first hot air engine you have made, it is highly probable that you will be content for some time to leave it as is and simply watch it quietly spin a nicely finished flywheel! But the remaining parts are non-precision jobs and therefore offer a pleasant and relaxing change from the careful engine work — especially from the feverish activity that occurs whenever an engine is nearing completion.

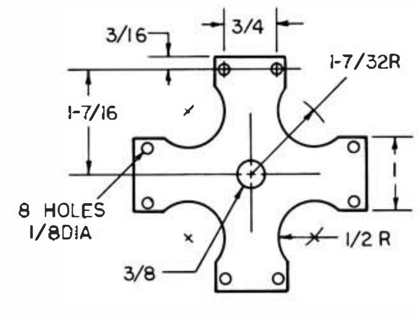
You will probably want to make the **FAN BLADES** first to "see what she'll do." Simple sheet metal work finished in one evening. I purchased a pop rivet tool to fasten the blades to the web and fell in love with the device. Since then it has been invaluable for restoring broken toys and sad faces! You may wisb to experiment with the pitch angle of the blades for maximum breeze, or perhaps even try curving the blades.

The legs for the **FRONT STAND** and the **REAR STAND** are bent up from ordinary ½" angle iron. The astute engineer will note that many of the dimensions in the drawings of these items are redundant; the point is, of course, that you can follow those most convenient for your shop. The dimensions need not be critically followed; but the legs should turn out identical for the sake of appearanee. To this end, I made a jig by bending a length of angle to the desired shape and reinforced it by welding short lengths of angle to the back. Then four generous lengths of angle were cut, placed in the jig, clamped by one end in the vise, and bent into the jig with the aid of a pipe handle slipped over the free end of the leg.

After bending, the legs can be cut to exact length and welded to the mounting pieces. The rear stand is secured to the engine by 8—32 acrews that enter the tapped holes in the engine base below the power cylinder. An alternative would be to use long screws to hold down the

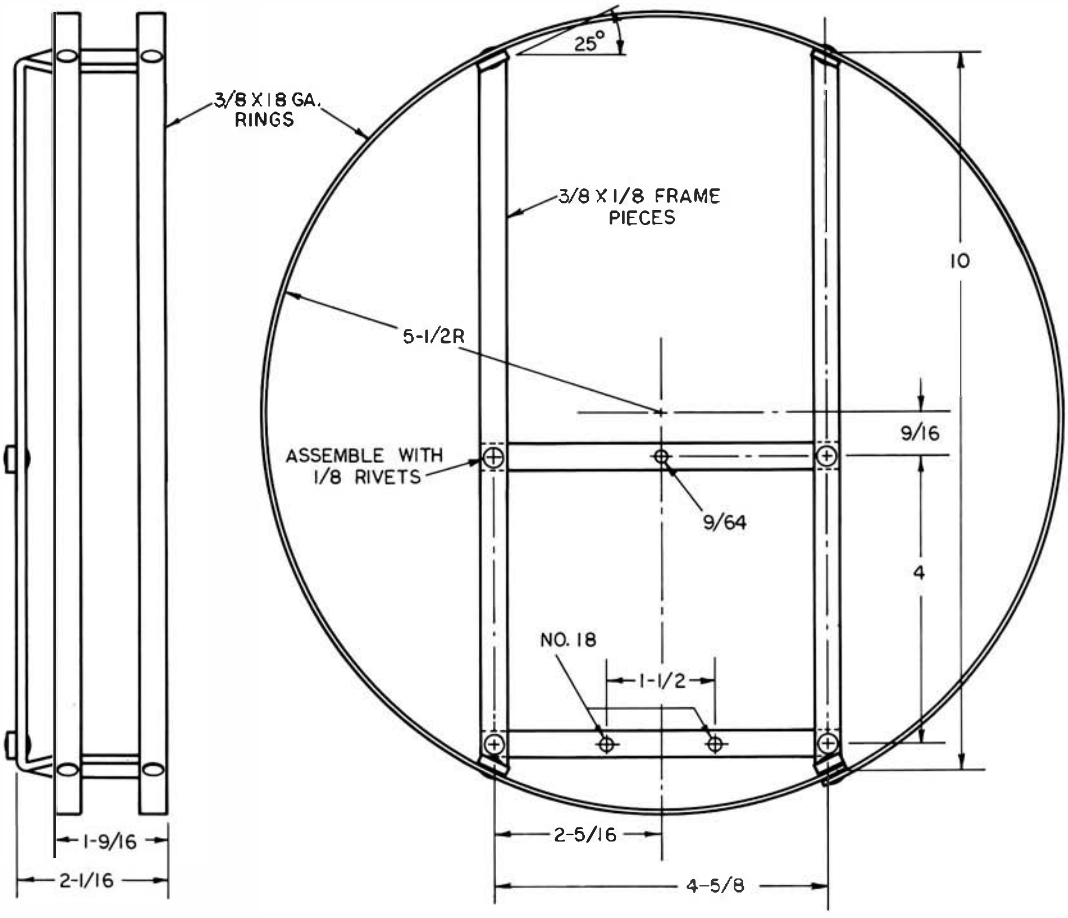


FAN BLADE - 18 GA. ALUMINUM
4 REQ

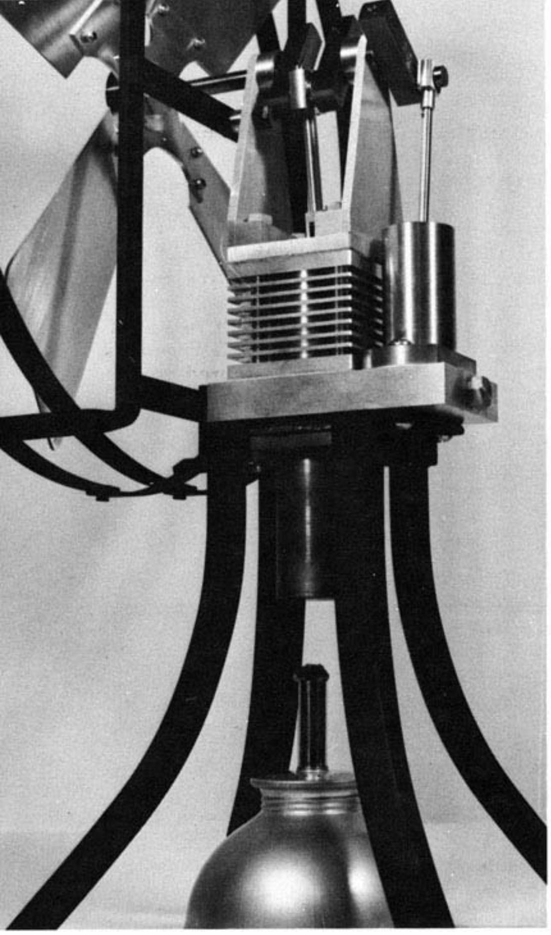


TWIST EACH TAB 20°

FAN WEB
14 GA. ALUMINUM



FAN GUARD - STEEL



power cylinder and nuts on the underside to capture the rear stand. The front stand is secured by two 8—32 screws to the front of the engine base; these screws also pass through the lower cross bar of the fan guard.

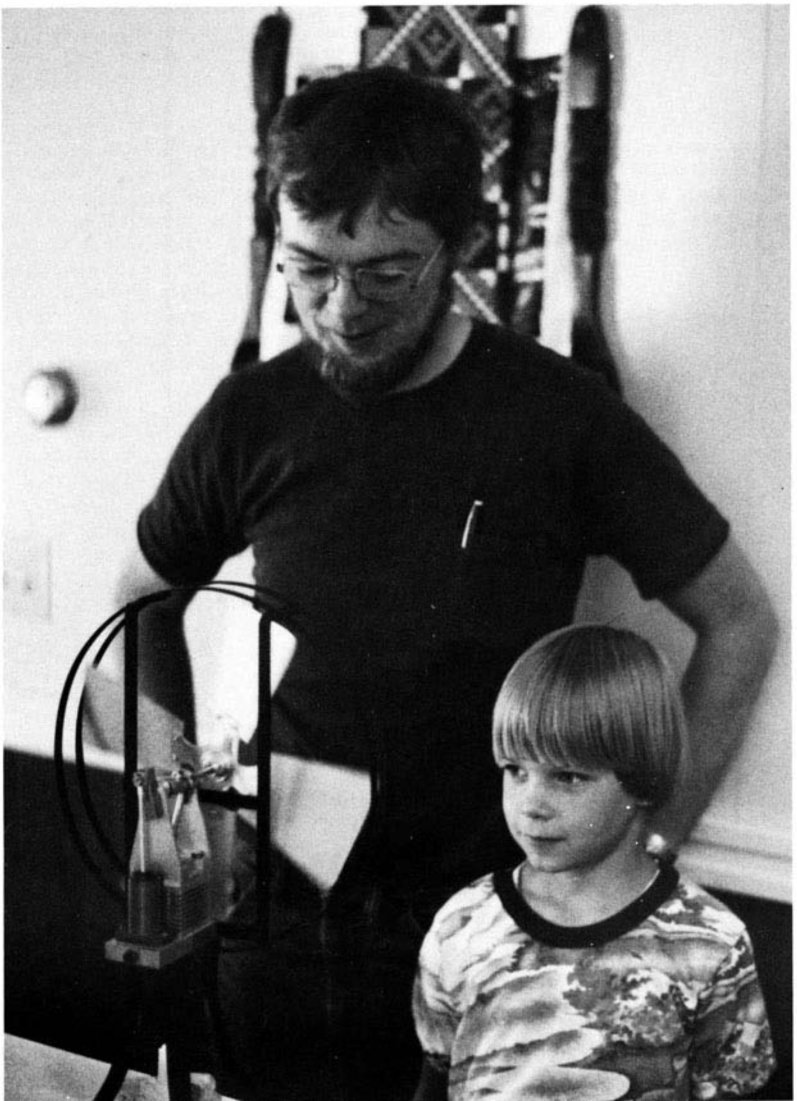
I found the FAN GUARD to be an interesting task — once again the pop rivet tool could be used! Cut out and drill the cross pieces and bend the U-shaped uprights. You may wish to increase the depth of the guard; in fact, if you use a larger pitch angle for the fan blades, the depth must be increased. Simply increase the 2-1/16" dimension the desired amount and increase the 1-9/16" dimension by the same amount. Twist the legs 25° taking care that the legs are truly prependicular so that the rings will line up nicely. Drill the required holes in the uprights and rivet on the cross pieces securely. Turn a 3/8" O.D. by 9/64" I.D. by 3/8" long aluminum bushing and mount the assembly to the engine with the bushing between the upper cross bar and the front bearing stand, a 6—32 bolt passing through the three.

Bend the rings around any convenient round object to produce a diameter of approximately 11". Drill a 1/8" hole near one end of each and temporarily bolt to the frame. Adjust the positions of the rings till they form round identical circles, temporarily clamp in position, and mark off the holes and the exact length. Remove the rings, drill the holes, cut to length, and rivet to the frame. The lap joint should be made at one of the legs as depicted in the drawing for maximum rigidity.

With the stands and guard shaped to your liking, finish these pieces by painting. Flat black was used on my Moriya and contrasts nicely with the bright aluminum engine surfaces. The blades can also be painted if desired; perhaps grey or dark green. All that remains now is the ALCOHOL LAMP.

Jewelry and watch repair supply houses can furnish cute little alcohol burners which may be the right height for the job, but an ordinary oil can is easy to adapt to our purposes. Remove the spout from the filler cap, open out the hole if necessary, and solder a length of thinwall 3/8" O.D. brass tubing in its place. The top of the tube should be about 1" below the bottom of the hot end. Pack in string for a wick, but not too tightly so that the tank can vent itself.

Finally, you may wish to fit a flame shield against the front stand as on the "Ky-Ko" fan in an attempt to prevent the products of combustion from being pulled along with the cooler air. Also, some thick asbestos insulating material placed on the underside of the engine base will help keep the temperature of the cold end lower.



The author and his son, Victor, enjoy firing up Moriya on any occasion, just for the satisfaction of watching it operate.

With a few pleasant hours in your shop, you can build

A Steam Turbine

by Dale Hobson

Photos by the Author

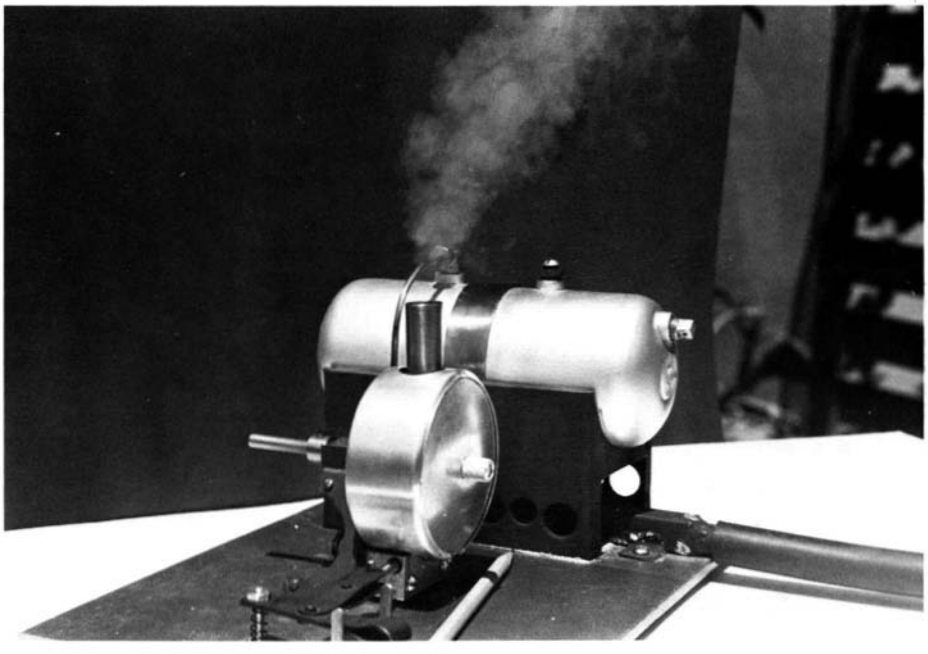
Several years ago, while watching my latest creation, a small two-cylinder stationary steam engine work, it occured to me that maybe the proponents of the steam turbine had something. Namely: — one moving part. So, off to the library to find out what I could. Well, they had a very simple principle and some sophisticated designs.

I started out to use both but after more discarded designs and material than I care to admit to, about all I retained was the simple principle. The design is prettybasic. It operates on 20 lb.-40 lb. of steam and actually whines at top speed.

There is one thing this little turbine can do that a lot of the sophisticated ones can't, and that is reverse. Even while turning up at top speed it can be thrown into reverse and it will stop, and start winding up in the opposite direction almost immediately with no harm done to anything.

It won't cost an arm and a leg to build either. The cost will be less than a night out with your girl friend, or even your wife. It is not complicated to build and, I believe, will be enjoyable.

Just where you start is pretty much up to you. I do suggest that you study the drawings and instructions first, however.



Turning up under full steam, the turbine whines and sends up whisps of steam

THE SUPPORT STAND

The stand is made from .028 mild steel, or similar. Scribe the lines as shown in the lay-out pattern; a coat of ink will make the lines stand out better. Center punch and drill the four holes where the broken lines come together to give relief to the corners when bending. The seven other small holes are for rivets, so you better drill these, too, while you have your 1/8" drill working and while the metal is still flat. Drill the two holes in the base for the hold down screws, but do not drill the 1/2" hole now. The edge of this hole comes very close to where the bend is made and it will be neater if you wait until after bending.

Now cut along the solid lines, getting the stand to its shape and also cut along the solid lines which end in the relief holes.

Making the bends will be much easier if you cut a block from a piece of 2" x 4" and another one from 1" wood, both the size and shape as shown in the rear view, or the part of the lay-out pattern enclosed by the broken lines. Place one block on the metal so its edges are along the broken lines shown in the drawing and the corners partly cover each of the four relief holes. Without allowing it to move, drill through at least two of the rivet holes and through the block. Lay the metal aside. Line up both blocks so their edges are even and, using the first block as a template, drill the 1/8" holes into the other block. Then, with the metal between the blocks and a couple of short pieces of welding rod through the holes, the metal won't shift while bending.

Clamp this concoction in the vise with the top up. Bend the top 90 degrees over the thick block. Then bend the 3/8" overhang on each side down to conform to the block. Turn the thing upside down and do the same to the bottom. Then you can bend in the two sides to conform to the block. The blocks have now served their purpose.

Before drilling the four rivet holes on through the sides into the top and bottom sections, use a square and be sure the top and bottom are at 90 degrees to the front. Then go ahead and drill and rivet the stand together. Now you can drill the 1/2" hole in the front and file and clean up the edges and corners. With this done you can get started with the rotor housing.

THE ROTOR HOUSING

Start with a round disk 2-7/8" diameter with a 1/4" hole in the center. This is of the same material as the base, .028 mild steel. This should be flat and perfectly round. Next cut the piece of .028 mild steel 1¼" x 9-1/8" as shown in the drawing. Make the hole for the exhaust stack and the 1/8" hole, then form it into a circle over a can, or something similar, beging careful not to kink it where the stack hole is. Lay the disk on a flat surface and, with the short side of the edge of the 1-1/4" piece on the flat surface, draw it up until it fits snugly all the way around the disk.

To do this, and to hold it in place while brazing together, I recommend a hose clamp that has threads in the perimeter of the clamp. Also, if you cut a 1/2" strip of aluminum (.040 or such out of some scrap) and put between the clamp and the housing, it will prevent any brass from sticking to the clamp. The walls of the housing must be perpendicular to the disk. The joint of the 1-1/4" piece at the bottom should not overlap. Trim if needed and then take one of the little scraps you cut from the ends of the 1-1/4" piece, place it over the joint on the outside and, with the walls perpendicular, braze it in place for reenforcing. Then, with the disk and the edge of the wall even all the way around, make a few spot brazes and then braze it all the way around on the inside.

File a little flat place on the bottom of the disk so it conforms to the opening in the 1-1/4" piece. This is where the valve goes and we want the valve to fit tight against the edges of the housing (except at the front) and also against the base when we put it together. There should be about 1/32" between the valve and the housing at the front. This is to drain off any condensed steam. One thing more — drill a 1/8" hole at the very bottom, the same distance from the front edge as the one at the top. These two holes are for a piece of 1/8" rod which will hold the front of the rotor case on.

Although it is possible to fabricate the rotor housing with lead solder, which I have done, I recommend brazing. Now for the next step, which is the exhaust stack.

Make the stack from a short piece of 1/2" or 5/8" copper tubing. Flare one end a little and with this end annealed (to anneal heat to cherry red and plunge in water), the aid of a piece of pipe or similar and a hammer, you can make it conform pretty close to the shape of the housing. Then solder it in place taking care to see that it is perpendicular to the bottom opening, as this opening will determine the position the housing is fastened to the base. When polished, the copper and aluminum in contrast to the painted stand gives a rather pleasing appearance.

THE BEARING BLOCK

The bearing block is made from a piece of aluminum or brass 3/8" x 3/4" x 1-1/8". Drill and ream to 1/4" a hole lengthwise through the center of the block. A small hole, say 1/16", is drilled from the top into this hole to serve as an oil hole. Two holes for 6-32 machine screws (use No. 25 drill) complete the bearing block if the ends are square and smooth.

One end of this block will butt up against the back of the rotor housing, so clamp it in place on the top of the base. Use a 1/4" rod to line up the hole in the block and the hole in the housing. Clamp the housing to the base so that the opening in the bottom of the housing will be such that the valve will be parallel to the bottom of the base. Then you can drill and rivet the rotor housing to the base.

Before drilling the holes for the machine screws which will fasten the bearing block to the base, make sure the block is aligned so that the rotor will have equal clearance from the housing all the way around. When you have done this and secured the bearing block to the base with the machine screws, lock washers and nuts, you can prime and paint.

THE ROTOR

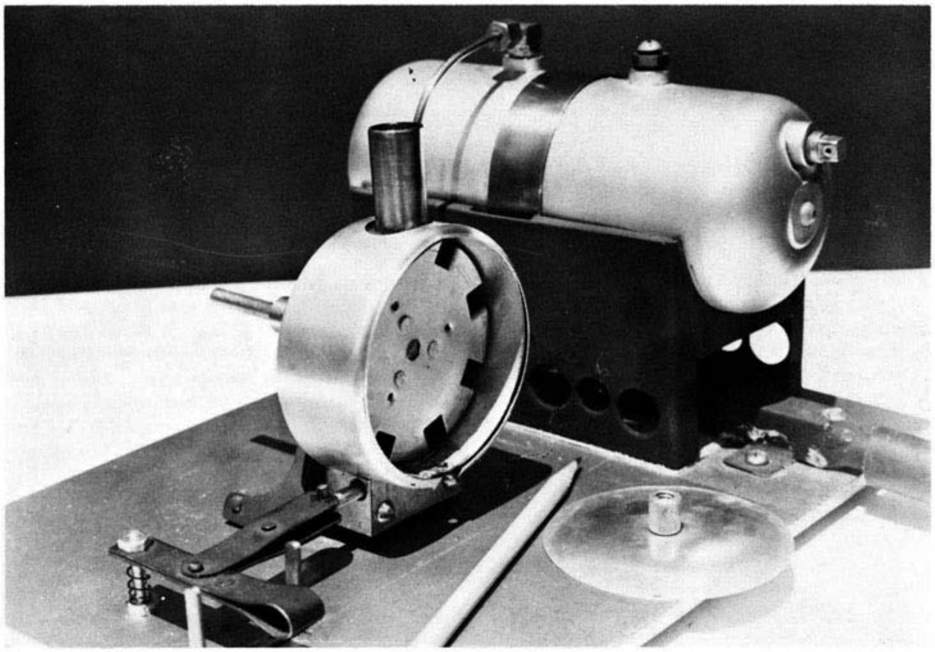
The rotor is made starting with two aluminum disks 2-11/16" in diameter with a 1/4" hole in the center. Trying to cut these with only shears is not satisfactory. Because of the speed at which the rotor will turn, balance is important. You can, however, make them on your lathe. If you don't have a better set-up, try this: Mark off two circles on a piece of .020 aluminum at least 2-7/8" in diameter and, while you're at it, making a couple of extra ones to allow for spoilage isn't a bad idea. Drill 1/8" holes through the centers and cut out the disks with your snips. Then mark and cut two pieces of smooth 3/4" pine board in a similar fashion. (I don't mean with your snips, I was referring to the size and shape.) Even if the two pieces of board are only sort of round, it will help. Drill 1/8" holes through the centers of these too. Put a piece of 1/8" welding rod through the holes with the two aluminum disks sandwiched between the pieces of board. Clamp them together, pull out the welding rod and make the hole 1/4" through it all.

Also, we need a couple of 1/4" nuts and two large-area flat washers with 1/4" holes. These might be a little troublesome to come up with, at least with a large enough area, so just take a couple of pieces of 1/8" flat iron 1-1/2" x 2", or similar, and drill 1/4" holes through their centers. Now this stuff is all ready, it's time to go to the lathe.

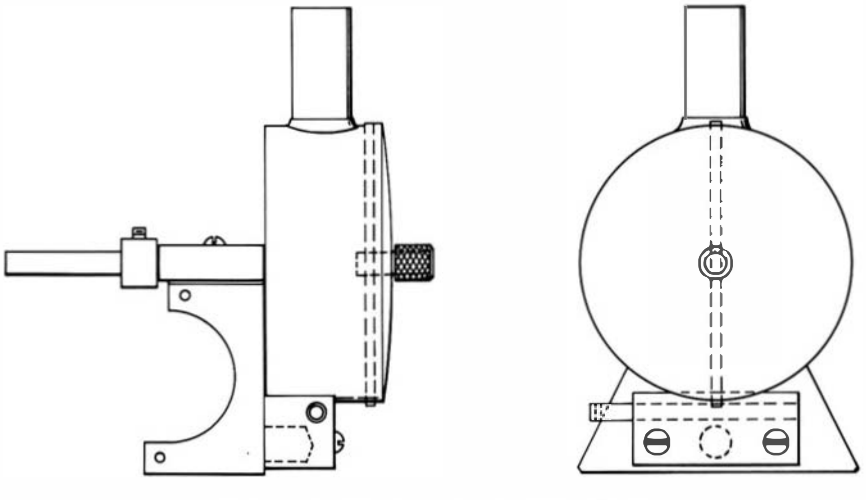
Take a piece of 1/2" steel rod or larger, long enough to chuck firmly and leave enough sticking out to put the washers, boards and disks on, plus at least 1/2" for the nuts. Center drill the end and then use the tail-stock center. Turn down to .248 with a square shoulder at the headstock end. Back off the tail stock and carefully run at least 1/2" of threads on the end with your 1/4" die and some cutting oil.

With this completed, put one washer up against the shoulder, then the wood pieces with the disks between the other washer and the two nuts. Before tightening the first nuts, put the tail-stock center firmly into place and then tighten the nut, but good. The second nut is a jam nut. Now you can go ahead and turn the disks (and the wood) down to size. The sharp tool bit, ground with plenty of relief and taking small cuts, will get the job done.

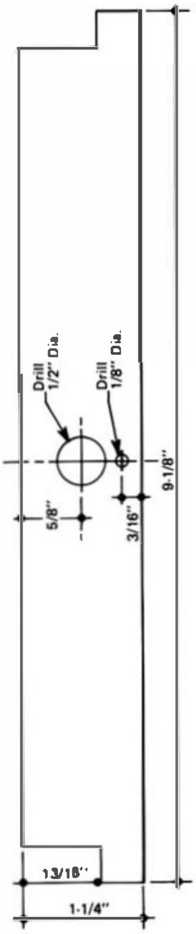
To finish the rotor halves, a jig is necessary. You can make it from 3/8" square steel stock. Take two pieces about six inches long and two pieces about one inch long. The one inch pieces go between the longer pieces at their ends and all on the same plane. Use machine screws. Two will be needed at one end, keeping the screws as far apart as practical, and still go through the one inch long piece. Only one screw is needed at the other end to hold the long pieces tightly together with a 3/8" space be-



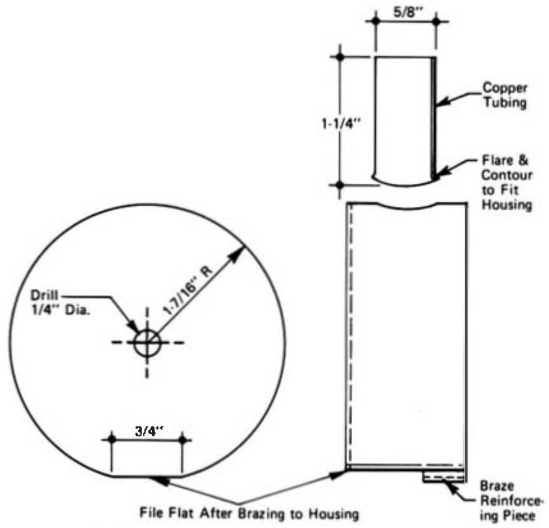
The Steam Turbine at rest to show size in relation to pencil.



ASSEMBLED TURBINE - WITHOUT CONTROL HANDLE OR BASE



ROTOR HOUSING LAYOUT



HOUSING BACK
(.028 Mild Steel)

ROTOR HOUSING

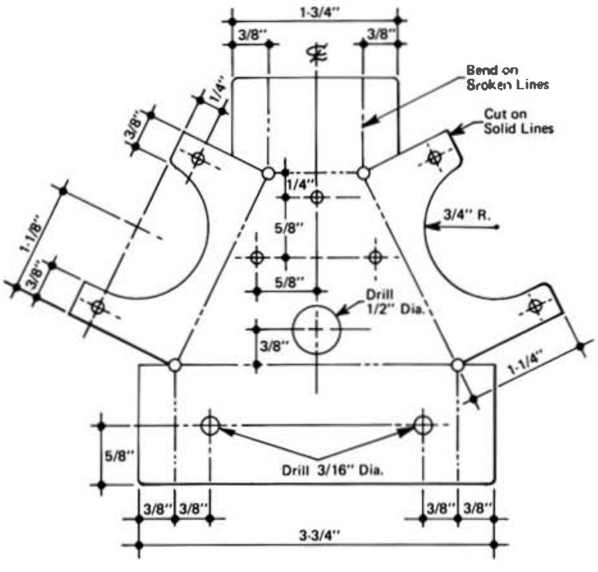
Drawings by E. T. Larson
from originals by Leo Egan

tween them (except at the ends).

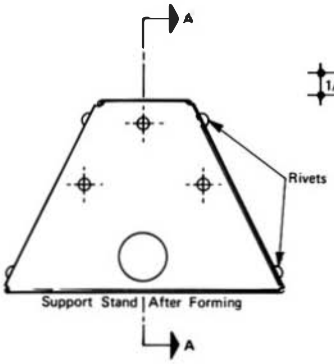
At the end with the two machine screws, drill a 1/4" hole from the top and in the center of the one inch piece. This is to accommodate a short 1/4" rod and is where the center hole of your disks will go. One more piece of this stock, about 2-1/4" long is required. This will do the cutting and bending. Grind one end of this piece square. Then at this end, but along one side, which will be the bottom, grind a bevel of 10 degrees, or so, that extends back about 1/2" from the end. This piece goes in between the two long pieces and is hinged at the end opposite the bevel by drilling a hole through all three pieces and using a machine screw to hinge it by. The hinge point is located just so the cutting end will cut in 3/8", or slightly less, from the edge of the disk. The bevel, of course, goes down. On the inside of the side rail where the bevel is, it will be necessary to remove enough material with a file to accommodate the vane when it is bent over. Also, you should round off the top inside edge a little so the bend radius is not too sharp. It will be easier to do this before assembly. I waited to mention this so you could see its purpose. When you have it put together, including the short piece of 1/4" rod in its hole, all that remains is forming the vanes.

Around the circumference of the disk, mark off eight equal divisions with a scribe. The divisions are 45 degrees apart. With the 1/4" rod through the center hole of the disk and the aid of your vise, you can go ahead and cut and form the blades. Holding the disk down firmly with a small block will help to make neater bends.

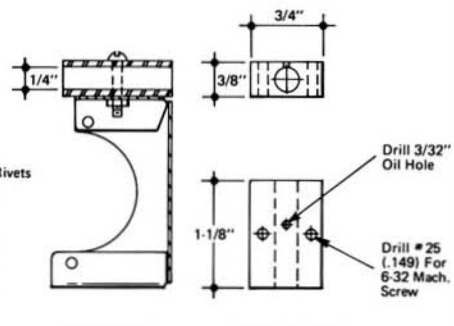
With two of these rotor halves that suit you, it's time to finish the rotor. A piece of 1" round aluminum, cut enough thicker than 3/8" to allow for facing off both sides is needed. If you can't get aluminum, steel will do about as well. Chuck this in your lathe, center drill it and then drill and tap it for 1/4" threads. Next take some 1/4" steel rod about 3-1/4" long and run some threads on one end of it for distance of 3/8". Thread the one inch piece onto the rod and really jam it up tight. Use vise-grips or something. Face off both sides of the 1" piece and get the thickness down to 3/8" and make it run true. Before taking it out of the lathe you can make a light mark with the tool



SUPPORT STAND (.028 Mild Steel)

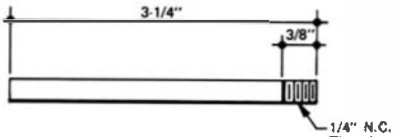


Support Stand | After Forming

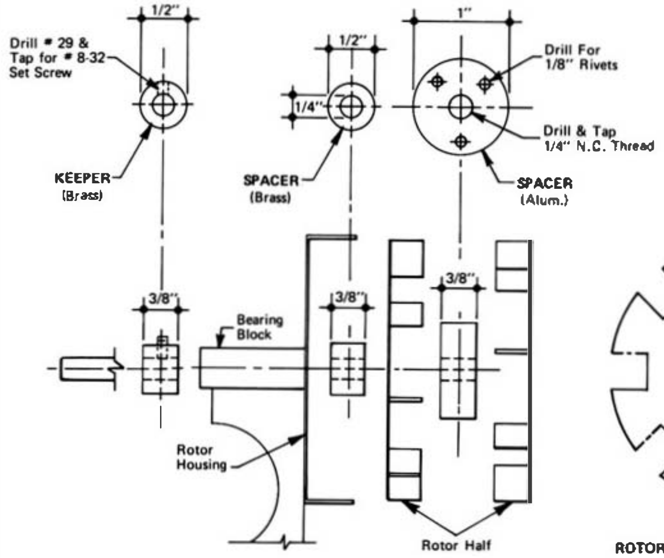


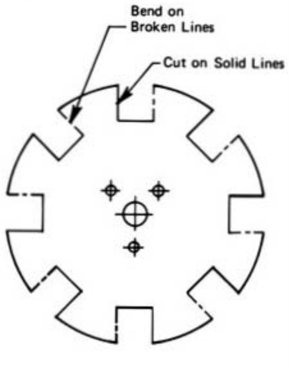
SECTION A-A

BEARING BLOCK (Brass)



STEEL SHAFT





ROTOR HALF - LAYOUT PATTERN (.020 Aluminum)

on the outer face about 5/32" in from the perimeter. When you take it out of the lathe, mark for three equidistant holes around this mark and drill for 1/8" rivets. Do this on a drill press so the holes are parallel to the shaft. Then getting the holes through the rotor halves will be simple. After you have drilled and deburred the holes is the best time to chuck the one inch piece up in your lathe and, with some fine emery cloth, polish the shaft so that it turns freely in the bearing block.

Having done this, take one of the rotor halves and slip it over the shaft so that the vanes are pointing away from the 1" piece and, without allowing it to move, drill the three rivet holes through it. Take it off the shaft, deburr and put it on the other side with the vanes pointing the same direction they were, in toward the shaft. Put a couple of rivets part way in to hold it in place, take the other rotor half and put it over the shaft with the vanes pointing in the opposite direction. With the vanes on this half positioned just half way between the vanes on its counterpart, drill the holes through it and rivet the project together.

To complete the rotor about all that's needed is two pieces of 1/2" round brass. Drill 1/4" holes through the centers on your lathe and face off the ends to a length of 3/8". That finishes the spacer. Half way along the length of the other one, drill into the center hole and tap for an 8-32 set screw. Put the spacer on up against the rotor and push the shaft all the way into its bearing. File a little flat spot on the shaft just beyond the besring block where the set screw will set; it will prevent scoring the round part of the shaft. Polish off any roughness the file may have left before taking the shaft out. For the final assembly, leave a few thousandths end clearance between the retainer and the bearing block, being sure the sbaft turns freely in the bearing. Don't forget a drop or two of light oil once in a while, particularly on final assembly.

At this point, you have completed the engine and ahould have a goodly amount of satisfaction from this project.

To make it operate, however, you will need to make the controls and control valve that will permit you to stop, start and reverae this little power plant. It takes a little study and attention to details but once you have them in mind, you are ready to go.

THE CONTROL VALVE

The control valve is the tricky part of the turbine. A drill press with vise, is almost a must. A little patience may come in handy, but only a limited supply of cuss words should see you through.

The valve is made from a piece of brass or aluminum 3/4" x 3/4" x 1-3/4". All surfaces should be square and smooth. Half way between the ends of this block mark off center lines on what will be the top and back. On one end scribe a line 3/16" down and parallel to the top. Do the same from the front edge. At the junction of these two lines, make a center punch mark. Then, with the block on its end and lined up accurately in the drill press vise, drill a 15/64" hole through the length of the block. I suggest, though, that you run a smaller drill through first. After you have the hole drilled, bevel the ends a little. This will help in getting the "O" rings on the piston started in.

Now for the .040 holes which will require a No. 60 drill. Along the top and 3/16" from the front edge, scribe a line the length of the block. This will be directly over the center of the 15/64" hole. On this line, and 1/4" from the center line, make two center punch marks. If you make these marks a little deeper, with just the point of a small drill, it will help get the No. 60 drill started at the required angle. The two .040 holes are drilled into the 15/64" hole at an angle of 30 degrees and are 120 degrees apart, so it will be necessary to set the block in the drill press vise at an angle of 60 degrees from the horizontal.

Getting the little No. 60 drill started at this angle may use up a dab of your patience, but it can be done. Drill from the bottom-most punch mark, down toward the end of the block, lifting the drill out several times to clean it. With these two little holes drilled, drill the two holes for the machine screws, as shown in the drawings. Next, drill the 11/32" hole in the back of the block as shown, being careful to stop the drill so that you leave a little wall between the end of this hole and the 15/64" hole. Next drill a 1/16" hole from the bottom of the 11/32" hole, where the bevel starts, into the nearest part of the 15/64" hole. Now you can tap the 1/8" pipe threads and go ahead and ream the 15/64" hole out to .250.

It is important that this hole has a smooth finish. It's the cylinder of your valve. The two innermost edges of the No. 60 holes (where they come through the cylinder wall) will have sharp edges and, if you blunt these sharp edges a little, it will add considerably to the life of your "O" rings. I use a bent pick, but a lot of things would work as well. Be careful not to damage the wall and, after this operation, make sure the No. 60 holes are clean. You will probably want to run the reamer through again.

Now it's altogether possible that your two No. 60 holes aren't exactly the same distance between centers as the drawing calls for. (I have a jig that I drill these holes with and the drawing was made from this.) However, it's no big deal if they aren't exactly the same as the drawing. What is important though, is to know just where these holes come through the cylinder wall, so you will know just how far apart to make the grooves for the "O" rings on the valve piston. With a sharp scribe and your No. 60 drill stuck in the holes (one at a time) you can make a drawing on the front face of the valve housing that will tell you what you need to know.

The piston made from 3/16" brass rod is pretty simple and, I believe, explained sufficiently in the drawing. The grooves for the "O" rings should be close enough together so that in the OFF position, they seal the steam from both outlets, and still far enough apart so the 1/16" inlet hole and one outlet will be between the "O" rings in the running positions. It will be necessary to grind a lathe tool to cut the grooves. The shape of the "O" ring will tell you how to grind the tool, but make it a bit narrower than the groove will be, so you can move it back and forth slightly and not cut on both edges at the same time. The width of the grooves should just accommodate the "O" ring and be deep enough so the "O" ring fits snugly in the cylinder without excessive drag. It is a matter of cut a little and try the fit until you get what you want. After the first groove you can take a reading and know how deep to cut the other groove.

The "O" rings are 1/8" I.D. and 1/4" O.D. You can get these from an auto parts or hardware store. Wouldn't hurt to pick up a couple of extra ones. They aren't expensive. Oil the rings and the cylinder wall before assembly and once in a while thereafter.

When you pick up the "O" rings, also get a straight brass compression fitting with nut and ferrule for 1/8" copper tubing. This fitting must have 1/8" pipe threads on the other end. Also you need some 1/8" copper tubing for the steam supply line from the boiler to the valve.

With the brass fitting tightened in the control valve and the valve center in the opening of the rotor housing and held firmly against it and the base, drill the holes for the machine screws in the base, put in the screws and tighten the nuts.

The front cover of the turbine is a 3" diameter disk with a 1/4" hole in the center. It is held in place by a short length of 1/4" rod with threads on one end and a 1/8" hole drilled through the other end. A piece of 1/8" rod, upset on one end so it won't slip through the hole and cut a little longer than the diameter of the rotor housing, goes through the 1/8" holes in the housing to hold the 1/4" rod. You can make a respectable looking nut from a short piece of 1/2" aluminum rod.

If you have the rotor in place you can finish putting your little turbine together.

There is one more thing I should mention here. That is the trim ring which goes around the rotor housing. It doesn't have anything to do with how well the turbine operates but it does have a lot to do with its appearance and eye appeal.

About now you may be saying, "To heck with that. I want to see how this thing runs." I don't blame you. After you see how it runs and feel like dressing the little demon up a bit, here is how you can make the trim ring.

Turn down a piece of wood supported in your lathe by whatever means you choose (the Rotor Section may help give you an idea) to a width of slightly over the thickness of the turbine housing and the diameter a little less. Round the edges a little. Cut a piece of your .020 aluminum 1/4" wider than the housing and long enough so the ends just meet when clamped around the wood. Cut out from both ends to clear the valve and base. Make a hole for the stack in the middle. This hole should be at least 3/16" larger in diameter than that of your stack. Clamp this strip (with a protective strip between it and the clamp) down on your wood circle so that about 1/8" overhangs both edges. Now, with your best metal spinning technique, turn the edges down against the sides of the wood circle. Use a fast spindle speed and a block of wood to do this and start in from the edge applying sufficient pressure with the block to roll the edges down.

You can hold the trim ring in place on the rotor housing by drilling a small hole back a little from each end and bending a small tension spring to snap in the holes.

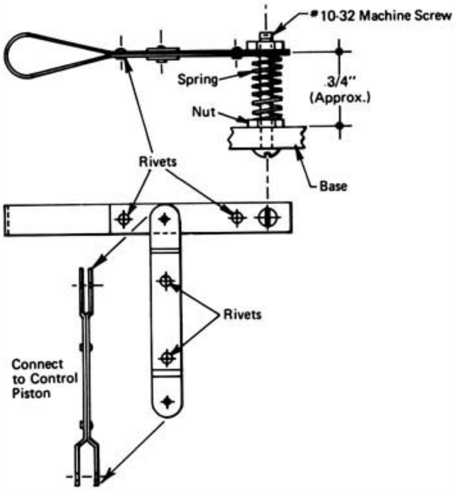
CONTROL

The control shown in the drawing is a simple affair. It consists of a handle with a hole in one end which goes over a machine screw anchored in the base. This should be held off the base by a spacer or short length of spring so that it is in line with the valve piston. The other part is the linkage between the handle and the piston. This is made of two pieces riveted together and connected to the handle and piston by a couple of cotter pins through the 1/16" holes. Just be sure they're free and don't put any bind on the piston while operating.

The material leaves a lot of latitude. One suggestion is the steel strapping used to bind crates and packages for shipping. A lumber yard or hardware trash pile should supply this.

The material for the base on which your turbine and oiler are mounted is pretty much up to you. Tempered Masonite and particle board are worth considering, with some 1/4" thick blocks at each corner and a piece of asbestos under your burner and boiler. Mount the turbine as close to the boiler as practical without it getting too much heat from the burner.

When you get the turbine mounted you can locate the control. It will work from either side. With the control connected to the piston and the piston in the cylinder, determine the OFF or neutral position by putting compressed air through the line and into the valve. If you don't have air, get up a head of steam. When you have the OFF position, you will know where to drill the hole through the base for the machine screw that goes through the hole in the handle. Put the screw up from the bottom and tighten a nut on the top to hold it firmly in place on the base. Then, with the bushing (or spring) and the handle in place on the screw, put another nut and pal nut



CONTROL HANDLE

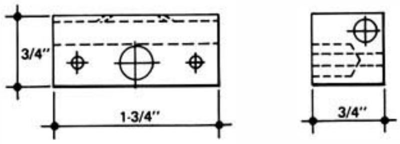
to keep the handle from coming off.

You will want some stops for both the forward and reverse positions. Locate these by determining the position of the handle at which the turbine is turning at the maximum R.P.M. and place the stops so the handle can not be moved further than that in either direction. Then, with a head of steam up, push the handle over against a stop and let 'er go. With it winding up, push the control handle over against the other stop and watch the response as it almost immediately stops and starts winding up in the opposite direction.

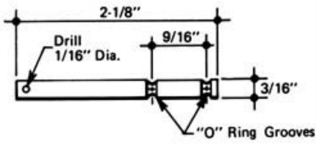
I use a simple boiler 2-3/4" diameter and about 6-1/2" long with a safety valve set at 40 lb. A home-made burner, a length of hose and my propane soldering torch provides the heat.

If you intend to put this little turbine to work you'll have to go a step farther. To utilize its speed, you'll need a speed reducer. I made a very uncomplicated one from the rubber wheel off a child's toy and a piece of rod. The rod, which is fastened to the wheel, is supported so that the wheel rests lightly on the turbine shaft. The axle is in a little slot, so that gravity is all that holds the wheel against the turbine shaft. A piece of rubber hose over the drive shaft and a metal wheel will work just as well.

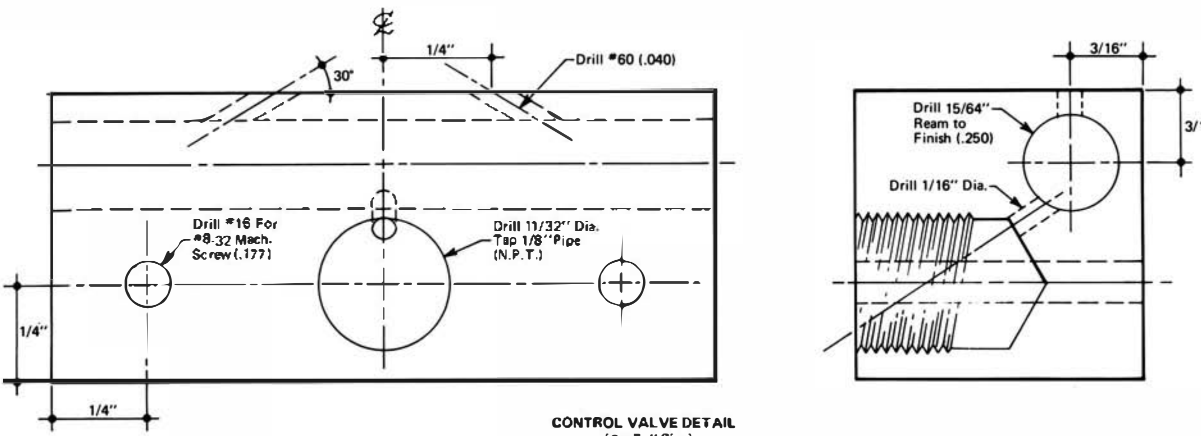
This little turbine won't replace the engine in your Volkswagon (offhand I can't think of anything it will replace) but I think you'll find it fun. I have operated a little crane with it but it could just as well be adapted to anything else within its limitations where reversing is desirable.



CONTROL VALVE (Brass or Alum.)



CONTROL VALVE PISTON (Brass)



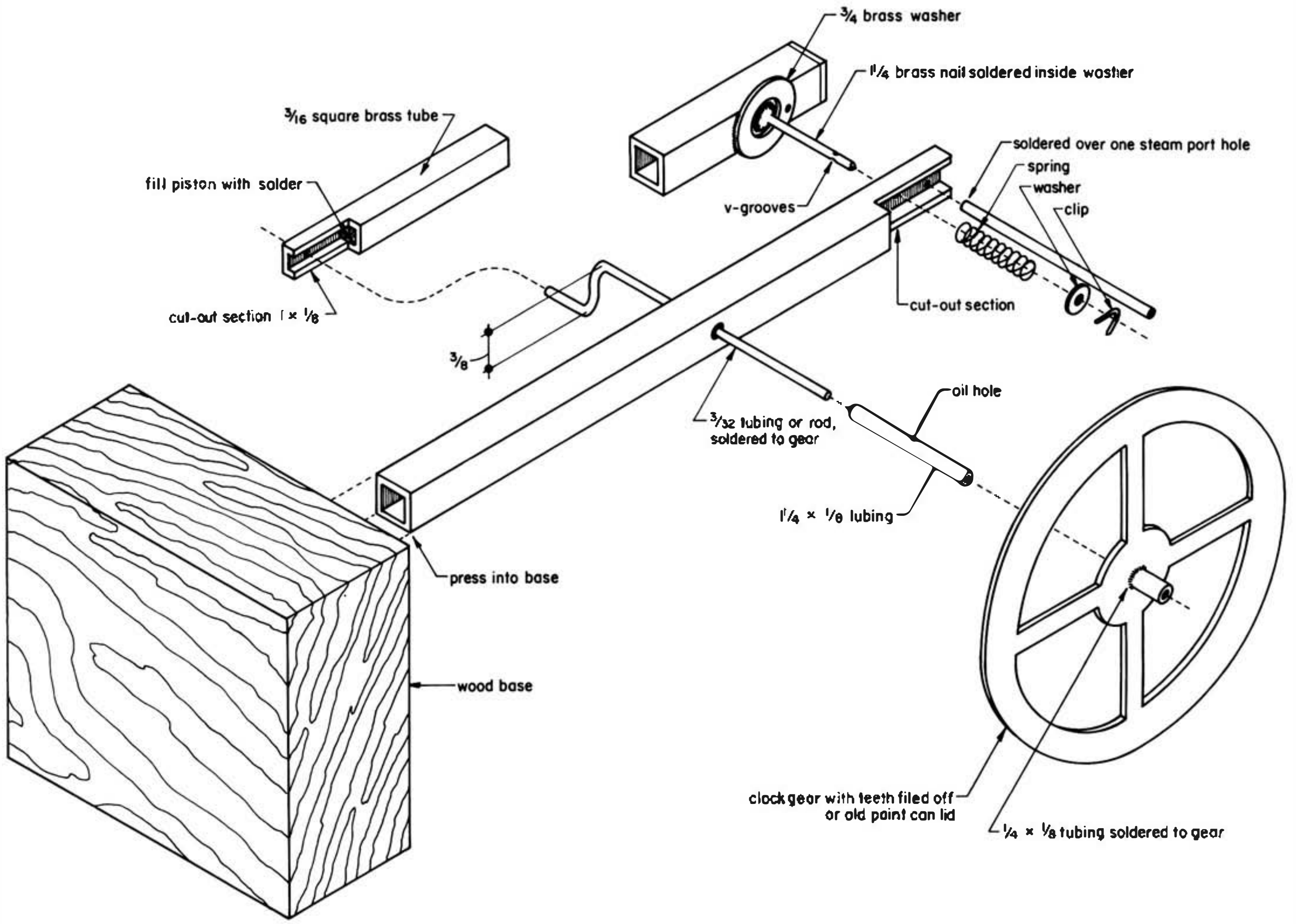
CONTROL VALVE DETAIL
(2 x Full Size)

For experience, or just for kicks, build a

Hand-Tool Steam Engine

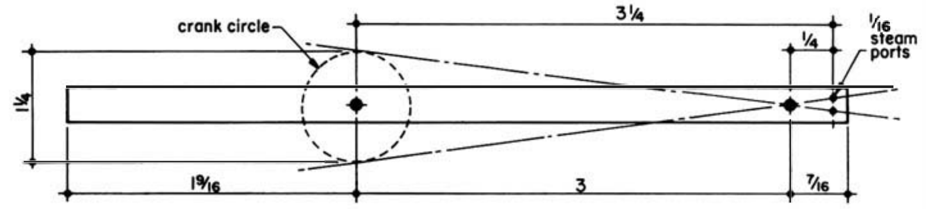
by Andrew Sprague

Photos by the Author



HAND-TOOL STEAM ENGINE ASSEMBLY DRAWING
Not To Scale

Drawings by G. R. Broad, Jr., from sketches by Andrew Sprague



METHOD OF LOCATING STEAM PORTS

There you are... sitting in your favorite chair... loafing through the latest issue of **LIVE STEAM**... What's *this*, you say! Sesame Street? Me with my great locomotives and fancy shop equipment? I didn't subscribe to this super steam magazine to read *kid stuff!*

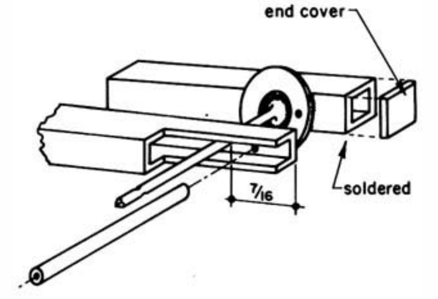
Well, all you smug types can just pass us by with a smile. We're here for those youngsters and newcomers who would like to enter the Live Steam Hobby but don't have quite enough knowledge yet, nor the tools required to build a working steam engine.

Here, then, is a steam engine which is about as simple to build as anyone could ask for. It requires little more to construct than a soldering iron or mini-torch, a hand drill, file and a hacksaw. And it's inexpensive enough you won't have to mortgage your mother to pay for it!

These engines are made entirely from common hobbyshop materials — 1/4" square brass tubing for the most part, a brass washer and nail and a spring from a motor brush. The flywheel is a clock gear with the teeth filed off or a paint-can cover, if that's handier.

Get started by cutting a 5" length of the 1/4" square tubing for the vertical member, to which all other parts will be attached. Drill a 1/8" hole through the tubing on the centerline for the crankshaft tube, 1-9/16" from one end.

The cylinder is of 1/4" square tubing 1 3/4" long. Solder a 3/4" brass washer flat against the cylinder so that the washer's centerline is 7/16" from the end of the cylinder. Using



CYLINDER COVER DETAIL

a 1¼″ brass nail. Solder its head exactly in the center of the washer hole.

To make the cylinder head, saw off a 5/16″ square from flat stock and sweat-solder it in position. Now file two vee-grooves on both sides of the nail about ¼″ from the end and vertical to the cylinder. These are for the wire clips that will hold the cylinder tension spring in place.

Cut a ½″ section of ⅛″ tubing and solder it to the center hole of the clockwork (or paint-can lid) flywheel. Insert the crankshaft through the tube in the vertical member and solder the flywheel to the crankshaft. The flywheel should spin easily.

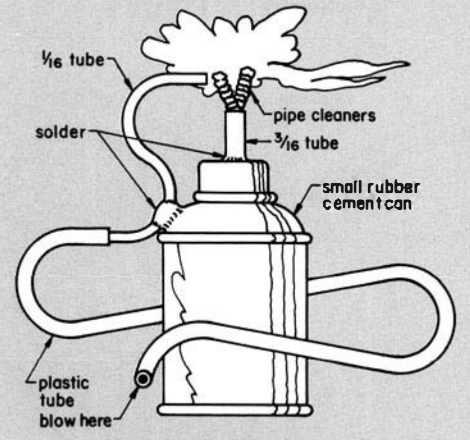
Next, calculate the placement of the steam ports by placing the vertical member with the crankshaft side up and rotate the flywheel so as to place the crankpin at a 90° angle to the vertical member. With a straightedge, line up the crankpin with the cylinder hole and mark the point at which it will line up with the center of the outer ring of the cylinder washer when assembled. Reverse the procedure to determine the location of the second port, then drill the 1/16″ holes.

The piston is constructed of a 3″ length of 7/32″ square tubing, split on the centerline to 1″ from the end. The larger portion is then filled with solder. Drill a 1/16″ hole on the center line at 3/16″ from the end of the split section and ream to fit the crankshaft so that it will revolve freely.

Again disassemble and, using a section of ⅛″ tubing, solder the steam pipe to one of the two holes, depending on which way you want the engine to revolve. If excess solder has filled the holes, re-drill the intake and exhaust ports.

Assemble the engine and attach a plastic or rubber tube to the steam pipe. By blowing into the tube, you should be able to make the engine spin rapidly. You can also have many hours of enjoyment by hooking it up to a tin can boiler and running it from a hotplate or the kitchen stove.

Well, a Kozo Hiraoka Heisler it's not, but it is a *start* toward the bigger and better things that we all find so pleasureable in the Live Steam Hobby!

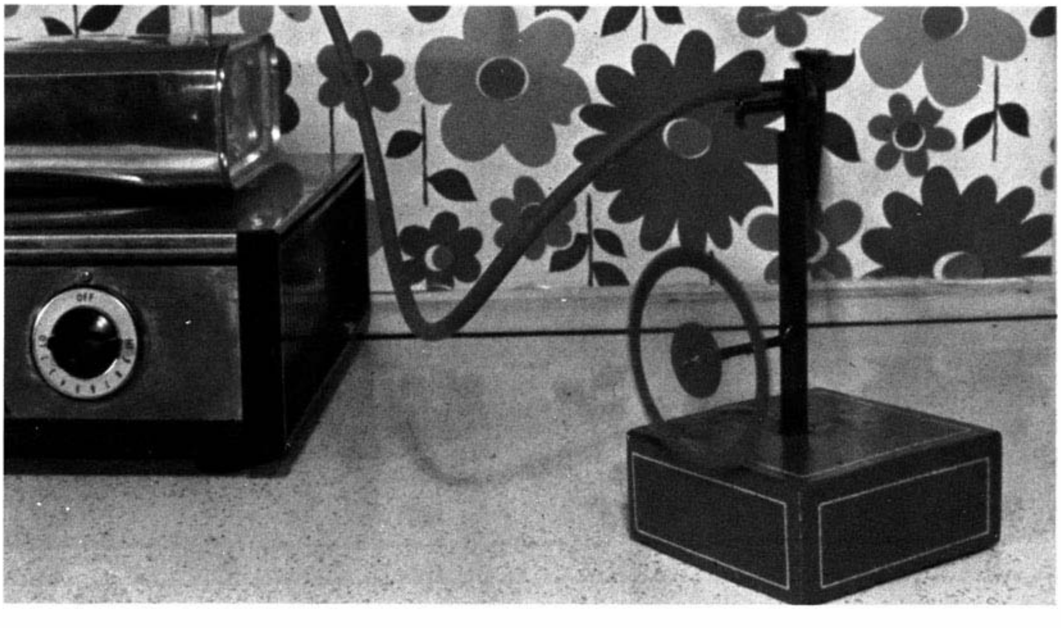


SOLDERING TORCH

There are two things I'm sure that hate me — coat hangers and soldering irons, neither of which I have ever learned how to control. For soldering these engines and the dozens of smaller ones I've made, I have found it much simpler to use a home-made alcohol blowpipe, such as the one shown here. The idea is about a zillion years old, but is inexpensive to build, easy to use and can be constructed in about 20 minutes.

Andrew Sprague

The cylinder and crankshaft are just a blur of speed as one of Andrew Sprague's Hand-Tool Steam Engines does its stuff. Note the "tin-can" boiler on the hotplate in the background. These boilers should never be used for more than a *very* few pounds pressure, nor should a soldered-seam be used.



A Word About Metrics

by William C. Fitt

During the past few years, Americans have been pressured into thought of conversion of the familiar terms and figures used for weight, volume and linear measure into unfamiliar metric terms. In typically bureaucratic manner, the "benefits" attributed to the change appeared in newspapers, television commercials and magazine articlee. The whole change was to be no more complicated than counting ones fingers or toes. In time, however, it became evident that the change was to be voluntary and the crash program of educating the public served better to kindle fires of objection. As a result, many Amateur Machinists developed serious objections to any reference to metric measurements.

This is most unfortunate . . . becauseit blocks the fun of learning which, after all, is a basic requirement of engineering. It also tends to restrict the amount of material available to The Hobby because a great many of our fellow hobbyists live in areas which use the metric system and their writings incorporate metric terms and dimensions. To by-pass some of these projects simply because they use unfamiliar terms would be a serious loss to many of our fellow hobbyists and, really, it's not all that difficult.

To assist in one way, we have a series of charts in the Appendix of this volume that convert all dimensions up to 1000.9 millimeters into decimal inches or conversely, all dimensions up to 39.404 inches to millimeters. Another chart lists all drills — fraction, letter, number or metric sizes — with their diameter in both inches and millimeters so that a specific drill size can be compared with its closest counterpart for selection.

Readers of **LIVE STEAM** Magazine have been very helpful in offering solutions to the conversion from one system to the other and a couple of these will be repeated here to assist readers of this book.

An Amateur Machinist from The Netherlands, W. Th. M. deGroot, uses a very simple way to build projects in metric dimensions (which are in use in his country) which are published in inches. He has very successfully built some of the stationary engine projects ... including the Unusual Steam Engine by Robert S. Hedin on page 6 of this book ... using his method.

He converts all measurements by making one inch equal to 32mm. In this way, his models turn out to be about 20% bigger than originally intended by the designer, but all materials, rods, screws, drills and measurements become metric. For example, using his system of conversion, a 1/8" drill becomes a 4mm drill. Sheet brass 3/32" thick becomee 3mm sheet brass and so on. Not even the slightest difficulty was encountered in finding the right materials and tools.

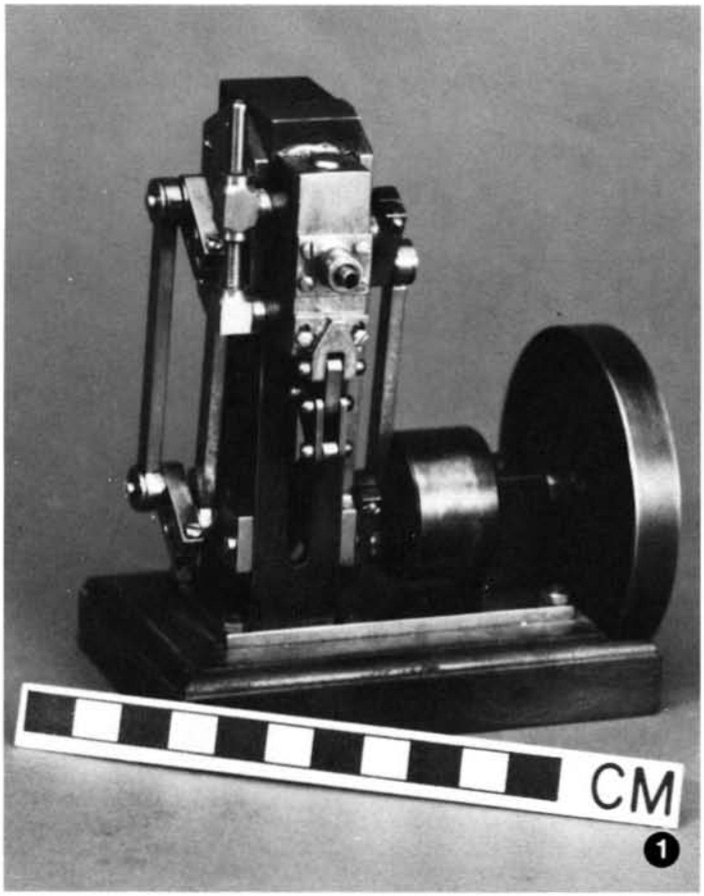
Mr. deGroot proposee that this system can be used for models which are not to a particular scale (such as required to fit a track gauge) and which require no castings. A metric design can be built to a 20% smaller scale by making each millimeter equal to 1/32". If a larger model would be better, a metric design can be made to a 60% larger scale by making each millimeter equal to 1/16".

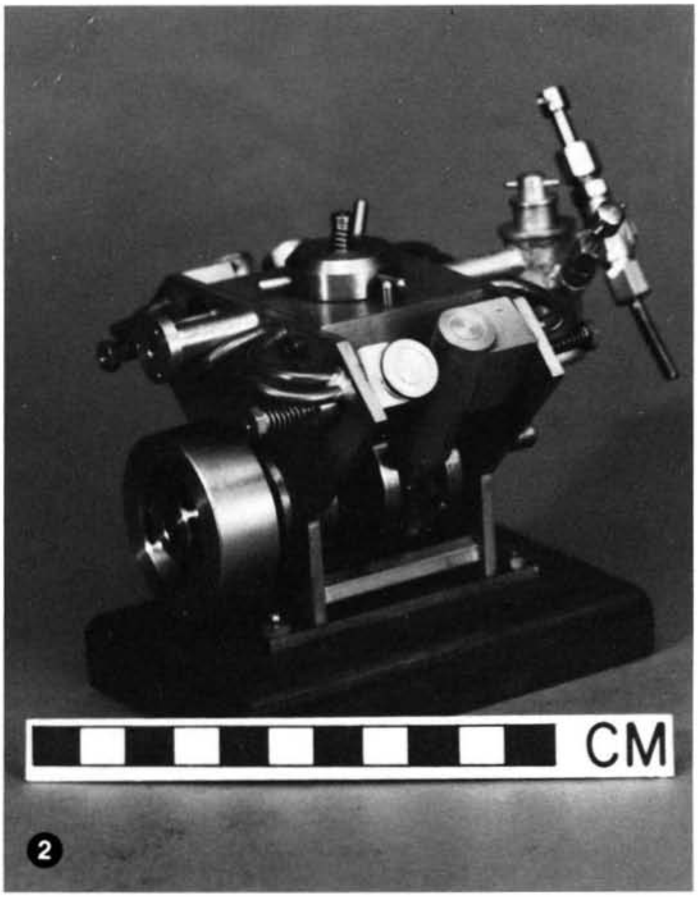
This simple conversion system for "non-scale, non-casting" models will enable Live Steamers and Amateur Machinists to utilize many more plans and designs than ever were available to them before and they may do it simply and conveniently.

A Canadian reader, George A. Calver, points out that we should look on this situation as an easy challenge. He points out that small metric conversion calculators are available for less than $25. You just punch in the measurement, hit the linear conversion key and presto! inches or metric or whatever you desire.

J. R. Tunney of New Zealand writes that he still works in the old English dimensions but he built Jan Gunnarsson's V-4 Oscillating Cylinder Engine (on page 86 of this book) with a regular pocket calculator which, he says, no workshop should be without. Simply enter the metric dimension into the calculator, divide by 25.4 and you've got it made! (Incidentally, he made the bore of the cylinders 3/8" and used only two sizee of screws: 1/8 Whitworth and 1/16 Whitworth. The pivot pin springs he salvaged from old ball-point pens.)

In the designs included in this book, you will find projects using both inch (English) and metric dimensions. Without any compelling pressure, we invite you to give them a try. You will not only be able to build another project but will discover a whole new field of interest.





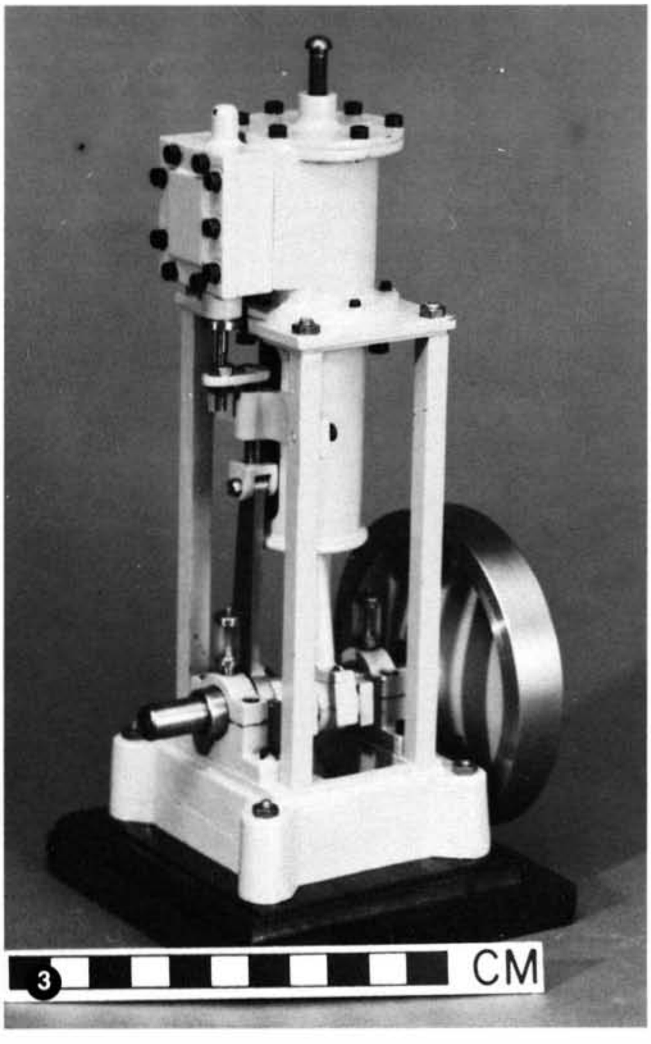
Variations on a Theme

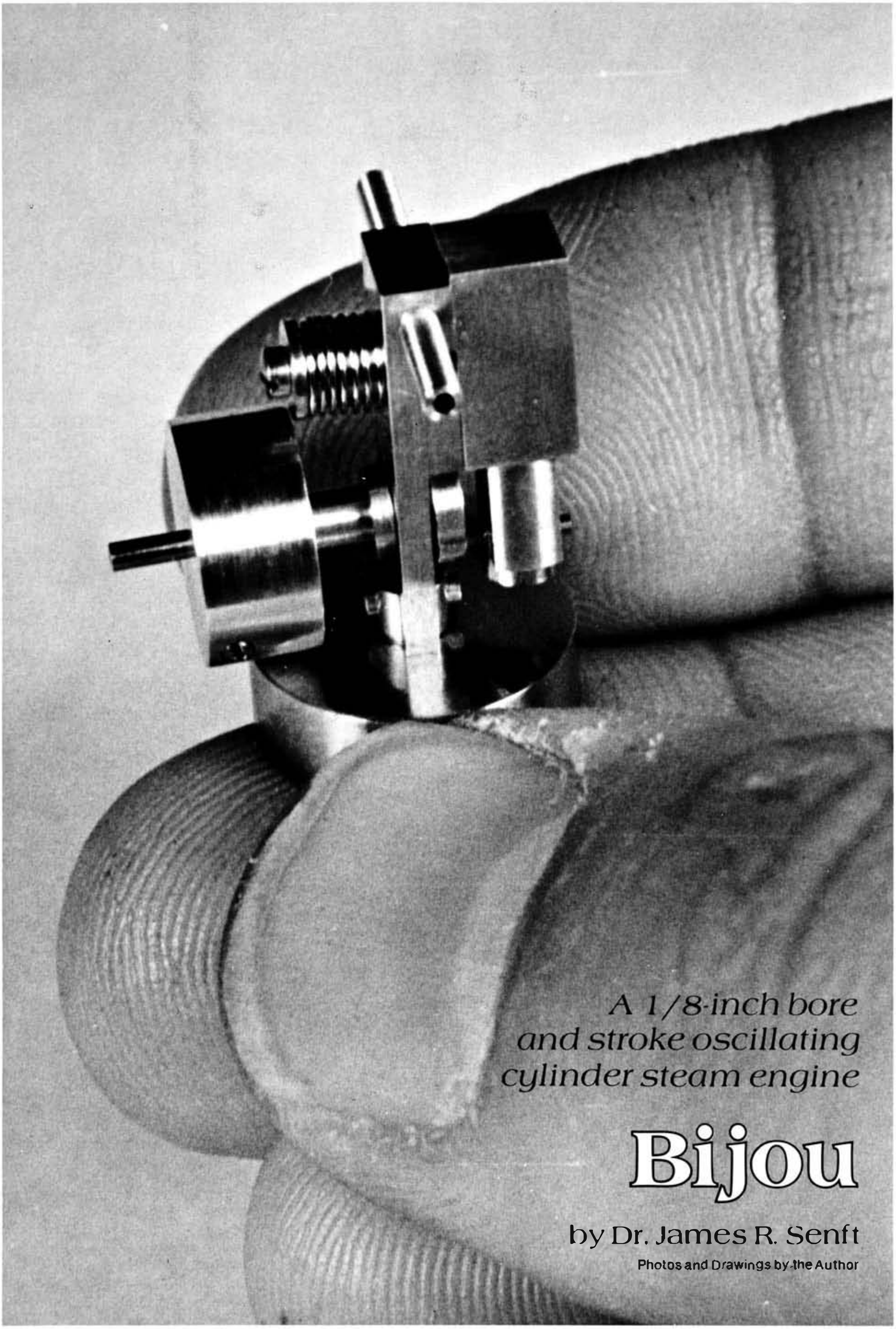
Every once in a while a fellow comes along who can turn out engines in his home workshop faster than most of us can decide to tackle a project. These craftsmen are admired (and envied a bit) by all of us.

Such a man is Gary R. Slack of Iowa who built the three engines shown on this page in a little over a year after beginning his subscription to **LIVE STEAM** Magazine. All three of these designs appear in this book.

The *Unusual Steam Engine* **(photo 1)** built from Robert S. Hedin's design on page 6, he says, was a lot of fun to build and runs good, but shaky. The *V-4 Oscillating Cylinder Engine* **(photo 2)** from Jan Gunnarsson's plans and instructions on page 86, he rates as his best and it runs real smooth at 60 RPM and on up. Since he prefers small engines, Gary built Henry Greenly's *Half-Horse Marine Engine* (on page 11) at half the size shown in the drawings and it, too, is a smooth-running engine **(photo 3)**. If you're wondering about the screw on the top of the cylinder, he says not to worry . . . he neglected to remove it before his brother took the picture!

Here, then, is still another option that you can employ in building the designs presented here: try them at a size that suits your personal equipment, qualifications and interest. There is no limit to what you can do!



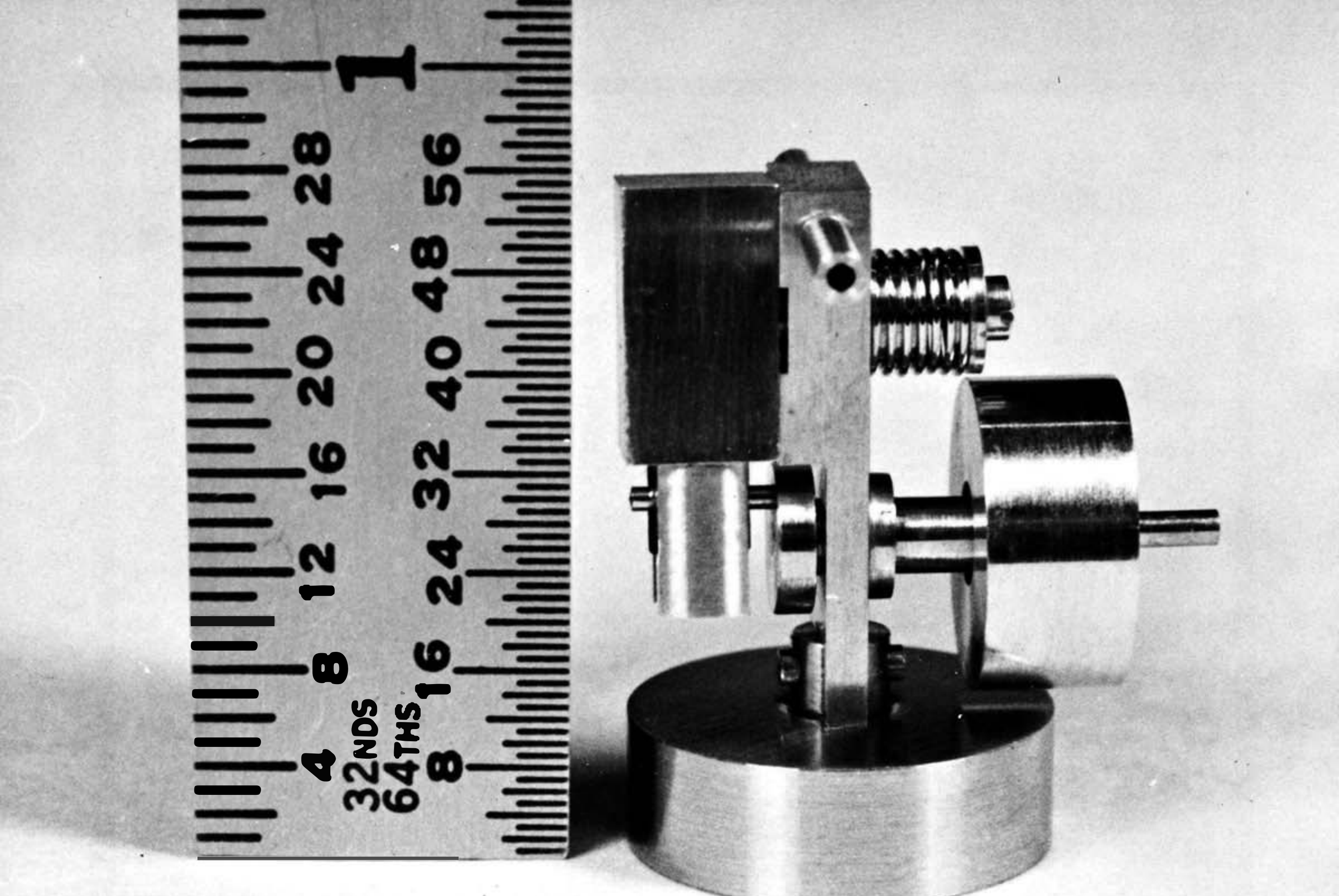


A 1/8-inch bore and stroke oscillating cylinder steam engine

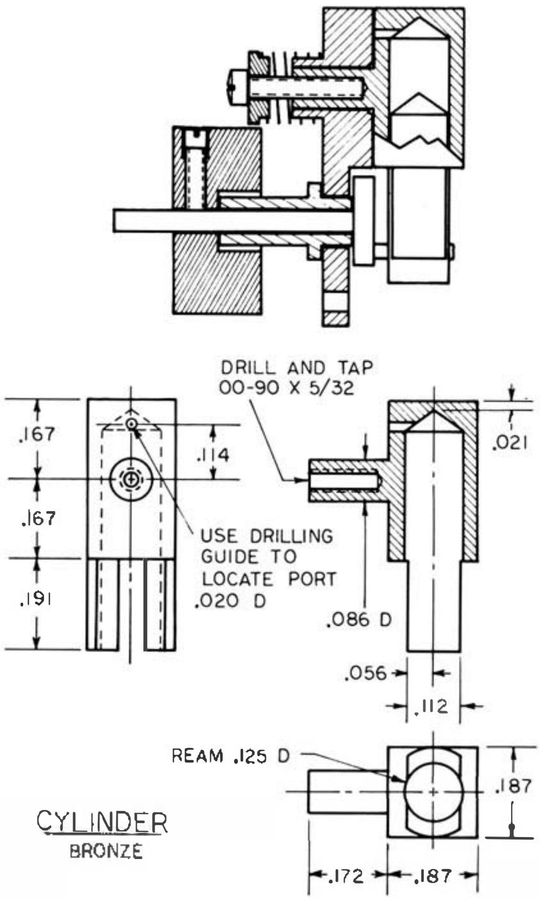
Bijou

by Dr. James R. Senft

Photos and Drawings by the Author



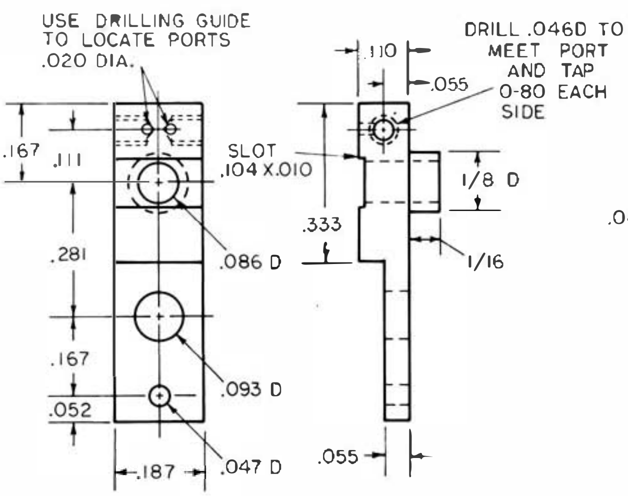
PHOTOS AND DRAWINGS BY THE AUTHOR



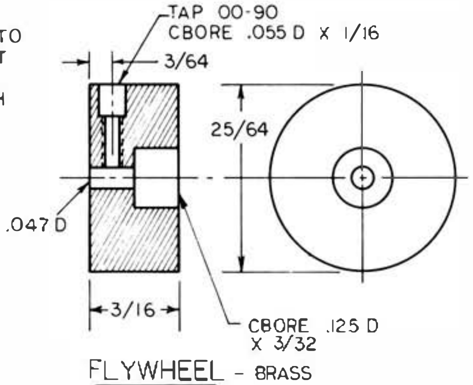
Bijou is an exceptional engine, but not only because of its size. Its single acting oscillating cylinder incorporates a trunkguide similar to the crosshead guide in fixed cylinder engines, a feature which greatly reduces friction and extends piston and cylinder life over that of the common oscillating model or toy. Performance is exceptional also; the tiny engine comes to life on a mere 5 p.s.i. but buzzes with a character all its own on 25 p.s.i.

Despite its small size, Bijou is not hard to build; it is an ideal short project for a small lathe such as the Unimat. Nearly all the dimensions given in the drawings can be varied three thousandths — very easy tolerances to live with in machine work. Exceptions occur where one part must mate another in a running or press fit, but even here the tolerance applies to one of the parts. Furthermore, a simple two-piece fixture used to drill the steam ports assures correct location of these items so critical to the proper operation of any oscillating engine.

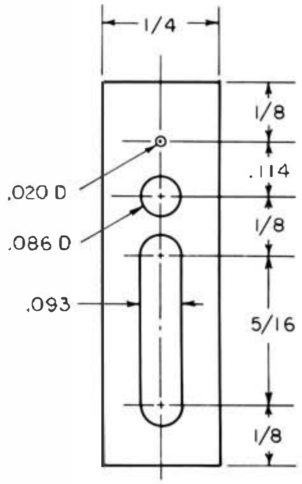
Begin construction with the standard. Chuck a block of brass 3/16 x 3/8 x .667" in the 4-jaw using a dial indicator to accurately position the block for turning the 1/8" dia. pivot bearing boss. Leave a little more than 3/16" of the block protruding from the chuck. Now machine away the block to form a boss 1/8" dia. but about 3/16" long. Remove the piece, chuck by the boss in the 3-jaw, and face the port surface to a width of .110". Drill the .086 dia. pivot hole at the same chucking so that it is truly perpendicular to the port surface.



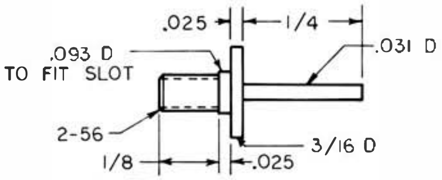
STANDARD - BRASS



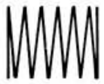
FLYWHEEL - BRASS



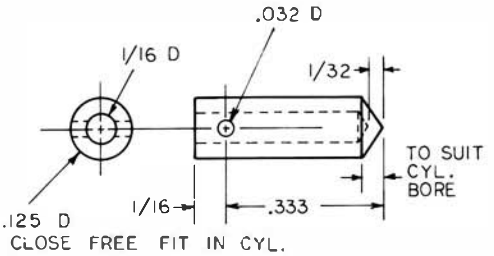
PORT DRILLING GUIDE
.031 THICK STEEL



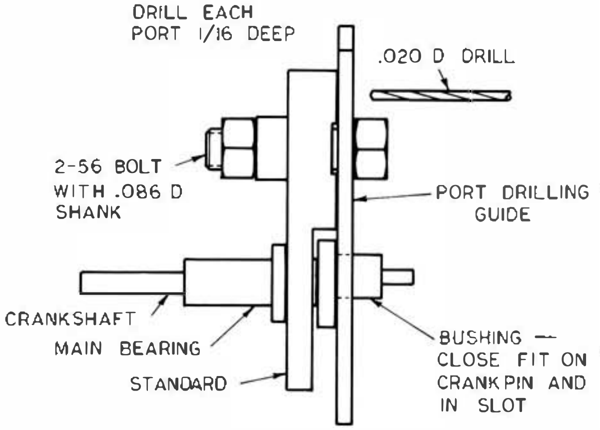
GUIDE PIN - STEEL

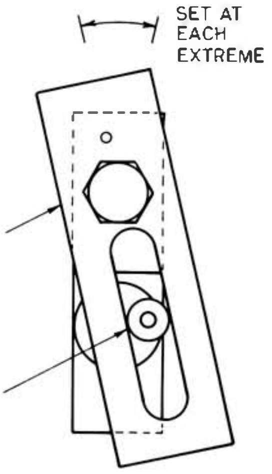


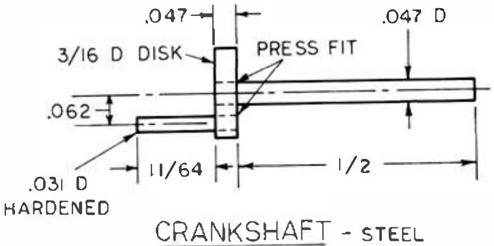
SPRING-.012 D WIRE
6 COILS - 1/8 I.D.
3/16 FREE LENGTH



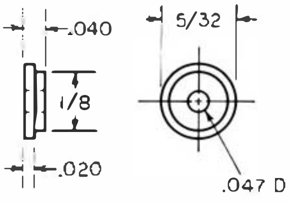
PISTON
STAINLESS STEEL



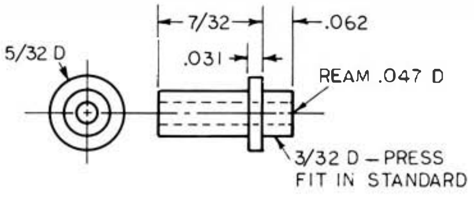




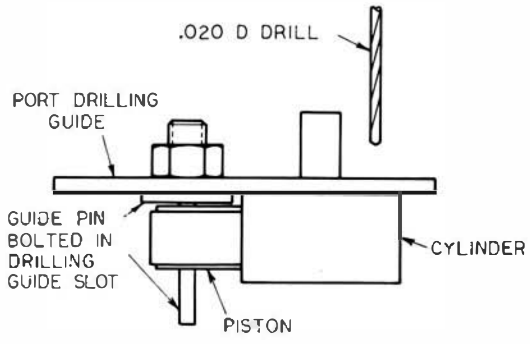
CRANKSHAFT - STEEL



SPRING WASHER
BRASS



MAIN BEARING - BRONZE



Remove from the chuck and cut the boss to the correct length of 1/16". Now drill the 3/32 dia. hole for the main bearing; the .281" spacing here is important, so set up in a milling attachment or mount the standard on an angle plate on the cross slide and use the micrometer feed to space the holes exactly. Mill or file the step and the slot and drill the .047 dia. mounting hole. The inlet and outlet passages can be added later, after the ports have been drilled. These passages are drilled and tapped 0-80 so that 1/16 O.D. brass tubing can be used for steam pipe. Alternately, the passages can simply be drilled 1/16 dia. and the pipes carefully soldered in place.

To make the cylinder, cut and machine to size a rectangular block of bronze .187 x .359 x .525 inches; S.A.E. 660 bearing bronze is ideal material to use here. Now chuck the block in the 4-jaw for turning the .086 dia. pivot; use a dial indicator to position the block precisely. Now machine away to form the pivot. Aim for a good finish on the port surface and turn the pivot to a close but free fit in its mating hole in the standard. Drill and tap the pivot 00-90 by 5/32" deep for the pivot screw. Out of the chuck, check the cylinder with a mike to make sure that the port face is parallel to the back surface of the cylinder; if not, chuck by the pivot and carefully take a light skim cut or two across the back.

Turn up a brass bushing 3/16 O.D. x .089 I.D. x 3/16 inches long, slip it over the pivot, and rechuck the cylinder in the 4-jaw to machine the bore; one of the chuck jaws bears on the end of the bushing thus protecting the pivot end from damage by the jaw. Center the 3/16" square portion of the cylinder with a dial indicator and leave a little more than 3/16" protruding from the chuck. Centerdrill, then drill the bore to depth first with a 3/32 dia. drill and followed by a .120 dia. drill. Ream the bore with a 1/8" dia. chucking (machine) reamer in good condition to obtain a smooth surface. Now turn the lower portion of the cylinder to just under 3/16 dia. Remove from the chuck and file or mill this lower portion to form the slot for the crankpin. Only the port remains to be drilled, but this is done after the piston and the drilling fixtures are finished.

Turn the piston from stainless steel; polish to remove tool marks and obtain a smooth and close but free fit in the cylinder bore. Crossdrill the piston in a milling setup to ensure that the crankpin hole is truly perpendicular to and through the axis of the piston.

To make the crankshaft, chuck a short length of 3/16 dia. stainless steel in the 4-jaw to run eccentrically .125 t.i.r. with a dial indicator. Face locally and drill the crankpin hole. Reset to run exactly true, face, and drill for the shaft. Part off and carefully press fit the crankpin and shaft in the disk; these two shafts must be parallel or binding will result. The shanks of old 3/64 and 1/32 dia. drills are ideal materials for these items. Turn the main bearing, press squarely into the standard, and you're ready to make the port drilling fixtures.

The two holes and the slot in the port drilling guide must be truly collinear. Clamp a 1/4" wide strip of steel in a milling setup or to an angle plate mounted on the cross slide. Then with a 3/32 dia. endmill, cut the slot. Use the micrometer feed to space the .020 dia. and the .086 dia. holes exactly, first making a dent with a small centerdrill for the drills to follow. Using only the cross slide feed to mill the slot and locate the holes will ensure collinearity.

The guide pin can be made by turning the lower portion, drilling through the center, and then pressing in a length of .031 dia. rod. But check to be sure the rod goes in absolutely concentric to the lower portion. The 3/32 dia. step should be a close fit in the drilling guide slot.

The ports in the standard and cylinder can now be drilled. The photos below and the drawings show the use of the fixtures. Note that you'll need to turn up a short bushing .031 I.D. to fit the crankpin and .093 O.D. to fit the slot in the drilling guide. Use a drill exactly .020 dia., run it at good speed, and feed gently.

The flywheel and spring washer are simple turning jobs in brass. The 00-90 flywheel set screw is a standard fillister head machine screw with the head reduced to about .052 dia. Wind the spring from .012 dia. stainless steel spring wire — the kind used for wire fishing leaders.

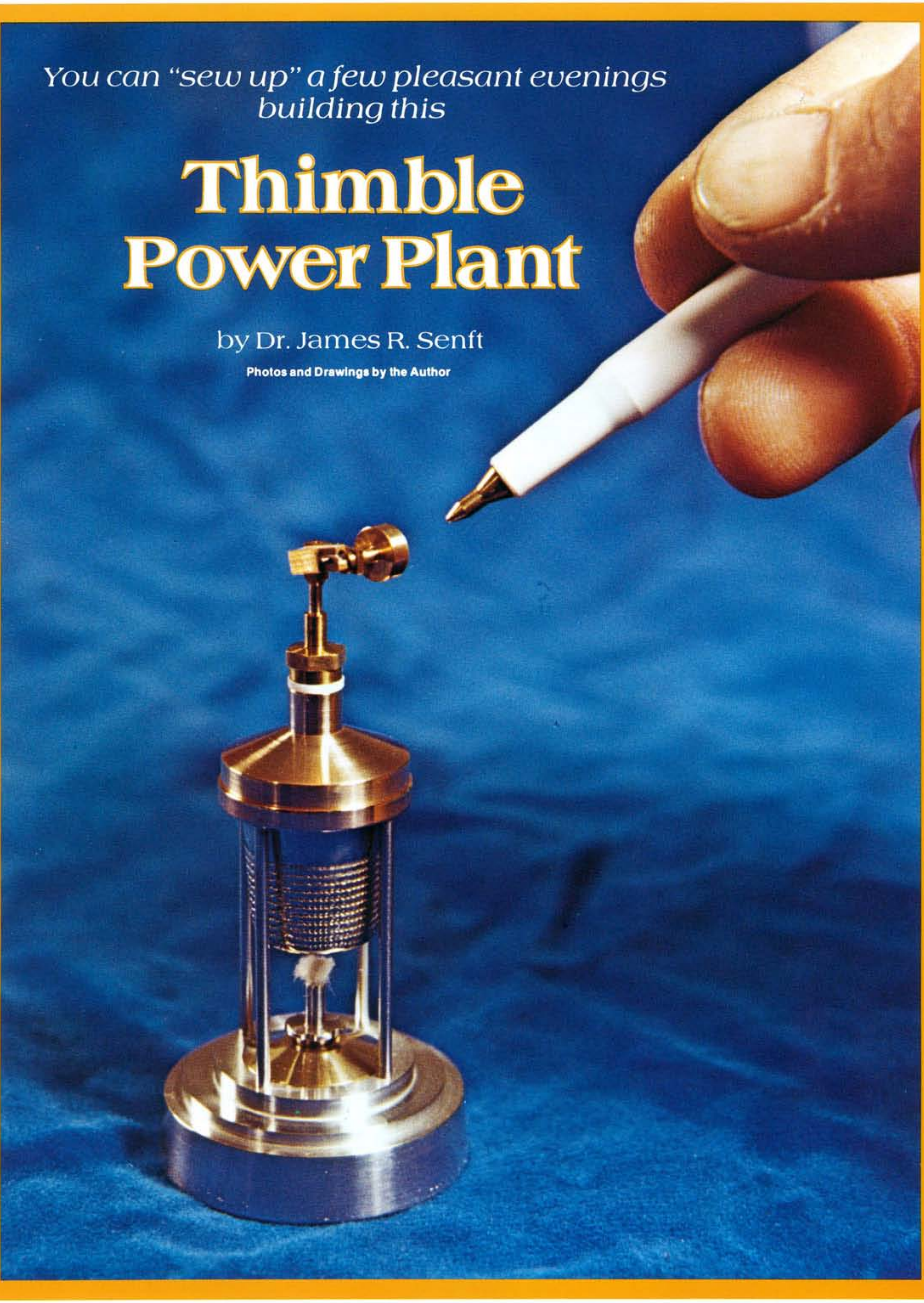
When assembled, the engine should turn absolutely free — make sure there is not the slightest bind or tight spot. Adjust the spring pressure to just keep the port faces in contact at the steam or air pressure supplied.

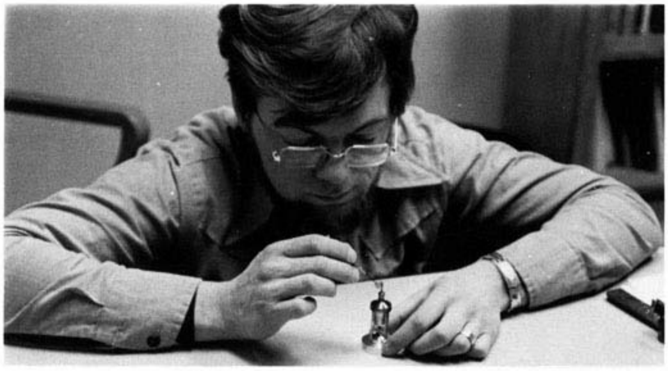
You can "sew up" a few pleasant evenings building this

Thimble Power Plant

by Dr. James R. Senft

Photos and Drawings by the Author





The Author, filling the boiler of his Thimble Power Plant in preparation for firing up. As he points out in his text, this is a miniaturized version of an engine he applied to a Steam Truck design built for his son. The truck, shown below, is not included in the projects in this volume.

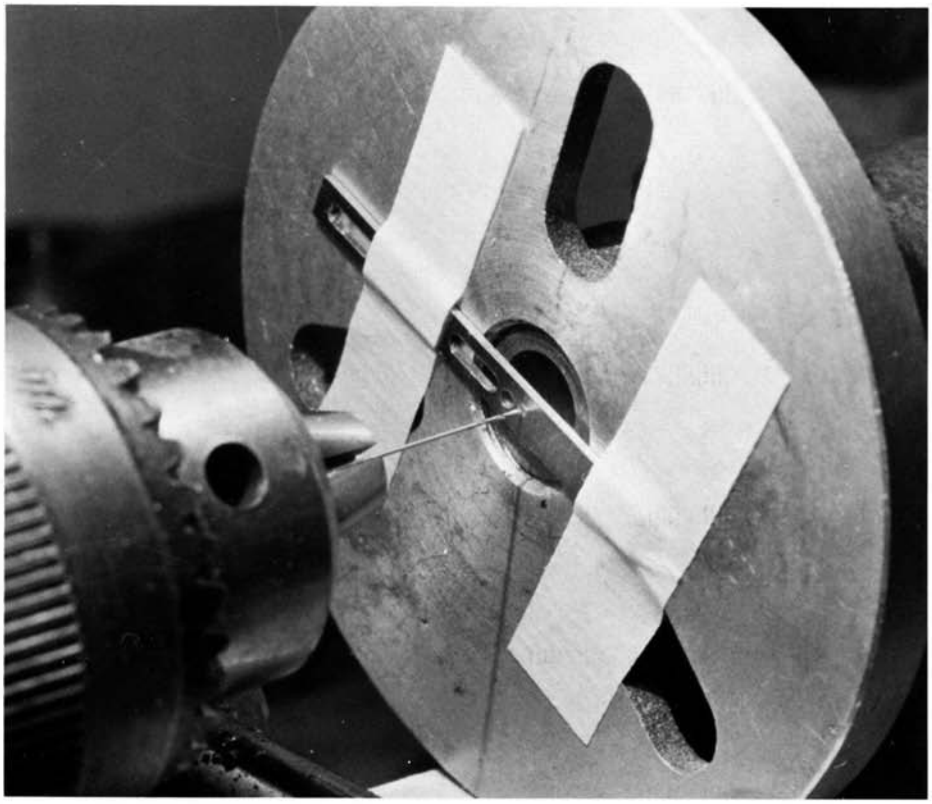


Photo 1. Completing the Drilling Guide by drilling the No. 80 hole; note the centerdot accurately located in the milling machine.

I must sincerely thank our Editor for suggesting this project. It has turned out to be a most enjoyable and highly instructive one for this model engineer for several reasons, but particularly because the engine served as a sort of final test of certain features of design for small single acting oscillating steam engines initiated by the author some time ago.

Readers of several years standing will note from the photos and drawings (in particular, see Fig. 1) that this engine is the junior member of the Steam Truck/Bijou family. The Steam Truck design evolved from two earlier but larger single acting oscillating engines. Both of these previous engines had compactness as their prime goal — minimum mass for a given displacement. Both incorporated the integral cylinder pivot and the long style piston for maximum bearing and sealing surface. Constructed at a very tender age, the first engine featured the trunk guide, but because of an unorthodox crank arrangement, suffered from excessive cylinder overhang and consequent rapid port face wear. The second engine, of ¼" bore and stroke, was much more successful, but omission of the trunk guide (probably for ease of construction) led to fairly rapid cylinder wear and eventual unacceptable leakage. Shortly thereafter, sight of the beautiful oscillating engine of Harry Wedge induced me to revert to the trunk guide; the Steam Truck engine followed.

With the desirability of the features incorporated in the engine of the Steam Truck now apparent from its performance, Bijou was very nearly a straightforward reduction of the Steam Truck engine. The Thimble Steam Engine too, had to share the same features, and thus its resemblance to its two immediate predecessors. But it was not obtained by simply halving Bijou's dimensions.

First, halving Bijou would have given a cylinder 3/32" wide with a minimum wall thickness of 1/64". There was some concern with the trunk guide legs "springing" during machining or being bent through handling, so the cylinder width was increased to .105". Next, a half-size Bijou would require .010" dia. ports, a size considerably smaller than the model engineer's box of number drills includes. It was therefore decided to incorporate ports of .0135" dia. and use a standard No. 80 drill. The crank-to-pivot distance was taken to be half of Bijou's to give the same angle of oscillation, namely 25.8 degrees, a value rather typical of many oscillating engines. Thus to accommodate the larger ports, the distance from port to pivot was increased until no "bridging" of the ports in the standard occurred. This increase was not very large since Bijou had slightly undersized ports. The length of the cylinder was also increased to maintain an adequate seal of the inlet port in the standard.

It is desirable to make ports in tiny engines a bit smaller than the port layout permits (provided of course that they remain large enough to do the job) to allow for slight inaccuracies in machining and erosion of the edges of the ports during the working life of the engine. The obvious course to follow in this case was to increase the port-to-pivot radius a bit more. But this in turn would have required an even longer cylinder. Instead, the distance between the ports in the standard was increased. This is easy to accomplish in metal by simply using a smaller diameter bushing on the crankpin when using the Drilling Guide (see Fig. 2). Although the ports in the cylinder and standard do not fully coincide, they overlap by about .010", the required amount.

This arrangement however, together with the "overscale" ports, apparently required a much wider cylinder in order to keep the ports in the standard securely sealed as the cylinder oscillates. At this point, a major departure from previous designs occurred. Since this engine was not intended to be reversible, and since the engine exhausted to the atmosphere, it was only necessary that the inlet port remain amply covered by the cylinder throughout its angle of oscillation. Hence the usual symmetric arrangement of the ports was discarded and the ports located .012" to one side of the centerline of oscillation. With the cylinder .105" wide, the distance from the edge of the inlet port in the standard to the edge of the cylinder was always more than about .027", whereas the usual symmetric arrangement would have given a minimum overlap of about .016". This was now more than enough sealing area.

At this point, I was sufficiently confident of the design to begin construction in earnest. So earnest in fact that the cylinder, standard, and port drilling guide were made before the dimensions of the remaining components of the engine were fully determined. Incidentally, most of the design work was carried out on a pocket calculator, finding it much more economical of time and paper than drawing port diagrams to 20 to 30 times actual size.

Another point on the cylinder design is the "overscale" pivot. The smallest screw and tap available from mill suppliers was 000-120, which has a body size of .034". A "scale" pivot would have been .043" dia., leaving a minimum wall thickness of .0045", a bit on the weak side for machining and handling. Although the specified .052" dia. is on the large side, the next number size down is .047", not much better it was thought than .043". A check showed that .052" could be accommodated by slightly chamfering the port face edge of the mating hole in the standard instead of cutting the clearance slot as on the previous engines. Finally, the thickness of the standard was made overscale and an "elbow" added to take a 1/16" dia. steampipe; the added thickness made the pivot boss unnecessary, which simplified the machining of this component.

Construction of the Thimble Engine does not require tiny watchmakers tools, although these could be used with definite advantage. A Unimat or similar size lathe is nearly ideal. With some care

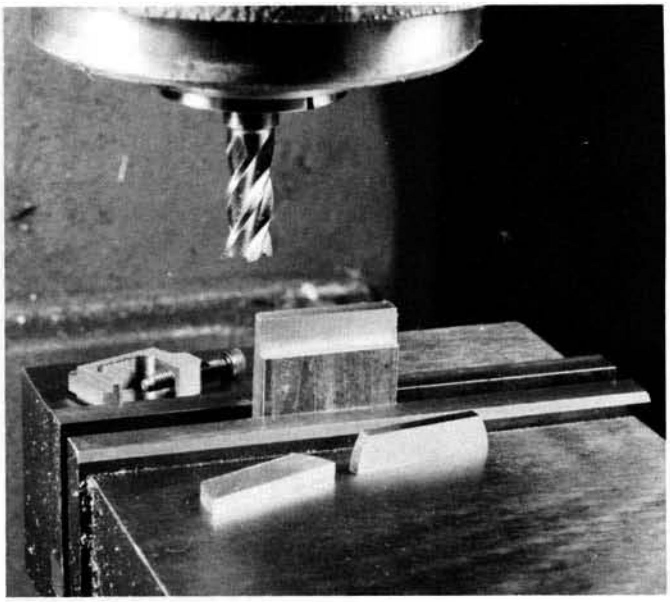


Photo 2. The stepped block for holding the cylinder stock; finished strips in the foreground.

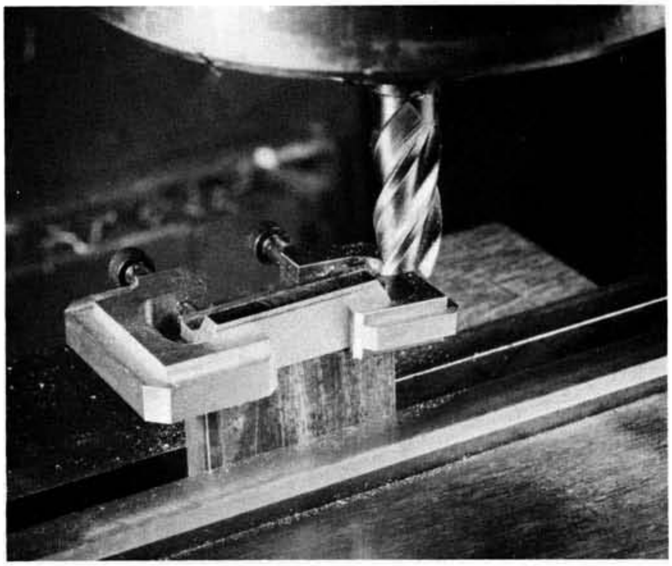


Photo 3. Milling the cylinder material to size.

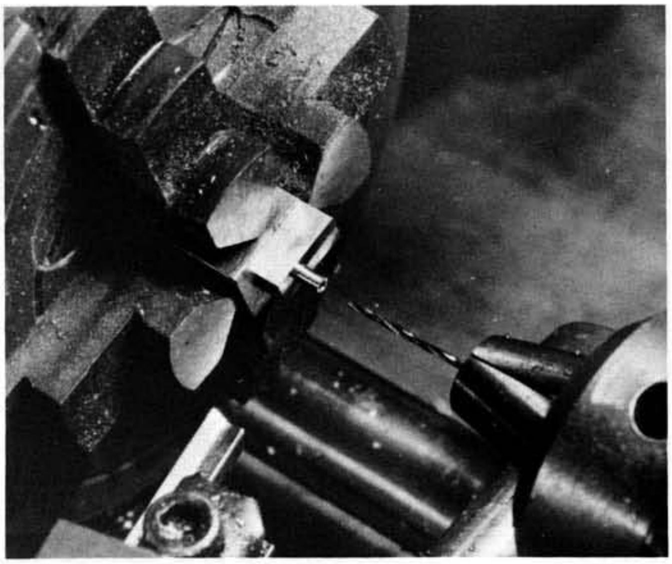


Photo 4. Turning and drilling the cylinder pivot.

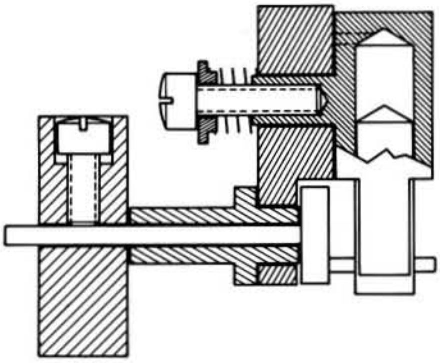


FIGURE 1 SECTIONAL VIEW OF THE THIMBLE STEAM ENGINE

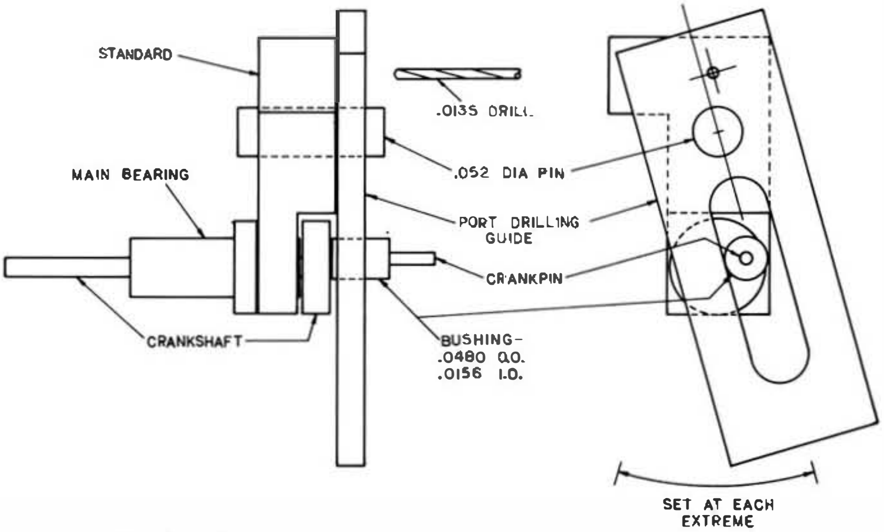


FIGURE 2 TWO VIEWS OF THE DRILLING GUIDE IN USE TO LOCATE AND DRILL THE PORTS IN THE STANDARD

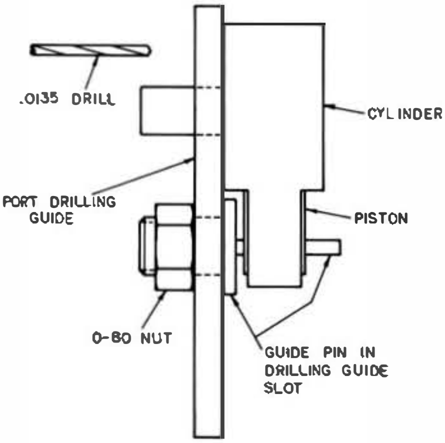
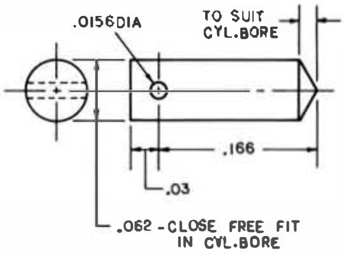
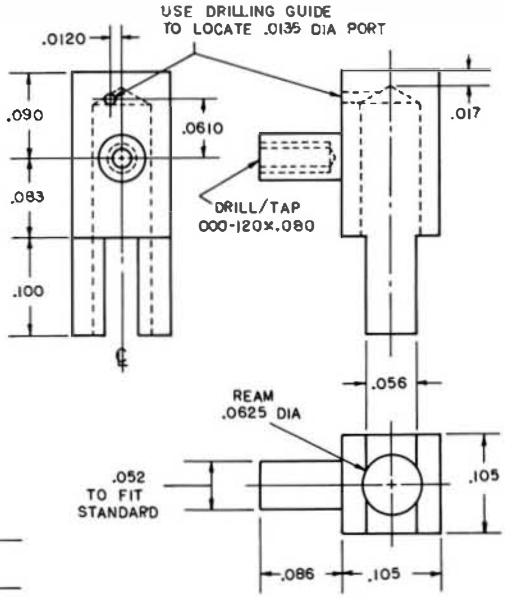


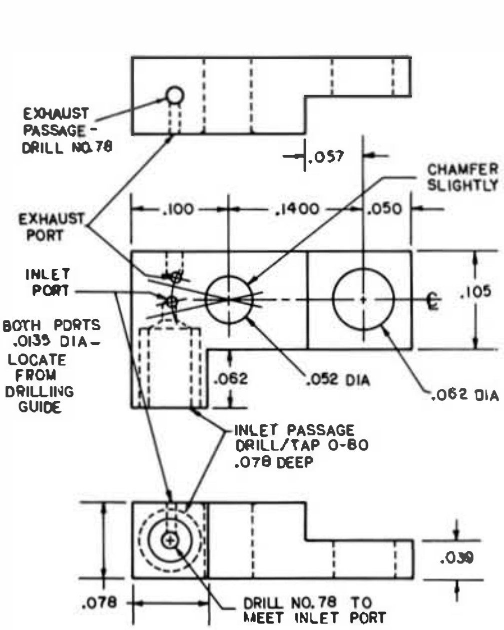
FIGURE 3 DRILLING THE CYLINDER PORT



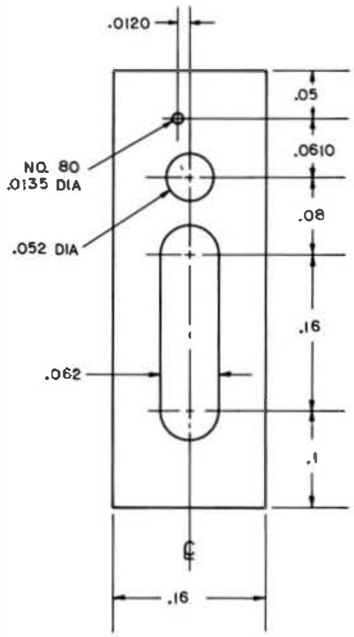
PISTON
STAINLESS STEEL



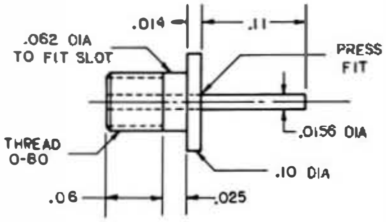
CYLINDER
BRONZE



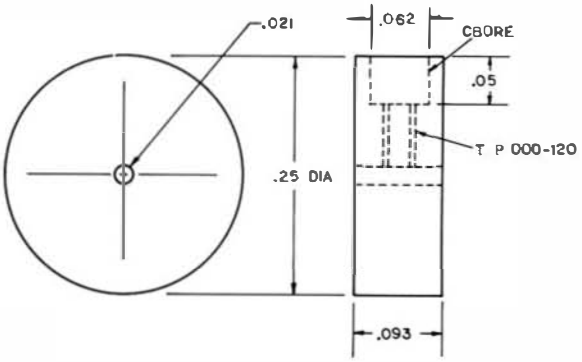
STANDARD
BRASS



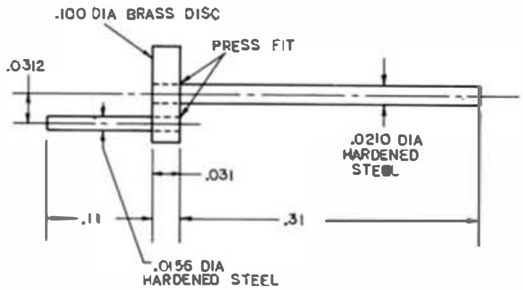
PORT DRILLING GUIDE
.031 THICK STEEL



GUIDE PIN
STEEL



FLYWHEEL
BRASS



CRANKSHAFT

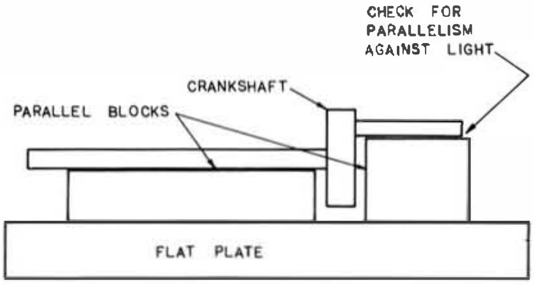
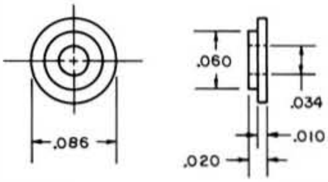
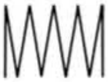


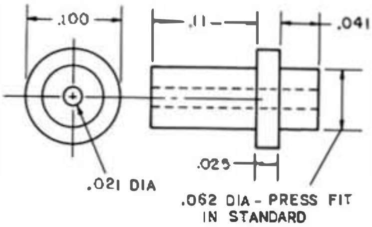
FIGURE 4 CHECKING CRANKSHAFT ALIGNMENT



SPRING WASHER
BRASS



SPRING
.006 DIA WIRE
5 COILS
.06 I.D.
.10 FREE LENGTH



MAIN BEARING
BRONZE

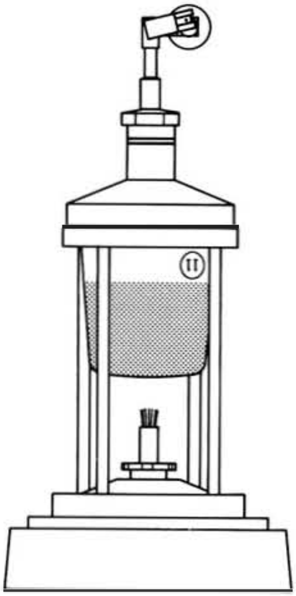
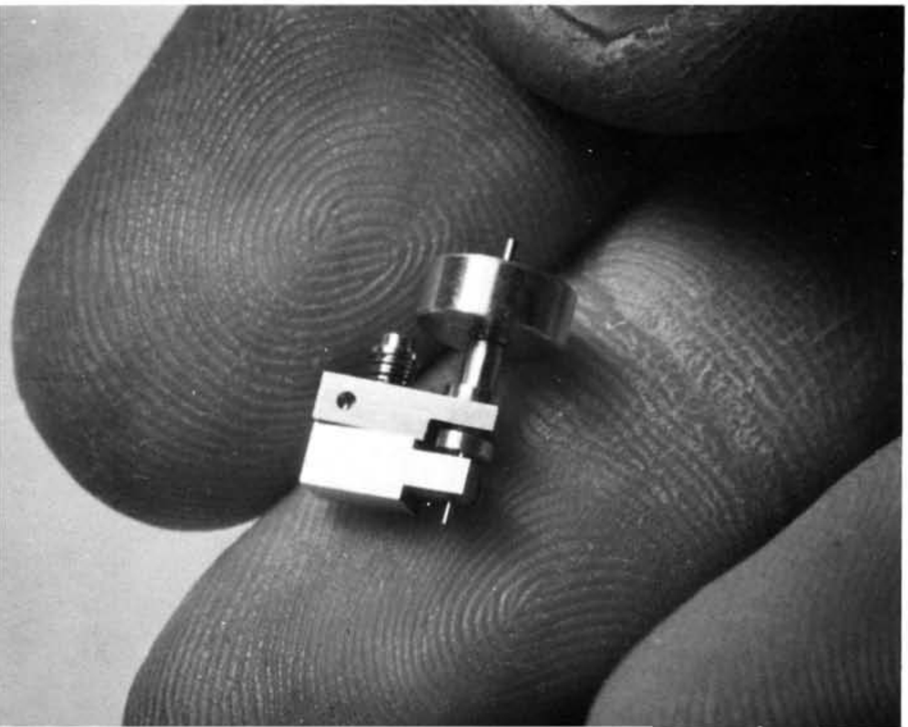


FIGURE 5



SPECIFICATIONS
Thimble Power Plant

Height	3-1/16 in.
Floor Space	1.77 in.^{2}
Weight	Engine & Boiler: .56 oz.
Engine	Single Cylinder Single Acting Oscillating Type 1/16 in. Bore & Stroke
Boiler	Inverted Thimble Type Alcohol Fired Size: No. 11 Water Capacity: 1cc Working Pressure: 10 psi* Running Time: 2.5 minutes
Horsepower	.00008 ihp**

* estimated
** estimated from the formula: Ihp = $(Ap_m Ln)/396000$.

however, a much larger machine can do the work. For example, all the milling operations on my Thimble Engine were carried out on an 800 lb. Rockwell vertical! The chief obstacle to using a large machine is drilling the tiny holes. I used the Unimat as a horizontal drill press (e.g. see photo 1) to drill the smaller holes after giving them a starting place with a centerdrill while still in the mill. The ports were also drilled in this setup.

A study of the drawings will indicate the cutting tools required. In addition to the usual, you will need some small number drills, a 1/16" dia. chucking reamer, a 1/16" dia. endmill, and a 000-120 tap. As for materials, I used a No. 11 Clinton thimble for the boiler; this is a quality thimble of heavy gauge brass chrome plated. You will also need two 000-120 fillister head machine screws, one to secure the flywheel to its shaft and the other to retain the cylinder spring. Phosphor bronze wire of .006" dia. was used for the spring, but music wire will do just as well. The shafts of the crank were taken from the shanks of old drills. The remaining material is bar stock — no castings needed!

Before beginning a description of some of the more important machining techniques, a few words are in order regarding the dimensioning of the drawings. The general rule followed was that the number of decimal places in a given dimension is inversely proportional to the permissible error in that dimension. Thus a four-place dimension is a highly critical one (to be held to within a thou) whereas a one place dimension is hardly critical at all. Of course there are exceptions For example, the piston and cylinder bore are nominally 1/16" dia.; one can depart from this dimension by several thousandths in one of the components, but the other must be held to within .0005" of the first.

Begin construction with the STANDARD. Clamp an oversize strip of say 3/32" thick brass to a piece of scrap aluminum and secure to the milling table. With an endmill, bring the strip to a thickness of .078". Now drill the main-bearing and pivot holes. The .1400 center to center distance is critical, so use the micrometer table feed to space these holes; start with a No. 0 centerdrill and follow with drills in good condition — the .052" dia. pivot hole in particular must be smooth. Check that the centerdrill runs truly and observe the drilling under magnification to be sure all goes as you intend. The ports are drilled later as shown in Fig. 2. Mill the step, remove, and cut, file or mill the outline to shape. Drill and tap the 0-80 hole for the steampipe being careful not to go too deep. If after drilling the inlet port, the two passages do not meet, the inlet passage can be extended with a No. 78 or larger drill.

The PORT DRILLING GUIDE can be made next. Clamp or solder a strip of 1/32" thick steel to a piece of scrap and mill the slot with a 1/16" dia. endmill; it will help to drill a small hole first at each end of the slot. The length is not critical and, in fact, is shown much longer than necessary. What is critical is that the .052" dia. hole be centered on the centerline of the slot, so do not touch the crossfeed when advancing the table to the location of this hole. Take the same care when drilling this hole as when drilling the standard above. Next locate the No. 80 hole; advance the table screw .061" and the crossfeed. 012". Touch the revolving centerdrill to the work to make a tiny dimple. If your equipment is sensitive enough, you can drill the No. 80 hole at the same setup. Mine was not, so the drilling guide was taped to a faceplate mounted on the tailstock ram of the small lathe as shown in photo 1; the tailstock ram was then advanced into the drill held in the spindle. The result was then inspected under an 18X jeweler's loupe to determine if the drill had gone the proper way. Happily, the hole was exactly centered in the dimple and it was not necessary to try again although another guide was prepared on the same strip just in case. This was a practice followed throughout the entire building of the engine. Two or more of each of the components were started with each new setup. In small sizes, setup time far exceeds actual machining time so making a duplicate or two took hardly any extra time (or material!). If an accident or loss in swarf occurred later, a spare was ready and work could continue in a forward direction. Retreats encourage surrender.

Turn attention to the CYLINDER next. Use a good quality bronze for this important component; SAE 660 machines to a superior finish. The cylinder is formed on the end of a .105" by .273" rectangular strip to facilitate holding. Now bearing bronze is more readily available in round bar rather than in rectangular bar or sheet form. Thus your first task will probably be that of obtaining a truly flat .105" thick disk of the bar from which the strip can be cut. In my case, one end of the bar was machined flat and a disk thicker than desired sawn off in the power hacksaw. A block of aluminum was then held in the machine vise of the mill and the top surface flycut flat and parallel to the table. A spot of 5-minute epoxy was mixed and the disk cemented machined side down to the aluminum block, applying considerable downward pressure to spread the glue uniformly. After curing, the disk was flycut to the desired thickness. Out of the vise, the block was heated until the epoxy loosened its grip.

Strips were then rough sawn from the disk and milled to the required width. To ease the task of holding the small pieces in my relatively massive milling vise, a piece of 1" by ¼" aluminum bar was tightly clamped in the vise and a step milled on the end as shown in photo 2. The strips were then held in the step by C-clamps for the milling operation. A particular advantage of this method of holding is that the strips are sure to come out perfectly parallel and square.

Having obtained a strip or two of cylinder material, next turn the pivot in the lathe. If you have followed the above procedure, and if your lathe and mill are separate machines, leave the step block in place since it can be used with advantage to drill and ream the bore; if your lathe and milling machine are one, another step block can be prepared when the time comes. Chuck the strip in the 4-jaw and position accurately with the aid of a dial test indicator. Note the slotted packing piece in photo 4 used to prevent marring three of the surfaces of the strip (two of these surfaces index the strip in the step block for machining the bore). Check at this point that the chuck is holding the strip with its long surfaces parallel to the lathe axis if you are at all unsure about the accuracy of the chuck. If shimming is called for, small bits of foil tape are convenient; allow say ½" of the material protruding from the chuck to run the indicator against. When the alignment is satisfactory, saw or face off the excess and proceed to turn the pivot.

The pivot should be a close but free fit in the standard and the port face as smooth as possible. Integral-pivot cylinders enjoy two important advantages over inserted-pivot cylinders. First, the pivot is absolutely perpendicular to the port face. Second, the distance between the cylinder bore axis and the port face is minimal the effect of which is to minimize loading, and hence wear, on the pivot and the extremities of the port face. On the other hand, the more conventional design in which the pivot is screwed into the cylinder wall, allows for easy lapping of the port face, namely while the pivot is removed. Another advantage is that the pivot can be made of harder material than the cylinder, for example stainless or carbon steel. Now in larger sizes, the integral-pivot cylinder need not lack these features. For example, a recess can be turned on the port face around the pivot and the cylinder face then lapped against a revolving flat lap with an oversize central hole to clear the pivot (the pivot can be protected by a thin coat of stick shellac). Furthermore, a thin steel bushing can be pressed over the integral pivot to improve its bearing qualities. These features could be incorporated on this engine at the expense of increasing its size, and the primary design objective here is compactness. With really fine machined finishes, lapping has proven unneecessary for successful operation and the pivot has held up very well. Indeed, the pivot of the Steam Truck engine has shown virtually no wear after many miles of operation.

Offer up the standard and inspect the joint against a light. You will have to slightly camfer the edge of the pivot hole in the standard to allow the port faces to come into intimate contact. If the pivot has turned out too small or the port face not flat enough for steam-tightness, rechuck the strip and give it another try (another advantage of using a long strip). When you have a fit with which you are satisfied, drill and tap the pivot 000-120. Photo 5 shows a setup which worked very well; the round shanked tap was gripped in a hollow pin chuck which in turn was slipped over a close fitting rod held in the tailstock chuck.

Drill and ream the cylinder bore next. Photo 6 shows the bronze strip clamped in the step block ready for centerdrilling. Locate the bore carefully. Note the stoppiece held in place

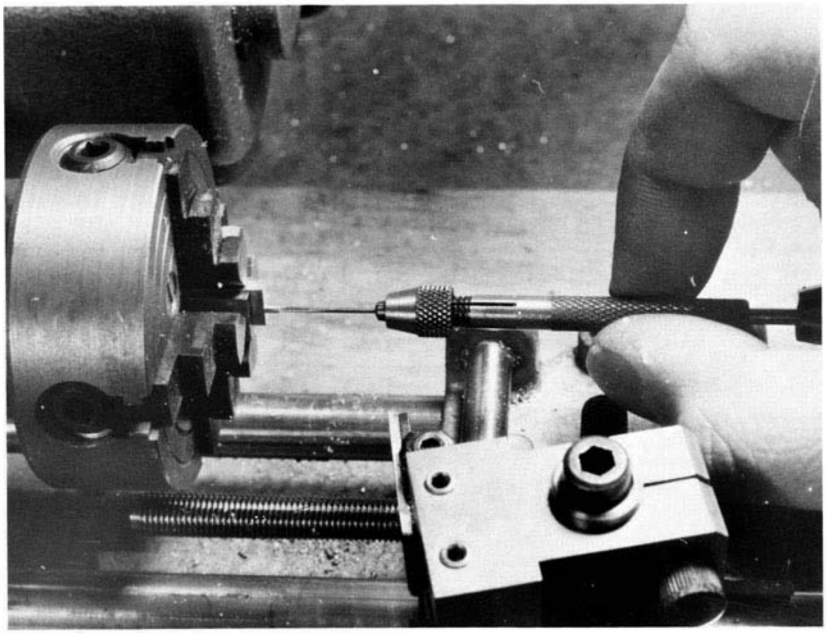


Photo 5. Tapping the pivot 000-120.

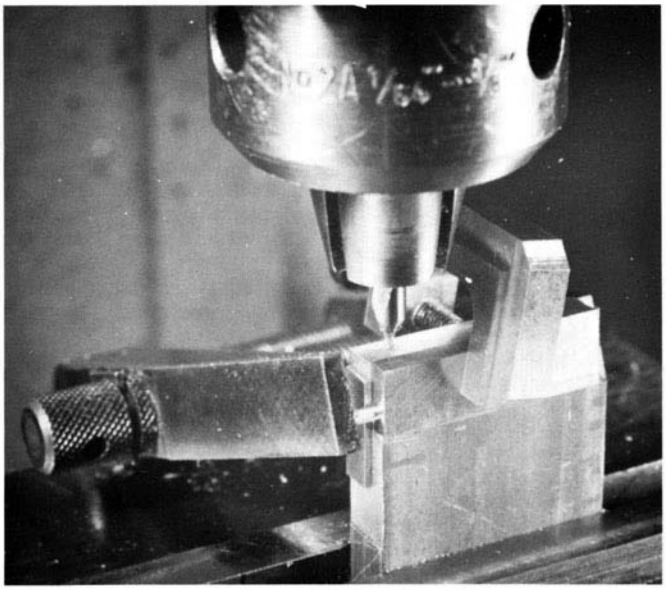


Photo 6. Setup for machining the cylinder bore.

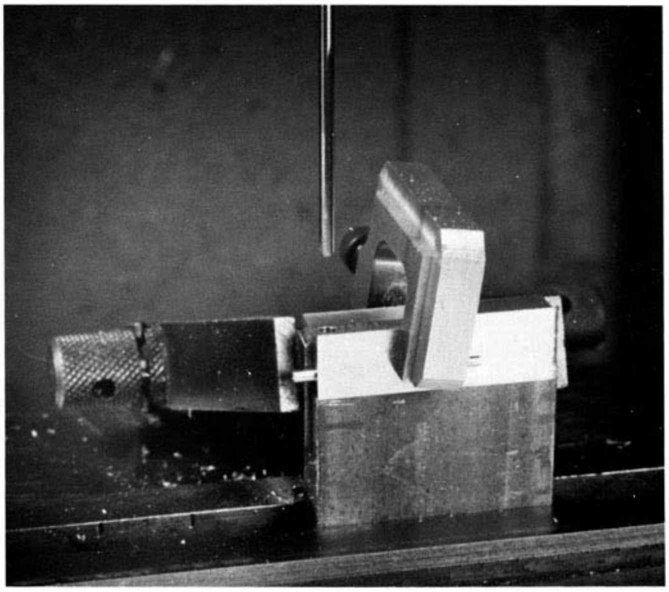


Photo 7. Reaming the cylinder bore.

with a toolmakers clamp; this permitted rapid positioning of the four cylinders which I machined. Centerdrill just deep enough to positively guide the .059" dia. drill. Watch depth when drilling; it is very easy to break through the top. Now ream the bore with a 1/16" dia. chucking reamer (photo 7). A hand reamer is unsuitable for this operation because the lands are slightly tapered for some distance back from the leading edge. The reamer must be in good condition and the bore it produces quite smooth. However the cylinder is held for this operation, make certain that the bore is quite parallel to the port face.

The cylinder can now be parted from the strip on which it has been taking shape. Photo 8 shows this operation being carried out with a jewelers slitting saw. This left an accurate and smoothly finished surface on the back of the cylinder. A small holding fixture was made next and the cutouts on the lower end of the cylinder were made with the same saw to form the trunk guide legs. However, these cuts could be made in the setup above before parting off. In any case, plug the bore with a brass rod to minimize burr formation during this operation; the plug should be left protruding from the cylinder just enough to be gripped for removal. Remove all burrs with a penknife. Be very careful on all deburring operations. A scratch in the wrong place may very well ruin a part. Use a magnifier to check that all burrs are removed. Only the port remains to be drilled, but this must wait until the piston is made.

A piece of centerless ground stainless steel rod was found to be a snug fit in the reamed cylinder bore; a little polishing with No. 600 "wet or dry" paper produced a nice close free fit for the **PISTON**. The difficult operation was crossdrilling the 1/64" hole for the crankpin. A length of the polished rod was set up on the cross slide of the lathe so that its axis intersected and was perpendicular to the lathe axis. A dimple was made with a centerdrill and then the 1/64" dia. drill was fed through. My first attempt was that easy. But inspection under the eye loupe showed that the hole was not truly central; under an 18X lens, an error of a thousandth or two shows up quite clearly. A check of the centerdrill showed that it was not running truly. The next attempt produced a blunted 1/64" drill. A bit of thought led to the conclusion that the tip of the centerdrill had been allowed to rub without cutting, thus producing a work hardened dimple in the stainless rod. With a new centerdrill and the experience gained on the first two attempts, a satisfactory piston finally emerged.

You will need the **GUIDE PIN** to drill the port in the cylinder. Make the body of brass or steel. Turn the .062" dia. portion to a close fit in the port drilling guide slot; reduce the end to .060" dia. and thread 0-80. Drill in No. 79 and part off to form the .10" dia. head. Press in a length of 1/64" dia. drill shank (the blunted one in my case). Press fits in these sizes do not require much interference; I have found that the 5-sided tapered broaches used by the watchmakers are very useful for opening out small holes. Check that the shank of the guide pin stands perpendicular to the drilling guide surface.

The port can now be drilled in the cylinder. Bolt the guide pin into the slot of the drilling guide as shown in Fig. 3; the piston should be located at about midstroke. Be sure that the setup has been made so that the port will be placed on the correct side of the cylinder centerline. After drilling, very carefully remove the burr around the hole; I used a straightedged razor knife while wearing the eye loupe. Again, be careful; we do not want the edge of the port enlarged nor do we want a scratch on the portface. The burr must be removed slight though it may be, for if left, it will wear a path between the inlet and exhaust ports in the standard.

Now make the **CRANKSHAFT**. Chuck a piece of 1/8" dia. brass rod in the 4-jaw and set to run eccentrically exactly .062" t.i.r. Face, centerdot, and drill in No. 79. Now set the rod to run exactly true, reface, centerdot, and drill in No. 76. Turn the end of the rod to .100" dia. and part off to the desired thickness. For the same reason given above, it is a good idea to drill deep enough to part off two or three of these disks. Cut the shafts from old drill shanks and press into the crank disk. I turned up little bushings to guide the shafts in straight; a small arbor press supplied the nudge. Check that the crankpin is parallel to the main shaft; Fig. 4 shows one way to do this.

Turn the **MAIN BEARING** from bronze. First drill through undersize and finish with a .021" dia. drill to obtain a close fit for the crankshaft. Press the bearing into the standard and assemble the parts you have. The mechanism should work smoothly. Make any necessary corrections before proceeding. Tiny burrs are sufficient to cause noticeable binding.

The ports can now be drilled in the standard. Turn a bushing to closely fit the crankpin with an O.D. of .048", or exactly .014" smaller than the width of the slot in the port drilling guide. Fig. 2 shows the use of the guide. Be sure to set the guide at each extreme before drilling. To hold the guide at this setting, a dab of hot shellac can be applied to an appropriate place. Again check that the guide is setup correctly. After drilling the ports, drill the No. 78 exhaust passage to meet the exhaust port and check that the inlet port meets the inlet passage. Remove burrs from the portface by rubbing the standard against No. 600 paper placed on a flat surface.

The **FLYWHEEL** and **SPRING WASHER** are simple tasks compared to what has already been accomplished. Wind the **SPRING**, assemble, and the great moment is at hand. Thread the end of a length of 1/16" O.D. tubing 0-80 and screw into the standard. Connect to a source of low pressure air (e.g. a hand pump). The engine should run merrily on 10 to 15 psi.

Most constructors will probably wish to make the **BOILER** next in order to try the engine on steam. It is only necessary to turn a top cover from brass or bronze bar stock to accept the thimble which is then silver brazed in place. In my case, the thimble was chrome plated as already mentioned, and therefore the plating was removed from the rim of the thimble before brazing. After brazing, the thimble was somewhat discolored, but a buffing wheel soon brought back the chromium luster. Photo 9 shows rather clearly the manner in which the thimble fits into the rim formed on the boiler top; this rim then rests on the ring stand also clearly shown in the photo. The center bush of the boiler top — turned integral with the top — is tapped 5-44 to accept the steam pipe to the engine.

The steam pipe is a simple turning from brass hex rod threaded at the large end to screw into the boiler bush and terminating in a 1/16" dia. portion the end of which is threaded 0-80 to screw into the engine. This fitting was purposely made long so that one's fingers could reach around the engine to grasp the hex section firmly enough to remove the assembly for filling the boiler. A Teflon washer seals the joint without excessive torque. Before screwing the steam pipe into the engine standard, the threads were lightly coated with 5-minute epoxy which sealed this connection very neatly.

If at this point you wish to try the engine under steam, you can arrange a loop of wire to support the boiler over a tiny flame. But remember that a tiny engine requires only a tiny flame. A few drops of ordinary steam cylinder oil — yes, the very same kind that the locomotive boys use — should be applied to the engine before each run and a drop pumped through the exhaust passage after each run. Do not overfill the boiler or priming will occur; 1cc is adequate for a No. 11 thimble.

Reference to the scale drawing in Fig. 5 will give the dimensions which I followed for the stand, but at this point you may wish to elaborate a bit more. The base was turned from 1½" dia. aluminum bar. An important feature is the central hole — visible in photos 9 and 10 — which easily clears the body of the alcohol lamp. Thus the lamp is not in any way fastened to the base; rather the base is placed down over the lamp. This arrangement permits easy access to the lamp for filling, wick adjustment, and lighting. The base was deeply drilled to accept the four 1/16" dia. stainless steel pillars which support the bronze ring into which the boiler fits. The ring was also drilled to accept the pillars which were then silver brazed in place. After pickling, the pillars were anchored in the aluminum base with Loctite.

The alcohol lamp body was turned from brass bar to an O.D. of 11/16" and a height of 9/16". The bottom of the lamp body was counterbored and a disk of brass cemented in place. The center of the domed top was tapped 3/16-40 to accept the wick tube fitting. This fitting was turned from stainless steel bar to minimize heat conduction from the flame to the lamp body. It features a notched rim which provides a finger grip for its removal and replacement during filling. The tubular tip is .100 O.D. by 1/16" I.D. and is packed loosely with soft string.

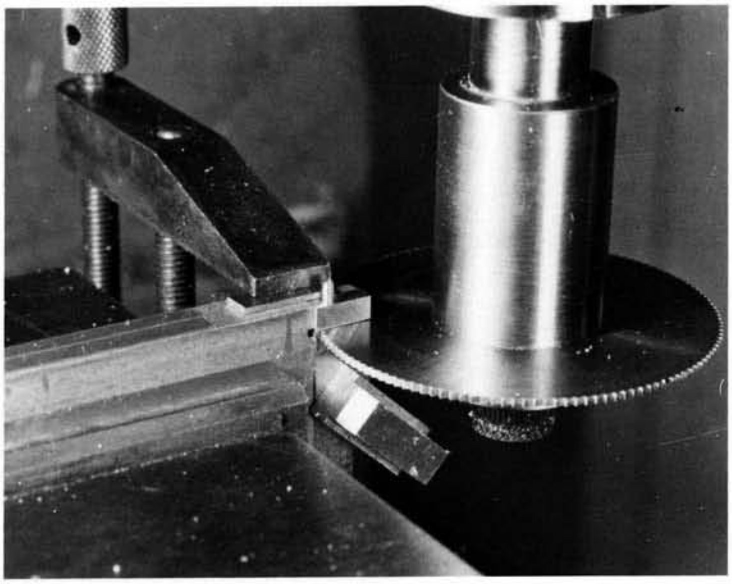


Photo 8. Sawing off the cylinder in the milling machine.

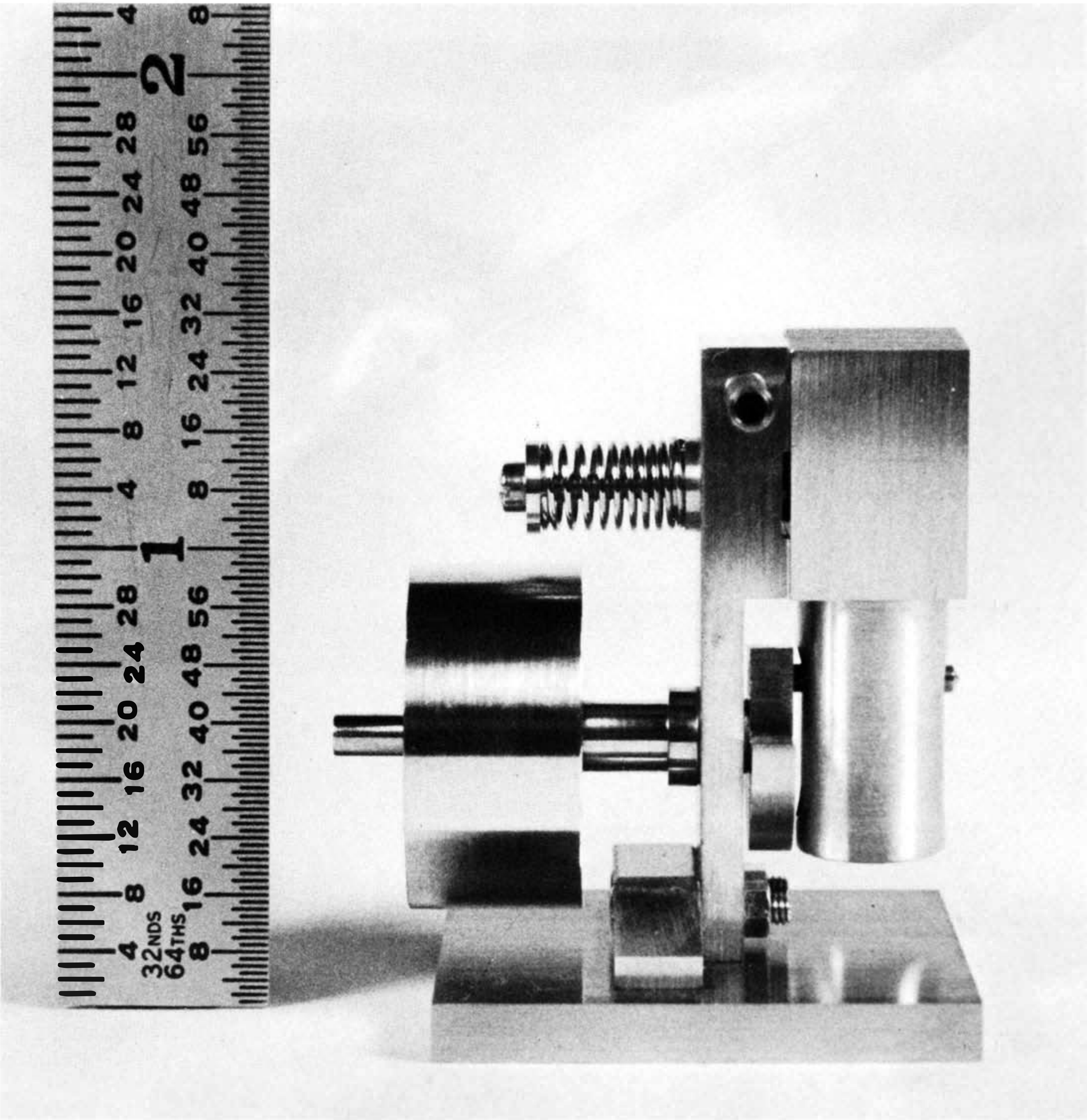
Photo 9. The power plant taken down for refilling.

Photo 10. Filling the boiler with distilled water prior to a run.

The "big brother" of the Thimble and Bijou engines:

Minikin

by Dr. James R. Senft



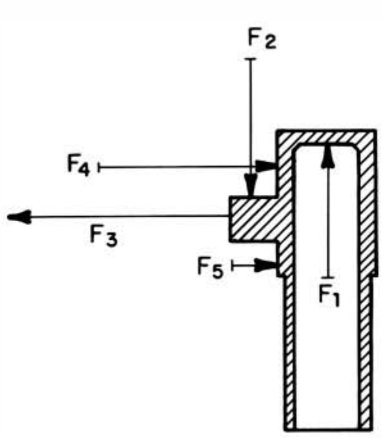


Figure 1

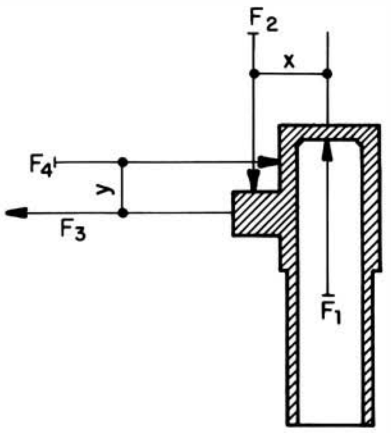


Figure 2

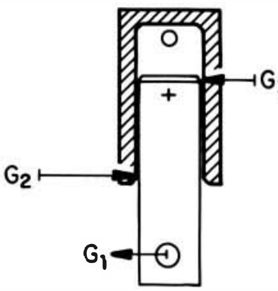


Figure 3

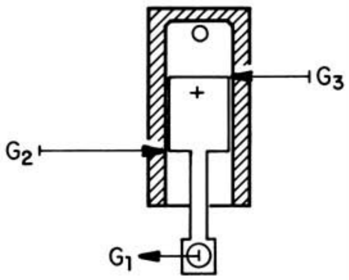


Figure 4

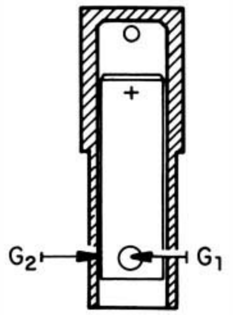


Figure 5

Minikin is the senior member of the *Thimble/Bijou* family of small, single-acting oscillating steam engines. A glance at the photos and drawings will at once reveal the family traits: cylinder pivot integral with the cylinder, trunk or crosshead guide on the cylinder, and long piston. I have long advocated these features as essential for the sound working of this type of engine.

Turning the cylinder pivot integral with the cylinder in the first place insures that it is truly perpendicular to the port face, an essential for good sealing. In the second place, it reduces "cylinder overhang," the distance from the cylinder bore axis to the plane of the port face. The heretofore commonplace alternative of fitting a pivot pin screwed into the cylinder requires a cylinder wall adjacent to the port face of sufficient thickness for a blind tapped hole. While perhaps acceptable in larger model engines, in tiny ones this method results in excessive overhang.

To see why overhang must be minimized, consider the simplified diagram of the major static forces acting on the cylinder shown in Figure 1. F_1 is the force on the cylinder due to steam pressure inside, and F_2 is a reaction force on the pivot from the standard. F_3 is the force supplied by the pivot spring, and F_4 and F_5 are reaction forces from the standard on the port face.

Now the spring force F_3 is constant, but F_1 varies throughout the cycle as pressure changes within the cylinder, and consequently so do the reaction forces F_2, F_4, and F_5. To determine the spring force required, let us look at the point where F_1 is maximum. Here F_5 is a minimum, which should be taken to be zero to minimize friction power loss. Then we have the simpler situation depicted in Figure 2. Here x and y are the respective distances between the two pairs of parallel forces.

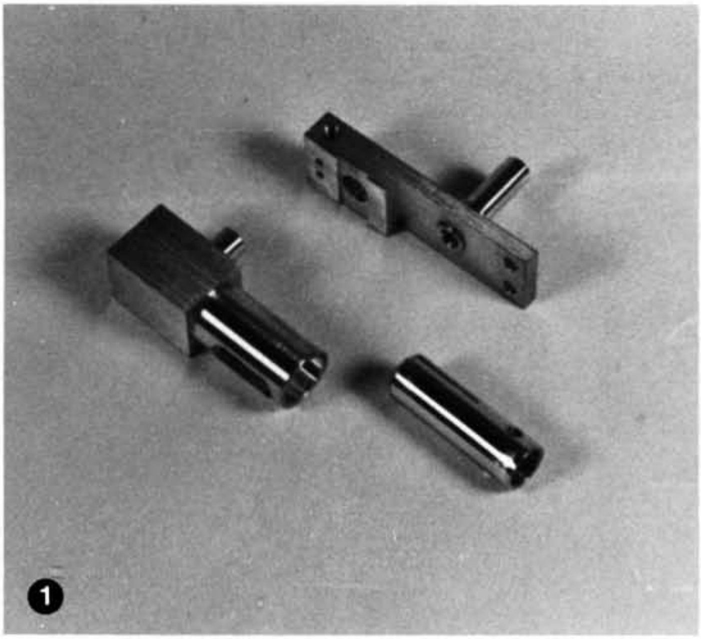
Now we must have $F_1 = F_2$ and $F_3 = F_4$ of course. The point of interest is that the torques produced by the two pairs of parallel forces must also be equal, that is, $xF_1 = yF_3$. This clearly shows that as cylinder overhang, and hence x, is increased, the spring force F_3 must also be increased to keep the cylinder against the port face. But the larger the spring force, the greater the friction power loss between the oscillating cylinder and the standard. Thus it is imperative to minimize cylinder overhang which the integral pivot pioneered by this author does admirably.

Note the importent role played by the spring. It is not, as often believed, merely required to counteract the steam pressure of the inlet port, a force so very small that it was neglected in the above discussion. Because of the usual short pivot and the unavoidable clearance between the pivot and its bearing, the spring, and not the pivot bearing, is required to hold the cylinder in contact with the standard against the very considerable pressure force within the cylinder. It is possible of course to build an engine with a very long and well fitted pivot, but the length required to realize a reduction in friction power loss is considerable, to say nothing of losing it as wear takes place. No, the spring works just fine; the point of this paragraph is to be sure to choose and adjust it with sufficient force to do its job, and just that.

The trunk or crosshead guide on the cylinder provides bearing surface in the optimum position to cope with the forces arising from the oscillation of the cylinder. Keep in mind that it is through the piston that the forces required to oscillate the cylinder are supplied. The trunk guide minimizes the side forces between the piston and cylinder, which results in minimum wear and friction power loss. Reference to figures 3, 4, and 5 will illustrate.

Figure 3 shows the typical major forces acting on the piston due to oscillation in a short cylinder bore. G_1 is supplied by the crankshaft. G_2 and G_3 are reaction forces from the cylinder. Note that G_2 is approximately twice the magnitude of G_1. Short pistons without crosshead guiding are similar as Figure 4 shows; piston wear is rapid. Figure 5 shows the same situation in a trunk guided cylinder. Here the only reaction force is G_2, and it is equal to G_1. The result is lower friction power loss and decreased wear.

Finally, I adopted the long style piston for several reasons. First of all, it gives the longest seal length possible in all crank positions; the more usual configuration of Figure 4 has a fixed seal length. Second, the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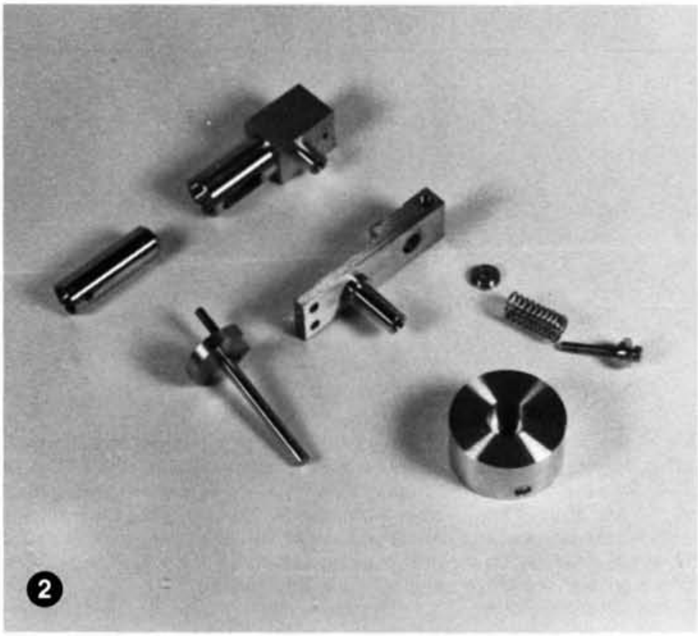
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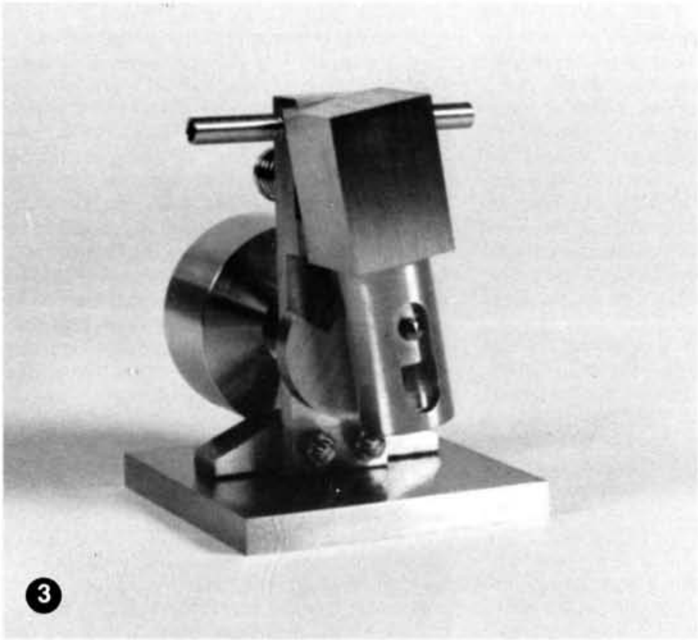
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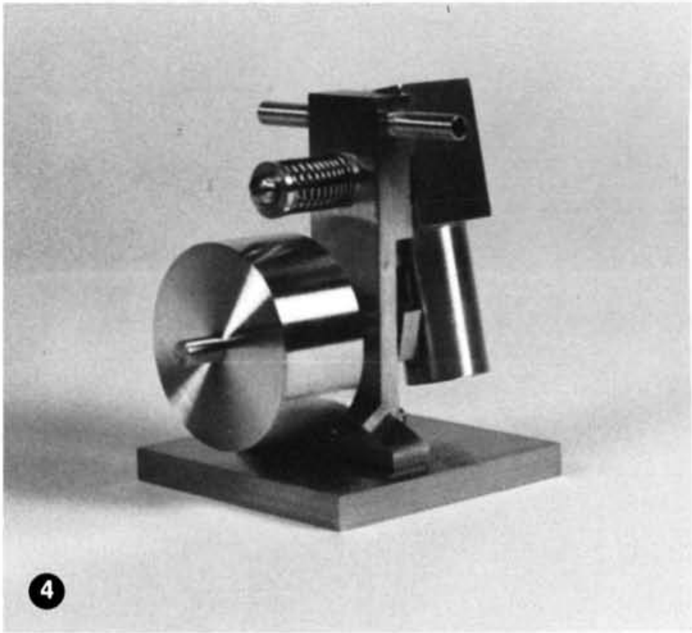
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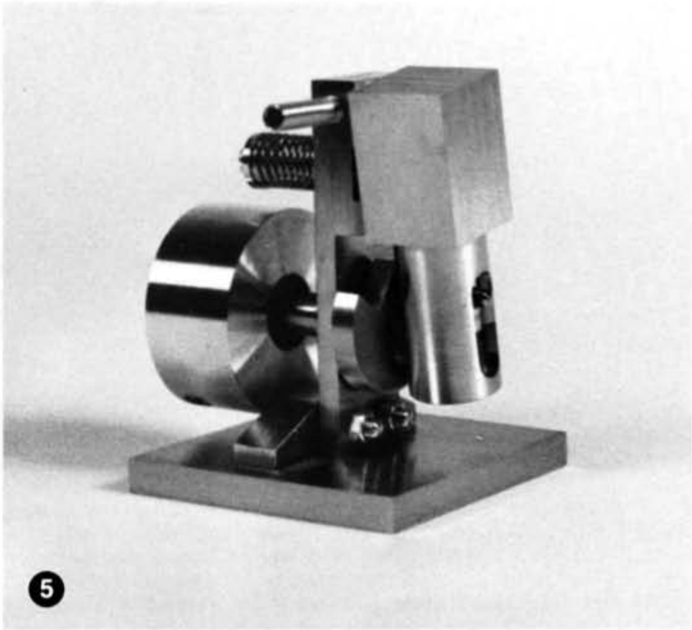
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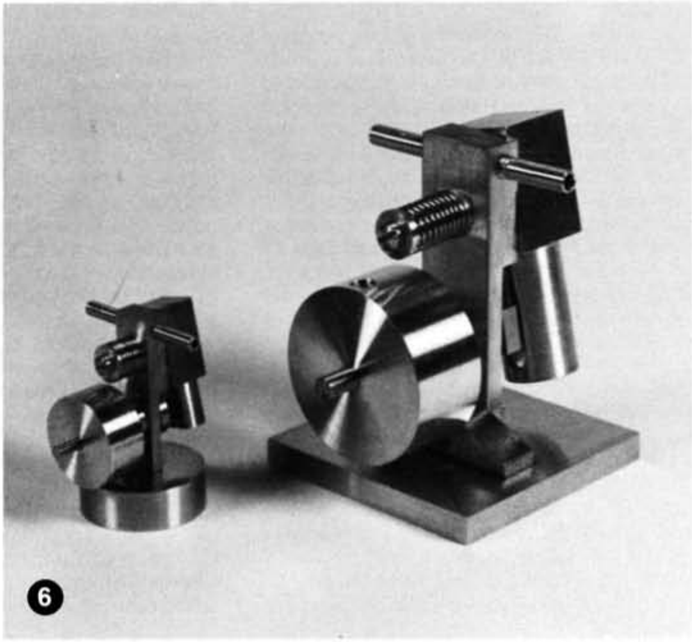
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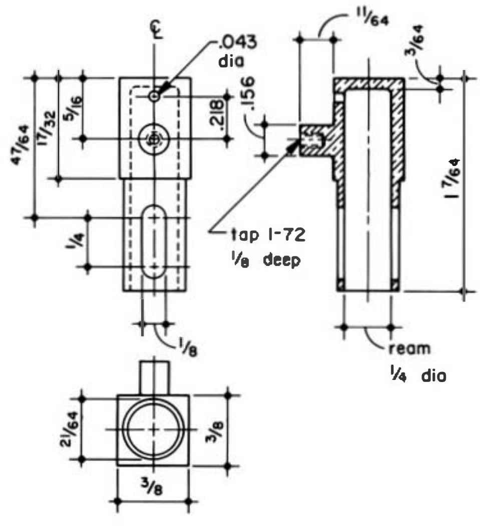
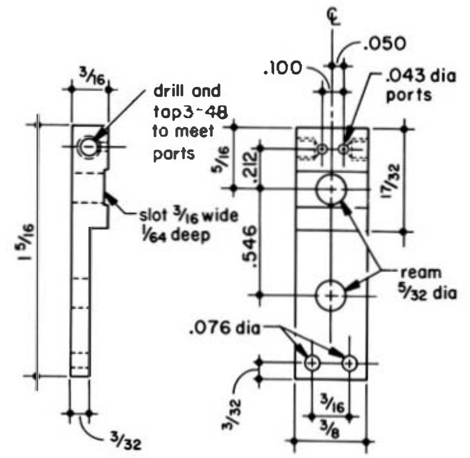
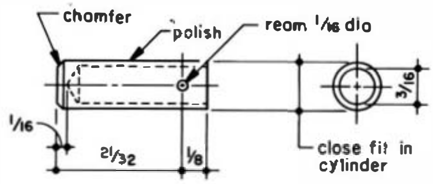


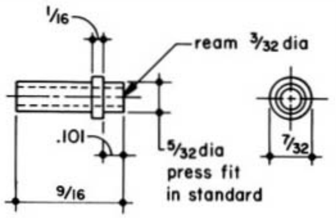
CYLINDER
Bronze



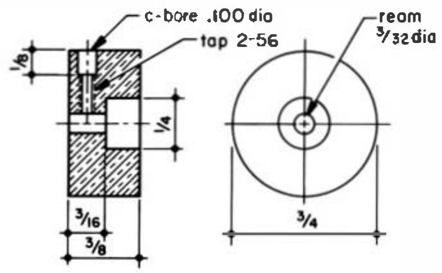
STANDARD
Brass



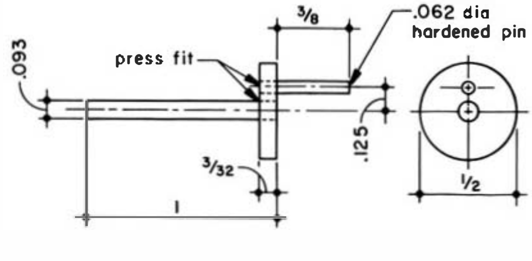
PISTON
Stainless Steel



MAIN BEARING
Bronze



FLYWHEEL
Brass



CRANKSHAFT
Stainless Steel

As the cylinder, piston and standard are completed (**photo 1**) *Minikin* begins to take shape. When your collection of parts resembles those in **photo 2**, you can assemble them into the finished engine shown in the other pictures. If you are working your way through the designs in this book and have the *Bijou* completed, your collection will resemble **photo 6** in which *Bijou* is on the left and *Minikin* on the right. Photos by Dr. James R. Senft.

long hollow piston is very low in mass. And third, it is just as easy, or easier, to make than the other.

Having thus justified the design principles of *Minikin*, and indeed again of its entire family, let us proceed to the actual embodiment. Most will find this engine somewhat easier to build than its smaller predecessors, but only because its size is within the range of the average machinist's experience. The old hand at the watchmaker's lathe of course would feel more at home with the *Thimble* engine on page 45. It is also a project that can easily be put to work. For example, it is large enough to power, say, a small model boat and yet is small enough to only require a simple pot boiler with a wick type alcohol burner.

Construction generally follows that of *Bijou* (see page 41) so it is not necessary to go through all the steps here again. But there are a few minor differences upon which it may be helpful to comment.

Again start construction with the **Standard** since two other parts must be made to fit, namely the cylinder pivot and the main bearing. Unlike *Bijou*, the standard for *Minikin* has no pivot boss, so it may be made from 3/16" thick flat stock. After cutting and machining to width and length, grip the piece in the vise of the milling machine or milling attachment on the lathe. The port face should be a bit proud of the vise jaws. Find the edge and then advance the feed to the centerline of the piece. Move to the location of the main bearing hole with the other feed screw; no great accuracy is needed for this location. Note the reading on the feed dial. Centerdrill, drill through, and ream 5/32" dia. Advance the feed exactly .546" and repeat.

The ports on *Minikin* are .043" dia., a size large enough to safely drill on even a large mill or slow turning lathe. So we may as well jig drill these rather than use the drilling guide system which I introduced for the smaller engines. Of course a guide is easily made if milling facilities are not available, and it ensures correct port location even if some of the important dimensions of the engine components vary somewhat from the drawings.

Advance the feed exactly .212" and then the other feed .050". Centerdrill with a #0 centerdrill (1/32" dia. pilot) but do not countersink; then drill .043" dia. to a depth of 3/32". Back the crossfeed exactly .100" from this reading being sure to take up the play, and repeat. Now, before breaking the setup, take a skim cut across the piece; this will ensure the port face is perpendicular to the pivot hole which is essential. Reposition the piece higher in the vise and mill the step and the 3/16" wide relief slot across the port face. Rub the port face lightly on a true stone to remove burrs.

Drill from each side to meet the ports for the steam inlet and exhaust pipes. You can tap 3-48 as suggested and then use 3/32" O.D. tubing for the steam lines; the threads can be sealed with Loctite or epoxy. Alternately, you can simply drill .096" dia. and solder the tubing in place. Finish the standard by drilling the mounting holes at the bottom. The drawing suggests two .076" dia. holes for #1 machine screws.

The sequence of machining the cylinder for *Minikin* is exactly the same as for *Bijou*. Again I used 660 bronze bearing stock. A disk was cut from 1½" dia. round bar and each side faced to a parallel ⅜" thickness. Then two diametrically opposite flats were milled; the distance across the flats was 1-7/64", exactly the length of the cylinder. This gave a fairly long rectangular section to grip in the 4-jaw for turning the pivot. Set up with the dial indicator. The piece was actually long enough for two cylinders, so after drilling and tapping the pivot, I reversed the piece and did it again! The cylinders were sawed apart and then milled to exact width. As with *Bijou*, make sure that this surface is parallel to the port face since it is used as a datum when chucking to machine the bore.

As on *Bijou*, make up a bushing to go over and protect the pivot, chuck the cylinder in the 4-jaw, and machine the cylinder bore and the cylinder skirt. Actually the bore in this case is large enough to finish machine with a boring tool if desired. I used a chucking reamer to finish after boring to within a few thousandths and got a beautifully smooth and true bore. The piston, made from centerless ground stainless steel, fit the bore to within a half a thou.

After milling the ⅛" wide slots in the cylinder skirt to allow the crankpin access to the piston, carefully hand scrape out the burrs being careful not to scratch the bore. Finish by drilling the .043" dia. port. If you are not using my drilling guide system, set up as I did in the milling machine, locate the pivot center with a dial indicator, and move up .218", centerdrill and drill. Again, do not countersink when centerdrilling lest the cylinder port span the inlet and outlet ports on the standard. Carefully scrape away the burr without materially altering the surrounding region; a burr left here would wear a "bridge" between the ports on the standard.

So much for the hard parts. Machine the crankdisk as on *Bijou*, again using a dial indicator to get the throw correct to within a few thou, the general rule to follow on decimal dimensions in my drawings. Of course, mating parts (as, for example, the piston in its bore or the shaft in its bearing) must be closer. A shank from an old (or new!) 1/16" dia. drill is ideal for the crankpin. Check the parallelism of the pin with the main shaft as on the *Thimble* engine; it is important for smooth operation.

Not shown on the drawings is the spring and its shoulder washers since your gadget drawers probably contain a suitable spring from which you can size the shoulder washers. *Minikin* uses two washers since the standard has no pivot boss. The pivot is just a bit shorter than the thickness of the standard, so both washers have a .076" dia. hole to clear the 1-72 pivot screw; one lies against the head of the screw of course and the other against the standard. As a guide, I wound a spring from .016" dia. stainless steel spring wire with an I.D. of 5/32".

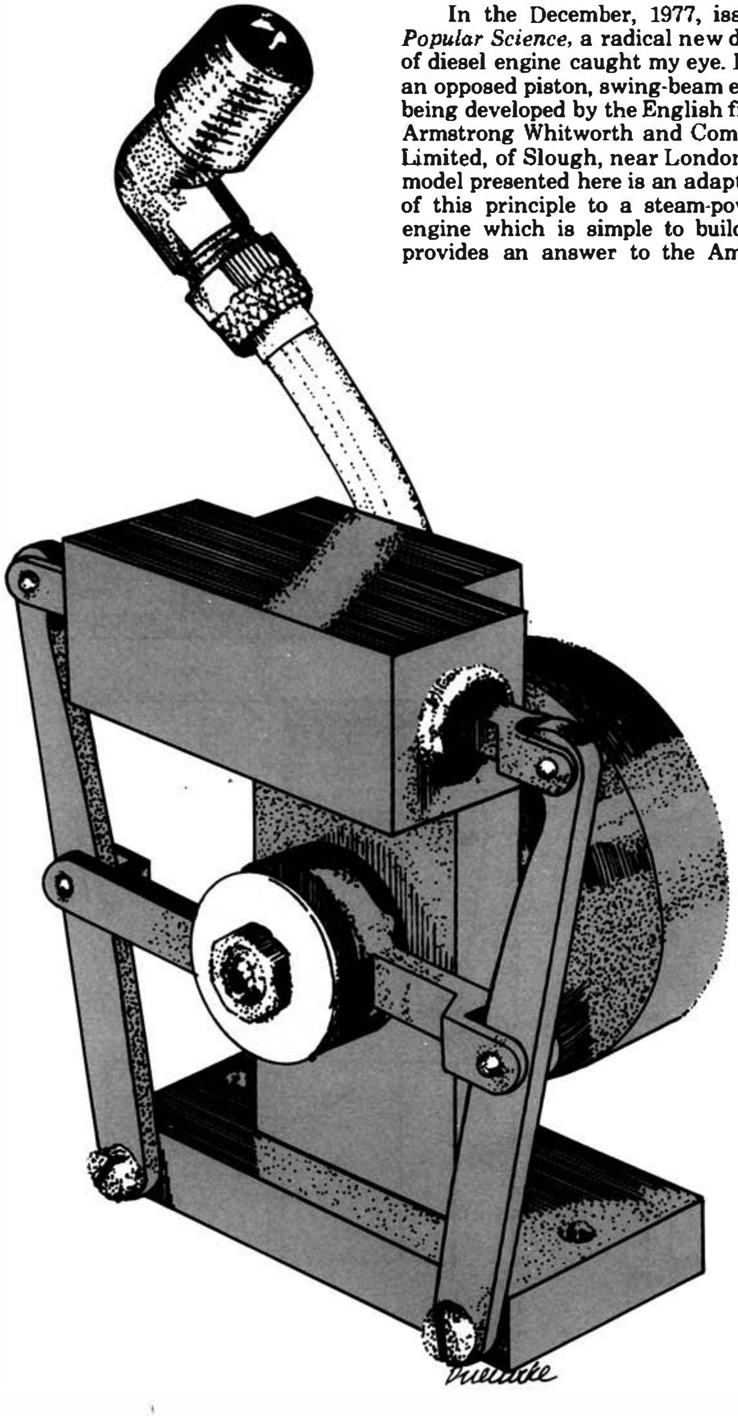
The flywheel set screw is a standard 2-56 fillister head brass screw with the head diameter reduced to 3/32" to allow it to enter the counterbore. Initially assemble the engine with no oil to check for tight spots; correct trouble spots before trying to run the engine, since tiny engines have a hard time trying to "wear parts in" to say nothing of the damage done to mating parts in the process. Often this dry test reveals burrs which were thought to have been removed long ago, so it is well worthwhile. When the action is smooth and free, oil and connect up to the steam or air line for the satisfying moment!

Build a simple

Opposed Piston Steam Engine

by Elmer Verburg

Photos by William C. Fitt



In the December, 1977, issue of *Popular Science*, a radical new design of diesel engine caught my eye. It was an opposed piston, swing-beam engine being developed by the English firm of Armstrong Whitworth and Company, Limited, of Slough, near London. The model presented here is an adaptation of this principle to a steam-powered engine which is simple to build and provides an answer to the Amateur Machinist asking for designs of small stationary engines which do not require castings.

I am unable to go into the fine points of determining stress and horsepower, but feel that for a simple engine, it does have several interesting features. It appears to be a balanced engine, but the weight of the arms and pistons and the speed do cause some vibration. The short throw at the cranks requires a high speed. The pistons travel twice as far as the connecting rods do at the cranks.

Also, there is room for some experimenting. The engine was first made with the exhaust only through the shaft, but it did not seem to run quite right. Two exhaust holes were then added to make a una-flow type exhaust. These, plus the other exhaust passage, lets it run like mad! If either of the two exhaust systems is closed off, the engine slows down, so both are needed.

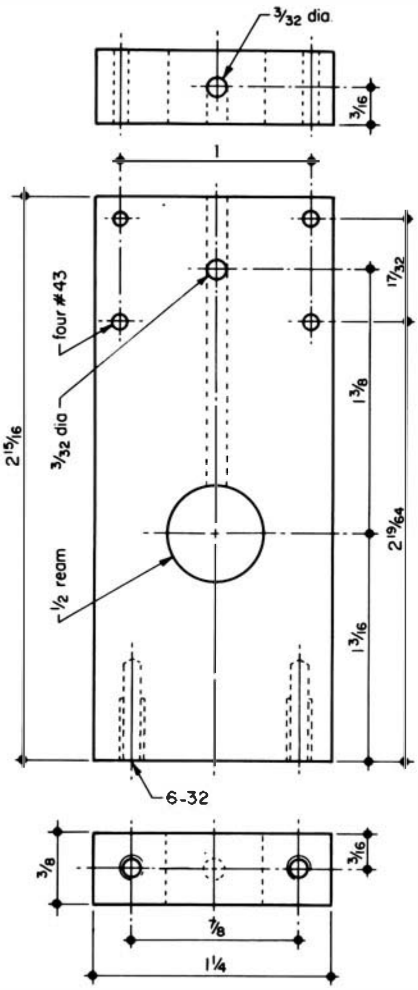
Another question involves the direction of rotation. There is a similarity in porting and it appears that the engine should rotate either way, but it will run only one way. The problem must lie in setting the eccentrics in the right relationship to the flat valve surface on the shaft. It is hard to do this right down to a fine point.

Something else to experiment with is the width and location of the flats on the shaft, to change the timing and cutoff.

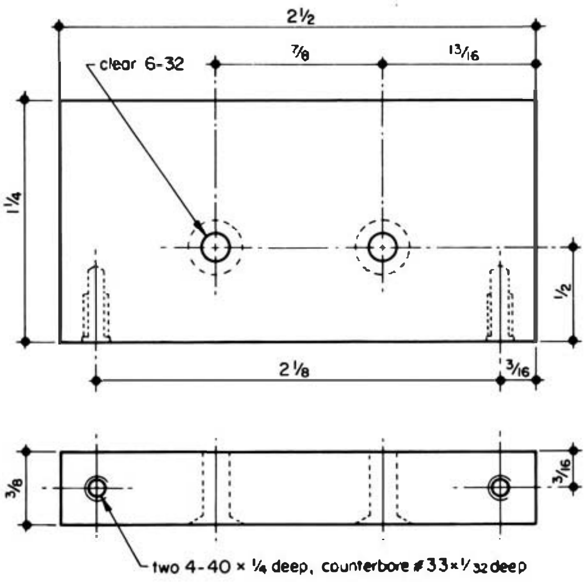
The material for this engine can be most any of the common metals. Since this was to be a display and conversation piece and not run very much, it was made of a fairly hard aluminum that was on hand. The pistons, bearings, eccentrics and screws are brass, the flat washers at the eccentrics are steel and the piston pin is drill rod.

The foot, column and cylinder are simple, straight pieces requiring squareness and accurate layout. Insert a short, 3/32" pin in the steam passages in column and cylinder as a guide, then square up and clamp together for spotting the four 2-56 tapped holes.

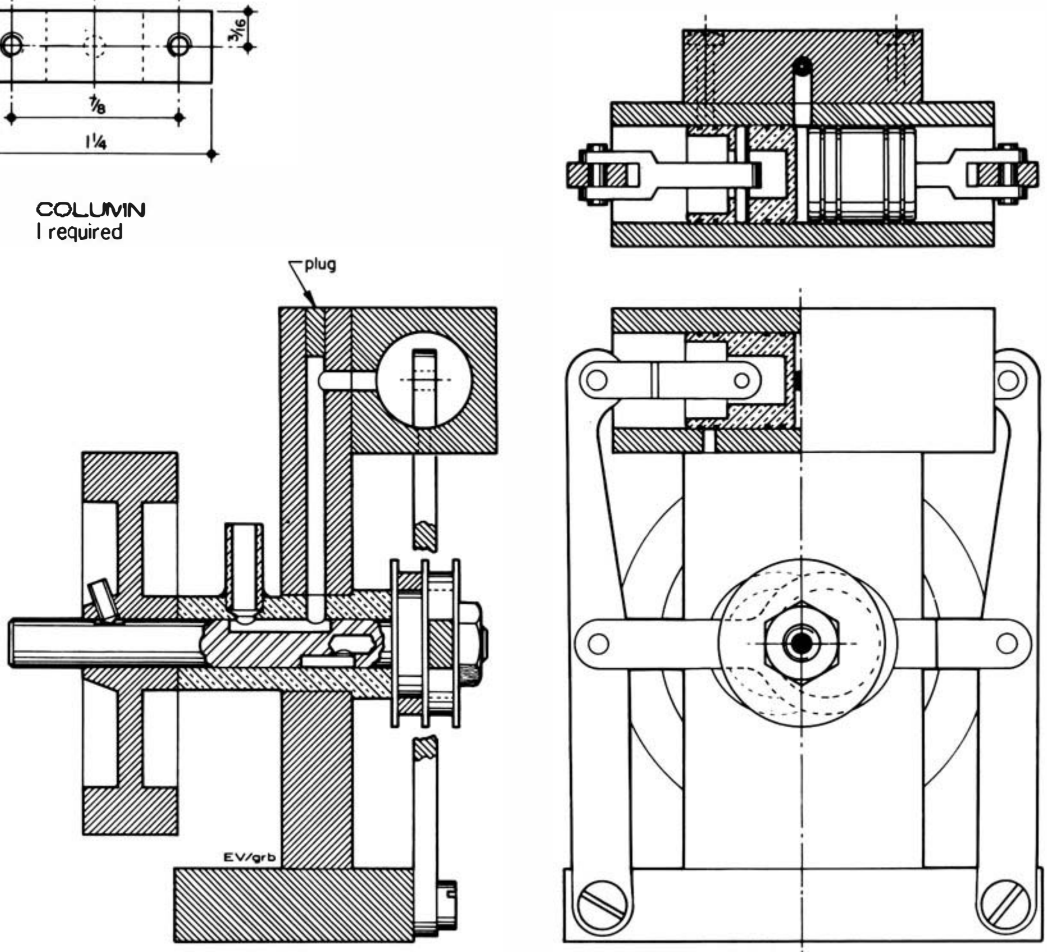
Make the rocker arms, shoulder screws, shaft and bearing. Assemble



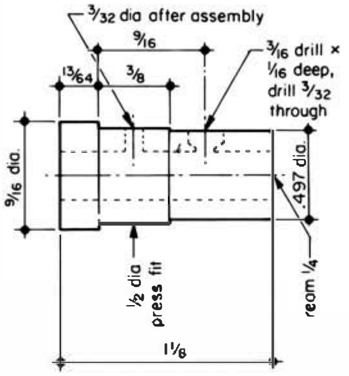
COLUMN
1 required



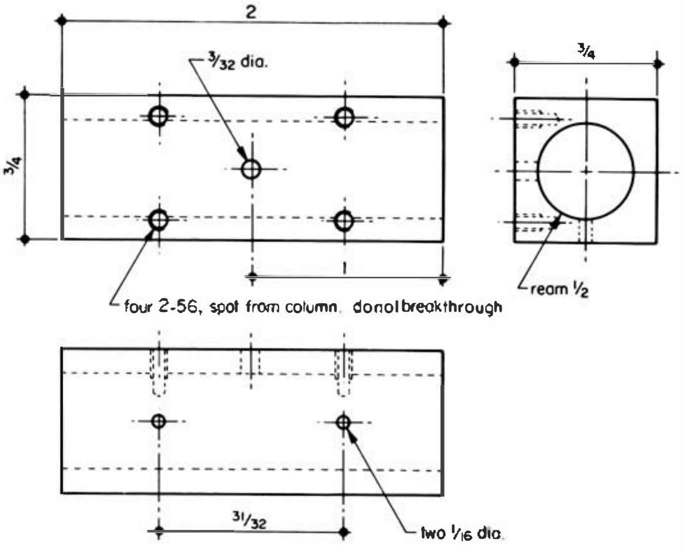
FOOT
1 required



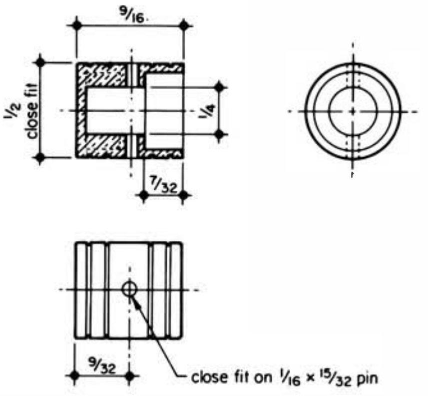
OPPOSED-PISTON ENGINE



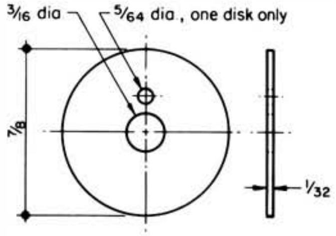
BEARING
1 required



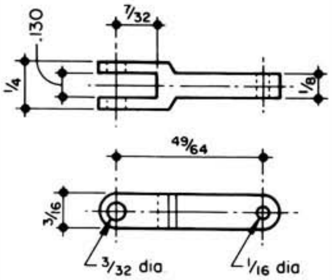
CYLINDER
1 required



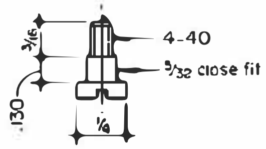
PISTON
2 required



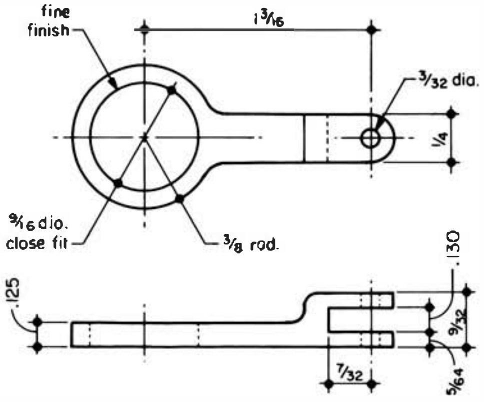
DISK
3 required



CONNECTING ROD
2 required



ROCKER ARM BOLT
2 required



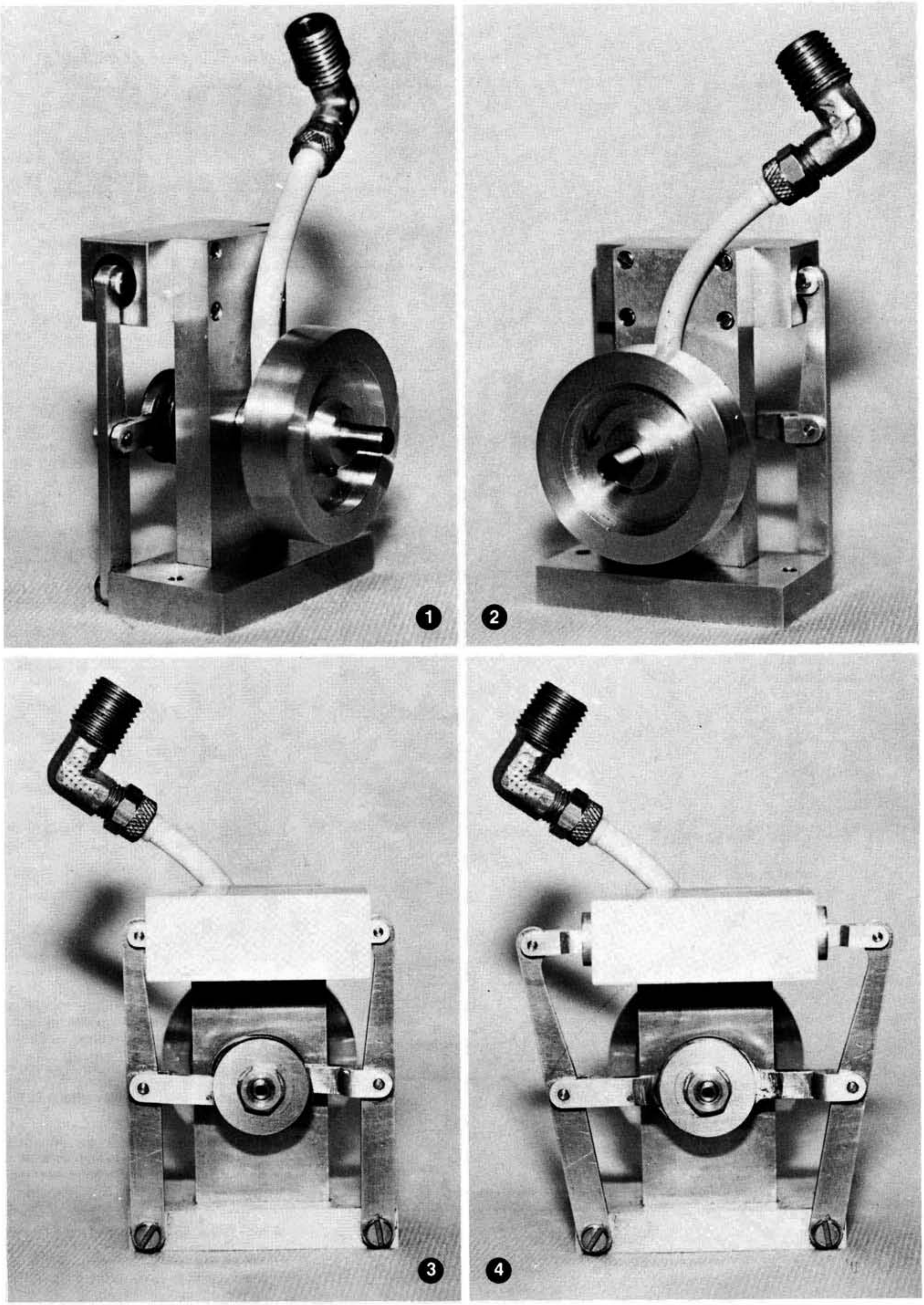
CONNECTING ROD
2 required

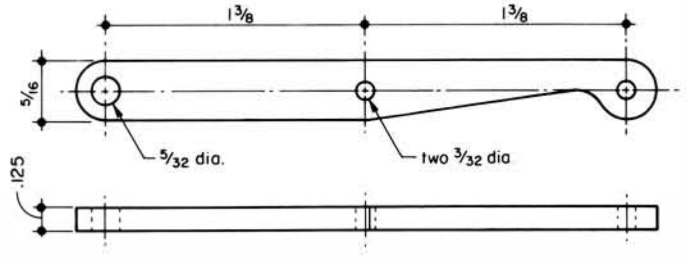
1 Shiny in bright aluminum alloy, the Opposed Piston Steam Engine makes a truly fascinating display piece and one that is simple toconstruct.

2 The direction o1 shaft rotation is shown by the arrow marked on the flywheel. This engine runs well for display on only a few pounds o1 air pressure.

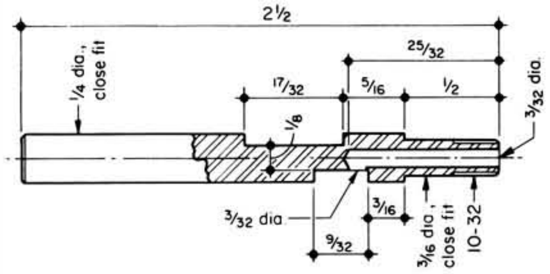
3 The action of the opposed pistons and connecting rods is demonstrated by these views of the crank end of the engine. Here, the pistons are close together and the valve is ready to admit steam to the cylinder.

4 In this view, the pistons have reached the end o1 their travel. Steam is exhausting both through the center of the crankshaft and directly through ports in the bottom of the cylinder.

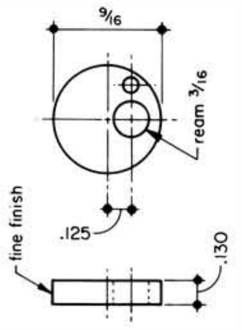

1
2
3
4



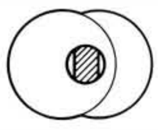
ROCKER ARM
2 required



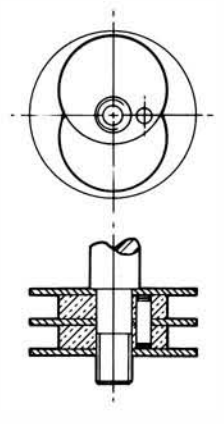
SHAFT
1 required



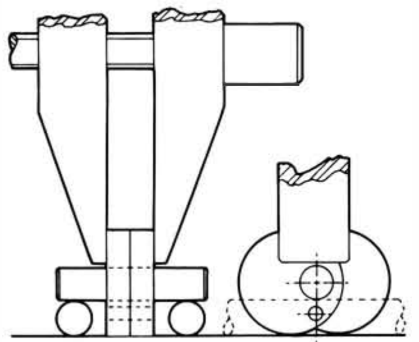
ECCENTRIC
2 required



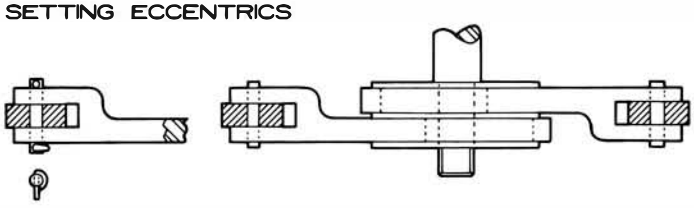
RELATIONSHIP OF ECCENTRICS TO VALVE FLATS ON SHAFT



ECCENTRIC ASSEMBLY



SETTING ECCENTRICS



CONNECTING ROD ASSEMBLY

the bearing into the column with the 3/16" hole on the vertical centerline. Drill through 3/32" for the steam passage. Solder a short length of 3/16" tubing in the bearing for a steam hose connection, as shown. I often run the engine on compressed air at 15 psi, so plastic tubing clings tight enough. For a more durable and steamtight joint, the tube can be longer and threaded.

When making the pistons, spot four oil grooves as shown, about .010" wide and .005" deep. If you can, take some weight out by undercutting to the dotted line. After piston, connecting rod and pin are assembled, very lightly prick-punch the pin hole rim over the ends of the pin to retain it. One very light punch per end is enough.

The eccentrics can be made in a four-jaw chuck. First, turn to an accurate 9/16" diameter, about ½" wide, then loosen the jaws slightly and, using the cross-slide for measuring, move the workpiece ⅛" off center. Ream 3/16" for the shaft. Return the workpiece to center (or near center) and make parting cuts for two .130" thick eccentrics. Mount the two eccentrics on a close-fitting 3/16" pin. Rest this pin on two more 3/16" pins on a flat surface, as shown. With the two eccentrics also touching the surface, clamp together with a small machinists clamp and drill the 1/16" pin hole. Mark with a stamp the two faces that touch, so the eccentrics can be reassembled in the same relationship in which they were drilled.

Make three disks. Use one of the eccentrics to spot the pinhole in the center disk only. This 1/16" pin, about 9/32" long, is retained by the two outer disks as shown. The o.d. of the disks can be finished by chucking the shaft to run true, then mounting the three disks and two eccentrics in place and hold them with a 10-32 nut.

There are several ways to make the four connecting rods. These range from plain hacksaw-and-file work to gang-milling the way Kozo Hiraoka does it (**LIVE STEAM**, February, 1975). For accuracy and finish, the 9/16" bore is a lathe job, using a center test indicator and fine cuts.

The four 3/32" pins in the rocker arms may be made in several ways. Here again, it isn't very good engineering, but a small prick punch near the rim of the pin will keep them in place. Tiny nuts and bolts can be made or make the pins long enough to take tiny cotter pins.

The flywheel should be about 2" in diameter and ½" wide, with a setscrew, to fit the ¼" shaft.

At final assembly, be certain that the relationship of the eccentrics to the valve surfaces on the shaft are correct. They are shown in the eccentric mounting detail drawing.

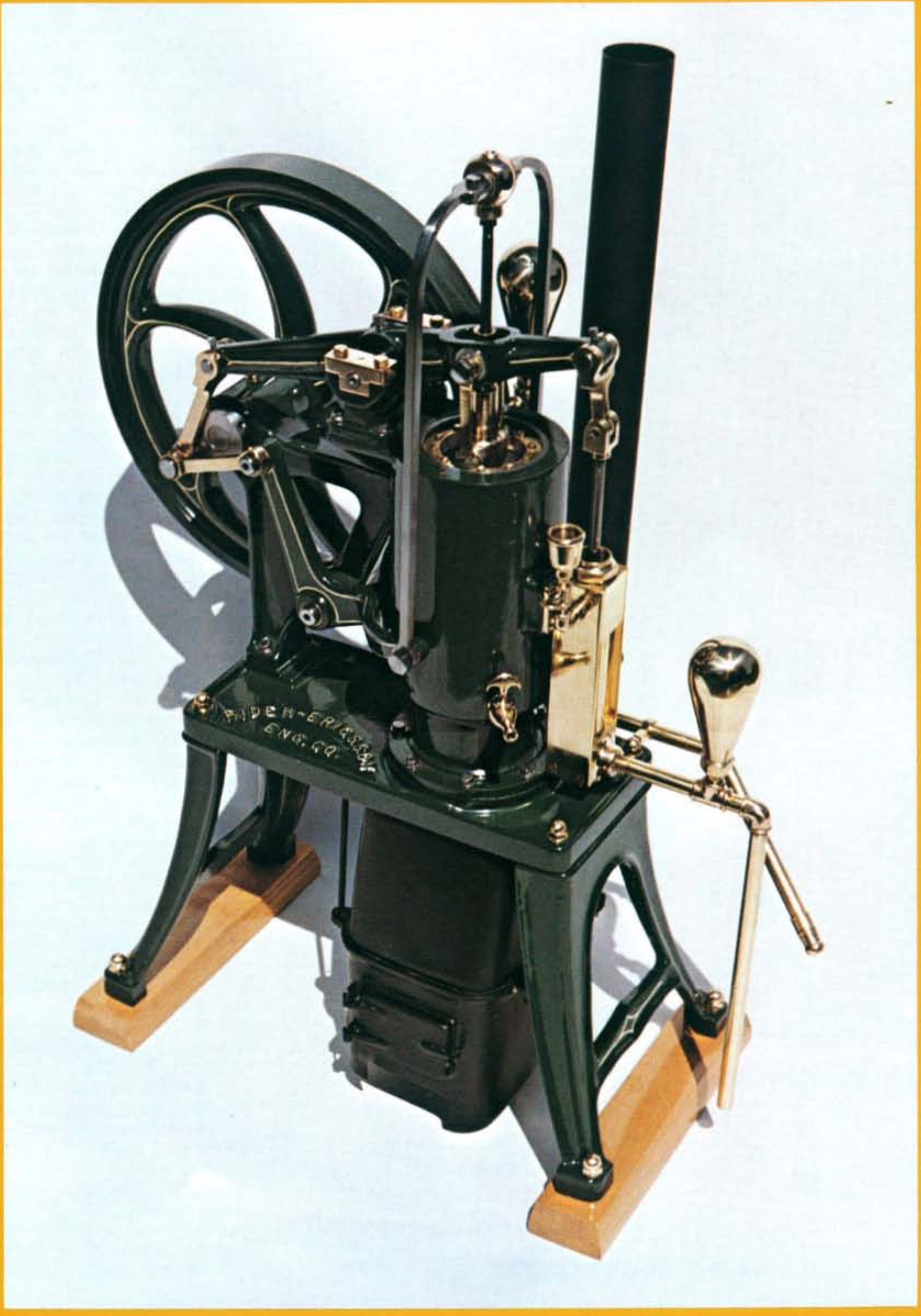
This simple and unusual engine should provide you with several hours worth of enjoyment in building and will be an interesting addition to your collection of steam engines.

A quarter-size Rider-Ericsson

Hot Air Pumping Engine

by Larry Kazyak

Photos by the Author



The hot-air or Stirling Cycle Engine was invented in 1817 by a Scot named Robert Stirling. Although such engines were quite low in poweroutputin proportion to their large size, they became popular due to their simple operation. Steam was the only other practical choice, since internal combustion engines were not invented until the 1880's. Steam engines, with their boilers operating at high pressures and the trained engineers require to watch over them, were often impractical for small or isolated installations.

The Ericsson Hot Air Pumping Engine was first patented in 1880. It was the creation of John Ericsson, who was born in Sweden in 1803 and emigrated to America in 1839. Many inventions are attributed to this prolific inventor. Perhaps one of the most noteworthy was the ironclad ship *Monitor*, built for the United States (Union) Navy during the Civil War. Another monumental—but only semi-successful—venture was the building of a 250' ship named *The Ericsson*. This vessel was powered by a hot-air engine having four cylinders operating at nine RPM. The pistons measured 14' in diameter and the stroke was six feet in length. The ship was launched on the east coast in 1853. Even though the ship had an engine of such heroic dimensions, it could travel at only seven knots, about half the speed of a comparable steam-powered ship.

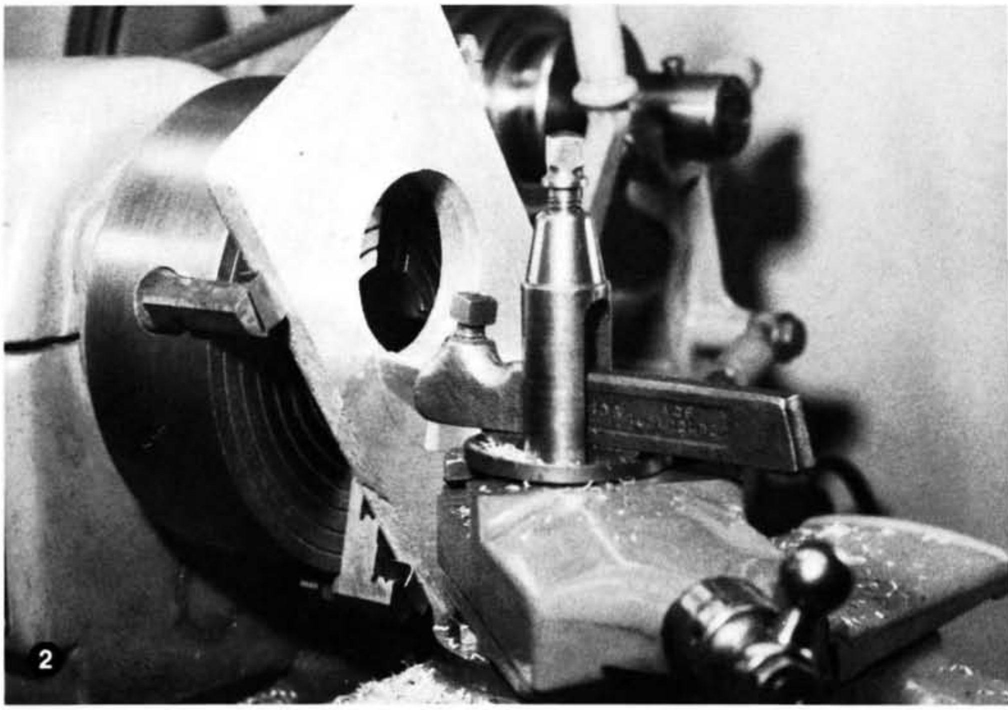
The fact that Stirling Cycle engines use an external heat source and that John Ericsson designed a solar-powered engine in 1872, point out that in one sense, there's really "nothing new under the sun."

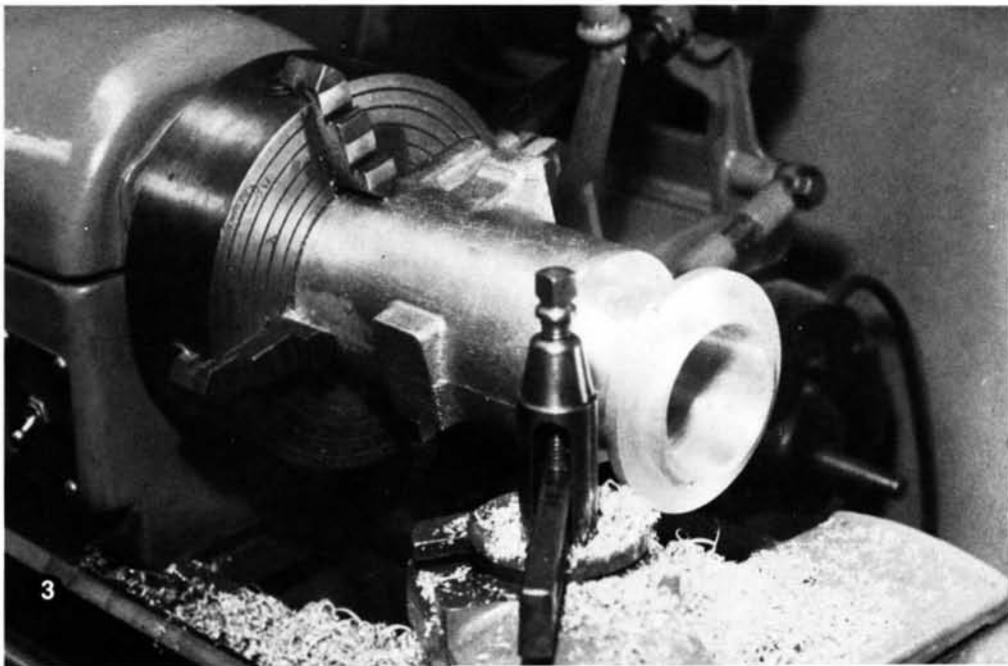
So much for background on the inventor. Let's get down to facts on the engine being modeled. The original is in the Henry Ford Museum, in Dearborn, Michigan. It is classified as an eight-inch engine, referring to the bore. The stroke is 3⅞". Operating at 100 to 120 RPM, it was capable of pumping 500 gallons per hour. The indicated horsepower was approximately ⅛.

Although the first Ericsson Pumping Engines were put into production in 1880, this particular engine was produced at the turn of the century. The main difference is in the legs and crankshaft bracket. Legs on earlier models were forged round bar stock instead of the cast type.

The Rider-Ericsson Engine Company (the successor to the DeLamater Iron Works, which was established in 1842) was established in 1870, with offices in New York, Philadelphia, Boston, Chicago and Sydney, Australia.

In operation, the engine was fired with wood, coal, producer gas or kerosene, depending on the type of firebox ordered. When the displacer cylinder reached operating temperature—usually in about fifteen minutes—the flywheel would be rotated by



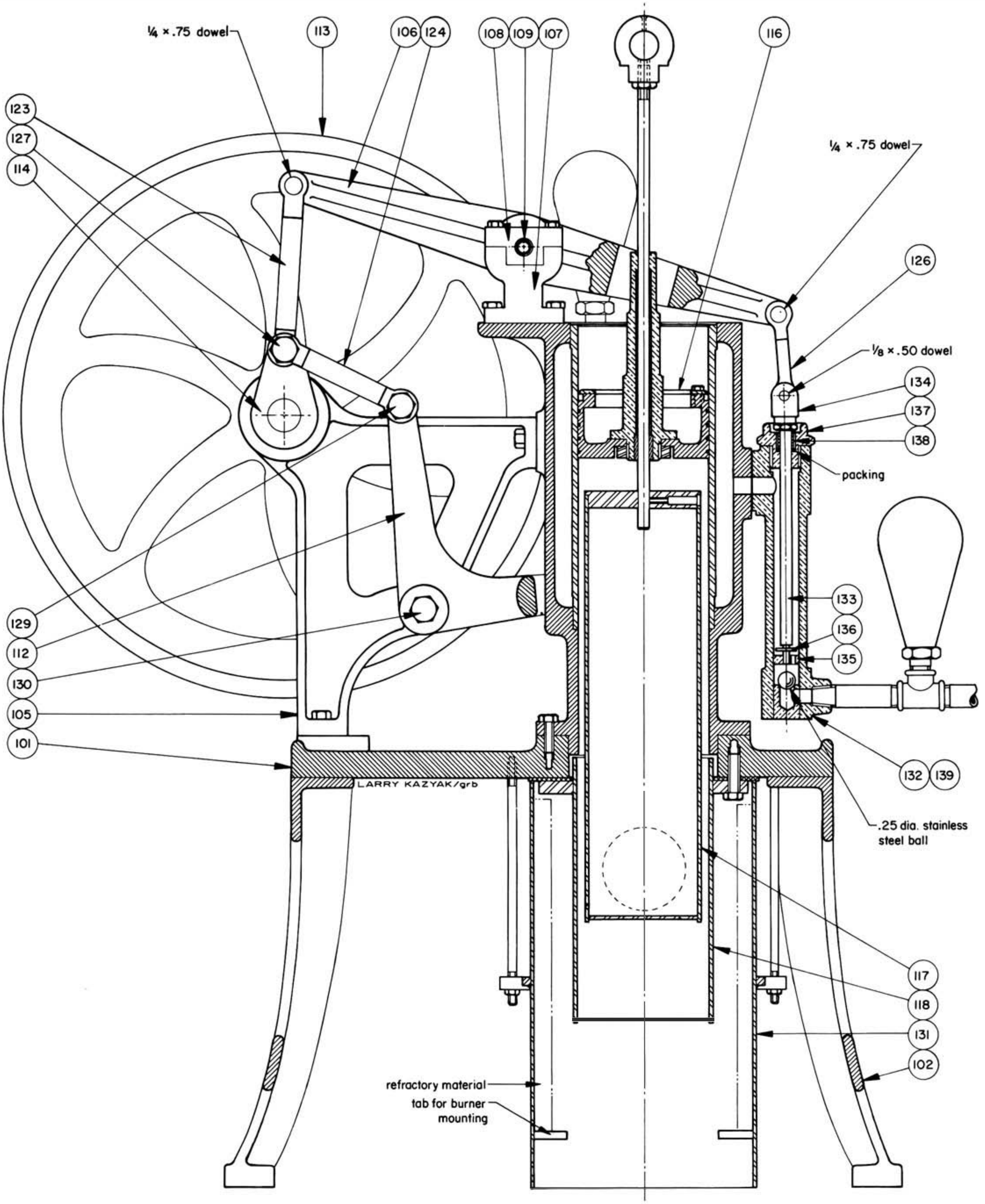


This quarter-sized model (opposite page) follows the prototype of an 8" Rider-Ericsson Hot-Air Pumping Engine, which is in the Henry Ford Museum at Greenfield Village, Dearborn, Michigan.

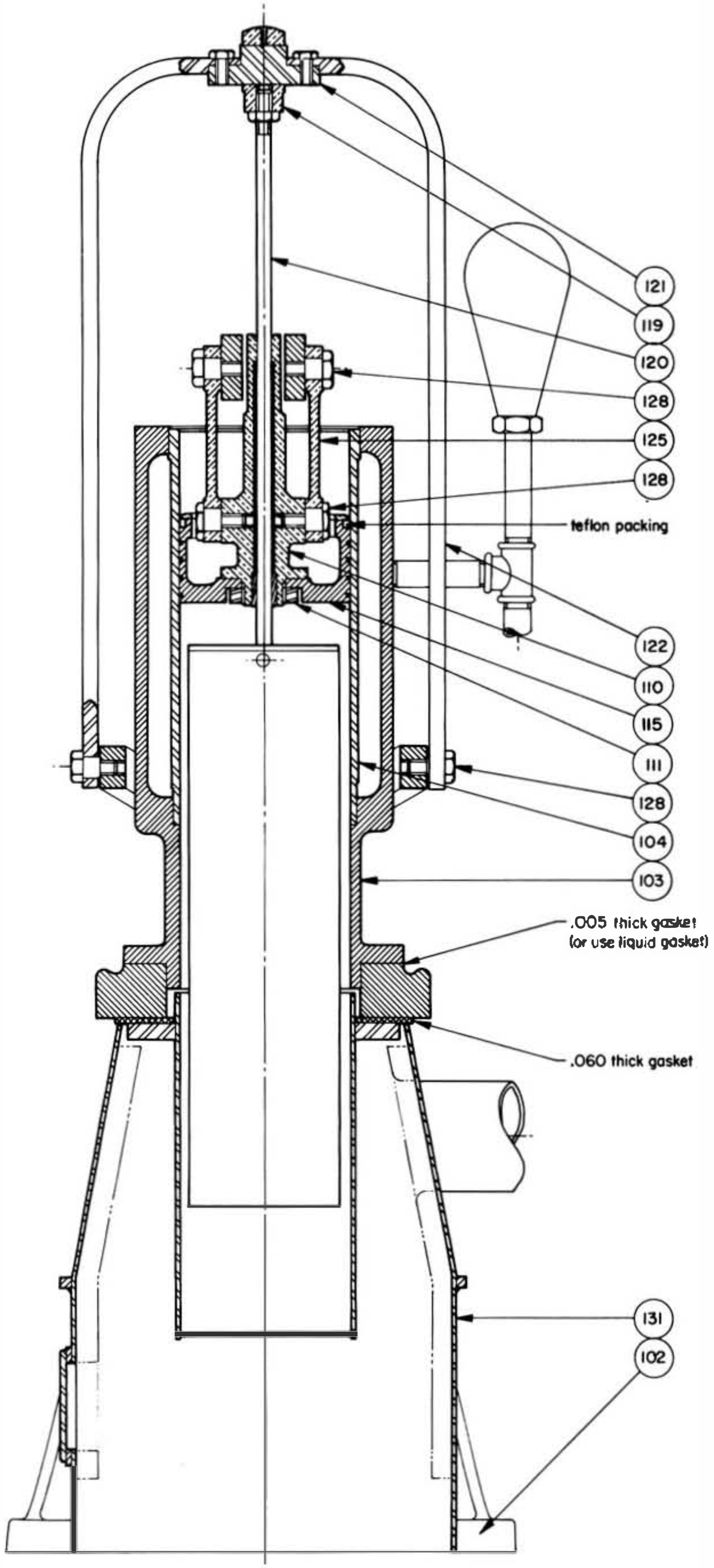
1 Facing the top side of the cast aluminum Base (101) in the lathe.

2 Facing the bottom of the Base.

3 Turning the bottom end and mounting flange of the Cylinder (103).

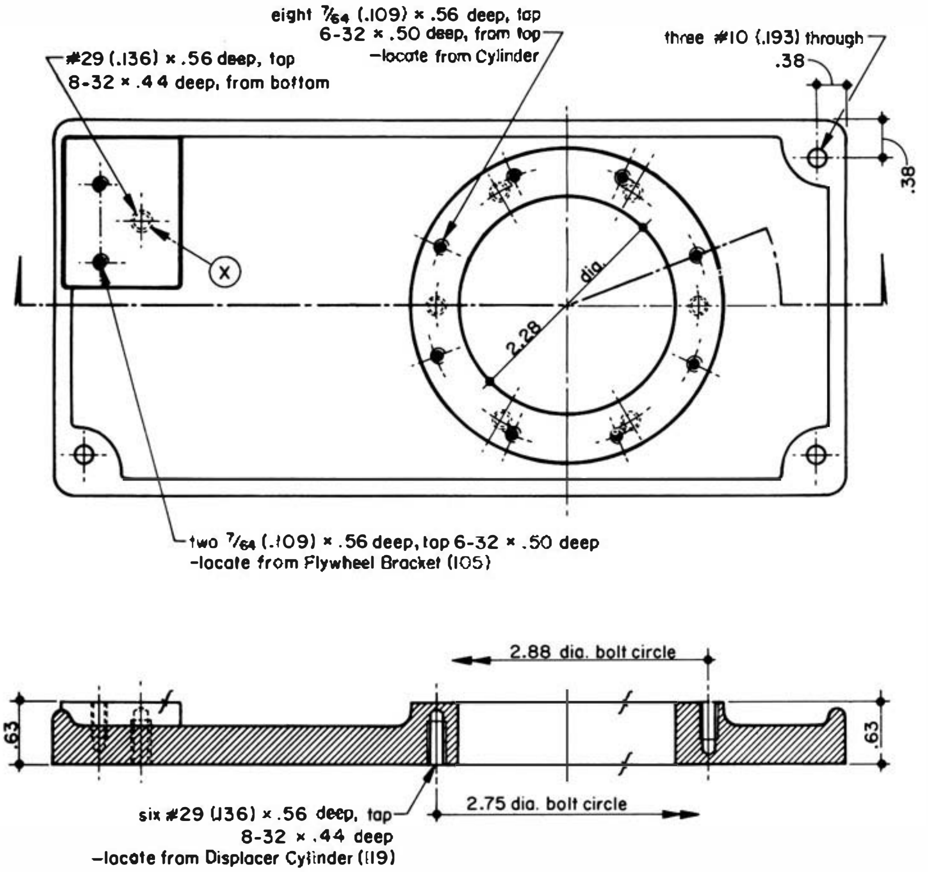


SIDE SECTION

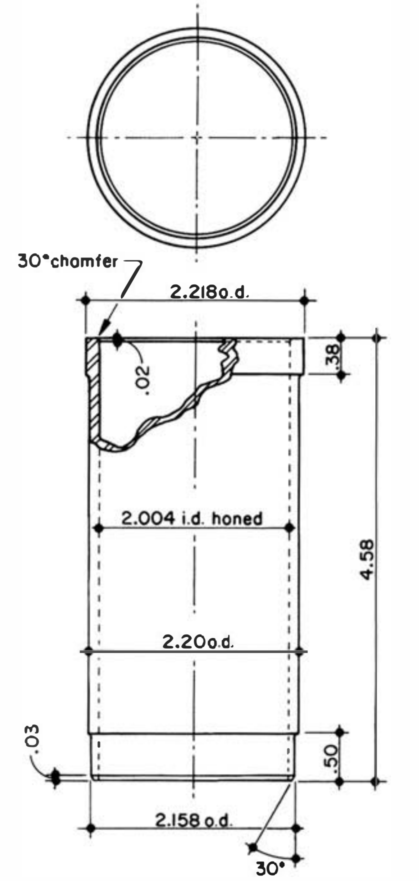


END SECTION

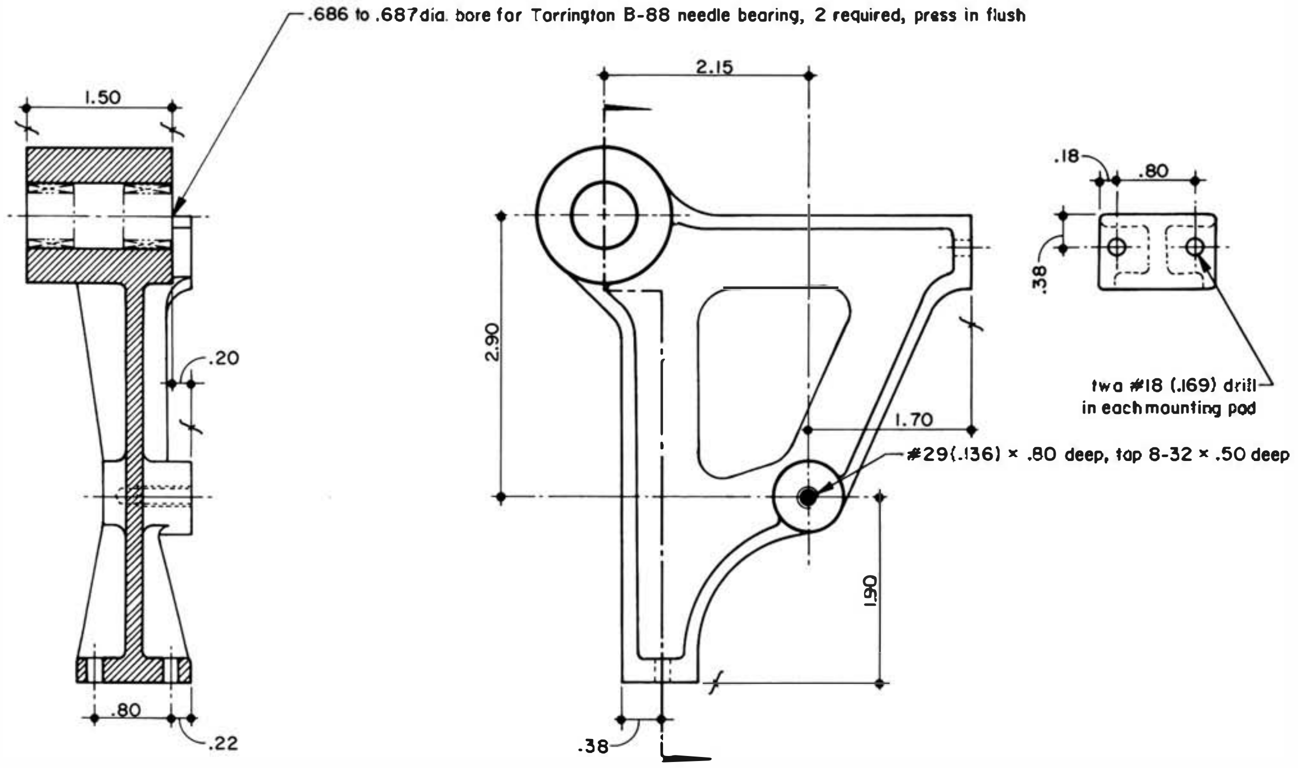
Ink Tracings by George R. Broad, Jr., from originals by Larry Kazyak



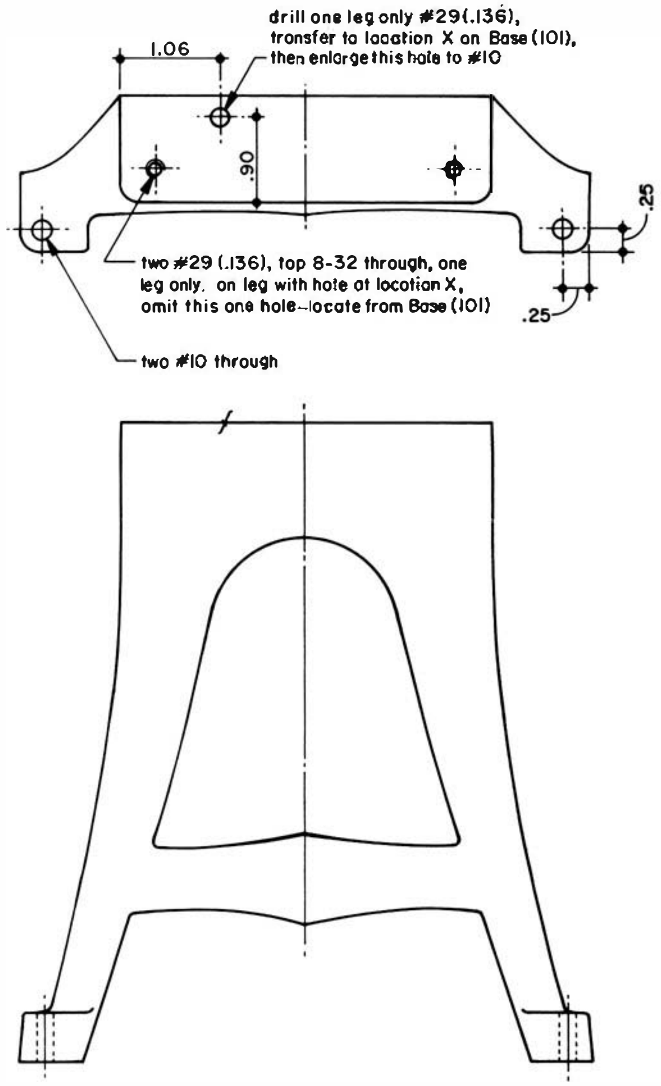
101 BASE
Cast Aluminum, 1 required



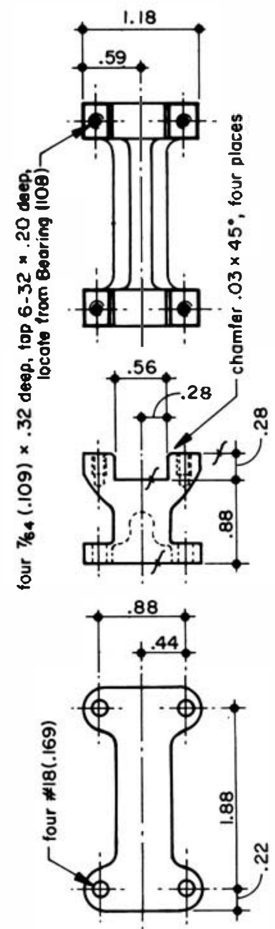
104 SLEEVE
Seamless Steel Tube, 1 required



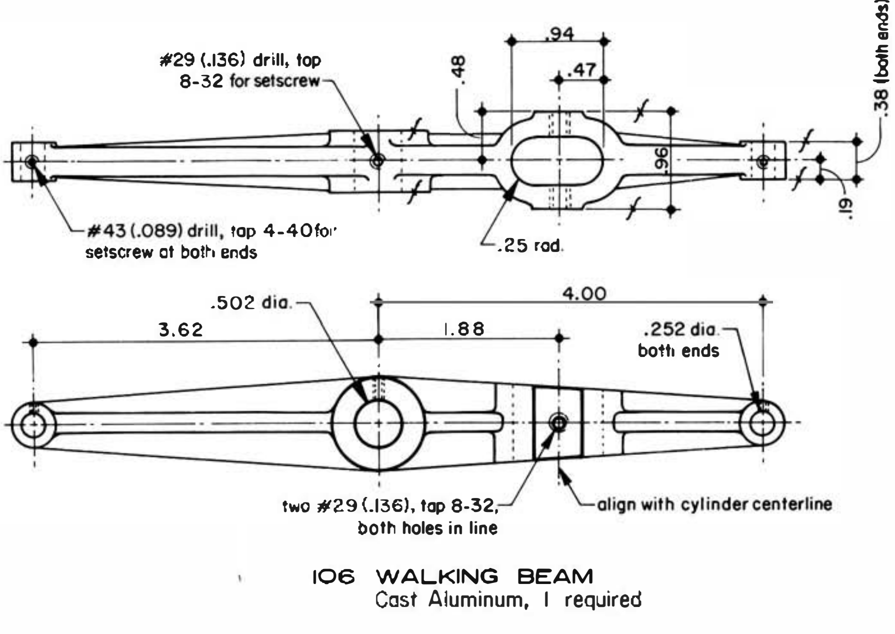
105 FLYWHEEL BRACKET
Cast Aluminum, 1 required



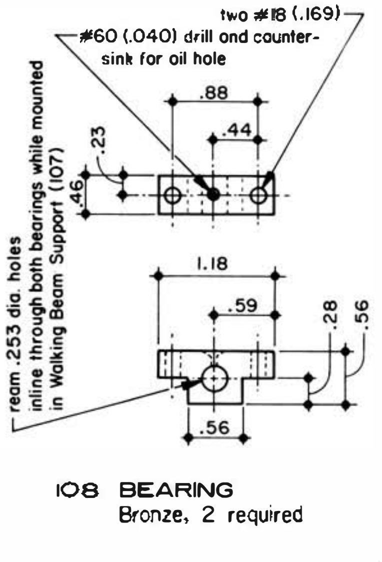
102 LEG
Cast Aluminum, 2 required



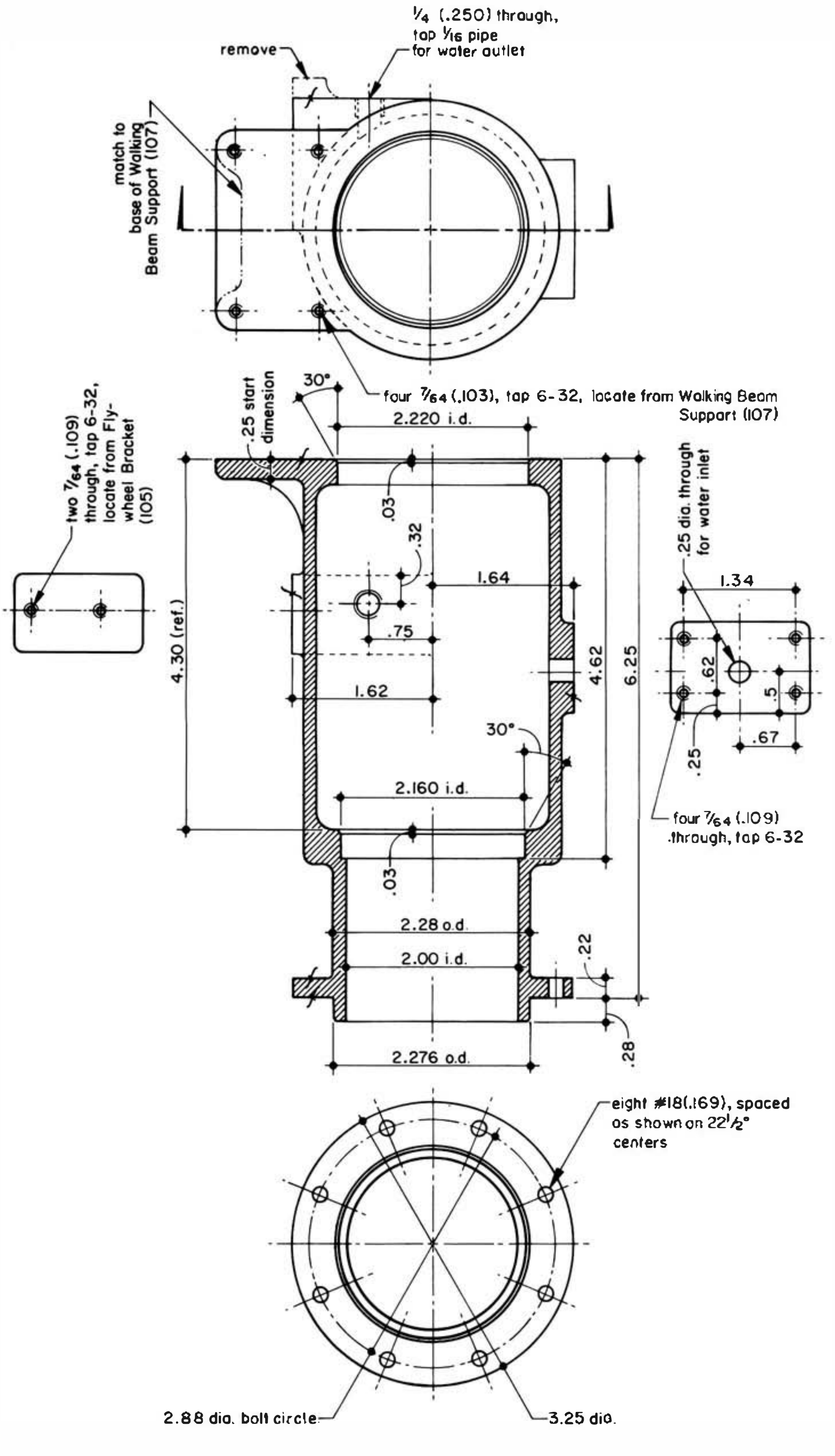
107 WALKING BEAM SUPPORT
Cast Aluminum, 1 required



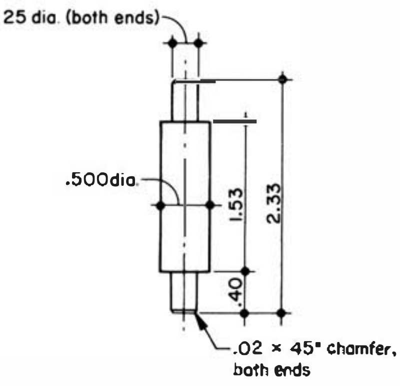
106 WALKING BEAM
Cast Aluminum, 1 required



108 BEARING
Bronze, 2 required



103 CYLINDER
Cast Aluminum, 1 required



109 PIVOT
Steel, 1 required

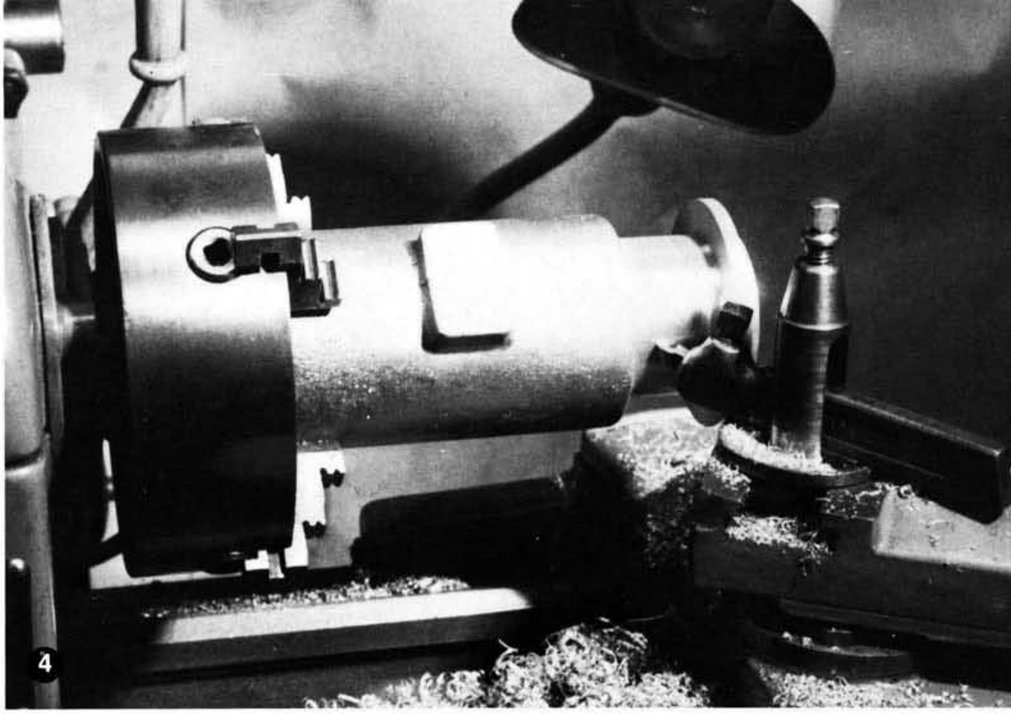
hand and the engine would run. The water pump was connected to the far end of the walking beam via a link. Water was drawn up through the lower inlet of the pump and into the main engine cylinder water jacket through a port in the pump mounting flange. The water was first used to cool the power piston portion of the cylinder, then it was expelled out the flywheel side of the cylinder to the storage tank or reservoir. The dome-shaped air chambers located at the inlet and outlet were used to cushion the pulsation created by the single-acting pump.

Construction is best started with the **BASE (101)**. Face the bottom and top to the .63" dimension, averaging out the stock on either side. **Photos 1** and **2** show this operation being carried out in the lathe. Having no mill, I have no other choice, but those of you blessed with one might find it easier to flycut both surfaces. Bore the 2.28" diameter opening next. Then, the corner holes for mounting the legs are done by drilling them with a #29 tap drill.

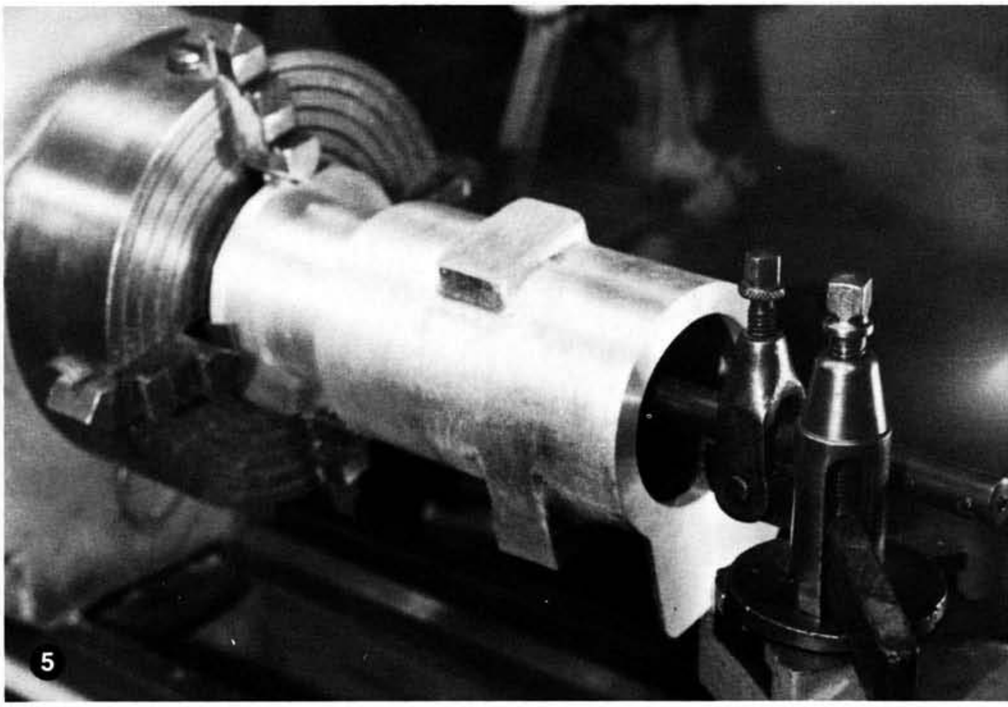
Take the **LEGS (102)** and dress the top surfaces by filing. Clamp them in proper position on the base and then drill through the #29 holes we just drilled in the base and into the leg mounting surfaces. This will assure proper alignment. Redrill the holes in the base with a #10 drill (with one exception) and tap the legs 8-32, inserting a stud into the leg and attaching it with a nut on top. The leg attachment hole under the corner pad is the exception. It uses a screw inserted from the bottom, through the leg, and threaded into the base. Tap the base 8-32 and use the #10 clearance drill in the corresponding hole in the leg.

The **CYLINDER (103)** is machined next, as shown in **photos 3, 4** and **5**. The top is faced off to the .25" start dimension, then turned around and rechucked so the bottom flange can be machined to 2.00" inside diameter and 2.28" outside diameter. Blend it into the cast portion of the cylinder. The casting is turned around again and the 2.220" upper bore and the 2.160" lower bore for the steel cylinder sleeve are machined. Mill the two vertical mounting pads. The eight 7/64" cylinder mounting flange holes are added next. The same technique described for the legs — using a tap drill first, transferring hole locations to the base for drilling and tapping, then enlarging the cylinder holes with a #18 drill — is an easy way to locate the bolt circle without need for an index head or rotary table. The other holes will be machined later.

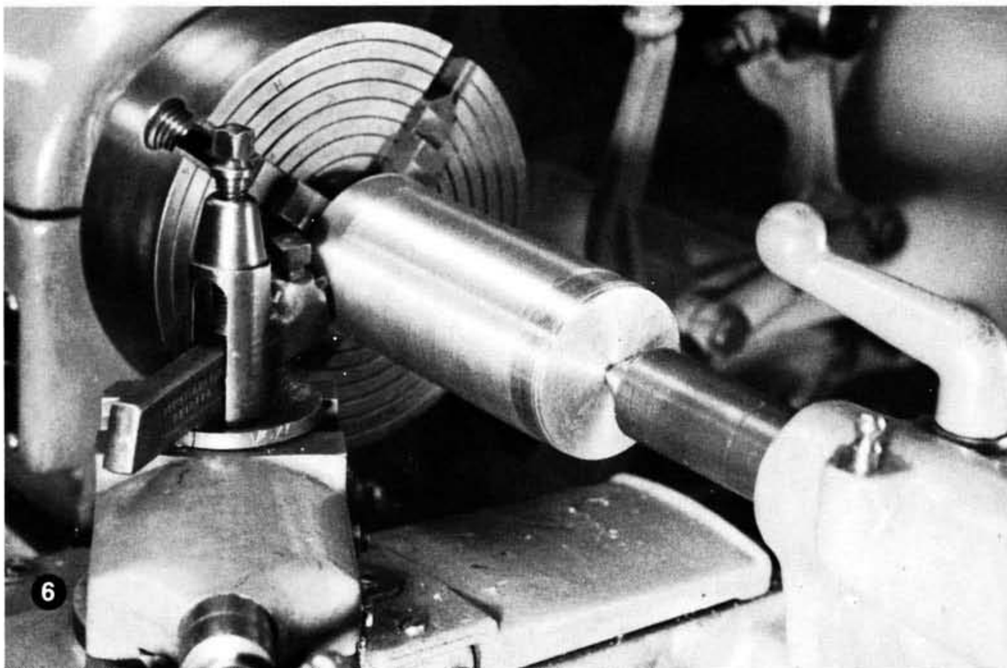
The steel **CYLINDER SLEEVE (104)** is the next item we will machine (see **photo 6**). The tubing used is 2.25" o.d. x 2.00" i.d. seamless, cold-drawn mechanical tubing. The inside diameter is not machined. The manufacturer's tolerance for roundness and size is adequate and it requires only honing.



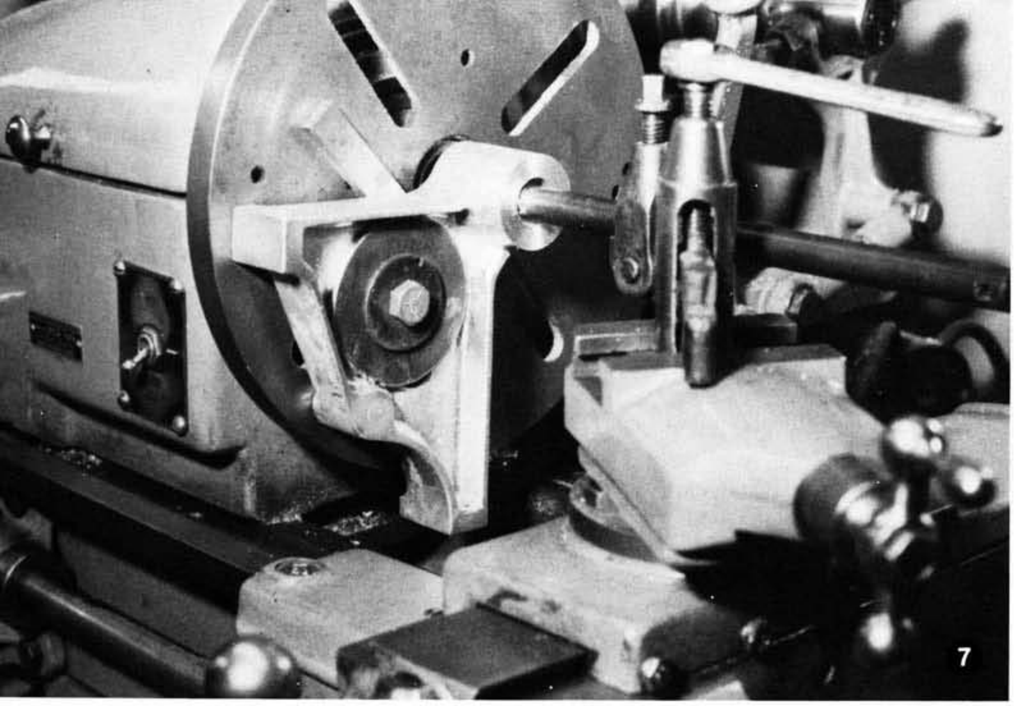
4 Blend the narrow portion of the Cylinder into the bottom flange and cast portion of the body with smooth, small radii.

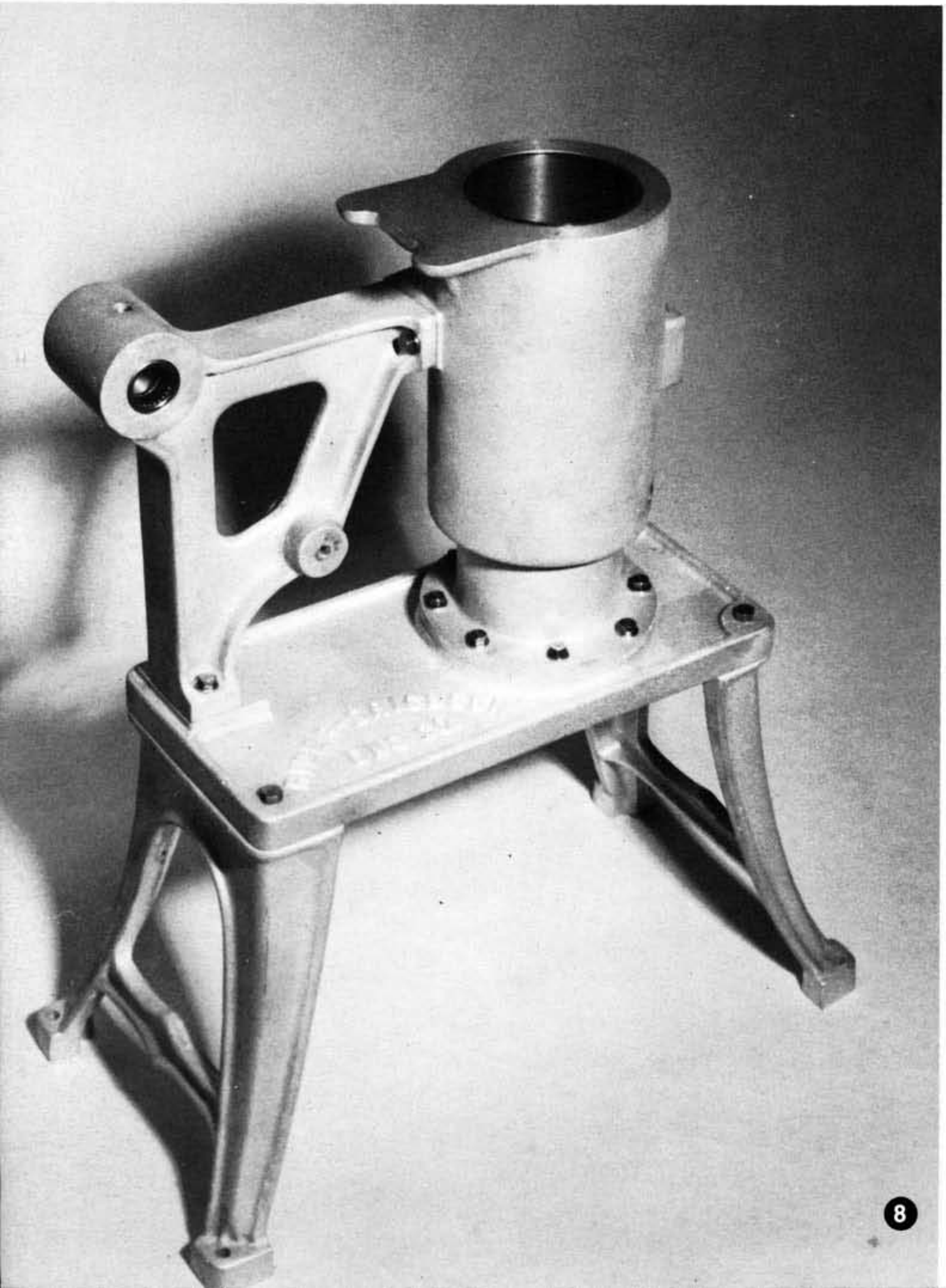


5 With the Cylinder casting turned around, bore the upper and lower bores for the Cylinder Sleeve.



6 Turn the Cylinder Sleeve (104) from cold-drawn seamless tubing, using a center plug in the tailstock end.





Turn a plug to fit the i.d. and center drill it. Insert it in the bottom for the tailstock center and chuck the top end by the i.d. Turn the o.d. and length. The top and bottom diameters should have a .002" clearance with their respective bores in the cylinder.

Finishing the bore comes next. A fine-stoned hone, used to clean up automotive brake cylinders, is what I use. They are quite inexpensive. These hones have spring-loaded fingers, to which the stones are attached and they are driven by a flexible shaft. This allows them to track in the bore being honed without exerting any uneven loads on the honing stones. Chuck the hone in a drillpress, insert it into the sleeve and turn the drillpress on, running it about 450 to 500 RPM, while hand-holding the sleeve. Use kerosene as a lubricant and flushing fluid and work the sleeve up and down constantly. The top 4" is the only portion requiring this treatment, because this will be the only portion in contact with the power piston. Be sure to hone all the way up to the top edge, but be careful not to let the stones come out of the bore while the drillpress is running.

The size of the bore is not too important as the power piston will be sized to it. What is important is that it be of *uniform* size. Using a telescoping gauge, check to prevent a tapered or barrel-shaped bore. Take your time. The stones cut slowly and the removal of a couple of thousandths is slow going.

Once the honing is finished, the sleeve and cylinder casting are ready to be assembled. On my first engine, I used a shrink fit. Even with .004" interference, due to the differential in expansion between the aluminum cylinder and the steel sleeve, a small leakage would occur after running for about half an hour. Since then, I have relied on a good grade of epoxy cement. As previously stated, about .002" diametrical clearance is required. The water surrounding the sleeve will keep the cement from overheating.

The **FLYWHEEL BRACKET (105)** is attached to a faceplate and the bearing hole bored (see **photo 7**) to a diameter of .686" to .687" for the Torrington bearings. Needle bearings require a press fit because the force exerted on the outer shell of the bearing brings it to a true round shape. *Loctite* or epoxy definitely won't do here! Also, if not for the press fit, the internal clearance between the bearing and the crankshaft journal would be excessive. Surface and drill the mounting pads and tap the 8-32 threaded hole.

Mount the cylinder and sleeve assembly to the base and leg assembly. Position the flywheel bracket and transfer the holes to the cylinder and base, drilling and tapping the two holes required in both mounting places. Bolt the flywheel bracket

7 The Flywheel Bracket (105) is faced and bored in the lathe, mounted to a faceplate.

8 With the Base, Legs, Cylinder, Cylinder Liner and Flywheel Bracket assembled together, the Hot-Air Pumping Engine will look like this. Note the needle bearings, pressed into the Flywheel Bracket. Also note how the upper surface of the Cylinder is contoured to match the base of the Walking Beam Support.

into place. Your engine will really start to take shape and look like **photo 8**.

The oil cup shown on the crankshaft boss portion is from Cole's Power Models, catalog number 29R2/4. On the model, it's purely decorative, the original engine having one located there. The model's Torrington needle bearings need only be lubricated once every 100 hours or so and that's a long time coming! Use a light-grade grease such as *Lubriplate*.

Next comes the **WALKING BEAM (106)**. **Photo 9** shows it chucked in the lathe, having its .502" bore machined. If you are using .5" diameter bar stock for the pivot, machine the walking beam bore to suit. Mill the slot .5" wide x .94" long. There isn't anything critical about the slot; it only provides clearance around the power piston center. The two .252" diameter holes on the ends should be added next, along with the two 8-32 threaded holes that intersect the slot. These must be parallel to the .502" diameter hole previously bored. The tapped holes for the setscrews are the final step. Square-headed setscrews (shown in **photo 11**) are in keeping with the aim of making the model an authentic copy. The 4-40 screws have .12" square heads and the 8-32 screw has a .18" square head. It's more work making them, compared to using commercial ones, but it's worth it.

The **WALKING BEAM SUPPORT (107)** is next. Mill or file the base flat. Then set up to mill the notches and top surfaces, as in **photo 10**. Drill the #18 mounting holes, but hold off on the 6-32 tapped holes for now.

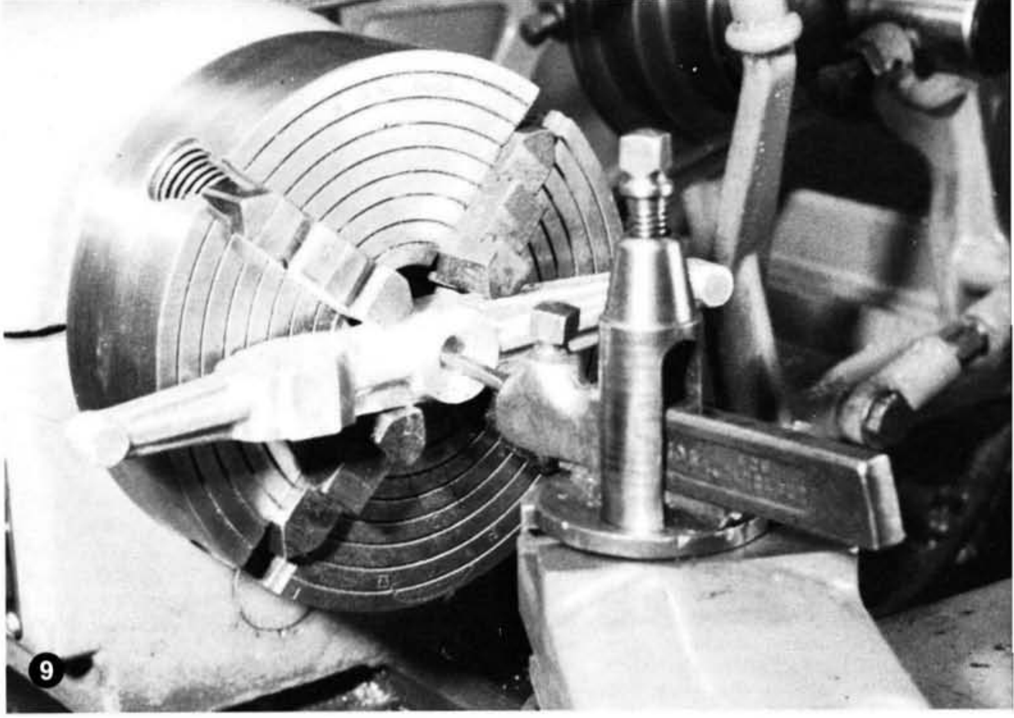
The two **BEARINGS (108)** are part of this assembly. The original engine had bronze bearings that were split on the pivot bore to allow for wear takeup. Our model won't experience this problem, so the bearings are shown in one piece. Machine them as shown, but omit the .253" diameter bore. Mount the bearings in position on the beam support and transfer and drill the mounting holes. Tap the support, enlarge the holes in the bearings and mount them in place. Brass 6-32 x ⅜" hex-head bolts should be used.

Now, the .253" bores in the bearings can be line-bored, keeping their axis parallel with the support mounting surface.

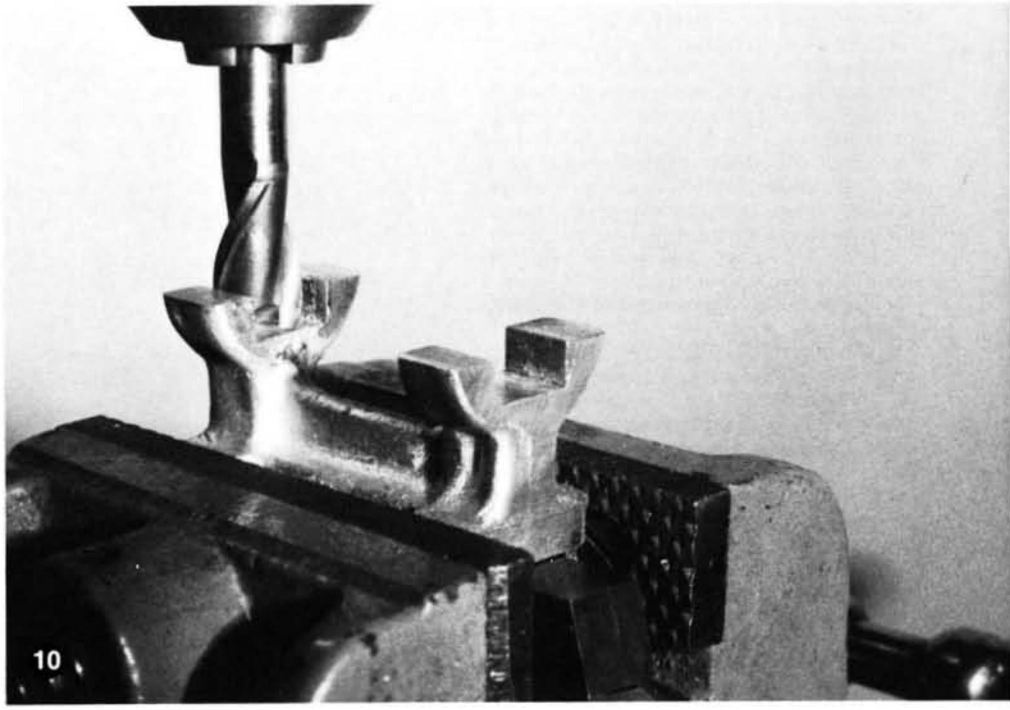
While these parts are assembled, the **PIVOT (109)** should be machined and the 1.53" dimension checked to see that it will allow about .010" end shake between the bearing blocks. Size the two .250" diameter bores to their respective bearings.

The assembly of the walking beam, its support, the bearings and pivot are shown in **photo 11**.

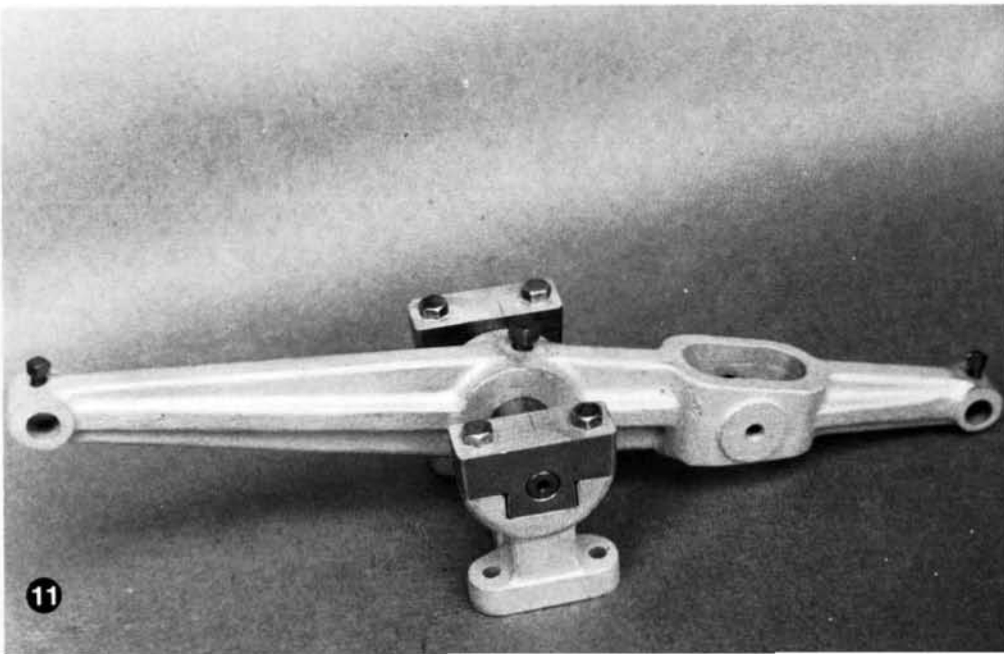
Now is a good time to step back, take a look at all you have accomplished and take a deep breath before tackling the next step.



9 Machining the .502" bore of the Walking Beam (106) in the lathe.



10 Milling notches in the Walking Beam Support (107) to accept the Bearings.



11 The Walking Beam assembled with its Support, Bearings, Pivot and square-headed setscrews.

The **POWER PISTON CENTER (110)** will be the next item that we fabricate. The body portion is turned as shown, complete with the .189" diameter bore at the top and the ¼" x ⅜" deep bore at the bottom, for the bushing to be pressed in. Note the .22" diameter bore through the center. Don't be tempted just to bore or ream the .189" diameter all the way through because without that .22" diameter relief, the .188" diameter displacer piston rod would have too much friction due to the extreme bearing length and the viscous drag of lubricating oils. These engines, with their low power, can't tolerate many power-robbing conditions.

The two .50" diameter bosses are next to be machined. Take .50" bar stock, chuck and drill with a #29 tap drill. The .30" radius necessary to make a good contact with the .60" main body diameter can either be hand-contoured with a file or milled. Tap drill the body portion at the .68" dimension from the bottom flange. To assemble, make up an aluminum 6-32 stud, 1.25" long. The major diameter of this stud should be only .134", which will allow it to be inserted through the tap-drilled holes in the side bosses and the body. With nuts applied to either end of the stud, the parts are now fixed together so that they can be soft soldered in place. With an acid soldering flux applied, bring up to temperature with a propane torch. Be sure the part is at a high enough temperature to allow the solder to flow into the joint by capillary action, so that a minimum amount will be used and the brass will be kept clean.

After soldering, the stud is removed and if it weren't aluminum, you'd have a tough time doing it! Now tap the 8-32 thread in each boss.

The **POWER PISTON NUT (111)** comes next. It's a straightforward turning job. **Photo 12** shows the power piston center with its bushing along with the power piston nut and the spanner wrench, which is used for tightening it when it is assembled to the power piston. The pins for the spanner wrench are .070" diameter bearing needles from a worn-out automotive universal joint. When a U-joint fails, usually only one or two of the four bearings are ruined, leaving a good supply of hardened pins for many uses.

The **DISPLACER YOKE (112)** is a relatively simple part. The tapped holes and the .250" to .253" diameter pivot hole are somewhat forgiving as to their location. Locating them centrally within their respective bosses is sufficient. The main consideration is to obtain a linkage which is true running and this requires that the axes of all the tapped holes and pivot bore be kept parallel with one another and perpendicular to the vertical portion of the yoke. Face the bosses to the dimensions shown. **Photo 13** shows the completed yoke with its pivot screw.

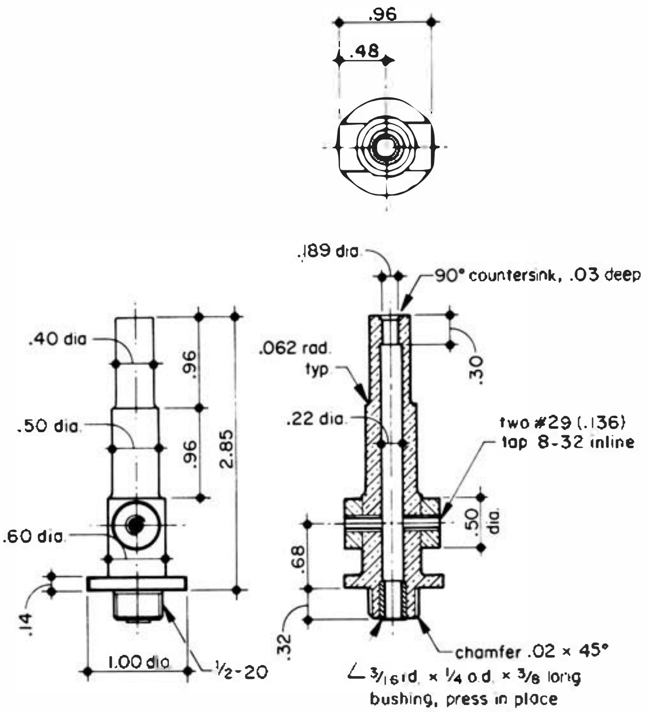
Machining the **FLYWHEEL (113)** is shown in **photos 14 and 15**. First mount it in a four-jaw chuck on the i.d. of the rim, centering it on the cast portion of the rim between the spokes. Machine the front face, both the hub and rim. Take a cutoff the o.d. of the flywheel, but not down to the finish dimension. Merely achieve a full 360° cut, then remove the flywheel from the chuck and remount it with the other face to be machined. You will use the rough-machined o.d. as the circular datum on which to indicate and the back face as the perpendicular datum. If you are within about .010" total indicator reading on the o.d., this will suffice, because you will bore the .499" diameter bore for the crankshaft and finish the o.d. with the same setup, which will assure you a true-running flywheel.

The **CRANKSHAFT (114)** journal is a .500" diameter dowel pin. The reason for using a dowel is that it is a good method of obtaining a hardened and ground shaft. The needle bearings which carry the crankshaft and flywheel assembly require a hardened surface of Rockwell C 58 as a minimum to run efficiently. The dowel called for is 3" long. The amount of extension from the flywheel is 1.84". This provides for the dowel to engage the flywheel 1.16". Since the flywheel is thicker than 1.16", the dowel will end .34" in from the back side of the flywheel. This allows us to machine a small stub of .50" diameter cold-rolled steel, which will be fashioned into the remaining portion of the shaft. A keyway is milled or filed into the stub and a dummy gibheaded key fabricated, in keeping with the goal of making our model a proper replica of the original engine.

The crank web is laid out on a piece of .32" thick cold-rolled steel. Rough saw it to shape and then chuck in a four-jaw to turn the 1.00" diameter, thinning out the remaining portion to the .25" thickness. Bore the .50" diameter hole to allow a light hand press fit when assembled with the .50" dowel. After removal, hand file the heel end to match the 1" turned diameter, hand-contour the toe end to the .25" radius, then blend between the two ends. Drill and tap the 10-32 hole, keeping it parallel with the .50" bore. The last operation is drilling and tapping for the 8-32 setscrew.

The **POWER PISTON (115)** is chucked on its o.d. A three-jaw chuck will have enough accuracy for both setups needed. The inner contour is completely machined, then the piston is chucked on the i.d. Do not apply too much chucking force, so as not to distort the piston. The outside diameter should be turned so that it is a fairly snug fit into the cylinder sleeve. The four grooves on the o.d. allow oil to be carried down the cylinder wall and also allow any small particles of dirt to migrate to the groove, rather than be trapped in the very small clearance between the cylinder and the piston. Machine the .500" diameter bore with the same set-up as is used for machining the o.d. Concentricity is thus maintained for the total assembly. The recess for the power piston nut is the last operation.

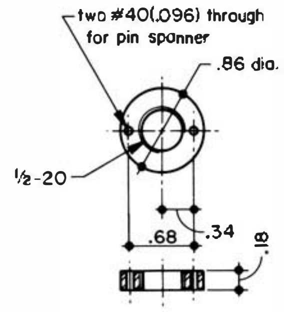
The **POWER PISTON TOP RING (116)** is machined from brass. Be sure that its o.d. does not come in contact with the cylinder. A radial clearance of .010" is desired.



110 POWER PISTON CENTER
Brass, 1 required

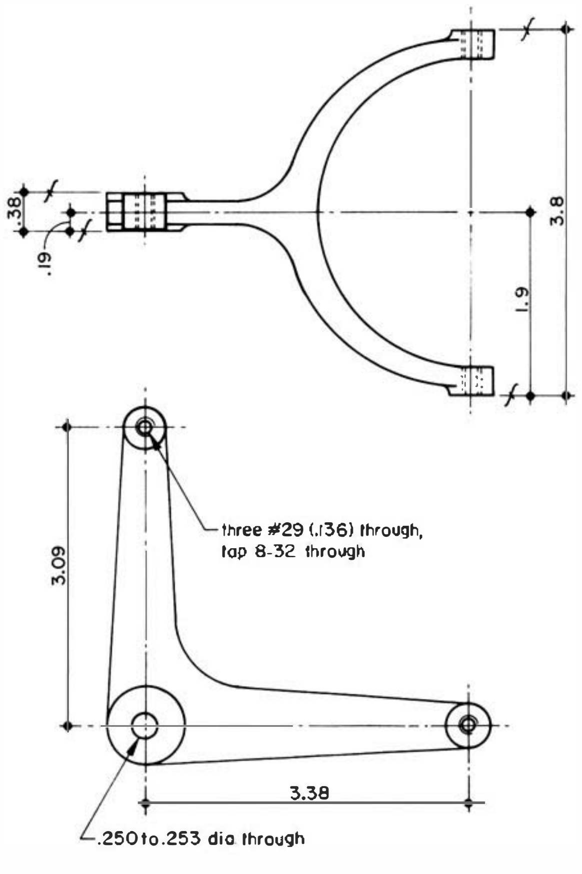
The full-sized engine uses a leather cup ring on the bottom of the piston to do all the sealing. The piston body acts more like a crosshead, for alignment only. Our model cannot tolerate the friction generated by this technique, so we shall lap the piston to fit the cylinder. The teflon packing, shown in the top groove of the piston on the engine layout drawing was purchased from a plumbing supply store. It is intended for valve stem packing, is circular in cross-section and is spiral wrapped with a thin sheath of teflon. With the top ring in place, it should not exert much pressure on the cylinder wall. In fact, if a good fit has been achieved from the lapping operation, it can be omitted. **Photo 16** shows the power piston components. The side links connect the assembly to the walking beam.

The **DISPLACER PISTON (117)** is an all-steel assembly that can either be silver soldered or brazed together. The steel tubing used is welded-seam automotive exhaust tubing. Machine the .25" thick cap to fit snugly into the i.d. of the tube. The .189" diameter hole should also be put in now, to maintain concentricity with the piston o.d. When fitting the steel tubing to the cap, be sure that the tubing is cut off square with its o.d. and check true placement of the cap using the .187" diameter

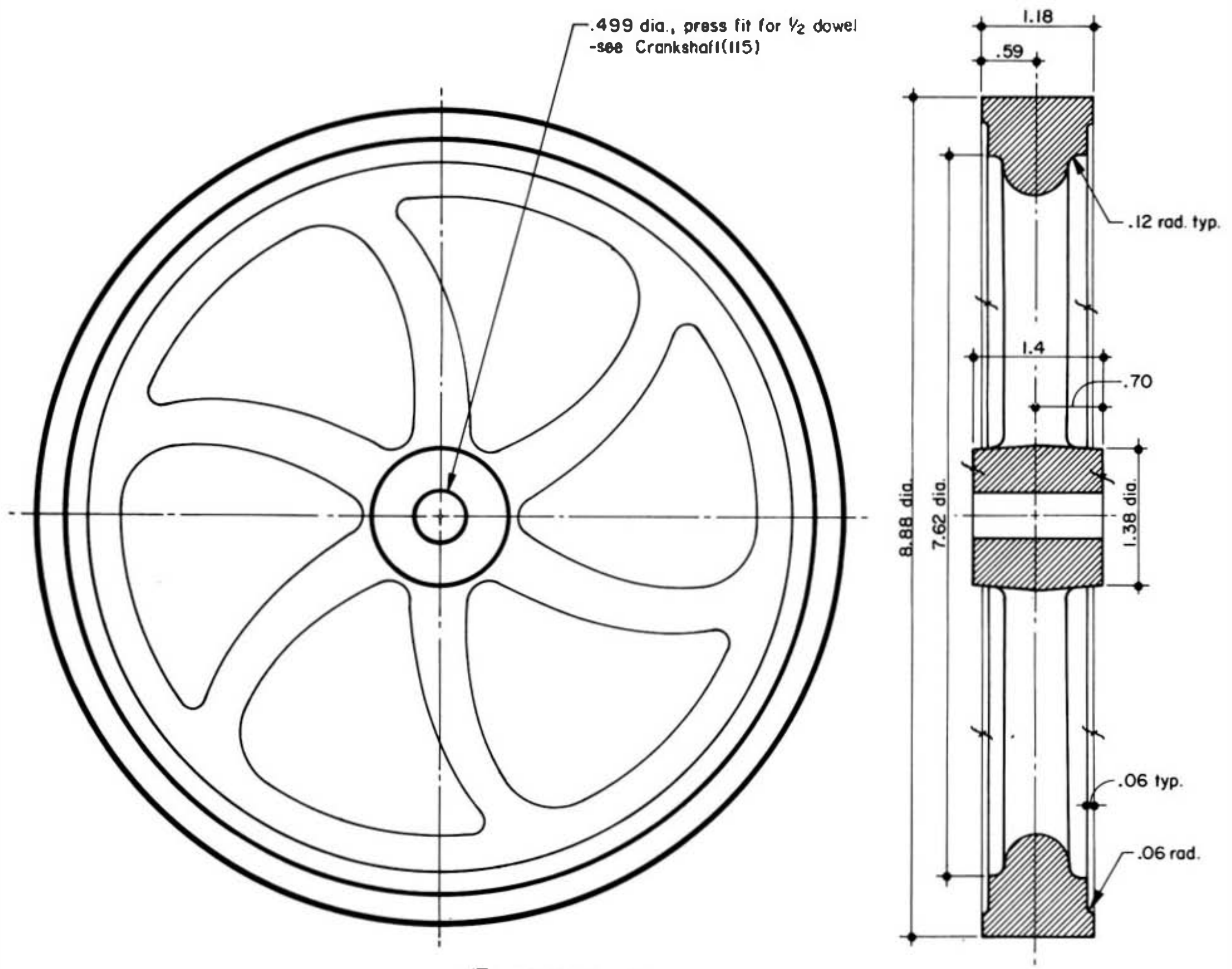


111 POWER PISTON NUT
Steel, 1 required

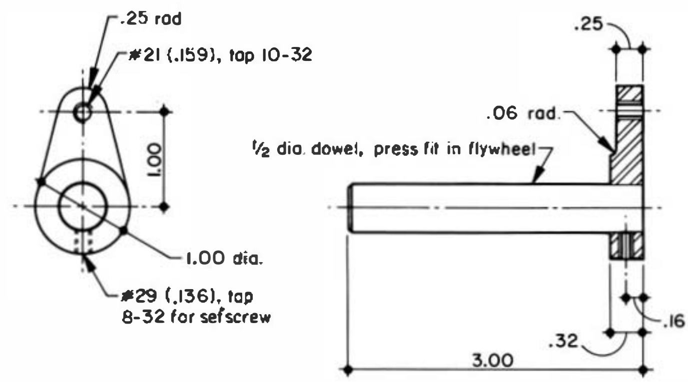
Drawings by
George R. Broad, Jr.



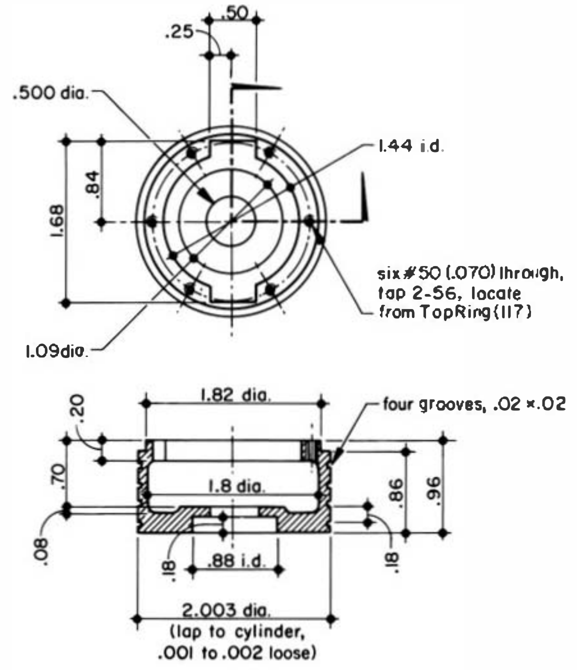
112 DISPLACER YOKE
Cast Aluminum, 1 required



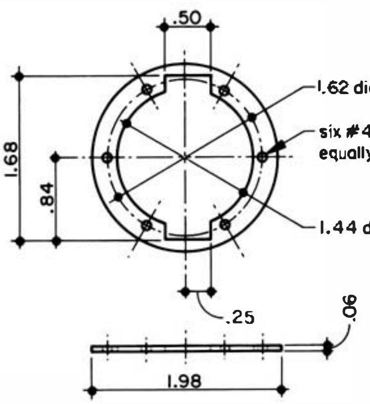
113 FLYWHEEL
Cast Aluminum, 1 required



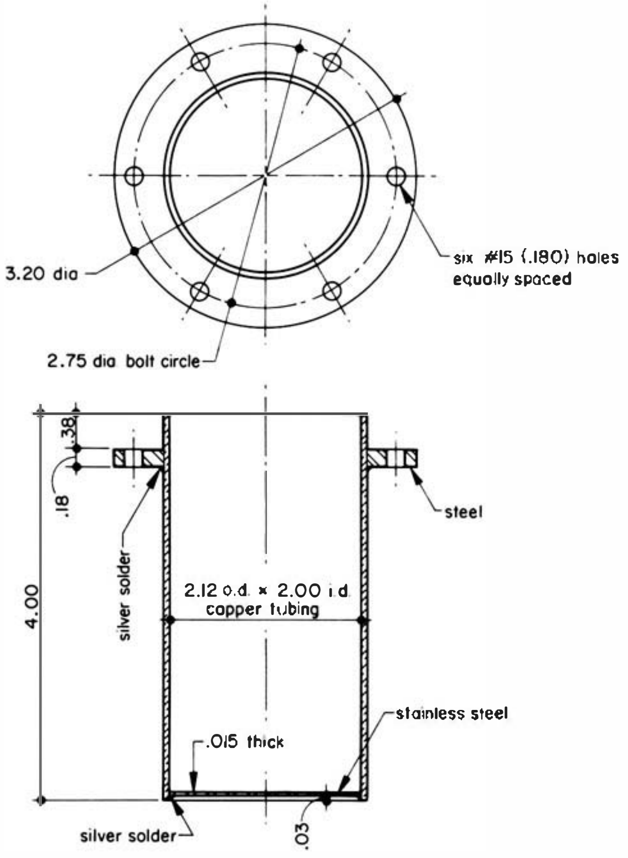
114 CRANKSHAFT
Steel, 1 required



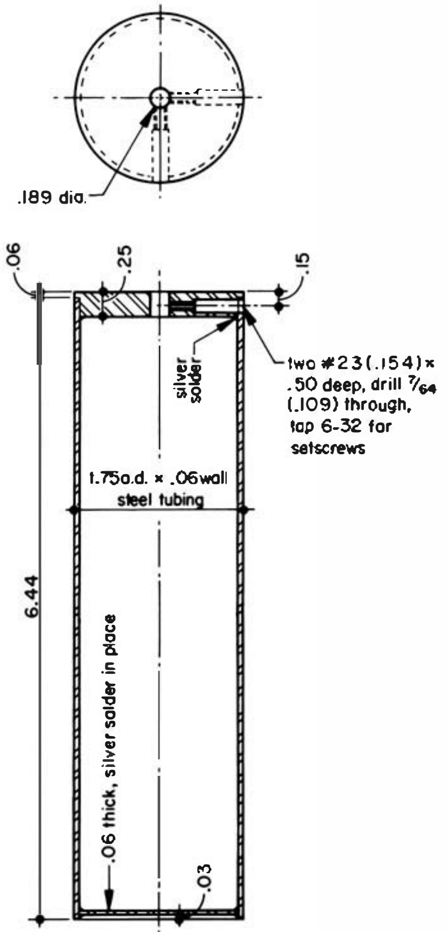
115 POWER PISTON
Cast Aluminum, 1 required



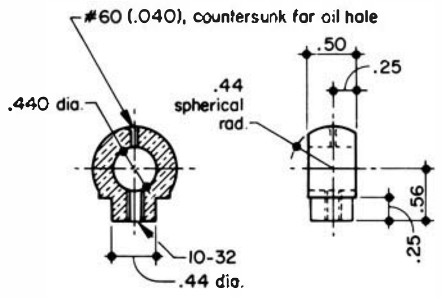
116 POWER PISTON TOP RING
Brass, 1 required



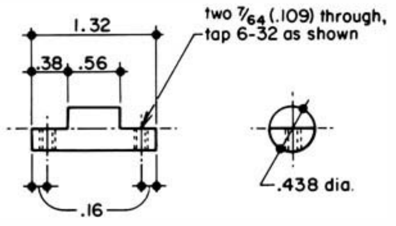
118 DISPLACER CYLINDER
1 required



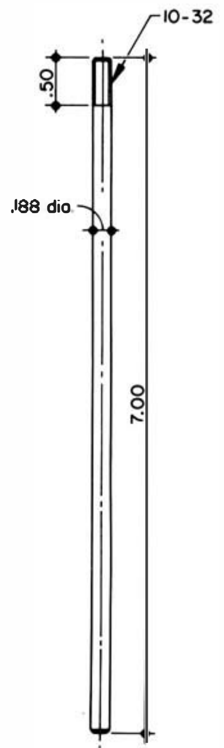
117 DISPLACER PISTON
Steel, 1 required



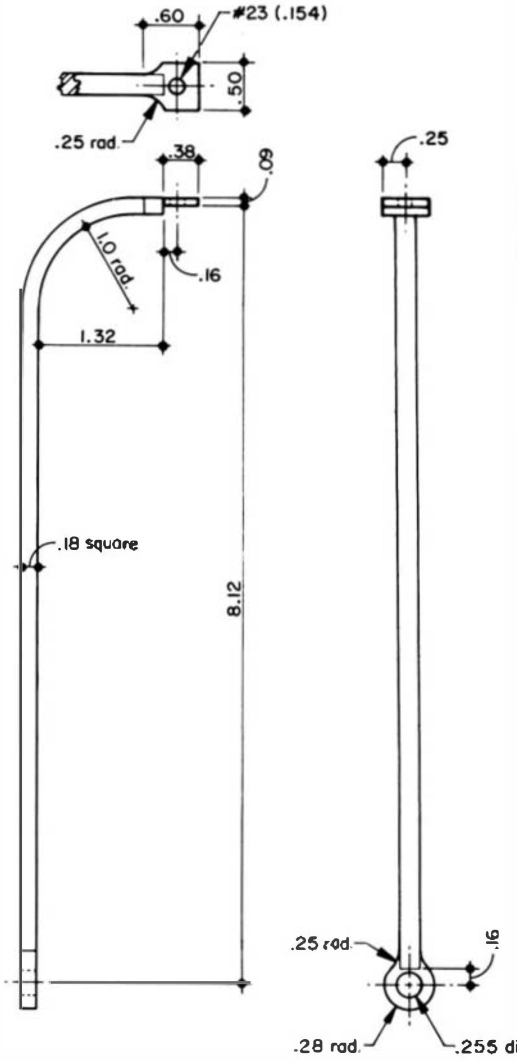
119 DISPLACER PISTON ROD END
Brass, 1 required



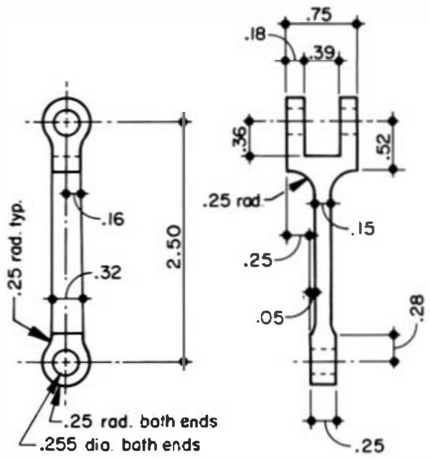
121 DISPLACER PISTON ROD END PIVOT
Steel, 1 required



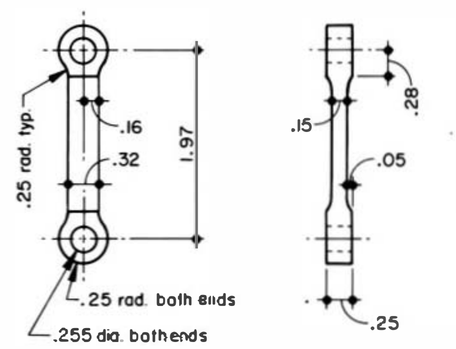
120 DISPLACER PISTON ROD
Steel, 1 required



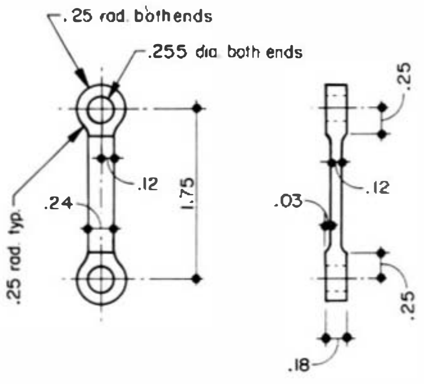
122 DISPLACER PISTON ROD YOKE
Steel, silver soldered construction, 2 required



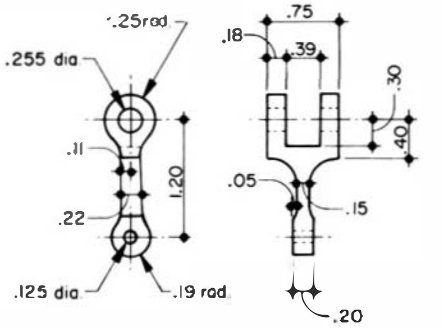
123 CRANKSHAFT LINK
Brass, 1 required



124 DISPLACER YOKE LINK
Brass, 1 required



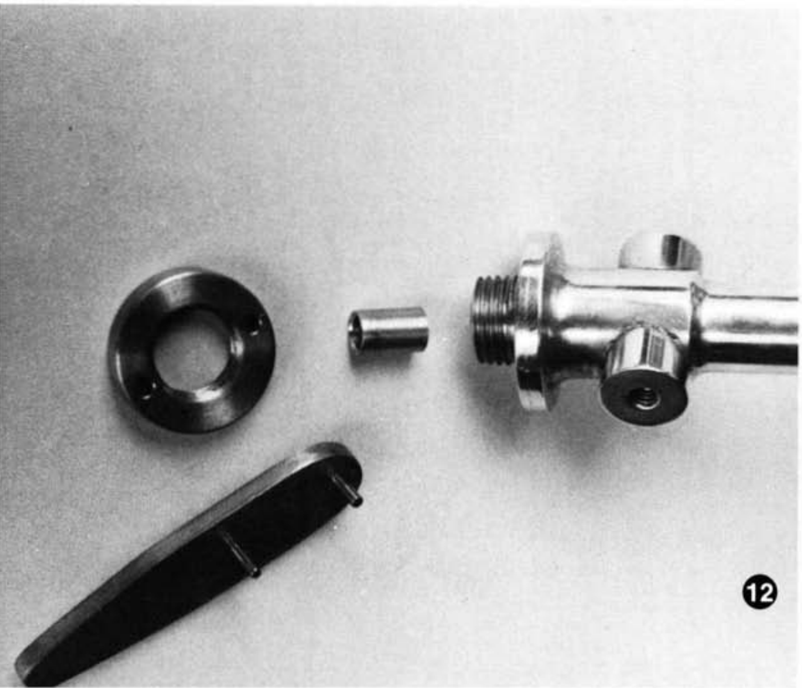
125 POWER PISTON LINK
Brass, 2 required

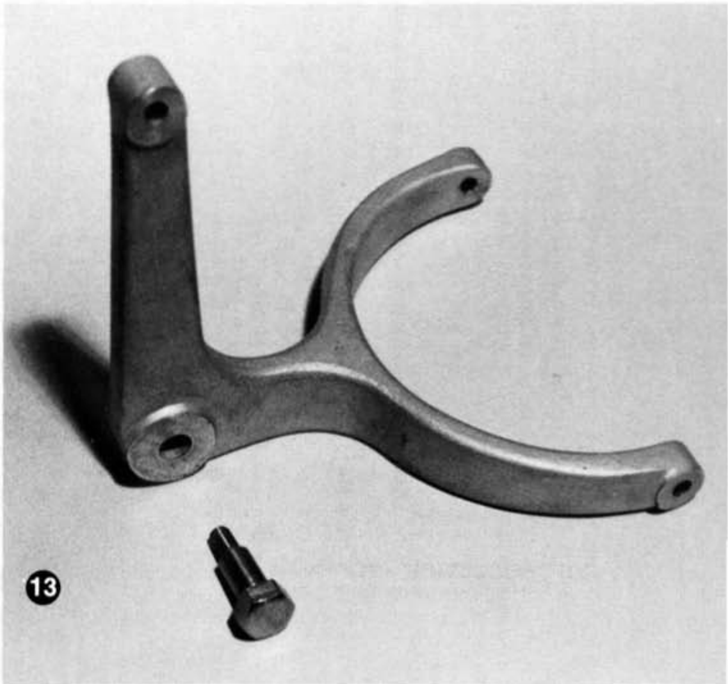


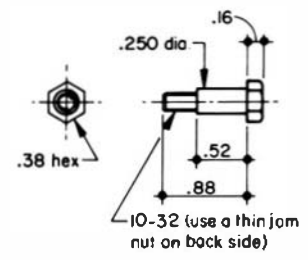
126 WATER PUMP LINK
Brass, 1 required

12 The power piston center and its bushing and the power piston nut and its wrench.

13 The displacer yoke and the shouldered screw which fastens it to the flywheel support bracket.







127 CRANKPIN
Steel, 1 required

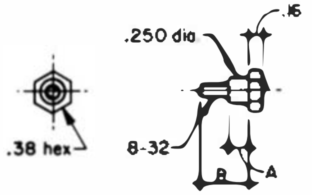
displacer piston rod, inserted into the piston as a gauge to insure that the rod will be parallel with the piston o.d. Silver solder on both ends. It is not mandatory that the piston be totally airtight, inasmuch as our engine is not pressurized. The two 6-32 setscrew holes are the last operation.

The **DISPLACER CYLINDER (118)** consists of three pieces silver soldered together, but the top steel flange and the copper cylinder are the only two pieces to be soldered together at this time. Turn thesteel flange so that the i.d. is a snug fit over the copper tube. The tube itself should be cut about .12" longer than shown. The actual length will be determined during a trial assembly of the power piston and displacer piston with their respective linkages, to insure that a minimum amount of dead volume is allowed into the engine. More about this later on.

While working on the cylinder, let's do something in the quest for greater efficiency. From just below the flange and for a distance down of about 2", turn the cylinder wall to a thickness of .020". This forms a heat dam which will minimize losses from heat conduction.

Transfer the flange holes to the base (101) and drill and tap the base for the 8-32 mounting holes, keeping the cylinder concentric with the 2.28" diameter in the base.

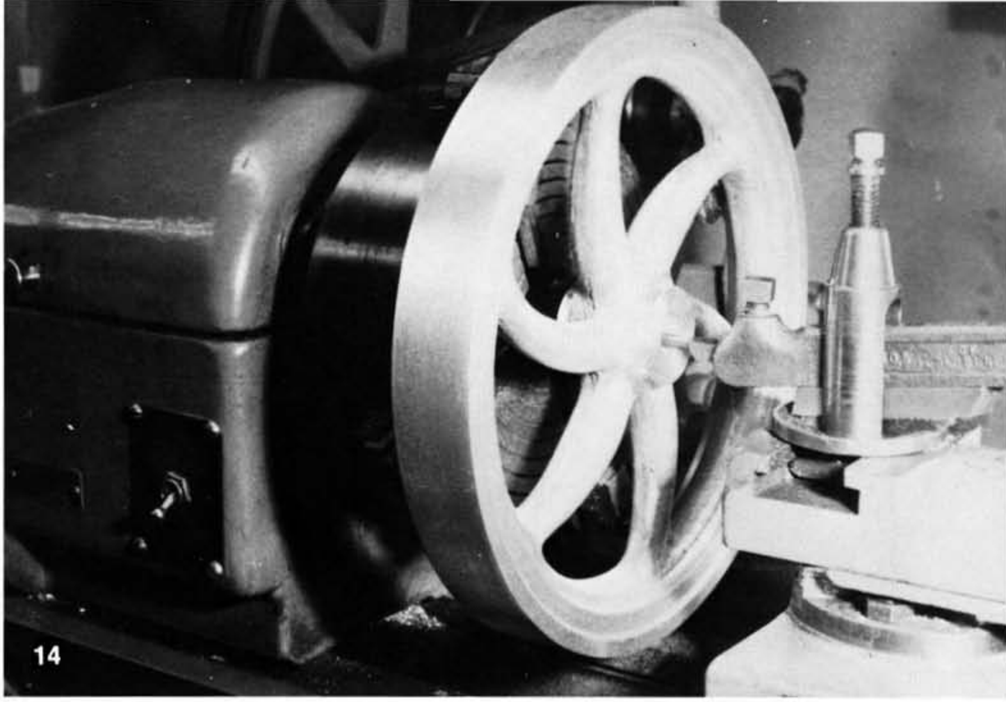
The **DISPLACER PISTON ROD END (119)** is machined from .88" diameter brass bar stock. Turning can be done in one setup by maching with the 10-32 hole toward the tailstock. Turn the .44" diameter and drill and tap the 10-32 hole, then use the tailstock with a center to support the piece. Using a template or .44" radiusgauge, turn the spherical radius, leaving about .25"



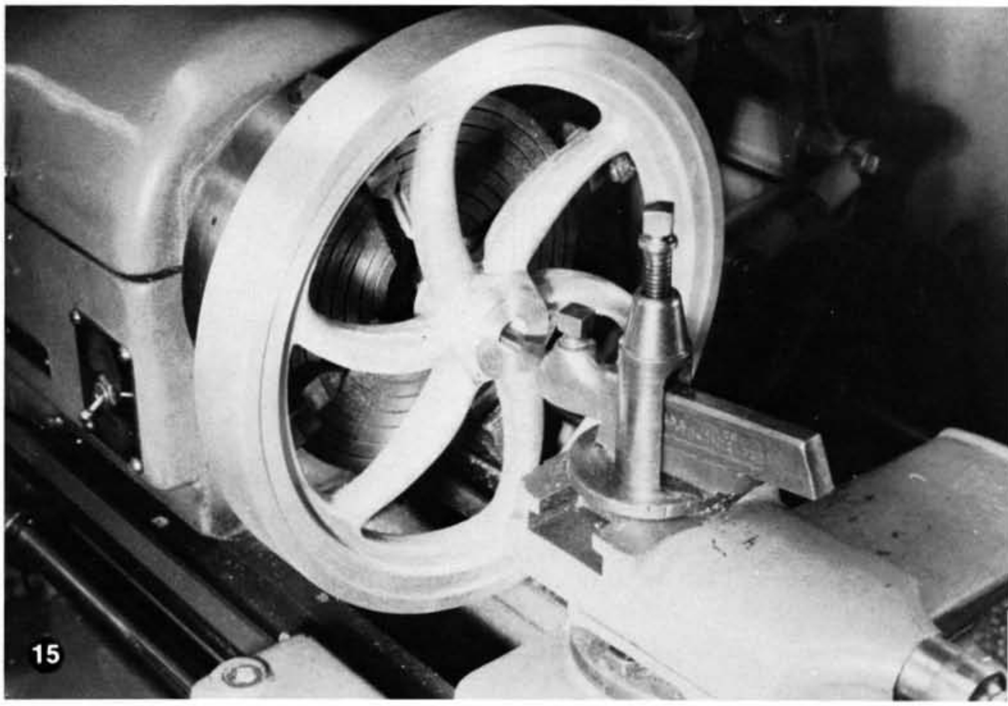
128 SHOULDER SCREW
Steel, 6 required, A=.20, B=.52

129 SHOULDER SCREW
Steel, 1 required, A=.27, B=.65

130 SHOULDER SCREW
Steel, 1 required, A=.39, B=.75



14



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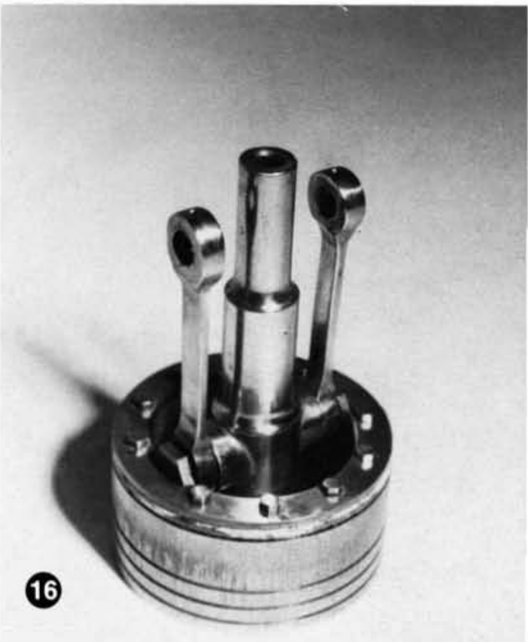
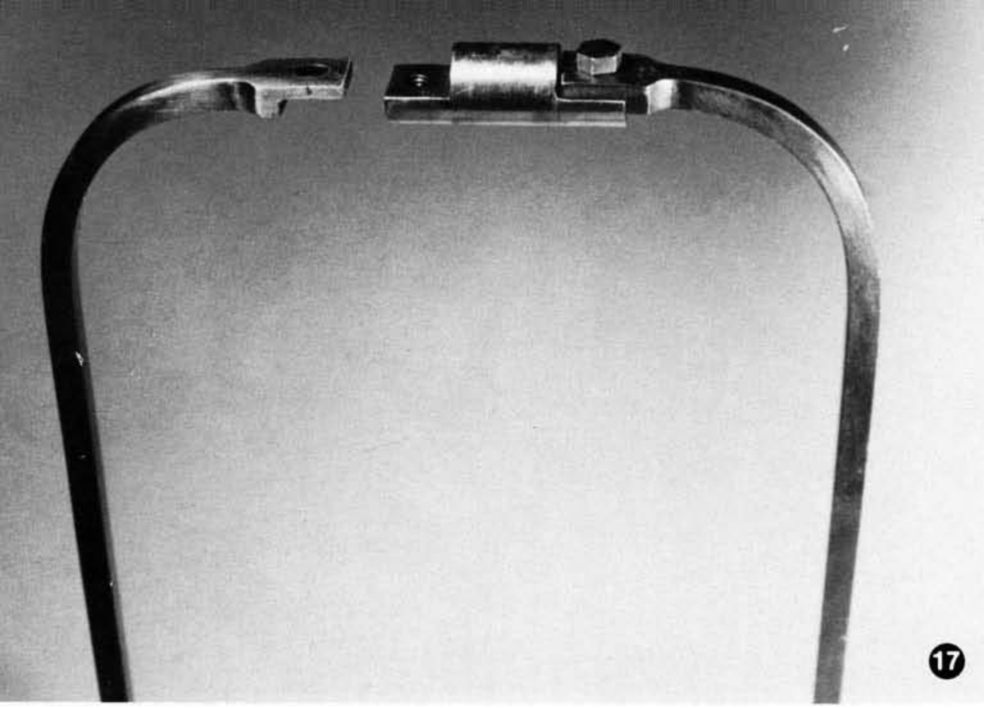


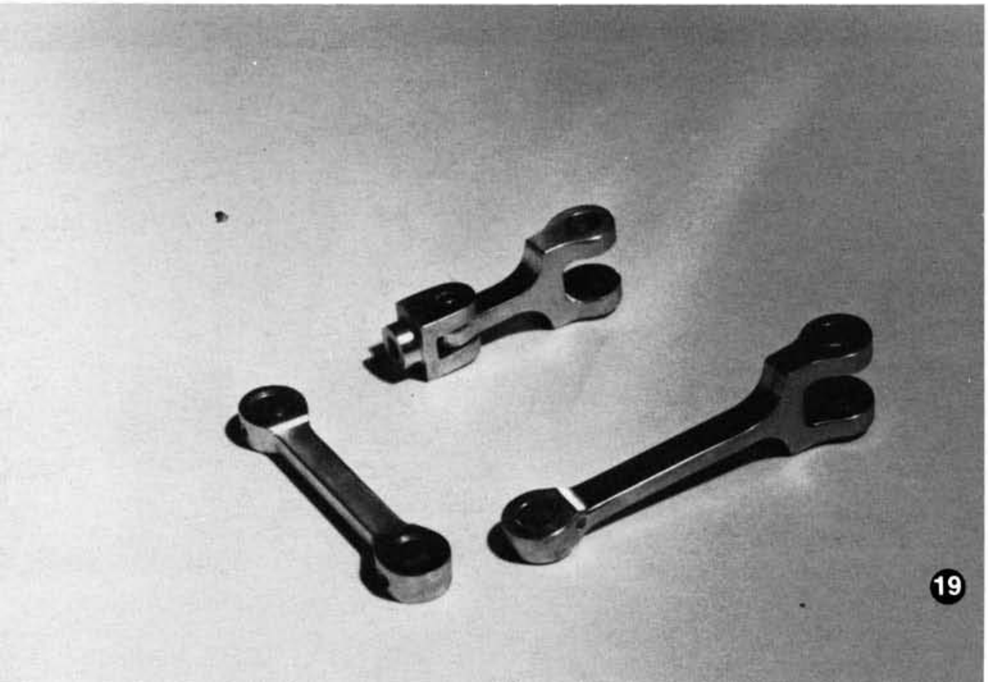
16

14 Facing the flywheel on the lathe.

15 Boring the flywheel hub for the crankpin.

16 The completed power piston, with its center, top ring, packing and matched links.





diameter at the top, which can be parted off and hand finished. Mill or file the two flats to the .50″ dimension. Bore the .440″ diameter, keeping it perpendicular to the 10-32 hole.

The **DISPLACER PISTON ROD (120)** is a piece of .188″ diameter cold-rolled steel rod. The surface finish should be smooth, inasmuch as it reciprocates within the power piston center. The fit should be around .0005″ to .001″ loose, to minimize air leakage around the rod.

The **DISPLACER PISTON ROD END PIVOT (121)** can be low carbon steel, also. The loads and velocities imposed on all the rods and pivots are so low that hardened surfaces are unnecessary. The .438″ diameter should be a close running fit into the rod end. The flats are then milled parallel with the journal diameter. The two 6-32 holes should wait to be transferred from the top ends of the yoke rods.

The two **DISPLACER PISTON YOKE RODS (122)** are fabricated from cold-rolled steel and silver soldered together. Bend the .18″ square stock to the 1.00″ radius as shown, allowing about .06″ extra on both ends. Make up the pieces as shown with the .18″ slots filed to a snug fit on the square rod. The ends of the square rod should be trimmed at a trial assembly with the yoke and the power piston placed into the cylinder with the piston rod, rod end and pivot assembly in place. Transfer and tap the 6-32 holes into the displacer piston rod end pivot and bolt the two top pieces of the yoke rod to the pivot. With the lower portion of the yoke rod end mounted to the yoke using the shoulder screws, the ends of the .18″ square rod can be trimmed so that the end result is a free-running linkage. If this process is not followed, the linkage will impose an excessive radial load on the displacer rod, where it rides in the power piston center bearings. **Photos 17** and **18** show the displacer piston linkage components.

The **LINKS (123, 124, 125 and 126)** are milled from brass bar stock. The end bores should be kept parallel. The two power piston links (125) should have their .255″ diameter bores put in simultaneously while the two are clamped together to insure even loading of the power piston. The profiles of the links can be milled to the proper contours, leaving the end radii to be hand filed, using a couple of filing buttons. Make them from drill rod, .50″ diameter and .12″ thick, with .25″ diameter center holes. After machining, harden them. By placing them on either side of the link ends and bolting them in place, the ends can be filed to a uniform size. **Photo 19** shows the finished links.

The **CRANKPIN (127)** and **SHOULDER SCREWS (128, 129 and 130)** are turned from cold-rolled .38″ hex stock. They can be left soft. A smooth finish with approximately .001″ to .003″ loose fit with their respective links is all that is necessary, due to the low velocities at which the linkage operates.

17 The displacer piston rod yokes fasten to the displacer piston rod end pivot with 6-32 hex head screws.

18 The completed displacer piston yoke assembly: two yokes, the end pivot and the displacer piston rod end.

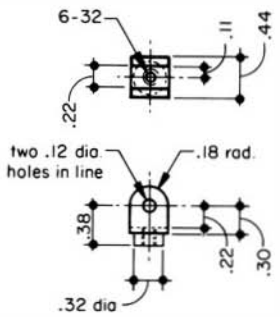
19 The crankshaft link, one of the power piston links and the water pump link.

The **FIREBOX (131)** is laid out from the full-sized pattern supplied with the casting kit and also reproduced here. Cold-rolled steel of .045" thickness is used. **Photo 20** shows the blank, after cutting. All the .62" radius corners are hard-formed around a piece of bar stock placed in a vise, 1" diameter stock being used to allow for springback. Put the hole for the door in after welding, to minimize distortion. The welded seams should be finished either by hand filing or by using an auto body grinder.

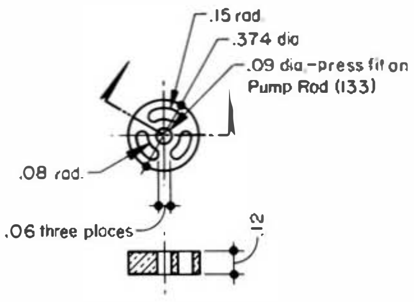
The .12" square stock should be formed around the perimeter of the box. On the full-sized engine, this is a flange on the lower firebox casting; the upper half of the firebox is trapped between this flange and the engine base plate. The square rod is brazed in place with the brazing rod applied only to the bottom side, allowing a fillet on the lower side of the square rod and a sharp corner on top, to simulate the original joint. The bosses for the four tierods that suspend the firebox from the engine base plate are then brazed on.

The door (**photo 21**) is fabricated from .12" thick stock.

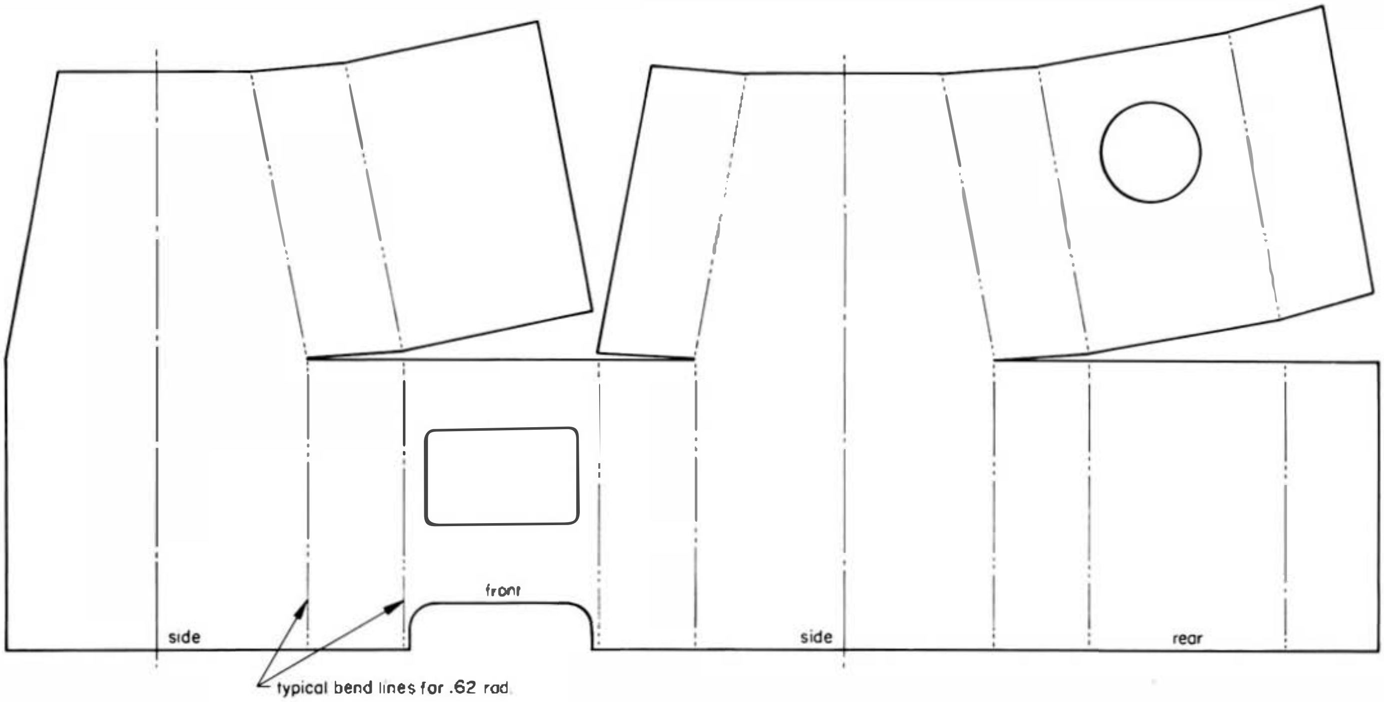
Photo 22 shows the completed firebox with the elbow for the chimney silver soldered in place. I prefer a two-piece stack which allows the vertical section to be removed for transportation purposes. The elbow shown is a 1¼" diameter brass sink drain, purchased from a plumbing store. It



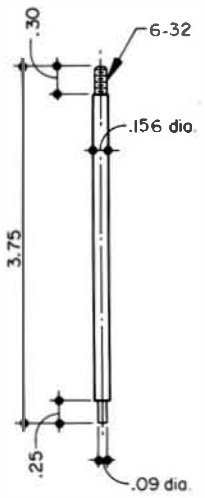
134 PUMP ROD CLEVIS
Brass, 1 required



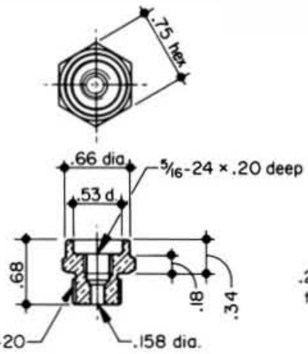
135 PUMP PISTON
Brass, 1 required
Shown actual size



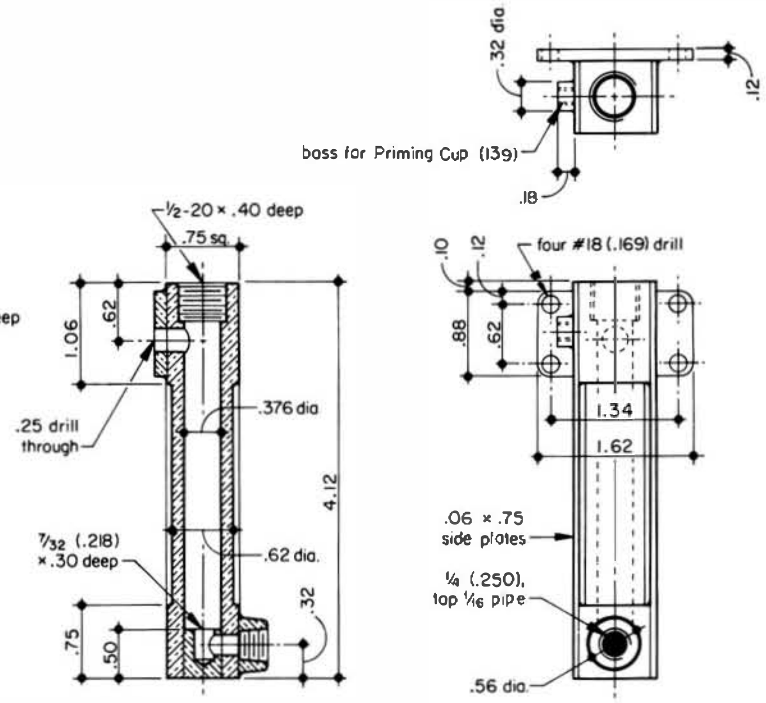
131(A) FIREBOX PATTERN



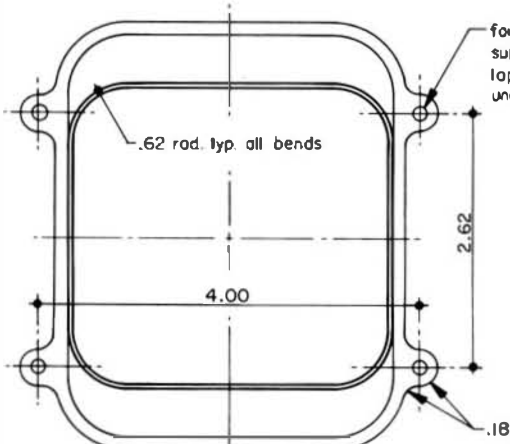
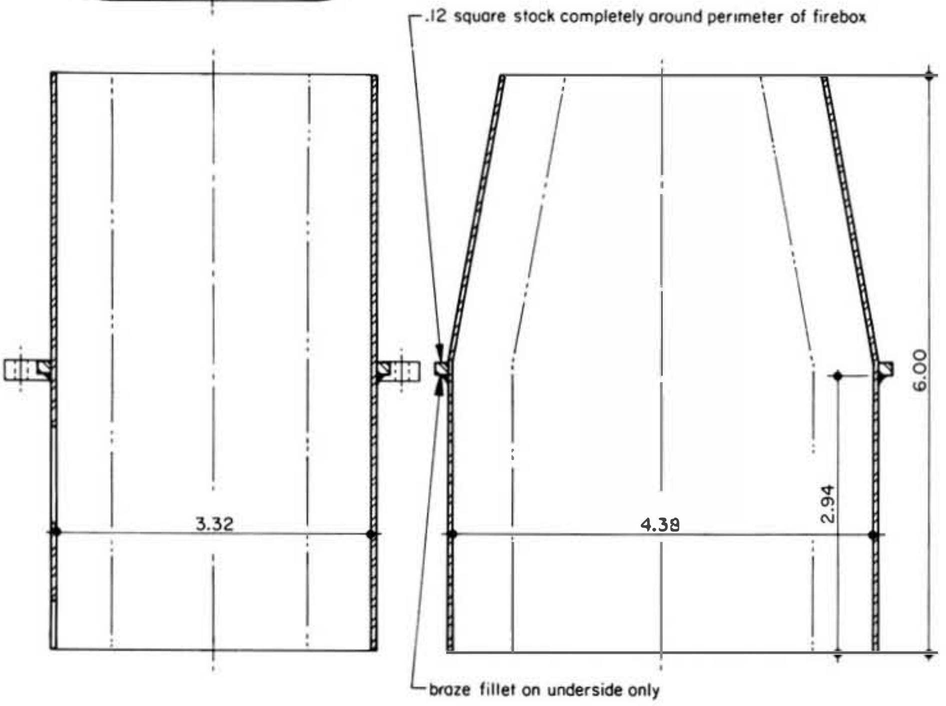
133 PUMP ROD
Stainless Steel, 1 required

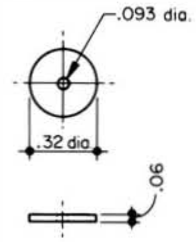


137 GLAND NUT
Brass, 1 required

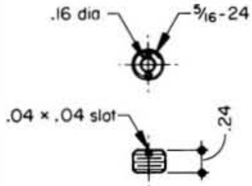


132 PUMP BODY
Brass, 1 required
Soft-soldered construction

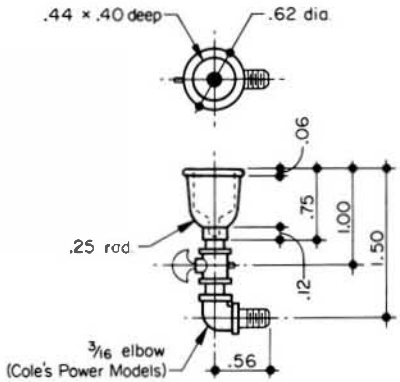





136 PUMP VALVE
Nylon or Brass, 1 required
Shown actual size

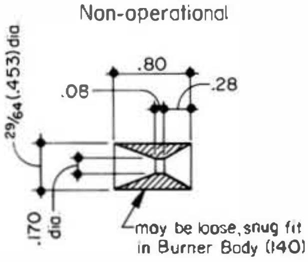


138 PACKING NUT
Brass, 1 required

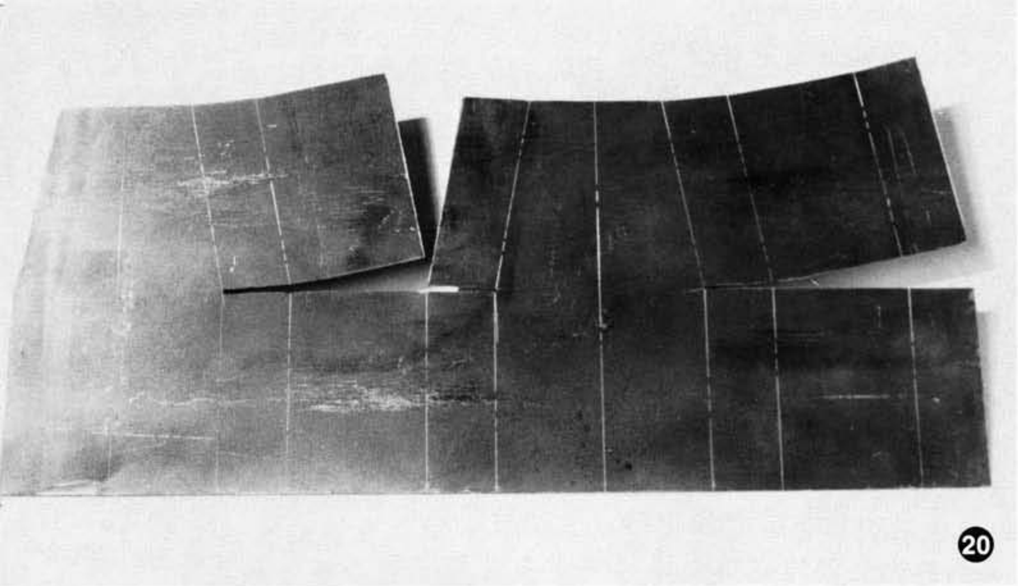


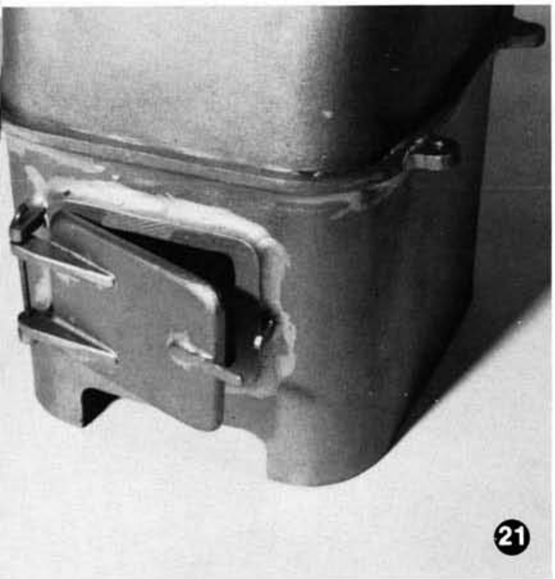
139 PRIMING CUP
Brass, 1 required
Non-operational

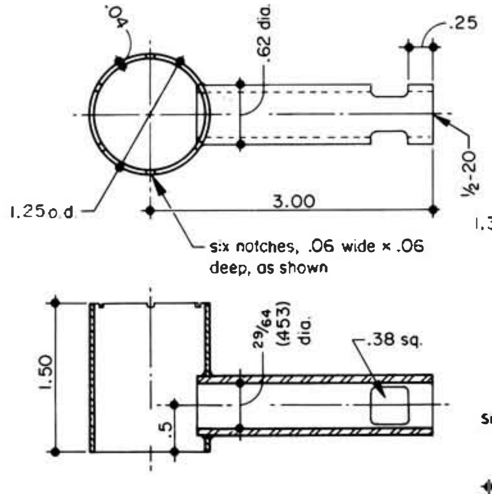
131(B) FIREBOX ASSEMBLY
.045 Cold-rolled Steel, 1 required
Welded and Brazed Construction



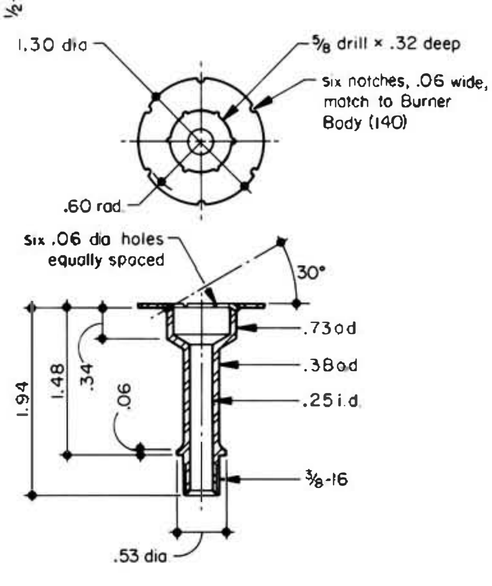
141 VENTURI
Aluminum, 1 required







140 BURNER BODY
Cold-rolled Steel and Brass, 1 required
Silver-soldered construction



142 TOP PLATE AND STEM
Cold-rolled steel, 1 required
Silver-soldered construction

provides a tight bend radius and a joint for the vertical stack to be slipped on.

Now that all parts for the engine proper are made, you're probably anxious to see the fruits of all your labor function, so let's put it together. We haven't yet built the water pump, but I prefer to assemble the engine and get it running before doing any final filing, filling or painting of the castings or finishing and buffing the brass components.

Using the assembly drawings as your guide, assemble the parts. The predetermined geometry of the linkage establishes the phase angle of the pistons, that is, the relationship of one piston to the other. The displacer piston on a Stirling engine will lead the power piston by 90°. The only thing yet to be done is silver soldering the displacer cylinder bottom, which can be done as soon as we determine its location. Adjust the displacer piston on its rod so there is .06" to .10" clearance between it and the power piston bottom, when the power piston is at dead center. Tighten the two setscrews in the displacer piston, which affix it in place. Now, advance the displacer piston to bottom dead center and note the relationship of the displacer piston to the end of the displacer cylinder. The end cap should be placed so there is .06" to .10" clearance from the piston bottom to the end cap. (Be sure the gasket between the flange and engine base is in place, because it affects the clearance.) By using this technique, the dead volume of the cylinder is minimized. (Dead volume is anything other than swept volume.)

Now, oil all the joints and power piston with a light grade oil; if an automotive type oil is used on the piston, too much drag is generated and it will keep the engine from operating. Put some water into the water jacket, to keep the epoxy cement from overtemperaturing. If you run the engine for over 15 minutes at a time, the water should be circulated.

Using a propane torch, spirit burner, sterno or some similar heat source, you are ready for start-up. It will take about 5 to 10 minutes to come up to operating temperature. Simply give the flywheel a turn and she will be running!

The water pump is not essential to the operation of the engine, except that water is necessary to cool the cylinder. This can be accomplished by using a separate water container of approximately one pint volume and plumbing it to the top and bottom of the water jacket, relying on the thermo-syphon method for circulation. But in the interest of having an authentic model, the pump is a necessity. And seeing the pump discharging water, even though it is only recirculating it from a small tank, completes the picture inasmuch as you can actually see it doing work.

The pump, as I have designed it, is a small departure from the original, mainly for simplification. Also, I have chosen to

20 The firebox blank (131-A), cut according to the pattern supplied with the casting set and with bend lines scribed in place.

21 Details of the built-up firedoor and door ring are easily seen in this photo.

22 The completed firebox, with the elbow for the stack extension silver soldered in place.

make it entirely from brass. The original had only the cylinder portion of the body in brass, along with the top gland nut, the body being an iron casting.

The **PUMP BODY (132)** is comprised of seven individual pieces, soft soldered together. The mounting flange is a good place to start, because it can be used as a template for locating the four 6-32 mounting screws and the .25" diameter water transfer hole in the cylinder. The cylinder portion itself is machined from a piece of .75" square brass stock. The .376" bore should have a smooth finish which is best achieved by reaming. A few imperfections are allowable, as long as they are not of a nature that would score the piston. The inlet boss at the bottom is turned on its o.d. only, having the .250" diameter hole and 1/16" pipe tapping operation done after the soldering. The ball check valve seat at the bottom must have a uniform contact with the ball. To accomplish this, before inserting the seat into the body, place a ball over the .218" drilled hole and give it a light tap with a hammer. This will brinell a narrow, spherical seat that matches the ball.

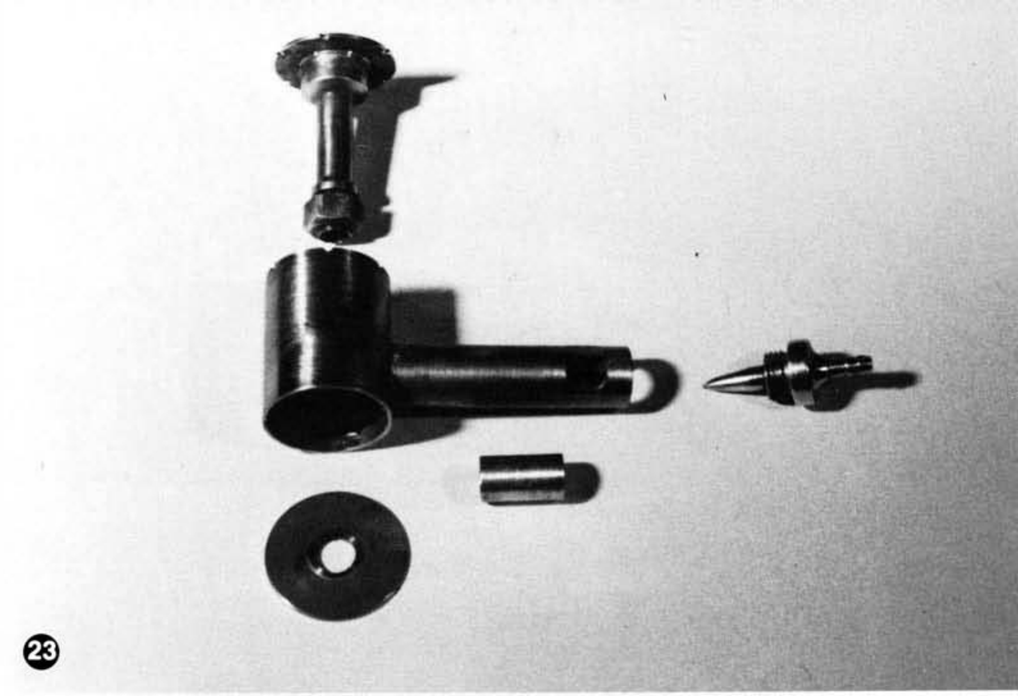
On my pump, I didn't solder on the two side plates. This allowed me to polish the complete body. After polishing the side plates, I attached them with epoxy cement and then clear lacquered the assembly to prevent tarnishing.

The **PUMP ROD (133)** is made from a piece of 5/32" diameter stainless steel. If stainless is not readily available, then cold-rolled will be acceptable. (Incidentally, when running my engine, I usually add a small amount of water-soluble oil to the pump water to prevent rust or corrosion from forming on the steel cylinder sleeve. This would also protect a cold-rolled pump rod.) The rod's outside diameter should be smooth to minimize friction in the packing gland. The **PUMP ROD CLEVIS (134)** is made of brass.

The **PISTON (135)** is a small brass wafer that is a press fit onto the piston rod. The ports for the passage of water can be drilled and filed to final shape. Some care should be exercised in not exceeding the .15" radius dimension, to insure a proper seal with the valve.

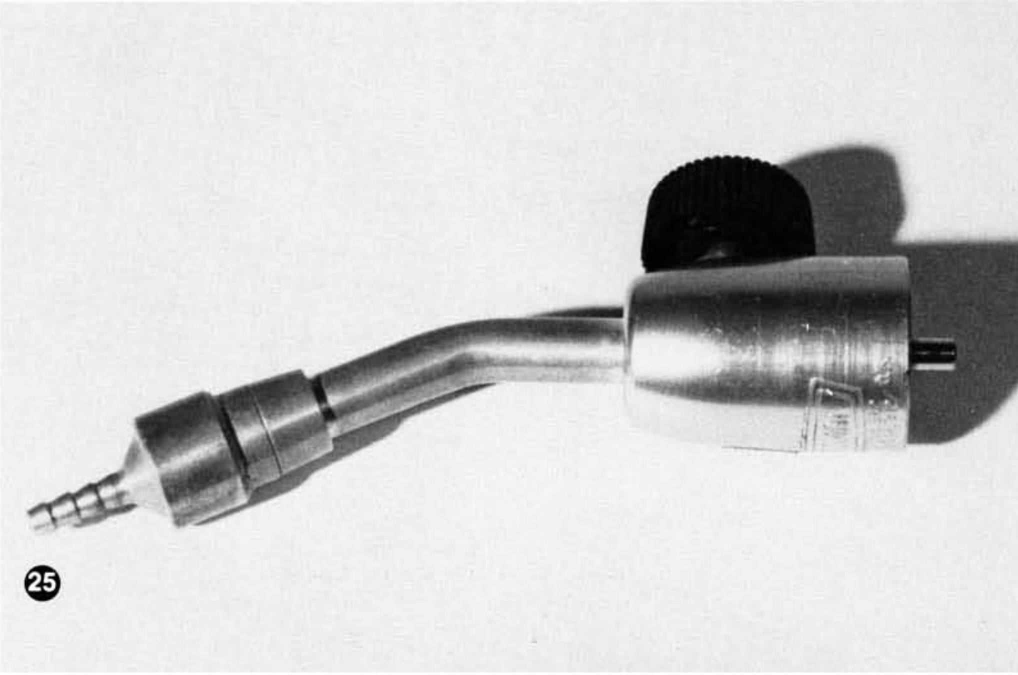
The **VALVE (136)** simply is a small wafer of brass or nylon. I prefer nylon because it does away with the clacking sound of metal on metal as the valve closes at the start of the upstroke and makes for a quieter-operating pump. This may seem like a small thing, but in the absence of other engine noises, it can be annoying. The valve must have the ability to slide freely on the .09" diameter of the piston rod, but not cock or bind on the rod. The .32" outside diameter must just cover the ports in the piston, but not be so large as to impede the flow of water around it.

The GLAND NUT (137) is turned from .75" hex stock. It would be best to size the .158" diameter to the already-constructed pump rod,

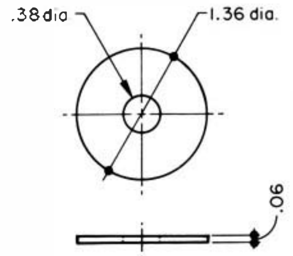


23 The various parts of the burner are seen in this exploded view.

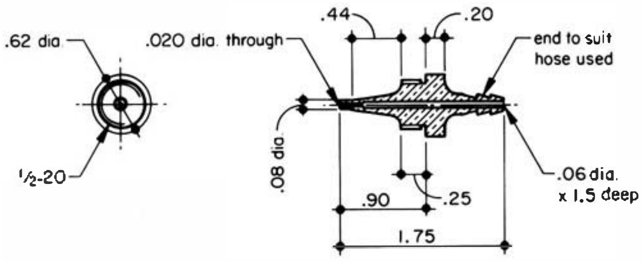
24 The completed burner assembly (145).



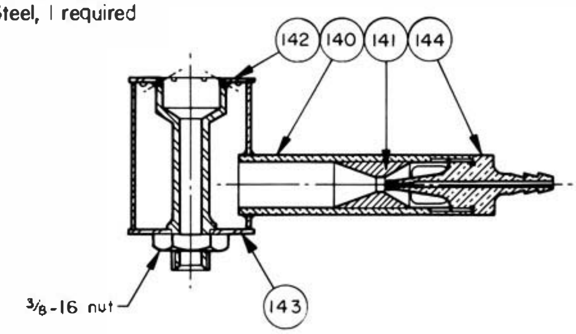
25 Gas regulation is accomplished by this modified Sears propane torch.



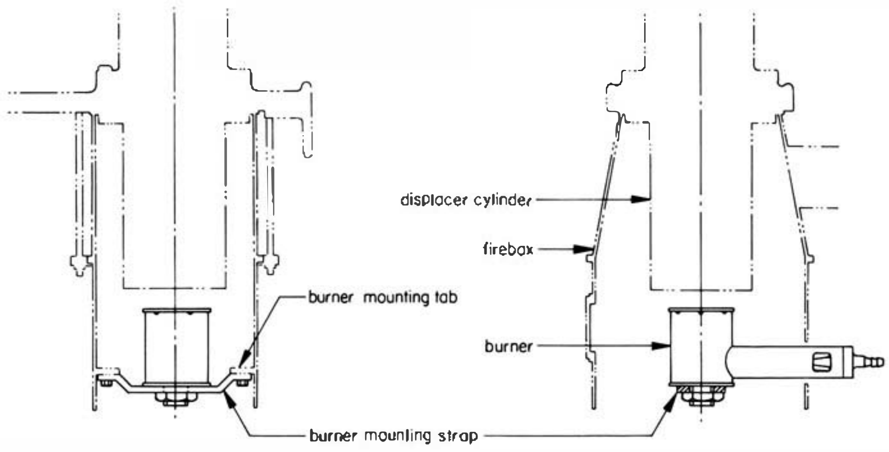
143 BOTTOM PLATE
Cold-rolled Steel, 1 required



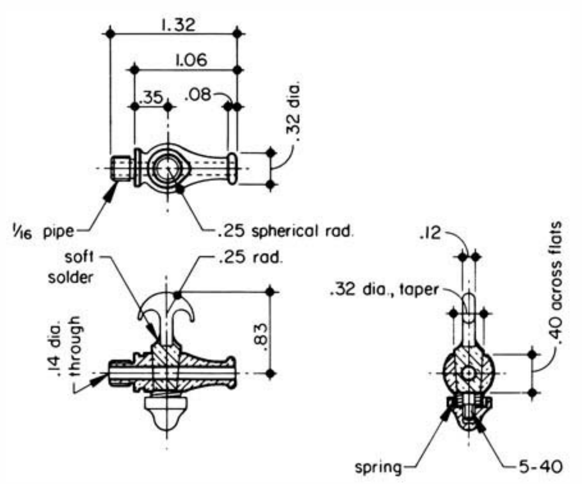
144 GAS JET
Brass, 1 required



145(A) BURNER ASSEMBLY



145(B) BURNER MOUNTING DETAIL



146 WATER DRAIN COCK
Brass, 1 required

to allow a smooth running clearance.

The **PACKING NUT (138)** screws in from the top, trapping a little teflon or similar packing beneath it. Do not apply too much load on the packing, because the friction generated can be enough to keep the engine from running.

The **PRIMING CUP (139)** is non-functional and is made purely for aesthetic purposes. It is turned from one piece down to the 90° elbow. A small hole is drilled through at the shut-off valve and a handle fabricated as shown. Pass it through the valve body and solder a small washer on the opposite side, allowing it to be rotated.

The air chambers shown on the engine cross sections at the inlet and outlet are non-functional also. Their purpose on the full-sized engine was to provide an air cushion to minimize water hammer. They can be turned from 1" diameter brass bar stock.

The tubing used for all the water piping is 5/16" o.d. x 7/32" i.d. brass tubing, threaded 1/16" NPT.

Only one last detail remains, the propane burner, and for some, it will be an option; if you prefer to use a spirit burner or some other flame source, the burner may be omitted, but personally, propane is by far the simplest and best fuel. It is readily available in small bottles and is comparatively neat and clean. The amount of gas consumed by the burner is small; a 14-oz. cylinder should last for eight to ten hours of operation.

The **BURNER BODY (140)** is a silver-soldered assembly. The 1.25" diameter tubing is a piece of brass tubing cut off the elbow used on the firebox. The .62" diameter stem is tap drilled 29/64" through and threaded as shown on its end.

The **VENTURI (141)** may be machined from aluminum and is made to be a light slip fit in the 29/64" i.d. which will allow for a fore-and-aft adjustment relative to the gas jet, to optimize the gas-to-air mixture. The flame notches on the top are best sized by starting out with smaller notches and working larger by trial, lighting the burner until satisfied with the flame shape.

The **TOP PLATE AND STEM (142)** is also silver soldered and is made from cold-rolled steel. The hole down the center is for secondary air circulation. The six .06" diameter holes should be sized by the same trial-and-error method used to size the notches in the body.

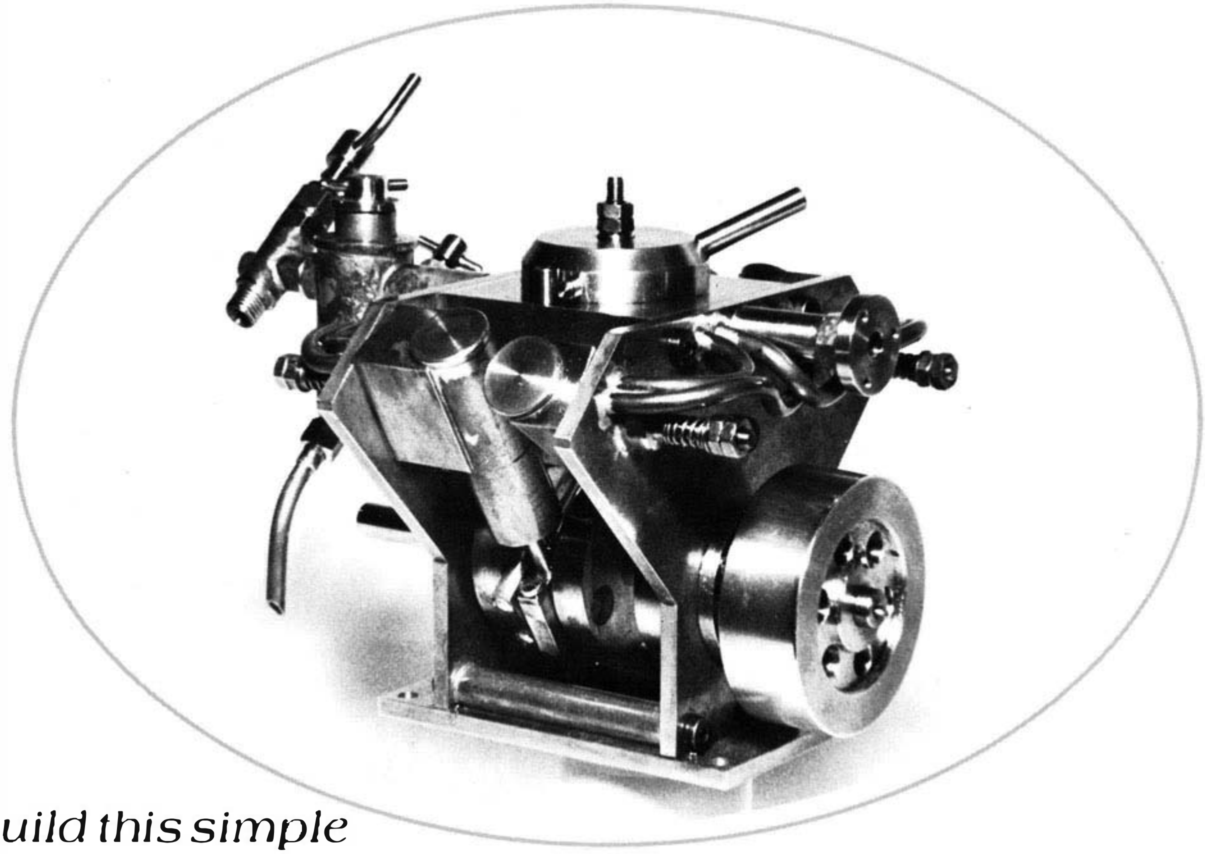
The **BOTTOM PLATE (143)** is secured to the threaded end of the stem by a 3/8-16 hex nut. The same nut can also mount the burner to a bracket in the firebox.

The **GAS JET (144)** is turned from brass, as shown. The .020" diameter hole can either be drilled to size or a piece of hypodermic tubing .020" i.d. and .032" o.d. can be inserted into the end. The connection end is machined to suit the hose used.

Photo 23 shows the parts to the propane burner. The complete assembly is shown in **photo 24.**

Photo 25 shows the modified propane torch, which I use to regulate the gas. This torch was purchased from Sears because of its somewhat unique design. It has its metering orfice built into the base, allowing the torch end to be cutoff and an adapter for the connecting hose to be soldered on. If a different make of torch head is used, be certain that the metering orfice is used.

Your quarter-size replica of an Ericsson Hot Air Pumping Engine is now complete.

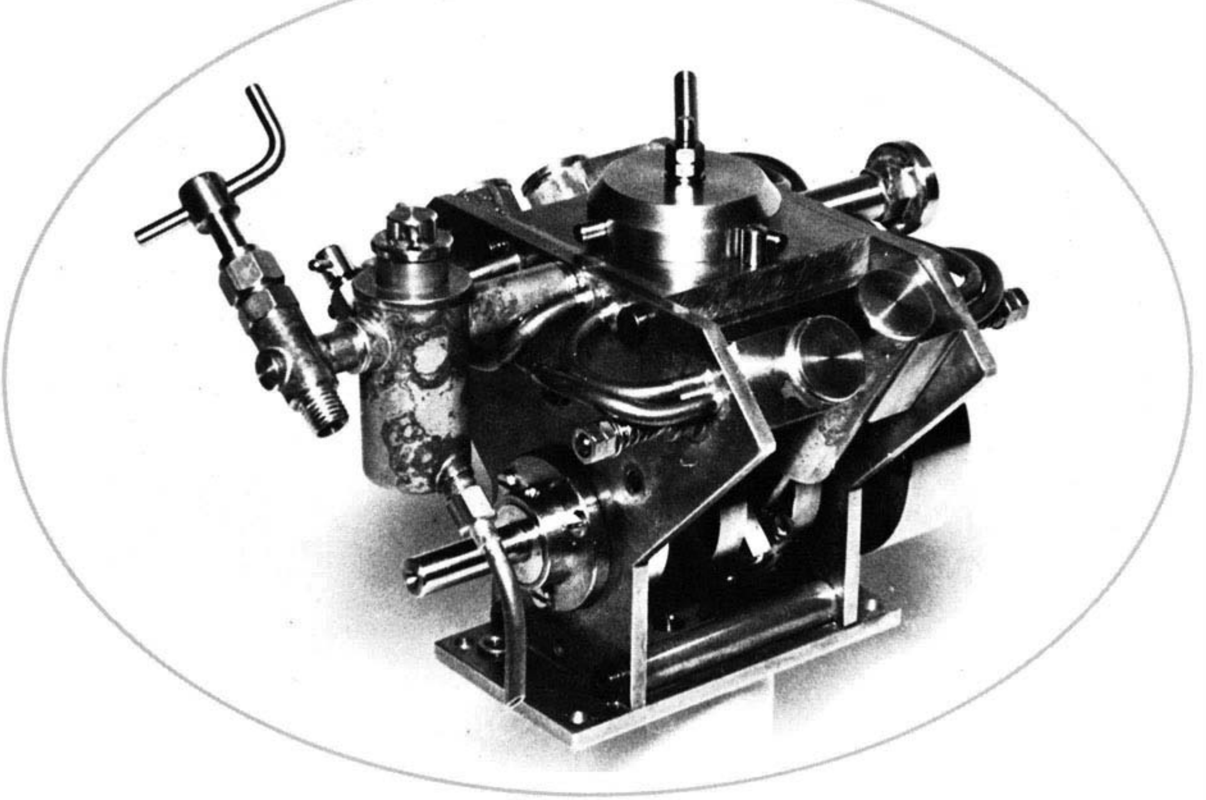


Build this simple

V-4 Oscillating Cylinder Engine

by Jan Gunnarsson

Photos and Drawings by the Author



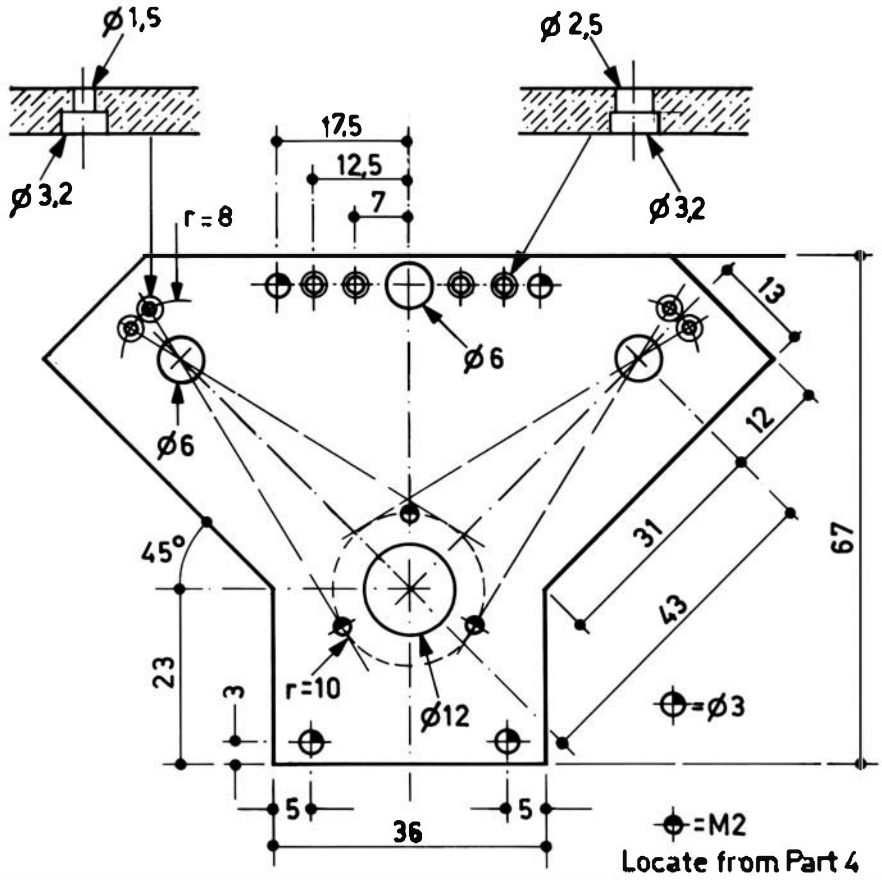
This small, simple steam engine (photos page 86) is mainly intended for radio controlled ship models. It is, strictly speaking, not a model, merely a small power unit. Radio-controlling the engine will require two channels, one for the throttle and one for the reversing valve. The engine is self-starting in all positions and relatively slow-running, so neither gearbox nor clutch is needed.

I managed to build my own engine in two weekends and the boiler in about the same amount of time. Add to that the time spent in making the boiler fittings, like the check valves, water gauge and the butane burner. These things can, of course, be purchased ready-made for a reasonable sum to save time, but they are easy and interesting things to make.

In order to keep things as simple as possible, the engine has single-acting, oscillating cylinders; thus there are no valves, valve gear or glands. The drawback with single-acting cylinders is that the engine must have four cylinders in order to be self-starting in all positions. By making it in the shape of a V-4, the crankshaft will then require only two cranks, 180° apart, which will simplify fabrication. I say fabrication, because the crankshaft is built up from rods and disks, stuck together with *Loctite* and pinned for additional security. No finish machining is required.

All parts are quite small, the whole project being well within the capacity of the smallest lathe, such as a Unimat. The materials required are easily obtained, brass, copper and silver steel, together with a few bits of bronze and stainless steel rods.

Regarding the engine being in the form of a V-4, this is nothing new. I have seen several engines built that way, but when I wanted to build my own I found that there were no finished designs available, so I had to make this one.



1 ENDPLATE
2 required

Because the engine is relatively slow-running, around 1000 RPM at 30 psi, it is best suited for a heavy hull with a large screw, like a tug. Of course, it can be run much faster, but I think it is better to keep down the RPM and use its torque instead. There is plenty of the latter. With 30 psi steam pressure it is difficult to stop the engine by gripping the output shaft by the fingers, if you forgive this primitive method of measuring power.

This engine can, of course, be used for purposes other than to propel ship models. As I never get around to building any ship models for my steam engines, I have been toying with the idea of installing the engine in a large toy truck. That would make a grand gift for a small boy. In this case I should, however, use a different boiler. A vertical one is more suited for this application.

If you detect a few small differences between the engine in the photos and the drawings and text, don't get puzzled. As I built my engine with just a few raw sketches, I made a few mistakes and there is no need for you to copy them. Just follow the drawings and the text and you'll be safe. As the general said to his men: "If you find any difference between the map and the country, it is the map that counts."

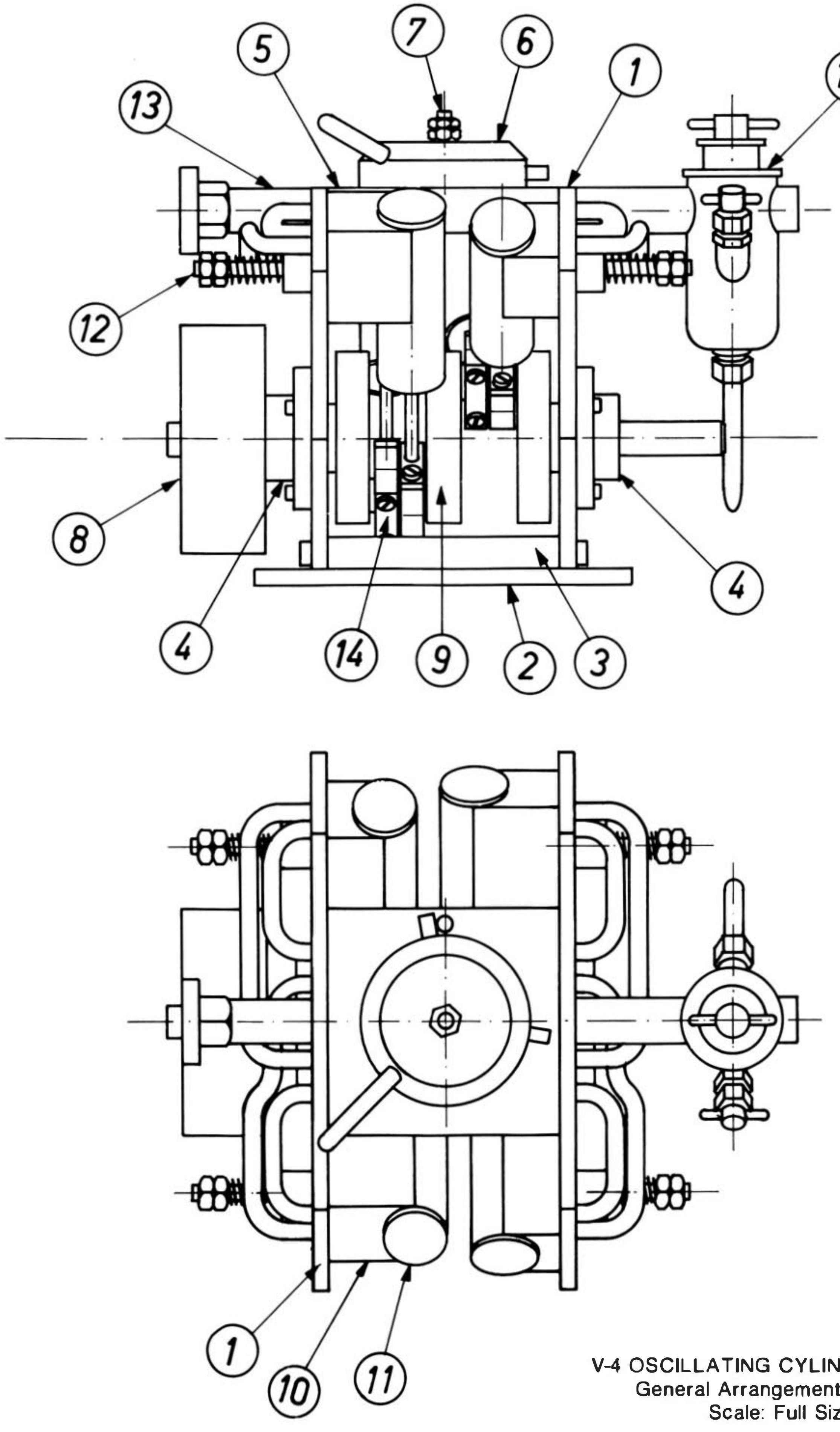
Now for the actual construction, the first parts are the two **ENDPLATES (1)**. As they must be identical, we'll make both at the same go. With a hacksaw, cut two pieces of 3mm sheet brass, 70 x 100mm. At least one side of each piece must be smooth and free from scratches. Clamp them together with the smoothest sides facing each other and mill the top and bottom edges until the height is 67mm. If you lack milling facilities (the Unimat will do nicely here), hand filing will do the job. The top and bottom edges must be straight and parallel and 67mm apart. Thereafter, mill or file the right side straight and square to the top and bottom edges.

Now on one of the pieces, scribe the vertical centerline 50mm from the previously-milled right side. For laying out work like this, a slightly modified vernier caliper is a very handy tool. Just grind its fixed jaw to a sharp point, as shown in Figure 3. The caliper must, of course, be of the hardened variety and the grinding done carefully, with frequent cooling by dipping it in water to avoid annealing it. The caliper's normal function will not be affected. Do not use it for scribing on hard steel however, or it will quickly become blunted. Your vernier caliper will now double as a scribing gauge, giving much better accuracy than using a steel rule and scriber. Using this instrument, lay out all hole centers except the four steam ports (1.5mm diameter) and the two pivot pin bushing holes (6mm diameter). Measure from the right vertical edge and use the vertical centerline 50mm from it as a reference.

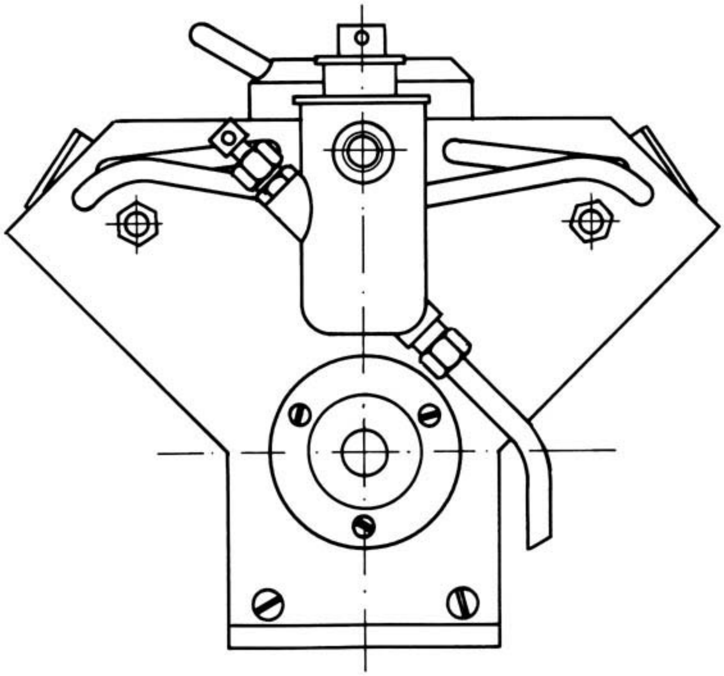
Scribe a line parallel to the top edge and 4mm below it. Mark out the positions for the six small holes on this line. For example, when setting out the right 3mm diameter hole, set the scribing gauge to 50mm-17.5mm = 32.5mm and make a crossmark on the horizontal line, measuring from the right edge. When laying out to the left of the centerline, add 50mm to the dimension found on the drawing, still measuring from the right edge.

Make a centerpop at each intersection. When doing this, use a sharp center punch. Hold the centerpunch leaning 45° to the right and set it down in the horizontal scribed line a short distance to the right of the crossing line. Move the point towards the crossing line until you feel the point click down in the line, then raise the punch to the vertical, change hand without shifting the punch and give it a light blow with a hammer. Using this technique, your holes will be located very accurately. After the centers of the ten holes have been laid out and centerpopped, the centers for the cylinder pivot pins can be laid out. To do this, use a protractor set to 45° or a fixed 45° square. Set it against the endplate's bottom edge and adjust its position so a line can be scribed through the crankshaft bearing center and 45° to the right. Turn the protractor over and scribe through the bearing center, to the left. Using a divider set to 43mm, make a short crossline on each of the two lines. Centerpop at the intersections.

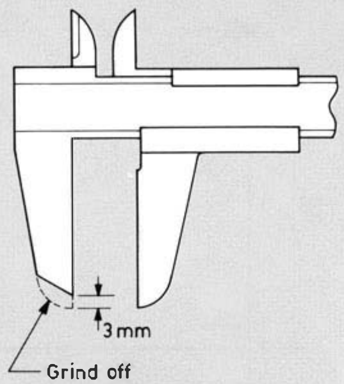
Mark out the endplate's outer contour, again using the protractor and the scribing



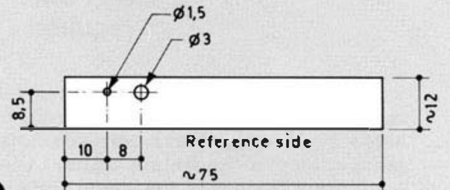
V-4 OSCILLATING CYLINDER ENGINE
General Arrangement Drawing
Scale: Full Size



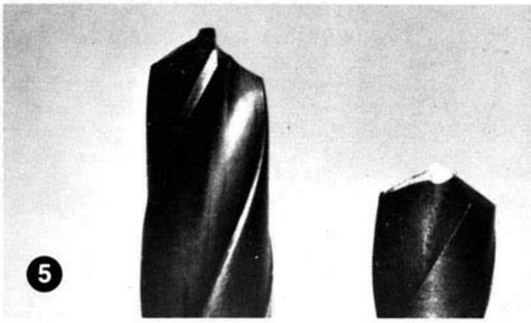
LUBRICATOR END



3 SCRIBING GAUGE



4 DRILLING FIXTURE



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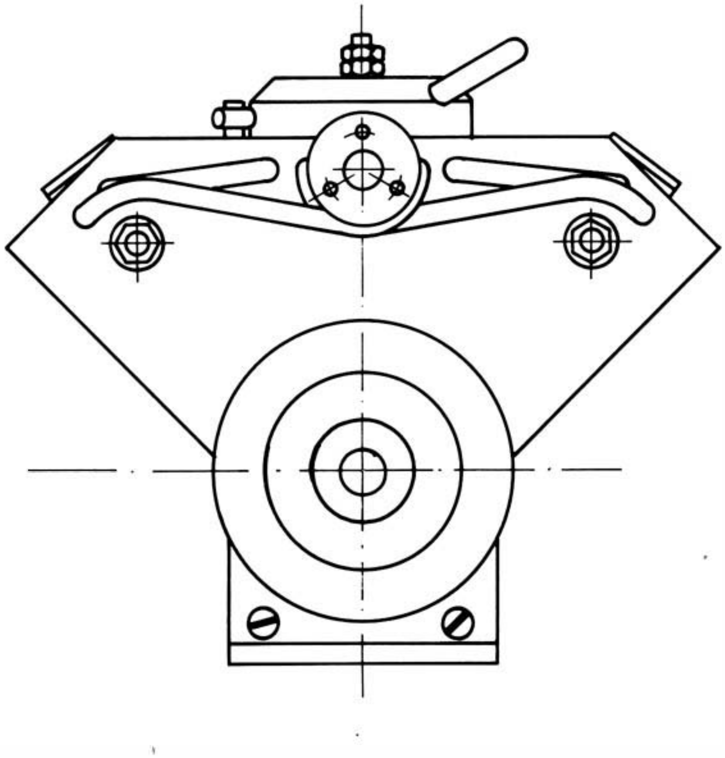
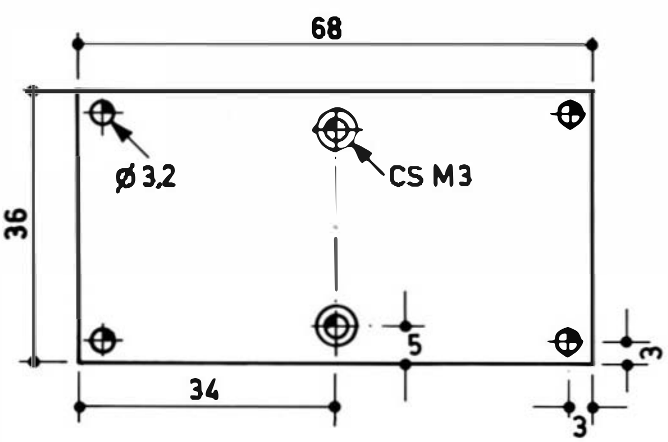


FLYWHEEL END

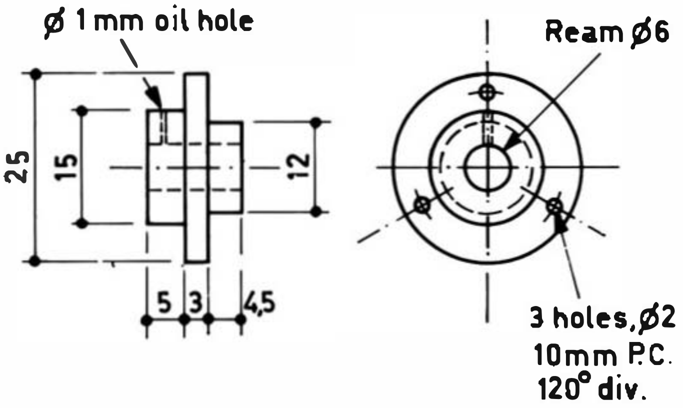
gauge. Clamp the two endplates together with a pair of toolmakers clamps, making sure their bottom edges are aligned by standing the sandwich on a flat surface before tightening up the clamps. Drill two holes somewhere outside the scribed lines marking the outer contours and rivet the endplates temporarily together through these holes.

Drill through at all centerpops, using a 1.5mm drill bit. Open up the four screwholes to 3mm. Also, using the 3mm drill bit, open up the crankshaft bearing center and the two cylinder pivot pin holes.

Next we need a simple drilling fixture for the steam ports, as they must be accurately located. The fixture, Figure 4, is made from a piece of flat steel stock, 3 x 12mm or ⅛" x ½". These dimensions are not critical. Locate and drill the two holes 8.5mm from the left edge. Mark this edge with a felt pen for identification. We also need two pieces of 3mm diameter silver steel rod, around 15mm long. To use the fixture, insert one of the silver steel rods in the crankshaft center hole on the endplates and the other rod in the left pivot pin hole. Put the fixture over it and butt up its left(marked) side against the rod in the crankshaft hole, from the right side. Lock in place with a toolmakers clamp. Using a 1.5mm drill bit, drill through the 1.5mm hole in the fixture and through the endplates. To drill the other steam port, just turn the fixture over on its back and butt it



2 BOTTOM PLATE
1 required



4 CRANKSHAFT BEARINGS
2 required

up against the left side of the rod in the crankshaft center hole. Repeat for the other side's steam port. Make sure you butt the marked side of the fixture against the pin every time. This way the steam ports can't help being spaced equally from a line through the pivot pins and the crankshaft center.

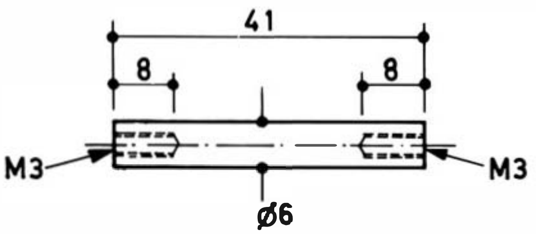
Now drill out the pivot pin bushing holes to 6mm diameter. Use a drill bit with the tip modified for brass, as shown in photo 5. By grinding off the lips as shown, the risk of catching when drilling brass is greatly reduced and it also produces smoother holes. Just grind a small vertical flat on each lip, a few seconds of work on the grinding wheel. By the way, this way you can get a new use for dull drills, if you don't care to sharpen them.

For the 12mm crankshaft bearing hole, we need a pindrill of that dimension. If you have a ½" pindrill, by all means use it and make the bearings to suit. The pindrill, Figure 6, is quickly made from silver steel. Turn down the shaft to suit your drill chuck. Face the other end of it and drill out to take the pin, in this case 3mm diameter. The cutting teeth are filed by hand. Harden the business end by heating it to cherry red and plunging it into cold water. Give it a few strokes on the edges with an oilstone slip and insert the center pin, which should not be hardened. If used carefully, the pin drill does not require tempering and is now ready to go to work.

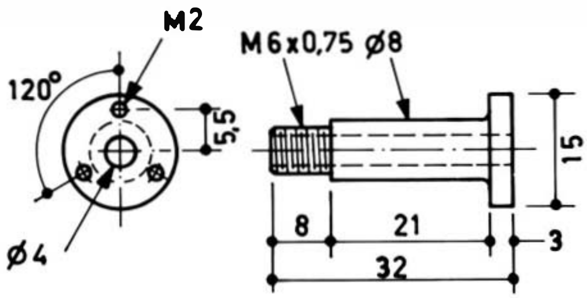
When the crankshaft bearing hole is finished, counterdrill the 8 small holes as shown on the drawing, to accept the steam pipes. The pipes will be made of ⅛" copper pipe. The counterdrilling should be about 1.5mm deep. Deburr all small holes lightly, using a drill bit held by hand. The bearing hole can be dealt with by a scraper (photo 7). Put 3mm screws with nuts on the back side through two of the 3mm holes. Then rough out the outer contours with a hacksaw. Trim with a file. Separate the endplates and deburr the holes on the backside, except the steam ports. This is important, for if the steam ports edges are chamfered the admission and exhaust timing will be upset, resulting in a poor-running engine. Instead, use a smooth, single-cut file to file the burrs from the ports if necessary. Finish by laying a fine emery cloth on a dead flat surface, such as a drilling machine table or a piece of plate glass, and rub the endplate against it. Chamfer all outer edges of the endplates very lightly with a fine file and they are now finished, as shown in Photo 8.

The **BOTTOM PLATE** (2) is made from the same stock as the endplates and calls for no further description.

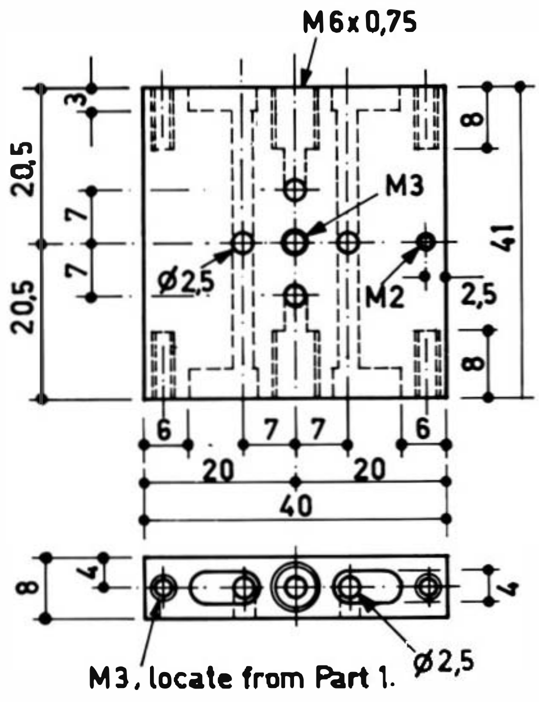
Now we'll jump a bit with the part numbers. The reason for this is that parts 3 and 5 must be of equal length and it is much easier to match part 3 to part 5, than the other way around. The **REVERSING VALVE BLOCK** (5) is made of a piece of brass 8 x 40mm. Cut off a piece with a hacksaw, say 43mm long. Clamp it to the milling table (if you are using a Unimat)



3 SPACERS
2 required



13 EXHAUST FLANGE
1 required



5 REVERSING VALVE BLOCK
1 required

with a spacer of, say, 3mm between the block and the table. If you own a dial indicator, use it to align the block parallel to the Unimat's longitudinal axis. If not, set it as good as you can by eye, tighten the clamps and mill one end, using a pin mill. Check for squareness with a small square without removing it from the table. Then loosen the clamps partially and adjust the block's position in the desired direction by gently tapping it with a plastic mallet. Retighten and make another cut. Check again and, if necessary, repeat until satisfied. Then mill the other end until the block's length is 41mm. Remove the block from the table and chamfer all sharp edges very lightly.

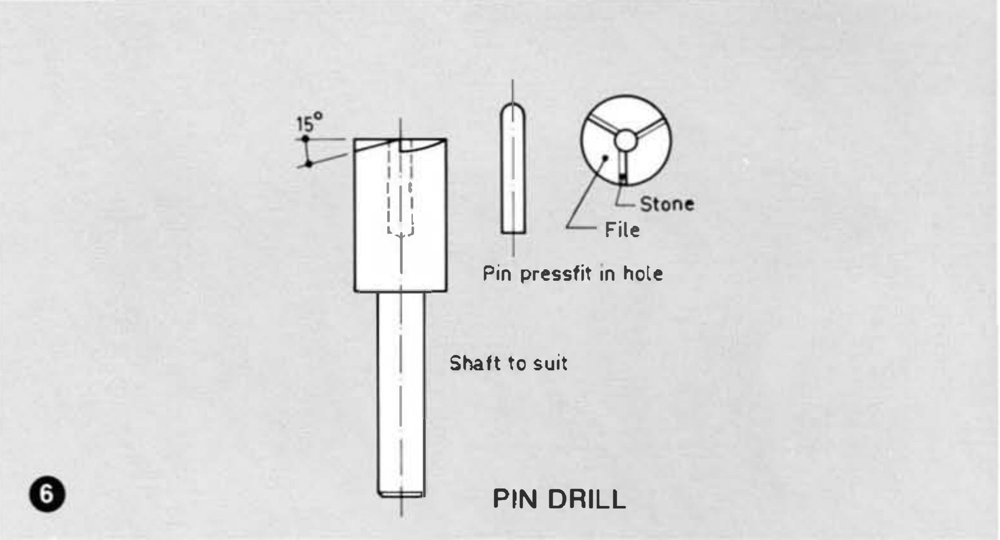
If you are using a large lathe, the block can, of course, be trued up quicker by setting it up in the four-jaw chuck and facing the ends. A proper milling machine with a machine vise makes an even quicker job of it.

Next, using the scribing gauge, mark out the position for the two holes marked M6 x 0.75 on the drawing. Centerpop and drill with a 5.3mm drill bit to 8mm depth. Change to a 3mm drill bit and drill to 16mm total depth. Tap the holes M6 x 0.75. Mark out the six small holes on the top surface. Drill the center hole straight through, 2.5mm diameter and tap M3. The hole marked M2 should also be drilled through, 1.7mm diameter, and tapped M2. The remaining four 2.5mm holes are drilled to a depth of 6mm.

In order to be able to temporarily put together the block with the endplates for marking out the positions for the assembly screws, we have to make the **EXHAUST FLANGE (13)** now. This is a simple turning job. Make the thread with a die held in a tailstock die-holder. The three M2 screwholes can be left until later. Attach one of the endplates to the valve block by means of part 13. To make sure that they line up properly, stand them upside-down on a flat surface and then tighten up part 13. The 3mm mounting screwholes can now be spotted, using a 3mm drill bit. Drill only about 1mm deep, then change to a 2.5mm drill bit and drill to 8mm depth. Tap both holes M3 and insert M3 screws. Then spot the four steam pipe holes, using a 2.5mm drill bit. Disassemble the endplate and repeat the process for the other end of the valve block. Then disassemble again and drill the channels through the block, using a 3mm drill bit. Drill only halfway from each end, until the drill bit breaks into the vertical 2.5mm hole. Next, mill the two oblong cavities in each end. Clamp the block in the machine vise, with one of the end faces upwards as in photo 9. Mill the cavities to a depth of 3mm. Repeat for the other end, then deburr with a smooth file. The top surface of the block must be smooth and flat to prevent the reversing valve from leaking. To obtain this, rub the block against an emery cloth until all scratches are removed. Treat the ends the same way and the block is finished.

Two **SPACERS (3)**, are needed and again are a simple turning job. They are made from 6mm diameter brass stock. It is, however, very important that both are *exactly* the same length as the valve block.

After this, we might as well make and fit the **STEAM PIPES** to the endplates. These pipes are simply pieces of ⅛" (3.2mm) copper pipe. Study the general arrangement and photo 10 carefully. It is important that the steam ports are connected to the valve



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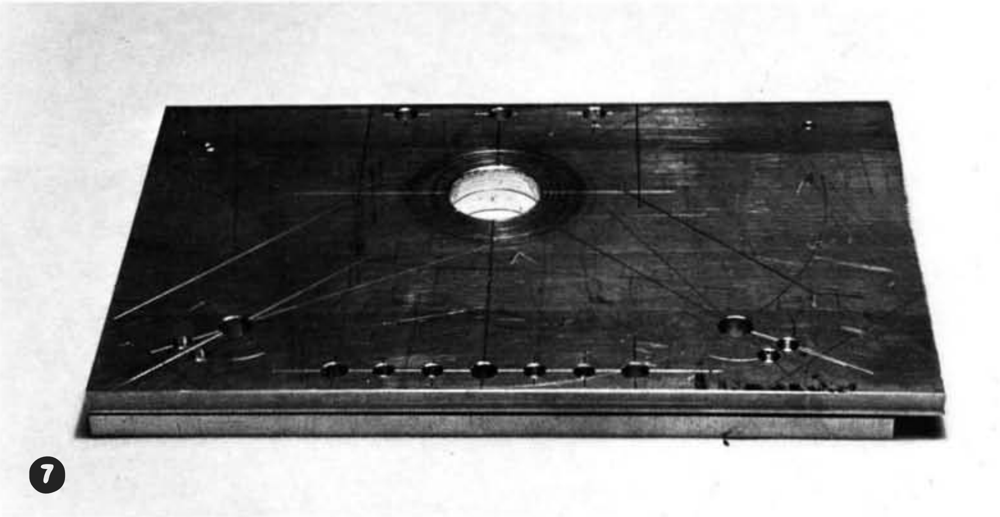

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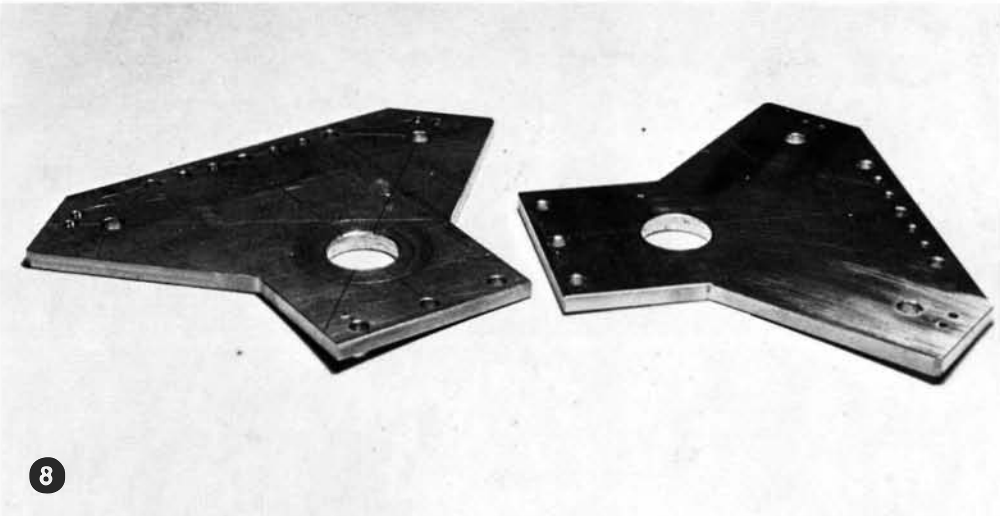

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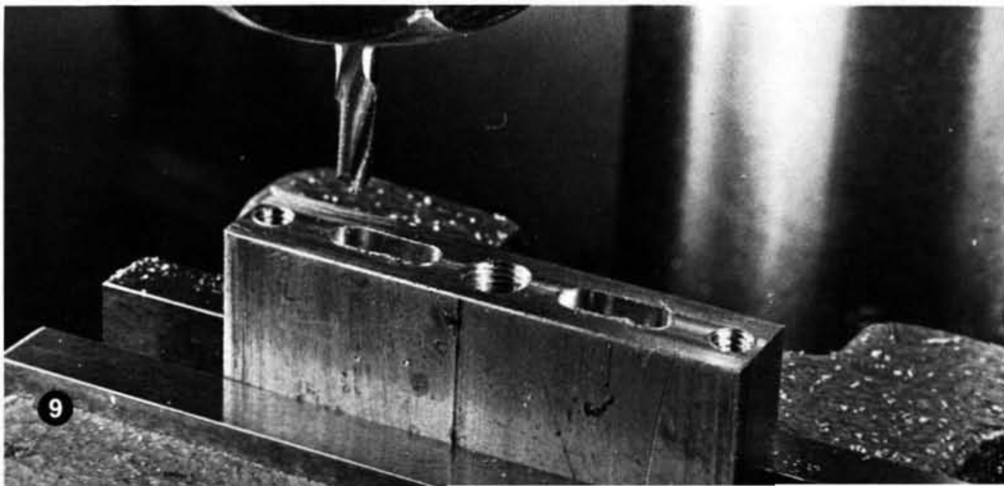

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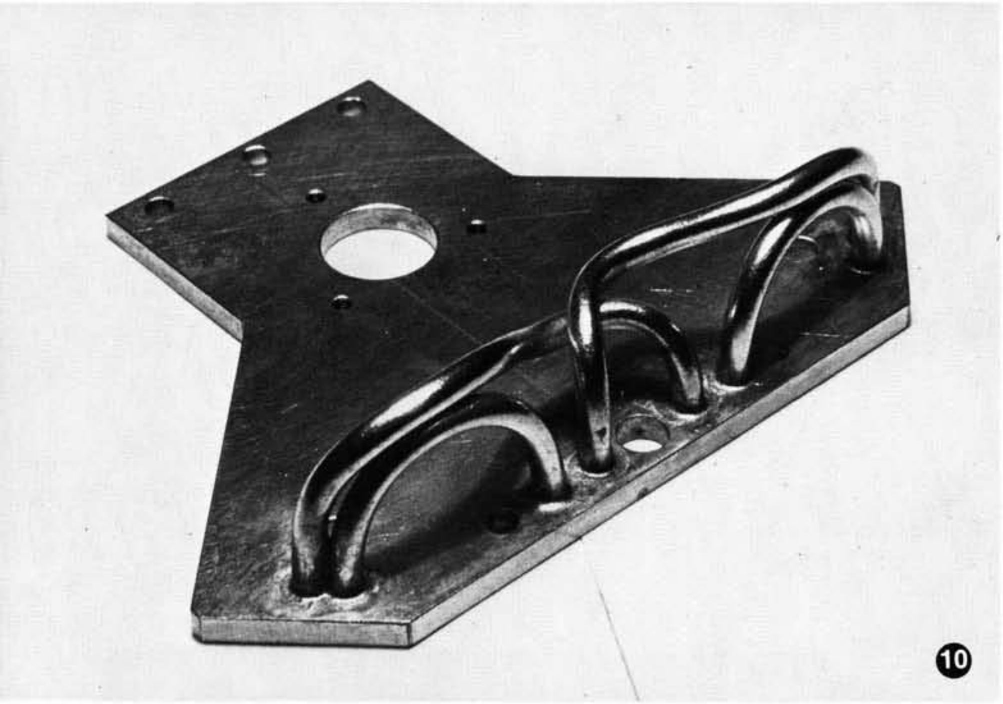

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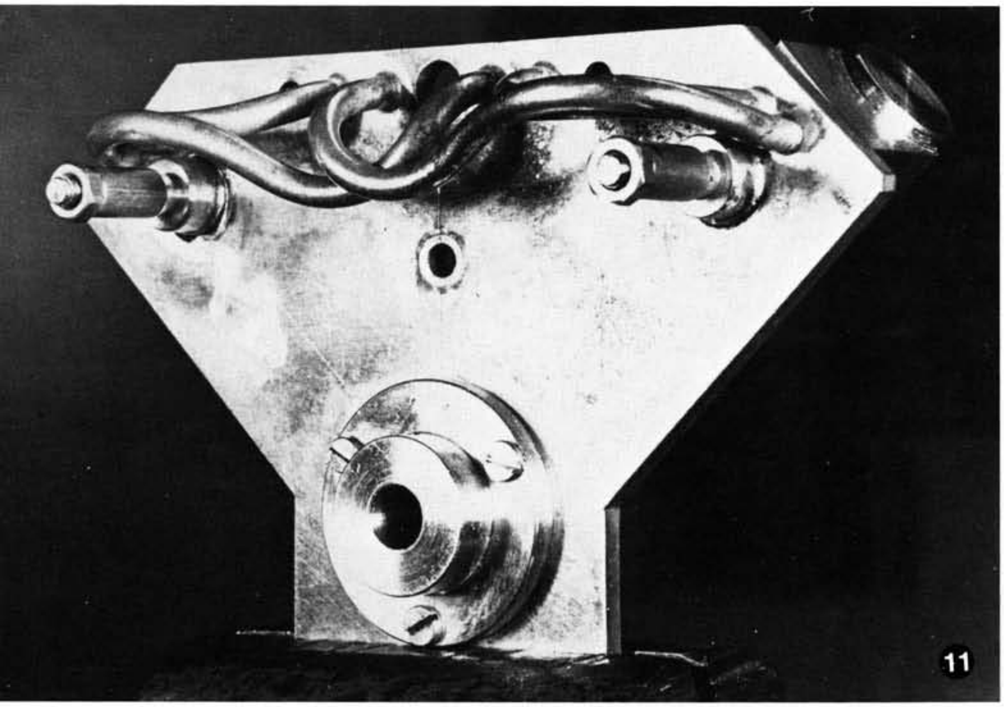


11

12

block in the manner shown, otherwise the engine will not run. Note that the pipes must be bent to clear the pivot pins and spring assemblies and the steam inlet and exhaust pipes (see photo 11). Cut the pipes over-length at first, in order to have something to hold on to when bending. Anneal the tubes by heating to dull red before bending. This will have to be repeated a few times as the copper will harden when being bent. When satisfied with the shape, trim to final length and insert in the endplate. Don't forget to deburr the insides of the pipe ends. When all pipes are in position, silver solder them to the endplates. Then put them in a pickle bath for a few minutes. Rinse in water afterwards, taking care that all traces of the pickle acid is flushed out of the steampipes.

The **CRANKSHAFT BEARINGS** (4) are turned up from a piece of 25mm diameter brass rod or even better, bronze rod. Cut off a piece approximately 35mm long and set it up in the three-jaw. Face it and then turn down to 15mm diameter for 5mm length. Chamfer the sharp edges with a file. Part off to 13mm total length. Repeat for the second bearing.

Set up one of the bearings in the three-jaw, gripping it across the 15mm diameter part and pressing the flange against the jaws. Turn the outer end to final dimension and chamfer the edges. Use the 12mm holes in the endplates as a gauge for the bearing stud, as the bearings should fit snugly in the endplates. Put a centerdrill in the tailstock chuck and center drill the bearing. Drill through with a small drill bit, say, 2.5mm. Open up the hole to 5.9mm and ream with a 6mm reamer, running the lathe on low speed. Chamfer both ends of the bearing hole lightly, using a scraper. Repeat the process for the other bearing. The three 2mm diameter screw holes are best done using the Unimat dividing head.

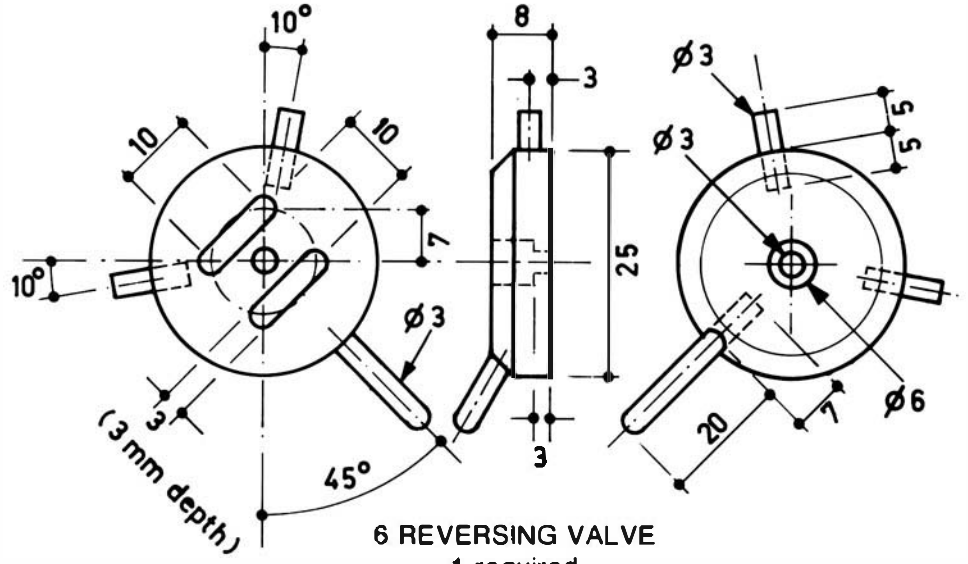
Clamp one bearing to each endplate and spot the screw holes. Drill through with a 1.7mm drill bit and tap M2.

We can now assemble the parts made thus far. Put together the endplates, valve block and spacers, using M3 x 8mm cheese-head screws, but do not tighten up yet. Stand the assembly upside-down on a truly flat surface. Press down the valve block and the endplates against the flat surface and then tighten the screws in the valve block. Turn the assembly right side up, press down the spacers and tighten the screws.

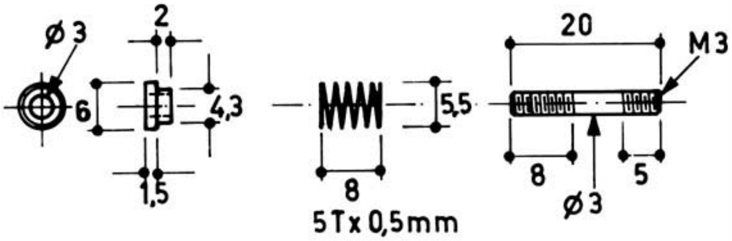
To make sure that the bottom plate will bed down properly on both the endplates and the spacers, set up the engine frame upside-down in the milling machine. Take a light skim on the bottom edges and the spacers, as shown in photo 12.

Clamp the bottom plate in place, using a pair of toolmakers clamps. Spot the two screw holes through the bottom plate into the spacers. Drill through, 2.5mm diameter and tap M3. Insert a pair of M3 x 6mm countersunk screws and tighten up. Remove the bottom plate and spacers together by taking out the four screws at the bottom of the endplates. Soft solder the spacers to the bottom plate. After cleaning, reassemble to the rest of the engine frame.

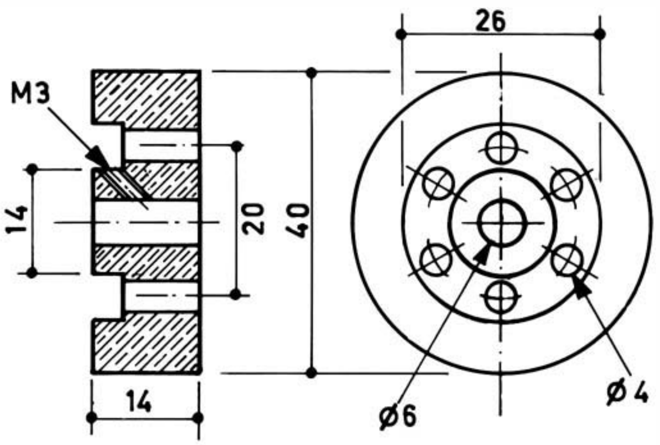
In order that the engine frame always be assembled in the same way, make some kind of indentification mark, such as a centerpop or stamp, on one of the endplates and at the corresponding end of the valve block and bottom plate.



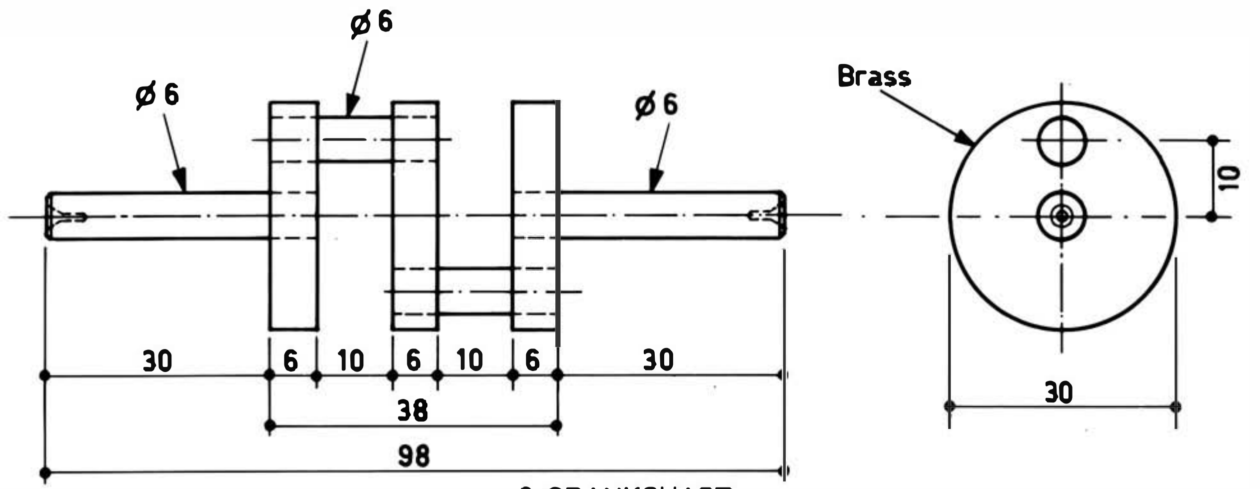
6 REVERSING VALVE
1 required



7 PIVOT PIN
1 required



8 FLYWHEEL
1 required



9 CRANKSHAFT
1 required

For the **REVERSING VALVE (6)**, set up a short piece of 30mm diameter brass rod in the three-jaw chuck and face it. Center-drill and drill 3mm diameter to 10mm depth. Counter drill, preferably using a 6mm end mill, to a depth of 5mm. Part off a disk about 8.5mm thick, reverse in the chuck and face to 8mm thickness. Using the dividing head, center drill the four holes on the bottom, spaced 90° and on a 7mm radius from the center. With a 3.5mm drill bit, drill these holes to a depth of about 3mm. Using the Unimat as a milling machine, mill the steam channels between the holes, also to 3mm depth (see photo 13). Setting up by sighting is sufficient since the exact location of the channels is not critical; what matters is that the position of their ends coincide with the four holes on the Valve Block, Part 5. Deburr the valve's bottom surface with a smooth file and by rubbing it against a fine emery cloth laid on a flat surface. The bottom of the valve must be truly flat and free from scratches to avoid steam leakage. Set up in the lathe and make the bevel at the top corner. Drill the hole for the handle, taking care not to drill through into any of the steam channels. The handle's position is not critical, it can be located by eye.

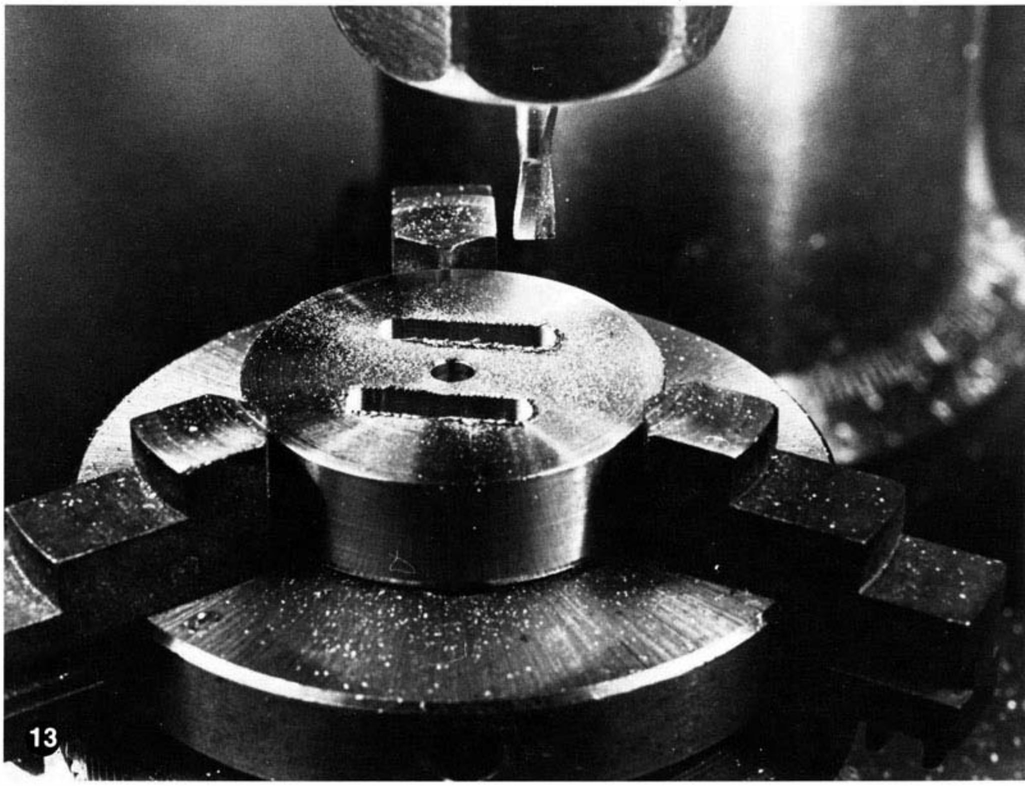
The **PIVOT PIN (7)**, is simply a 3mm diameter silver steel rod, threaded M3 at each end. By the way, all threading operations on the various pins should, of course, be carried out in the lathe, holding the pin in the lathe chuck and the die in a tailstock die-holder. This is to ensure concentricity of the threads. Always use cutting oil when threading either silver steel or stainless steel.

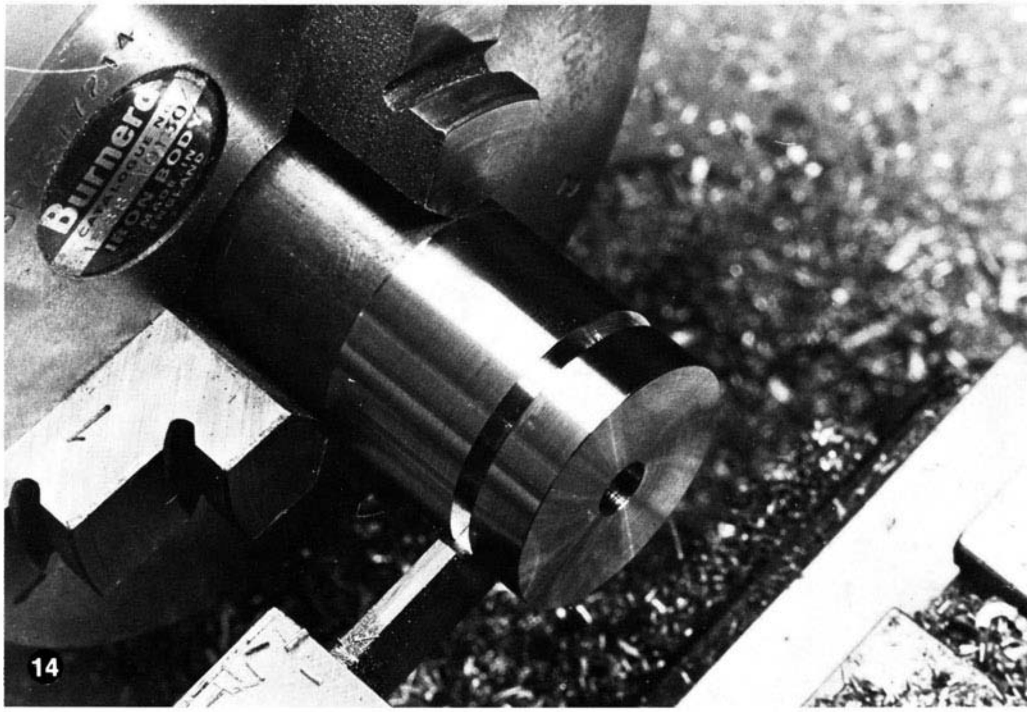
The valve retaining spring must be fairly stiff in order to cope with the steam pressure acting on the underside of the valve. Search the junk box for a suitable spring first. If none is found, wind one up in the lathe from 0.5mm music wire.

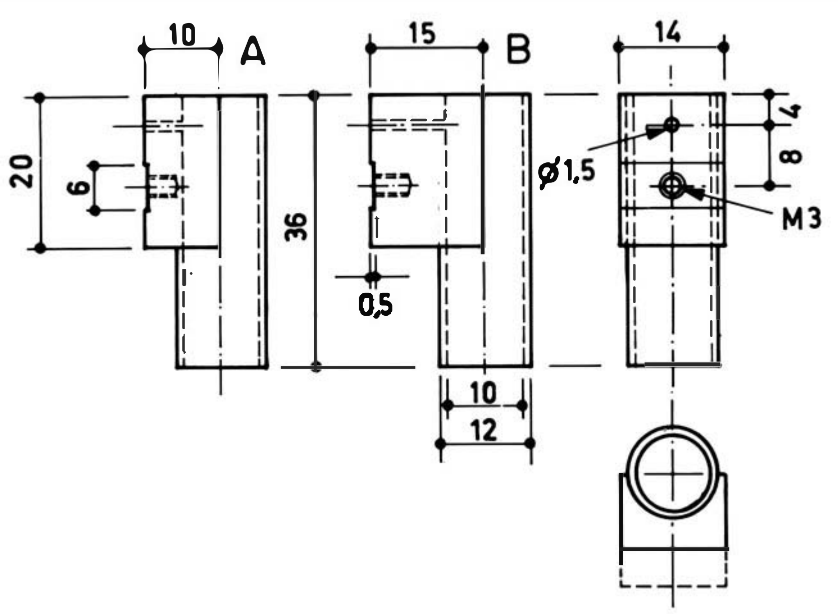
Make and fit the fixed stop pin to the valve block. This pin is simply a 5mm length of 3mm diameter silver steel rod, drilled through to take a M2 screw. To find the positions for the two stop pins on the valve, do as follows: fit the pivot pin to the valve block and slip on the valve, upside-down. Rotate the valve until the centerlines of the channels are 45° to the engine frame's centerline. Scribe a mark on the valve 1.5mm in front of the fixed pin. Rotate the valve clockwise 90° until the channels are again 45° to the centerline and scribe another mark, this time 1.5mm behind the fixed pin. Remove the valve and drill 3mm diameter, 5mm deep at the marks. Make the stop pins from 3mm diameter silver steel rod and fit them to the valve, using *Loctite*. Also make and fit the handle, then make the stepped washer of brass. Assemble the valve on the engine frame, putting a drop of oil on the valve face. Use two nuts on the pivot pin, so that they can be locked against each other.

The **CRANKSHAFT (9)** is made of a few bits of centerless ground silver steel rod and three disks of brass. Mild steel disks would, of course, do equally well. Start by parting off three pieces of silver steel rod, 6mm diameter. One of them should be 98mm long and the other two 22mm long. Make a deep center mark with a centerdrill in both ends of the long piece. Face the ends and chamfer the edges on all three pieces.

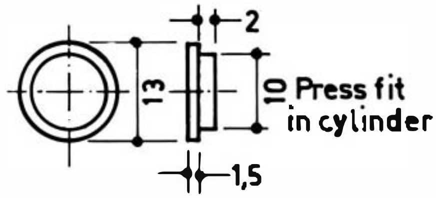
Set up a piece of 30mm diameter brass



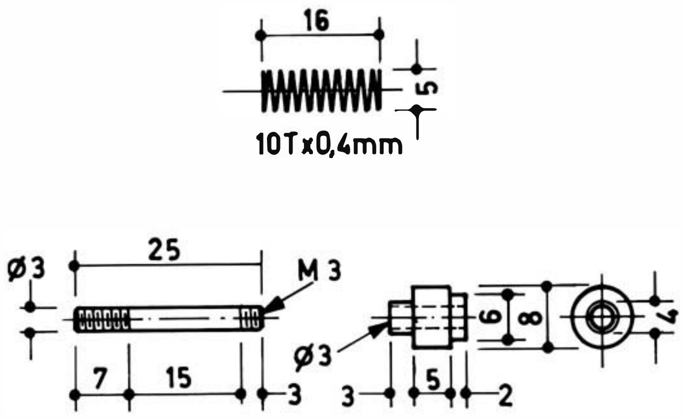




10 CYLINDERS
4 required



11 CYLINDER TOP COVER
4 required



12 PIVOT PIN, BUSHING AND SPRING
4 each required

rod in the three-jaw, with enough poking out to part off three 6.5mm thick disks. Center drill and drill out to 5.9mm. Put a 6mm reamer through, held in the tailstock chuck. Face and part off a 6.5mm thick disk, as shown in photo 14. Repeat for the other two disks, not forgetting to face before parting off. Set up one disk at a time in the three-jaw and face to 6mm thickness. If you are using the Unimat for this, reverse the chuck jaws before setting up. This way the disk can be firmly seated against a step in the chuck jaws to insure it does not wobble.

Set up the dividing head in the milling machine. Using the three-jaw, chuck one disk (photo 15). However, turn the chuck jaws the opposite way, not as shown in the picture. I goofed here, finding that I could not drill the second crankhole without hitting a chuck jaw. Instead, put a packing piece under the disk, as can be seen in photo 16. Put a piece of 6mm diameter silver steel rod in the milling chuck. Manipulate the feed-screws until the steel rod can be fed down into the center hole in the disk. Raise the rod and feed in the cross-slide exactly 10mm. Lock the slides.

Exchange the steel rod for a centerdrill and make a center mark, as in photo 16. Change to a 6mm drill bit and drill through the disk (photo 17). Then rotate the dividing head 180°, and repeat the process (photo 18). Repeat for the other disks, but note that they should have only one single crank hole. You now have the components for the crankshaft, as shown in photo 19.

Before we assemble the crankshaft, we need two spacers to put between the crank disks to get the correct spacing. Two short pieces of 10mm square rod or any scrap bits 10mm thick will do. The stuff used for bonding the crankshaft is *Loctite Retaining Compound No. 75*, or *Loctite Superfast No. 601*. If you use the latter, you will have to work really fast. If any part becomes stuck out of alignment, just heat the joint to above 220°C, after which the joint can be torn apart and redone. Before applying any *Loctite*, make a dry run, to see that all parts fit together. If not, one or more holes will have to be adjusted with a reamer until everything fits.

The first stage of assembly is to fit the two cranks into the center disk, as in photo 20. However, when doing this, put together all parts, in order that everything shall line up properly, but apply *Loctite* only to the joints between the cranks and the center disk. Set aside to cure for a couple of hours. Curing can be hastened by applying mild heat, no more than 70°C.

The next stage of assembly is to fit the shaft to the center disk, as in photo 21. Again, assemble all parts to avoid misalignment. Before the joint cures, check that the shaft is protruding 46mm on each side of the disk.

The final step is to fit the two outer disks. Both can be dealt with on the same go. Apply Loctite to the cranks and the shaft and slide on the disks. Put the spacers, mentioned earlier, between the disks to insure correct spacing. Let the whole assembly cure overnight.

For additional security, fit either taper or roll pins through all joints. They can be seen in photos 22 and 23. If you fit taper pins, their holes must, of course, be reamed with the proper taper reamer. Roll pins are easier to fit, as they only require a drilled hole. All that remains now is to cut away the unwanted pieces of the shaft between the disks, using a hacksaw. When doing this, protect the cranks by wrapping strips of sheet brass around them. Finally, trim the rough surfaces after the saw-cuta with a file.

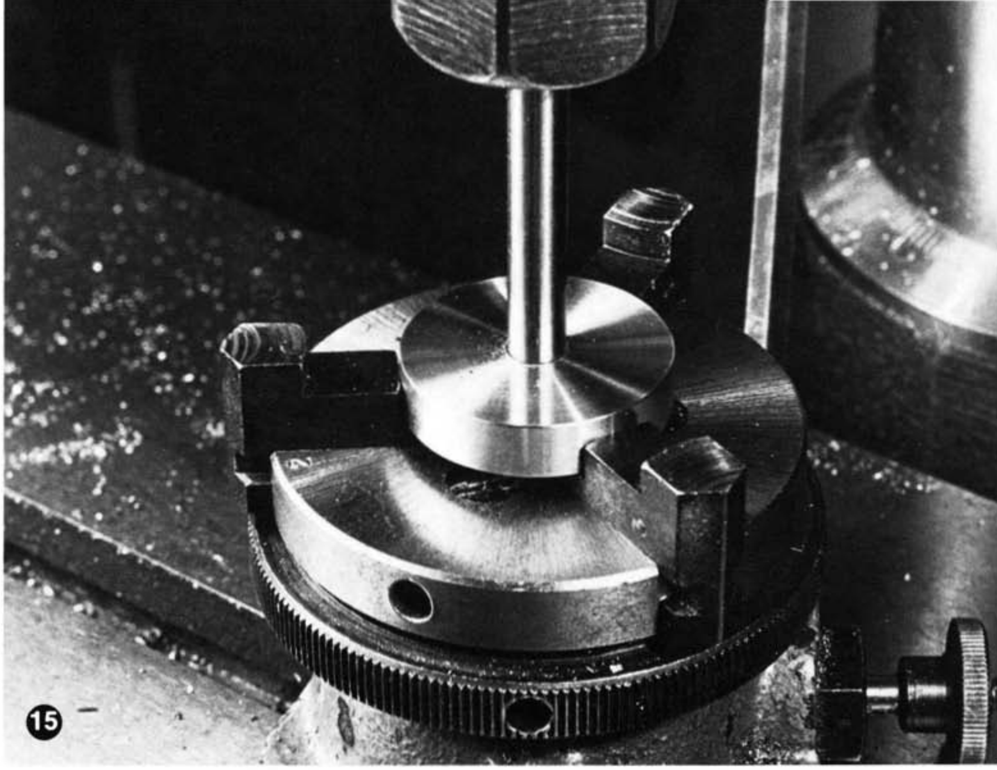
You may now want to try the crankshaft in place in the engine frame. You will then find that the crankshaft bearing registers are too deep. There is a purpose in that. Just set them up in the lathe and face an equal amount off each of them, until the crankshaft fits in the frame without axial play.

The **FLYWHEEL (8)** is another straightforward turning job. Set up a short piece of 40mm diameter brass rod in the three-jaw and part off so that a disk of around 15mm thickness remains in the chuck. Face, center drill and drill through using, say, a 2.5mm drill bit. Enlarge the hole to 5.9mm in steps. The flywheel must be a push fit on the crankshaft, so either ream or bore it until a test rod from the same stock as was used to make the crankshaft fits without shake. Turn the recess in the front face and break all sharp edges, using a file and a scraper.

Remove from the chuck and drill the slanting set-screw hole, 2.5mm. Hold the flywheel in a vise and use a center drill to start the hole. Tap M3. Poke a reamer through the axle-hole to remove the burrs, then set a short piece of 6mm silver steel rod in the lathe's three-jaw, with about 12mm protruding from the jaws. Check that it runs true. Put a setscrew in the flywheel and slip it on the rod, with the front facing the chuck. Tighten the setscrew lightly. Face the flywheel's back side and take a skim along the periphery. Break the edges with a file and remove from the rod. If you wish to make the six 4mm diameter holes through the flywheel, use the Unimat's dividing head to spot them. The holes have no function, merely making the flywheel a bit more fancy-looking.

When finished, install the flywheel on the crankshaft. Tighten the setscrew very lightly. Then remove the wheel again and file a small flat on the shaft where the setscrew has made a mark. This way, the setscrew will not raise a burr on the shaft which might make it difficult to remove the flywheel later on and also scratch the bearing if it has to be withdrawn. Install the flywheel and tighten the setscrew.

There are four **CYLINDERS (10)**, but please notice that two of them differ slightly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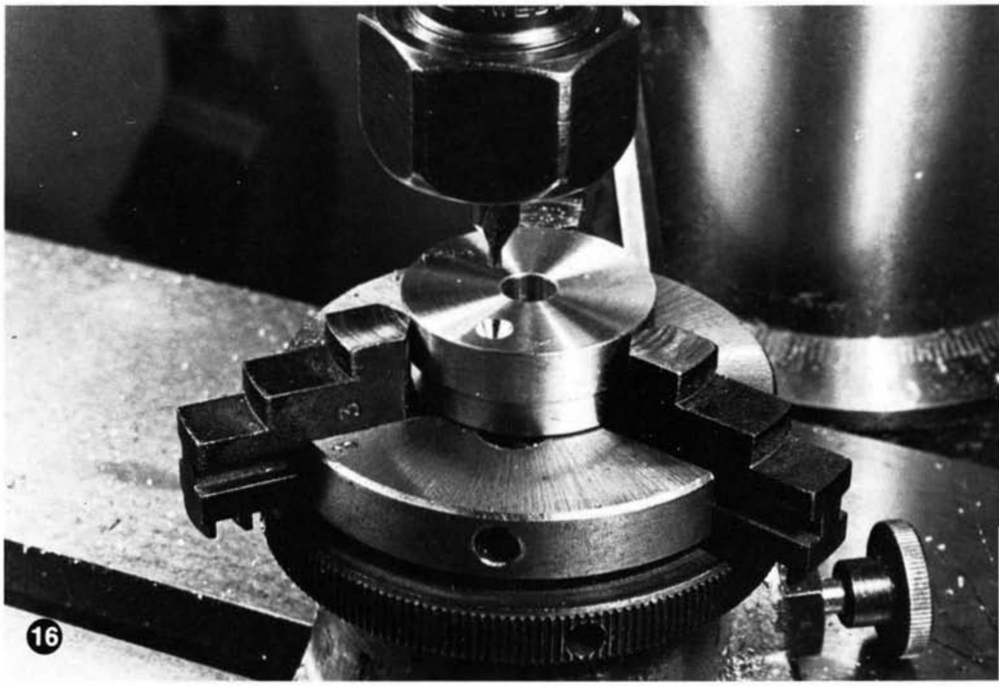
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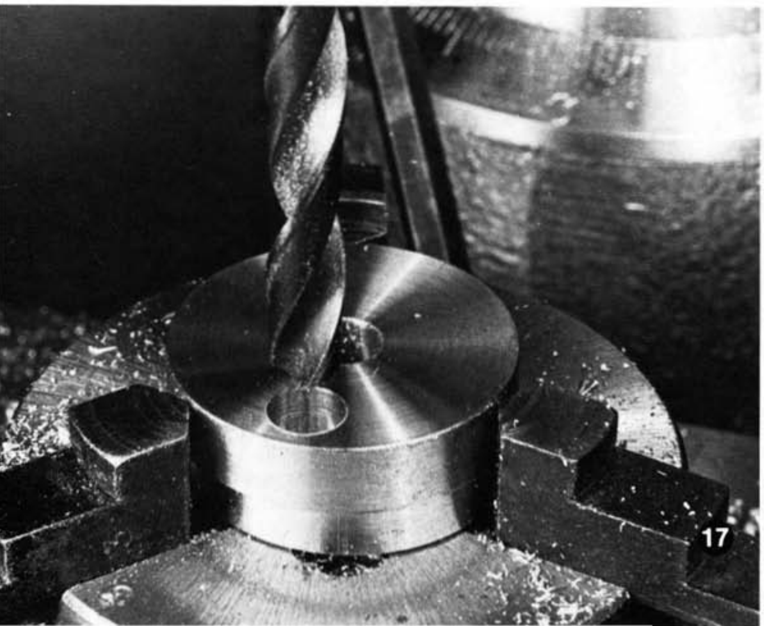
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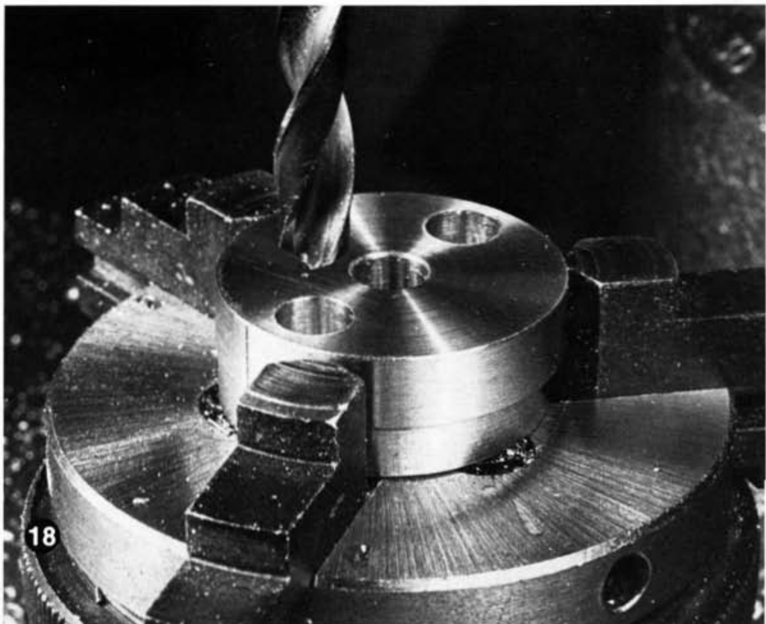
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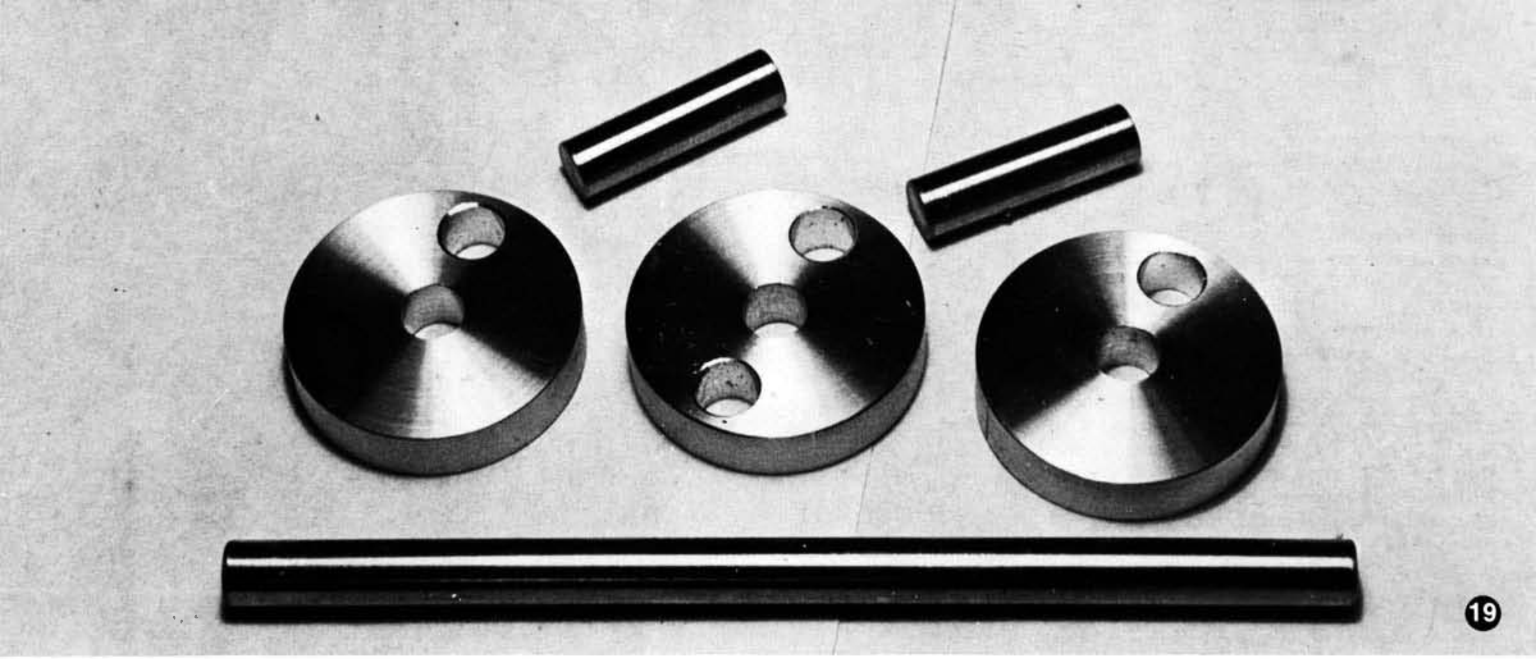

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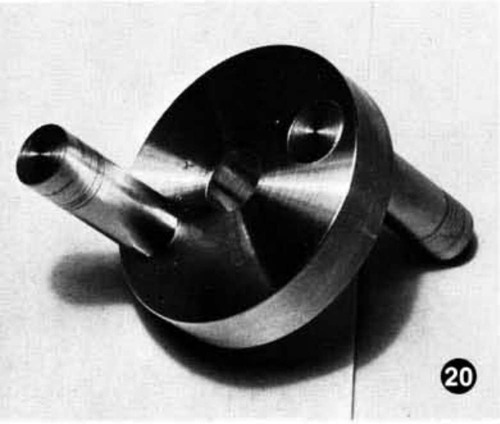

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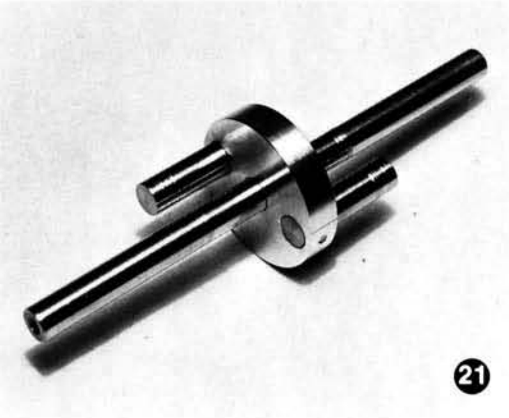

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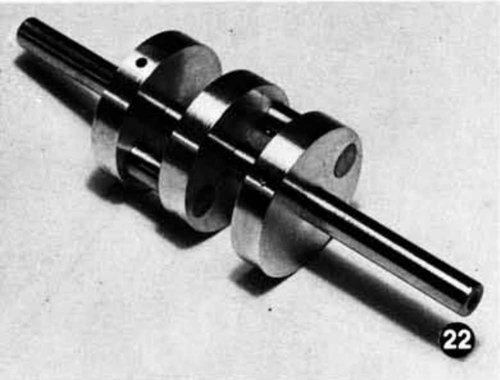

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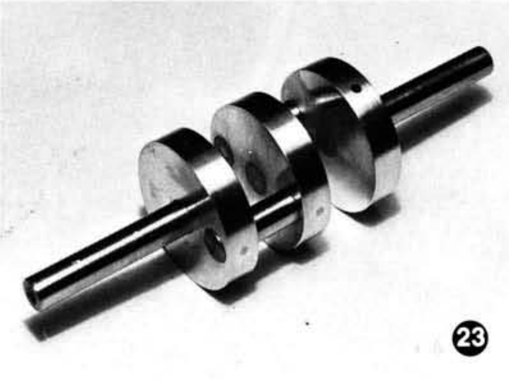

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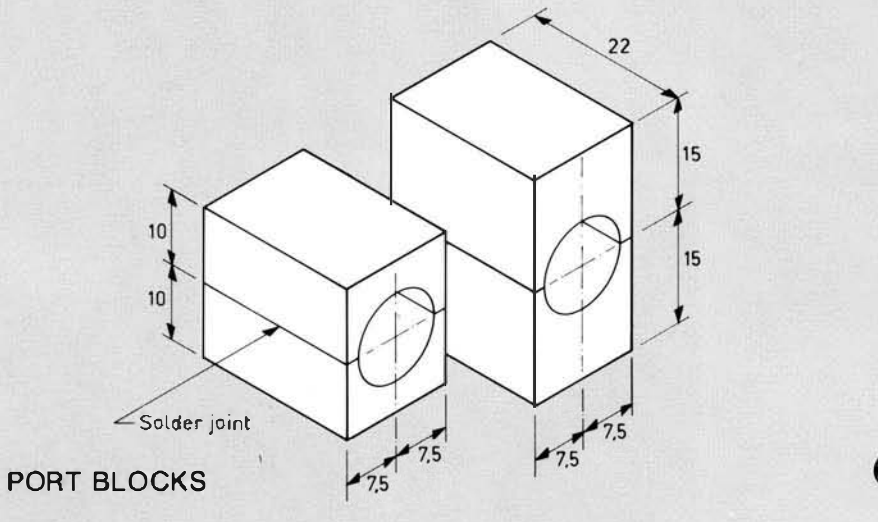

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from the other two. The difference is that two of them have 5mm thicker port blocks. This is to enable two of the connecting-rod big end bearings to work in tandem on each crank. The best material for the cylinder barrels is bronze, but hard brass will do as well. Avoid the soft, so-called screw-brass rod; it will wear too quickly.

First an explanation of the photographs. As I used a large lathe, I made the port blocks and barrels in pairs and parted off after silversoldering. If you are using the Unimat, this method would give excessive overhang, since the parts will not enter the Unimat's mandrel bore. Therefore, follow the text; there are just a few slight departures from the pictures.

Start with the port blocks. Four pieces of brass will be needed, two of them 10 x 15mm, the other two 15 x 15mm. All of them should be about 22mm long. Soft solder the two 10 x 15mm pieces together to form a block, 15 x 20 x 22mm. Set up in the four-jaw and face one end. Reverse in the four-jaw, and face the other end. The length is not critical, as long as it is over 20mm. Soft solder the other two pieces together, this time to make a block 15 x 30 x 22mm, and face its ends. Now, with the scribing gauge, scribe the vertical centerline on one end of each block, as shown in Figure 24. Centerpop carefully where this line intersects the solder joint. Set up one of the blocks in the four-jaw, with the centerpop facing the tailstock. Adjust the jaws until the centerpop runs truly. Center drill, and drill through with a 4mm drill bit, carefully, so it does not run out of line. Open up with successively larger drill bits to 12mm (photo 25). When using drill bits larger than 6.5mm in the Unimat, the three-jaw can substitute for the drill chuck, as it also fits on the tailstock. If the drill bits are modified for brass and speed and feed are kept down, no undue strain will be put on the lathe. The risk of the drill bit catching and wringing the workpiece out of the chuck will also be minimized. Alternatively, a simple, homemade D-bit could be used after drilling to 6.5mm.

When both blocks are drilled, melt them apart and remove all traces of soft solder with a file. It is important that no trace of soft solder remains, as this would prevent the silver soldering of the port blocks to the cylinder barrels.

From a 12mm bronze or hard brass rod, part off four pieces, say, 38mm long. The parts for the cylinders are shown in photo 26. Silver solder the port blocks to the rods (photo 27). Note that the cylinders in the photo were made in pairs as previously explained, to be parted off in the middle after soldering. When you solder your cylinders, the port blocks should be so positioned that the rods protrude 16mm below the block's lower end. Put the cylinders in the pickle bath after soldering.

Grip one of the cylinders by its round end in the three-jaw. Center drill and drill through with a 4mm drill bit, taking care that the drill does not wander off center. Enlarge with successively larger drill bits to 9.8mm and ream 10mm diameter, using low speed. As the Unimat's tailstock chuck will not take a 10mm reamer, the latter will have to be supported on a center held in the tailstock barrel. Hold the reamer with a wrench to prevent it from rotating and slide the tailstock forward to perform the reaming operation. If you lack a 10mm reamer, as I did, the cylinders can be finished by boring, using a long boring tool, as shown in photo 28. In both cases, use a short piece of the same 10mm diameter stainless steel rod which will be used to make the pistons as a gauge. It should, of course, be a nice, sliding fit in the cylinders. Repeat for the other cylinders. Face off the cylinders and port blocks until the latter are 20mm long.

Remove all sharp edges with scraper and file. Drill the steam port hole and the pivot pin hole in each cylinder (photo 29). It is important that the distance between them be equal to the distance between the corresponding holes in the engine frame. The steam port hole should go straight through into the cylinder bore, but the pivot pin hole must on no account do so. Drill the latter hole 2.5mm diameter and tap M3. As it is very important that the pivot pin is square to the port face, use the set-up shown in photo 30 when tapping. The tap is held in a pin chuck, which is slid onto a drill bit or rod held in the drill press chuck. Remove the burrs around the steam port hole in the cylinder bore with a small scraper.

Mill a shallow recess on the port face, 6mm wide and 0.5mm deep, across the pivot pin hole, as shown in photo 31. Repeat the above for all cylinders and they will now look like photo 32.


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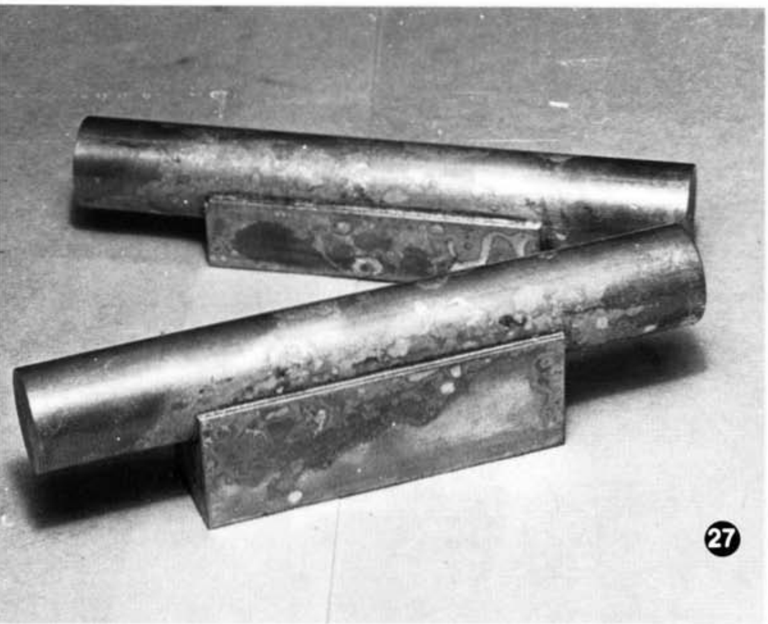
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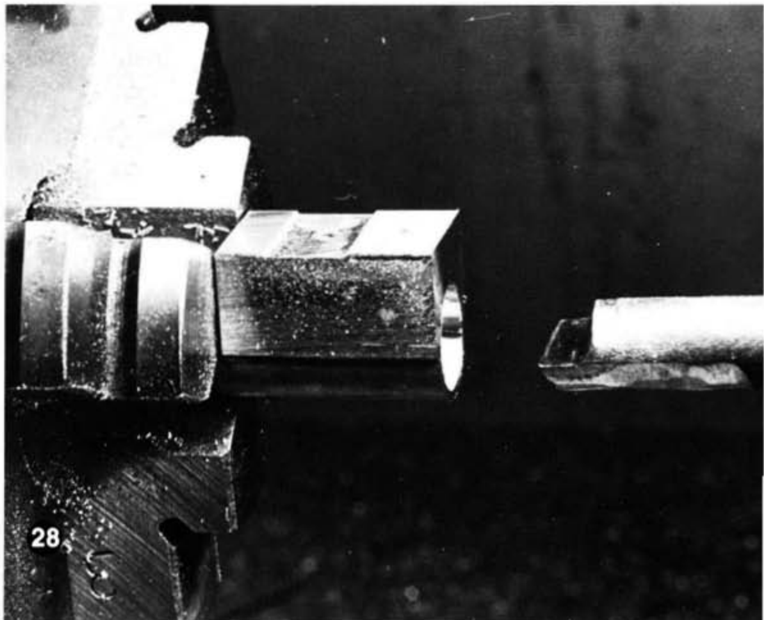
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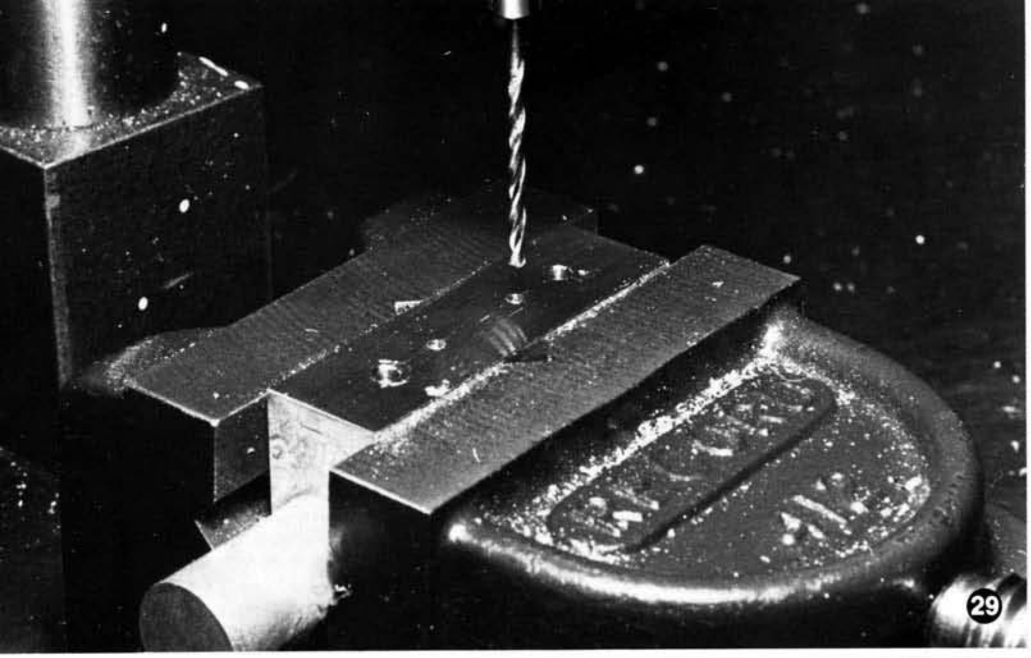
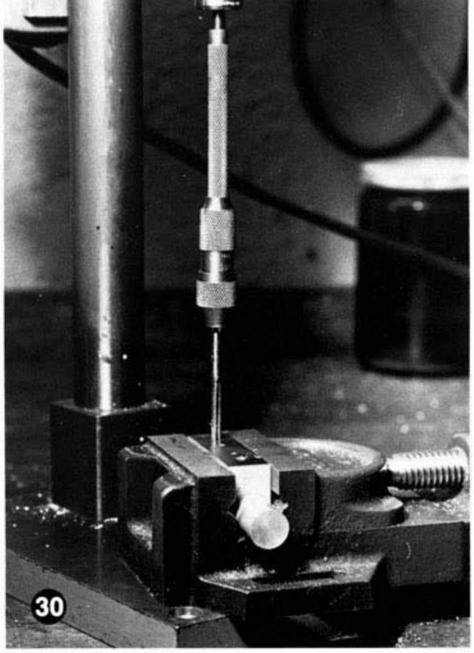
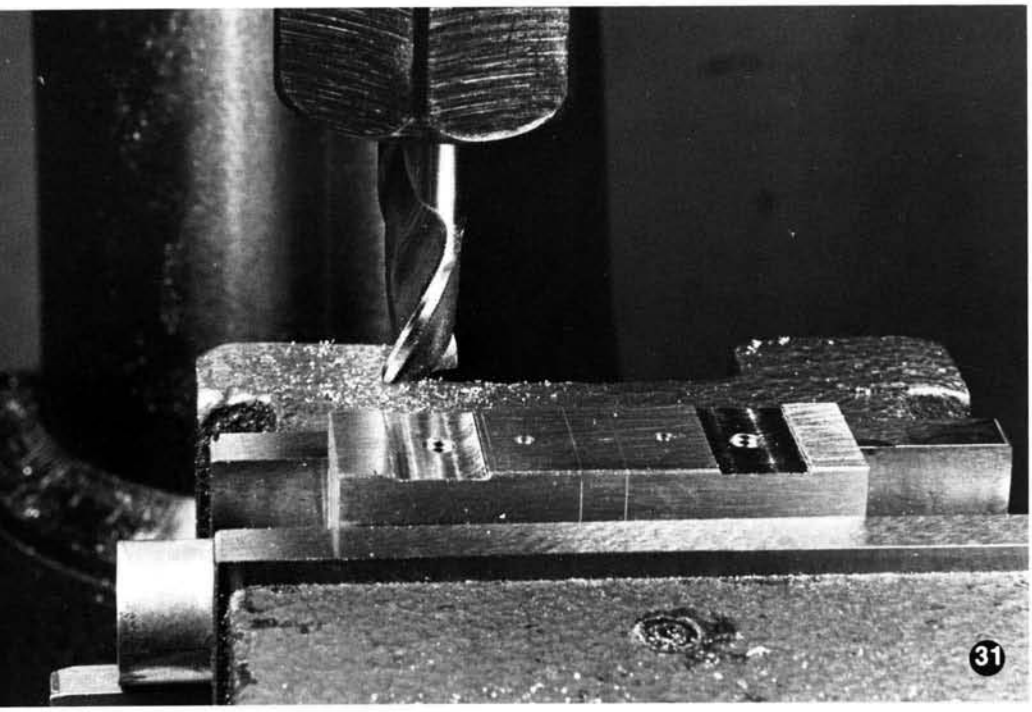
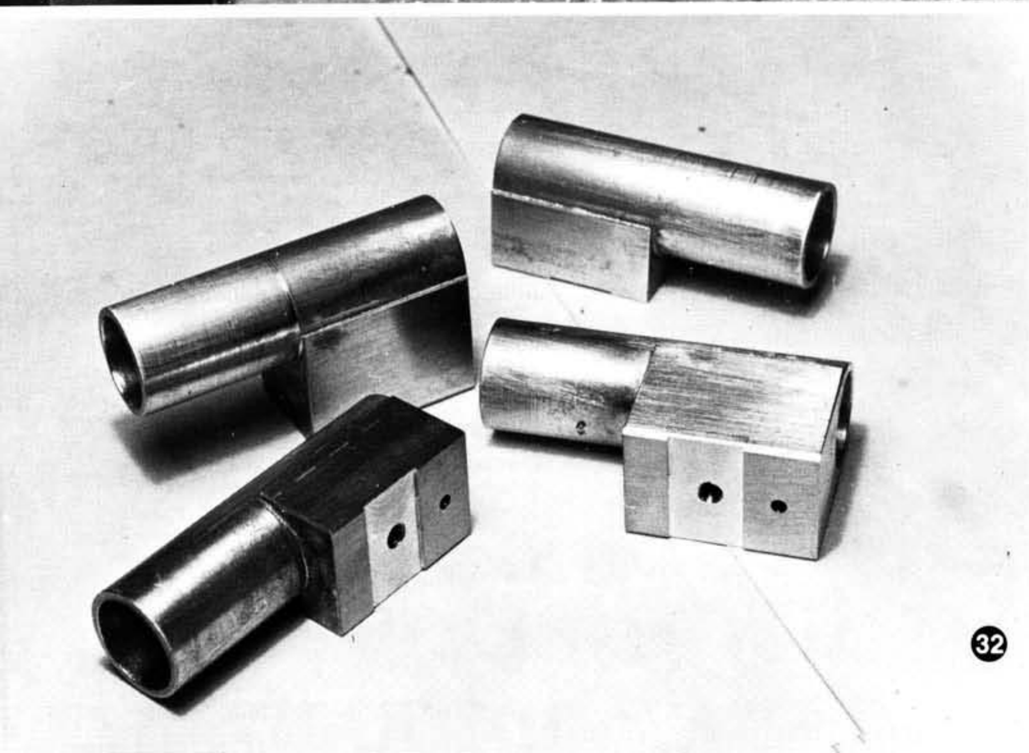








Make and fit the **CYLINDER TOP COVERS (11)**. They should be a tight press fit in the bores. Use a bench vise to press them into place, not forgetting to protect the cylinder bottom end and the cover by placing pieces of hardwood between them and the vise jaws.

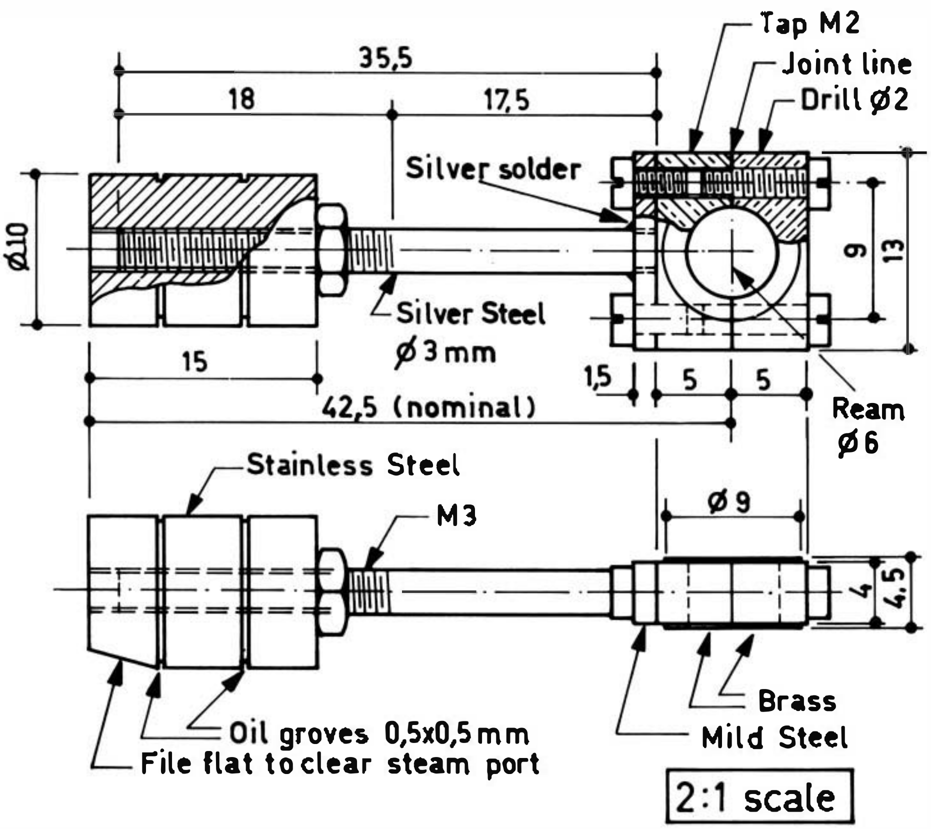
The port block sliding faces must be flat and free from scratches. To insure this, rub it against a smooth file laid on the work bench and then against a fine emery cloth laid on a flat surface. Chamfer the edges very lightly, but do not remove the edges from the steam ports, as it would upset admission and exhaust timing if these edges were chamfered.

Four each of the **PIVOT PIN, BUSHING AND SPRING (12)** are needed. The pivot pins are simply 25mm lengths of 3mm diameter silver steel rod, threaded at each end according to the drawing. The bushes are turned from brass rod. Their center holes should be reamed 3mm diameter to be a sliding fit on the pins. The bushings should fit loosely in the engine frame, as they are to be soft-soldered in place.

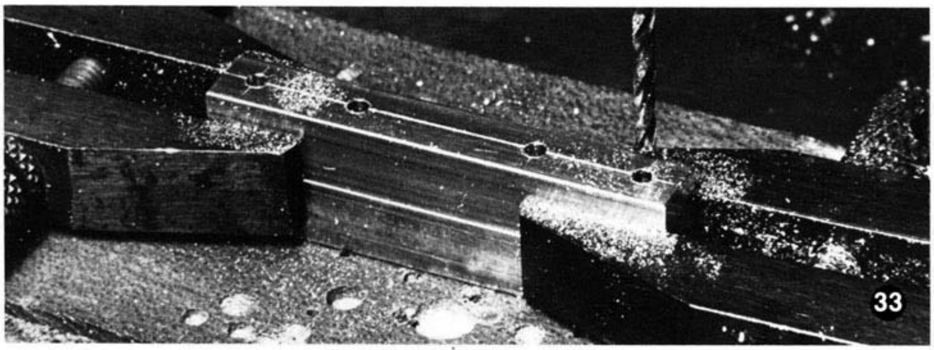
Disassemble the engine frame. Insert the pivot pins in their holes in the cylinder port blocks. The end with the short thread goes into the port block. Put a drop of *Loctite* in the holes before inserting the pins, and they will stay for keeps. Wipe off the surplus carefully. Smear a drop of oil on the port block surface, insert the bushes in the endplates and install the cylinders. Use a pair of 3mm i.d. tubes to hold the parts in place. (They can be seen in photo 11.) Put nuts on and tighten up, fingertight will do. Apply soft-solder flux to the joints between the bushes and the endplate. Soft solder, applying heat with a propane torch. Disassemble and wash in warm water to remove the remaining flux. Repeat for the other endplate.

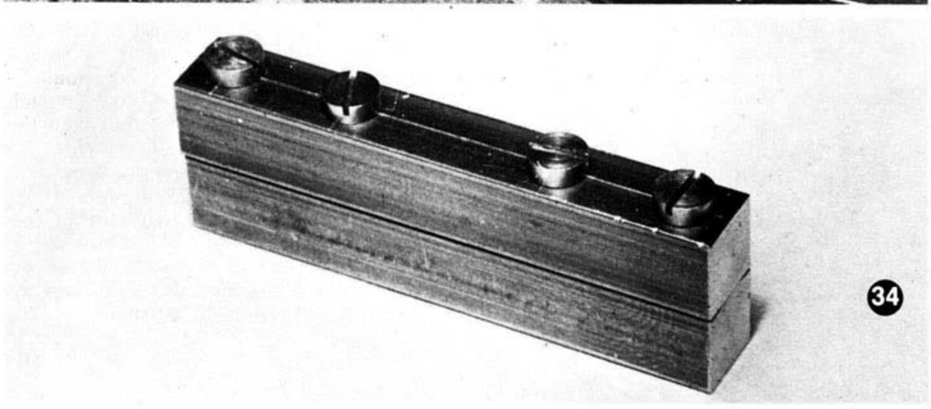
Assemble the engine again, with the cylinders in place. Note that there should be one cylinder with a thick port block on each side, diagonally opposite, as shown in the general arrangement drawing.

For the pivot pin springs, first rummage the trusty junk box. If not found there, wind them up on the lathe, using music wire around 0.4mm diameter. Put double nuts on the pivot pins, so they can be locked up against each other. Also, put a flat washer between the nuts and the springs.



14 PISTON AND PISTON ROD
4 required





To build the **PISTON AND PISTON ROD (14)**, let's start from the bottom, with the big end bearings or shall I just say bearings, as there are no small end bearings. The bearings are best made in pairs.

From 5 x 5mm brass stock, cut four pieces 40mm long. Mill or turn all four pieces to the same length. The exact length doesn't matter a bean, aslong as each pair is of equal length.

Scribe the centerline along the full length on one of the pieces. Make a cross mark 2mm from each end and another 11mm from each end. Centerpopatthe cross marks. Now, clamp this piece with the center marks facing upwards, on top of another piece. Line up the ends before tightening up, as in photo 33. Drill through both pieces with a 1.7mm drill bit, taking care the drill does not wander out of line. Separate and drill out the holes in one of the pieces to 2mm diameter. Deburr all holes. Tap the 1.7mm diameter holes M2. Rub the mating surfaces of both pieces on a file to insure that they are flat. Screw the pieces together, using M2 x 8mm cheese-head screws, as in photo 34.

Scribe a line on the side of the piece, 6.5mm from each end. Make centerpops where these lines intersect the joint line and drill, say, 2mm. Enlarge in steps to 5.9mm (see photo 35). Ream 6mm. As it is important that the bearing holes are square with the piston rods, both drilling and reaming should be carried out in a drilling machine or drill press. Repeat these steps for the other bearing pair and your bearings will now look like photo 36.

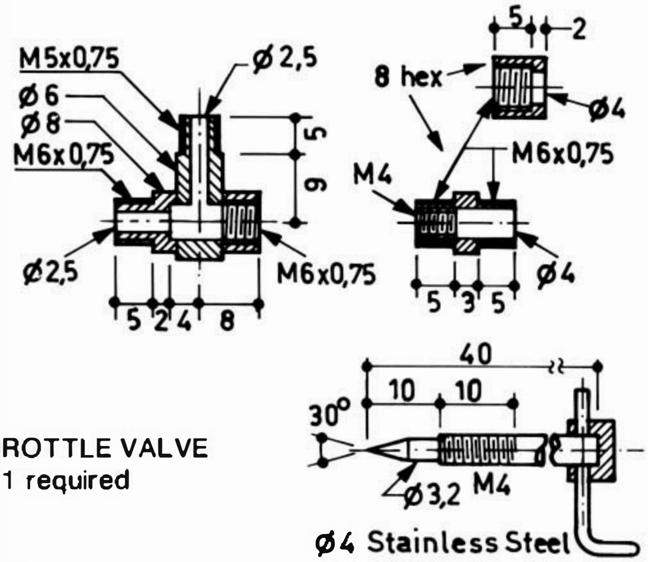
Mark out the length for each bearing; part off with a hacksaw leaving, say, 0.5mm for finishing. Do this in the Unimat by vertical milling.

Turn up a stub in the lathe, which is just a little too large to enter the bearings, say 6.01mm. Mount one bearing on the stub by slackening the M2 screws, pushing the bearing on the stub, and tightening up the screws. Face off 0.25mm on each side of the bearing. Turn the0.25mm relief on each side at the same time (see photo 37). Remove from the stub and break all sharp edges with a file. Chamfer the ends of the bearing bore very lightly by the discreet use of a scraper. Repeat for the other bearings. The bearings are now finished, as shown in photo 38. From now on, keep each bearing's upper and lower halves mated as there might be small differences between the units which could make assembling difficult later on.

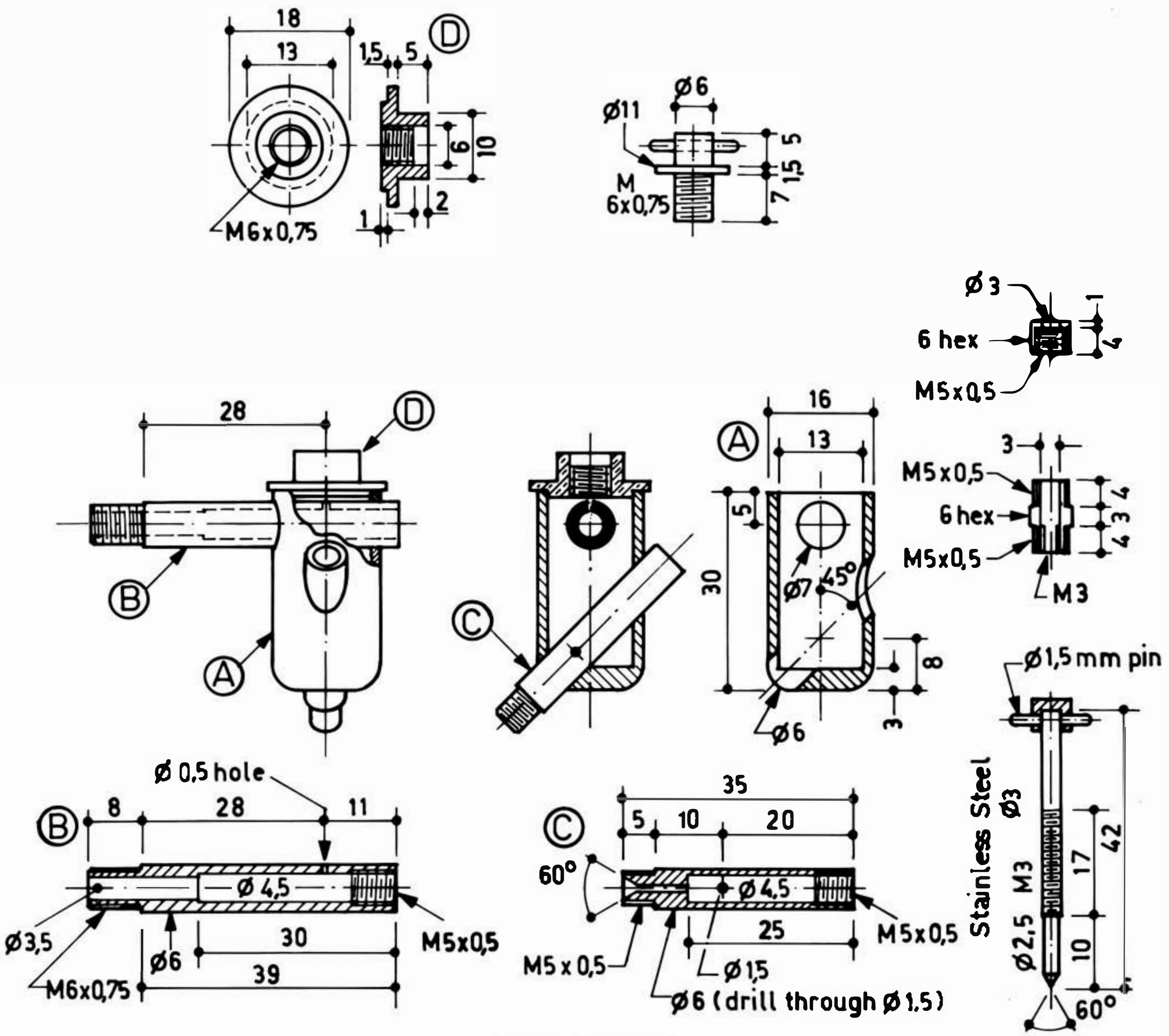
Now for the piston rods. Therod proper is made from 3mm diameter silver steel. To start with, make them 36.5mm, 1mm longer than shown in the drawing. Thread the bottom end for 3mm length and the top end for 18mm length. The bolting flange at the bottom end is made from a strip of 1.5 x 4mm mild steel. Use the lower halves of the bearings as drilling jigs for the 2mm diameter bolting holes. Mark out and drill the hole for the piston rod 2.5mm diameter and tap M3. Screw in the piston rod and silver solder the joint. After cleaning up, set up the rod in the three-jaw and face the bottom flange, also removing the protruding end of the rod. This way the flange will be truly square with the rod. The rods will now look like the left pair in photo 39.

The pistons are simply 15mm long pieces of 10mm diameter stainless steel rod, centerless-ground stock. Before parting off the pistons, turn the oil grooves. Their dimensions and positions are not critical. Remove the sharp edges and polish with polishing paper, running the lathe at high speed. Drill through 2.5mm diameter and tap M3. File the small flat and mount the pistons on the rods. Use a locknut under the piston's bottom to prevent the piston from unscrewing itself. The pistons will now look like photo 40. The purpose of the flat at the top of the piston is to prevent the steam port in the cylinder from being blocked when the piston is at the top end of its stroke.

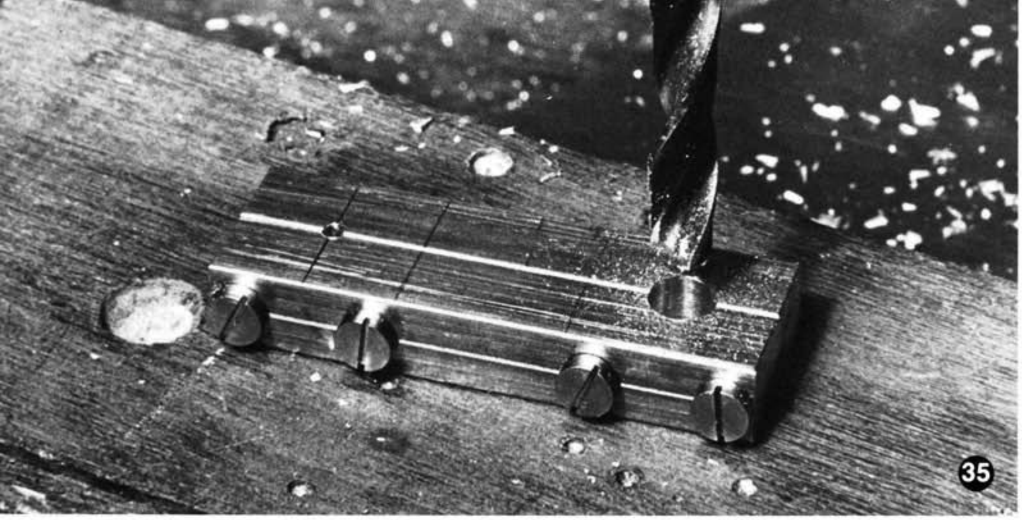
Assemble the pistons and the rods in the engine. Do not put on the bottom halves of the bearings yet, as each piston will have to be taken out several times while you adjust its position by screwing it up or down on the rod. The pistons should clear the cylinder top covers by about 0.5mm (one turn on the M3 thread). When satisfied with this, lock the piston on the rod by means of



16 THROTTLE VALVE
1 required



15 LUBRICATOR
1 required



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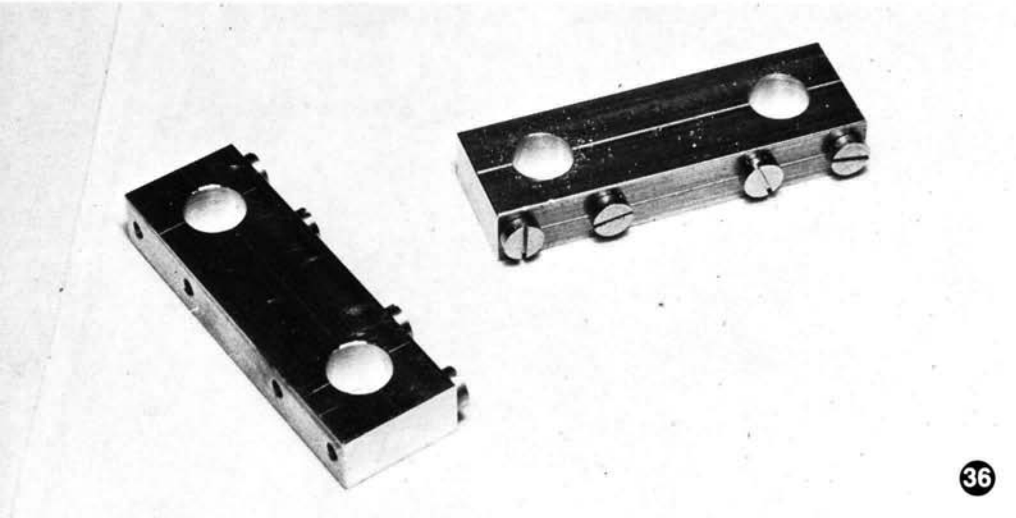

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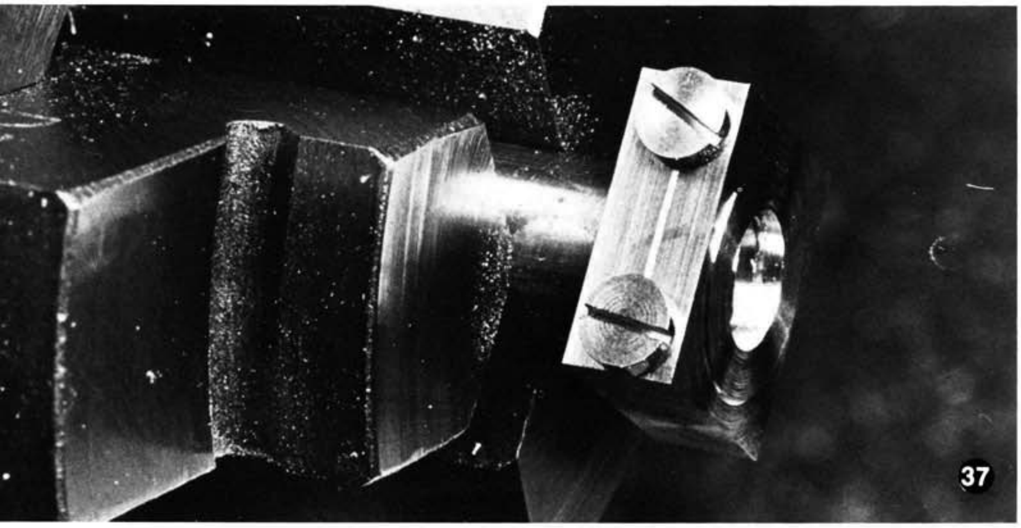

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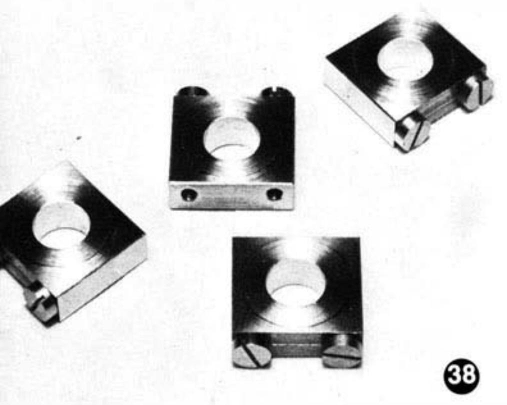

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39

the locknut. Put a drop of plumber's jointing compound between the nut and the piston, to prevent steam leaking through the thread. Make sure the flata on the pistons face the steam porta. Install the bearing lower halves. Put a little oil in the bearings and in the cylinders. Oil all moving parts, including the port faces.

Your basic engine is now completed, but will probably be alittle stiff, so I suggest you give it a run-in by gripping the output shaft in the lathe's three-jaw and let it run for an hour or so. Support the other end of the crankshaft on a live center held in the tailstock. Put a piece of soft wood between the engine's bottom plate and the lathe bed to prop up the engine and to prevent it from rotating. Keep it well lubricated and run the lathe on low speed. When the engine feels reasonably free running, remove it from the lathe and wash in kerosene. Oil all moving parts afterwards.

The **LUBRICATOR (15)**, begins with a body made of 16mm diameter brass rod. Part offto 30mm length. Drill the 7mm cross hole for the steam pipe, 5mm from one end. Then drill the slanti'ng hole, 6mm diameter, for the drain valve. Set up in the lathe and bore out the inside to 13mm diameter. Reverse in the chuck and round off the bottom.

Make the drain valve body from 6mm diameter brass rod. Do not forget todrill the inlet holes, as they would be very difficultto drill at a later stage. Part off a 70mm length of 7mm diameter brass rod for the steam pipe. You will now have the parts shown in photo 41.

Silver solder them together, as shown in photo 42. Note that the 7mm diameter brass rod should stick out around 30mm on the side which will later be screwed into the engine.

Turn up the lubricator's top. Thread the filler hole M6 x 0.75. Silver solder the top to the lubricator body.

Set up the lubricator in the three-jaw, gripping it by the shorter end of the 7mm diameter rod. Face the other end to correct length, turn down to 6mm diameter and thread M6 x 0.75 according to the drawing. Reverse in the chuck and part off the other end 3mm from the body. Center drill and drill 4.5mm diameter, about 30mm deep. Tap M5 x 0.5, then drill through the rod, using a 3.5mm drill bit. Remove from the lathe and drill the communicating hole 0.5mm diameter. Use a small centerdrill to spot the hole on top of the steam pipe inside the lubricator. Make and fit the filler plug.

The lubricator can now be installed on the engine. If it does not line up properly when screwed home, make a brass washer and put it between the lubricator and the engine. Adjust the thickness of the washer until the lubricator body lines up vertically when screwed in tightly.

Make the drain valve spindle and gland nut. When assembling, put a few turns of graphited yarn around the valve spindle below the gland nut. This will make the gland steamtight.

Make and fit the drain pipe and the lubricator is completed.

The **THROTTLE VALVE (16)** body is made of two pieces of brass rod, silver soldered together. First, part off a piece of 8mm diameter rod, say, 30mm long. Drill a 6mm diameter crosshole, 9mm from one end. Then part off a 6mm diameter rod to 30mm length. Insert this in the hole in the thicker rod and adjust until it protrudes equally on both sides. Silver solder in position. Grip the valve body by the longer 8mm diameter end in the three-jaw. Face the outer end until it protrudes 5mm from the soldered joint. Center drill and drill to 12mm depth, using a 5.3mm drill bit. Change the drill bit to a 2.5 and drill through. Chamfer the entrance of the hole slightly and tap M6 x 0.75 to 6mm depth.

Reverse the valve body in the chuck and part off to the correct length, 19mm. Do this carefully, as there is not much to grip on. Then turn down to 6mm diameter for 5mm length. Chamfer the end and tap M6 x 0.75.

Now grip the valve body by one end of the 6mm rod. Face the outer end until it sticks 10mm out from the body. Center drill and drill through to the other hole with a 2.5mm drill bit. Turn down and thread M5 x 0.5 for 5mm length.

Make the gland and gland nut from 8mm hex stock. These call for no further description.

The valve spindle is made of a piece of 4mm diameter stainless steel rod. Be careful about the length of the thread. Make the cap of 8mm diameter brass and secure it with a drop of *Loctite*. Drill a cross hole 1.5mm diameter and fit a handle of 1.5mm diameter silver steel. It too, could be secured with *Loctite*.

Assemble the throttle valve (photo 43) and fit it to the engine. If it does not line up in the desired position, fit a thin brass washer between the valve and the engine. Put a short length of graphited yarn in the gland nut, to render it steamtight.

Your steam engine is now finished and ready for testing, either on compressed air or steam, if you have a source of the latter. If you are using steam, fill the lubricator with steam oil before the first run. Ordinary oil will not do for cylinder lubrication, as it does not work together with steam. Make it a habit to drain the lubricator of the condensed water after each running session and refill it up to the communicating hole in the steam pipe inside the lubricator, with steam oil. The draining is best done while there is still a bit of steam pressure in the boiler. Put a small can under the drain pipe, open the drain valve one turn and crack the throttle. The steam pressure will force the condensate out of the lubricator. Close the throttle and the drain valve when steam or pure oil appears from the drain pipe (no reason to waste good oil). When the draining is done without steam pressure, the filler plug must, of course, be removed to let air in the lubricator.

If you are using air for test running, give the port faces and the cylinders a drop of machine oil now and then. In both cases the rest of the engine should be lubricated with machine oil.

You might find that the reversing valve retaining spring needs tightening to keep steamtight at the highest steam pressure, 30 psi, when running with the throttle wide open.

The springs for the cylinder pivot pins, on the other hand, should not be tighter than is required to prevent steam leakage at the port faces. We don't want to waste power in the form of friction here. Check this both at full throttle and while loading the engine until it stalls.

At this point your V-4 Engine should resemble the one shown on the next page.

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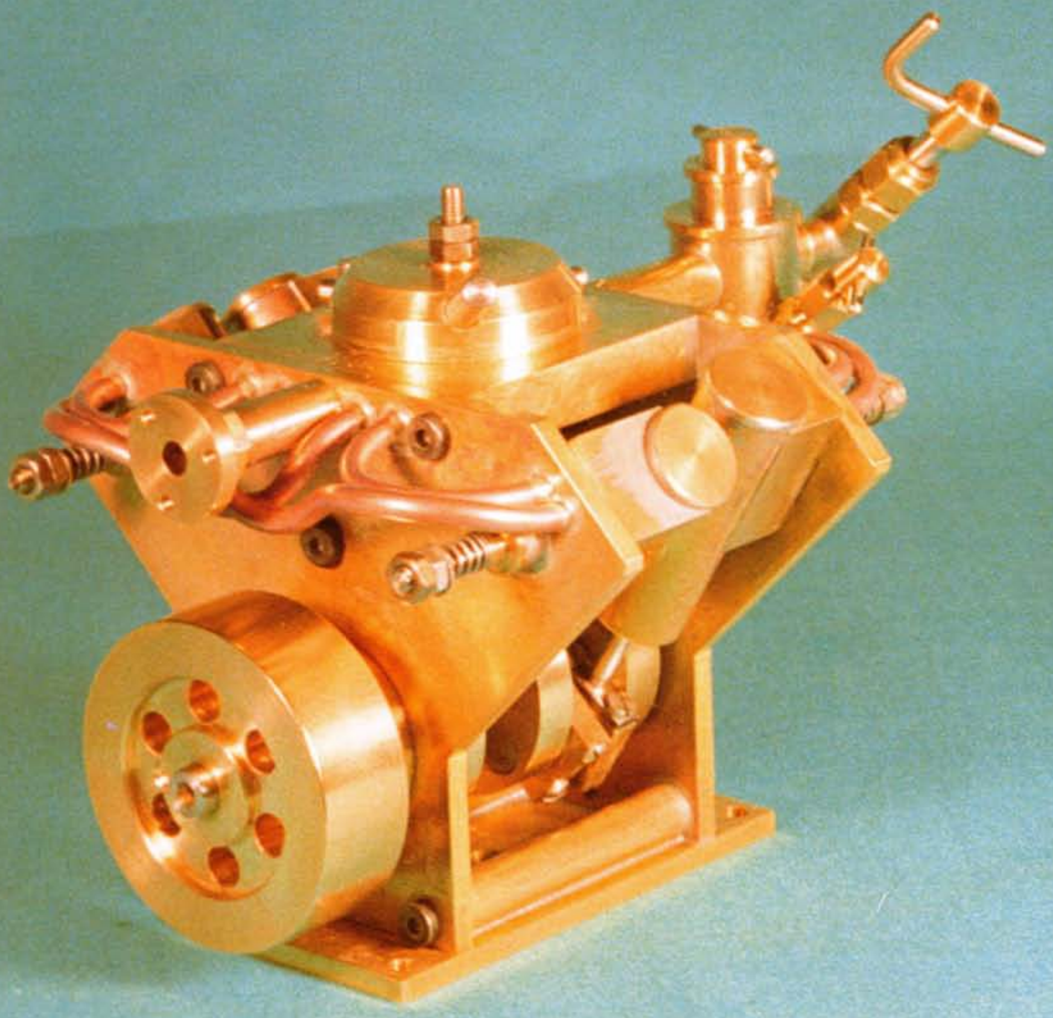
With your V-4 Oscillating Cylinder Engine complete, the next logical step is to provide a boiler to make it run. Author Jan Gunnarsson fulfills that requirement in the next article for the Miniature Boiler Works.

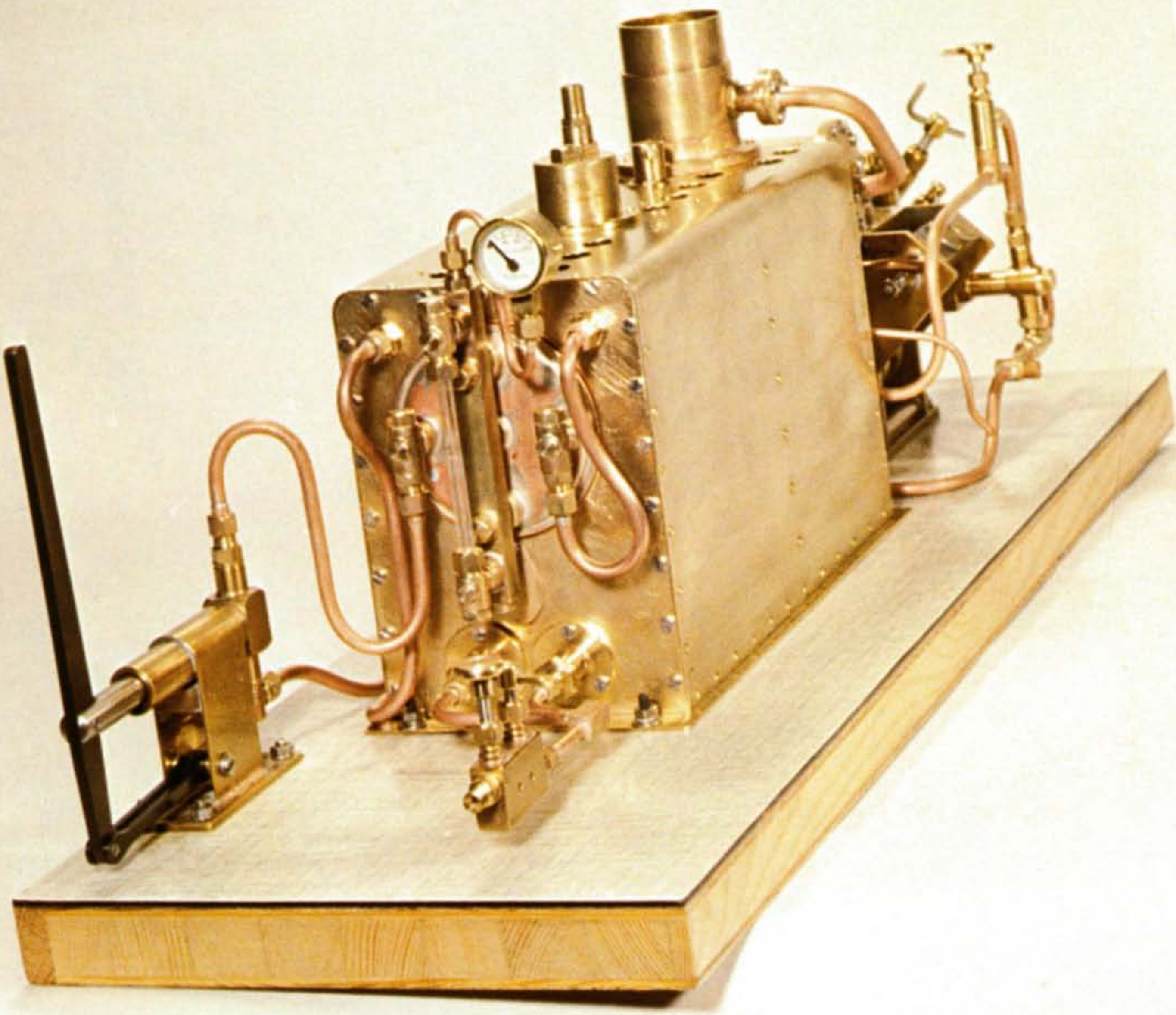


For marine or stationary use, construct the

Miniature Boiler Works

by Jan Gunnarsson

Photos and Drawings by the Author



Modelbuilder Jan Gunnarsson of Sweden has provided projects for Amateur Machinists in his country as well as the two featured in this book. In addition to those presented here, he has built beautiful miniature Live Steam locomotives which further express his interest and knowledge in matters of steam.

Professionally, Jan works in the area of computer technology for a Swedish firm and, between world-wide travels for his company, enjoys designing and building miniature steam projects. He has a steady flow of projects moving through his shop and Live Steamers are always anxious to see what he will turn out next.

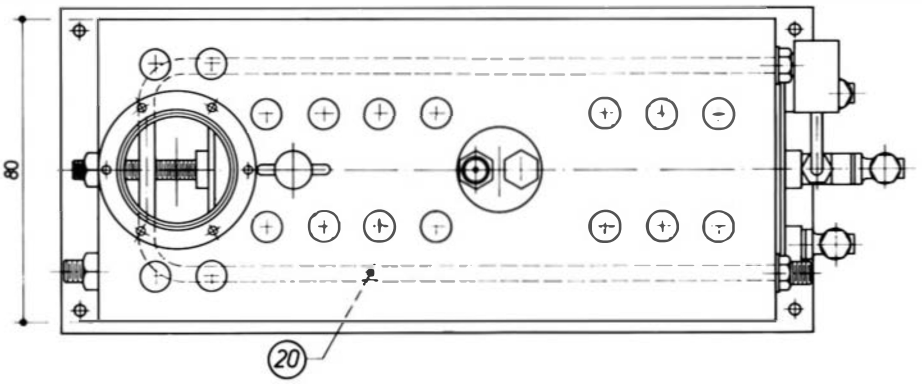
Here he describes a boiler suitable for most of the engines in this volume but specifically designed for the V-4 Oscillating Cylinder Engine.

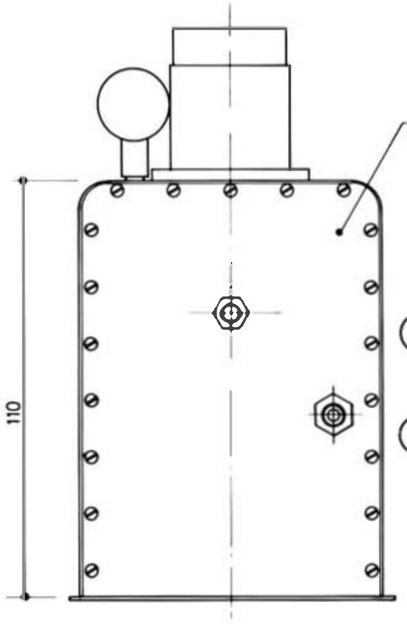
This boiler(**photos 1 and 2**) isintended as a companion to the previously described little V-4 Oscillating Cylinder Engine. As it is capable of generating steam at considerably higher pressure than the V-4 requires, it can, of course, be used for other steam engines, say, a Stuart 10 or similar. I even have used it for supplying a Stuart D-10, running under light load. The limiting factor in this case is the boiler's small water capacity. Although there is an engine feed pump included in the description, the water gauge will need frequent monitoring if the boiler is to steam such a demanding engine as the D-10.

Choosing between a firetube or water-tube boiler, it is my opinion that the former involves more work on the boiler proper, while the latter involves more thin-gauge sheet metal work in making the casing. I opted for the water tube boiler (and a small and simple one at that) because it does not require so much in the way of brazing equipment.

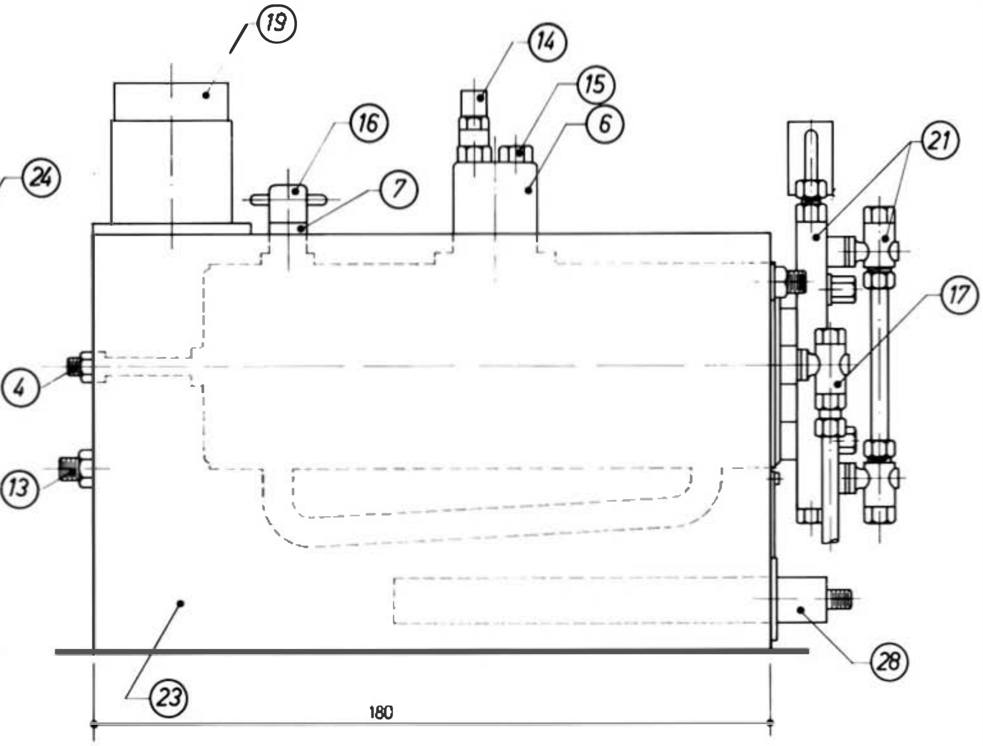
I have included a few features which, although they mean a little more work, are justified. The first is a steam dome, not usually found in boilers of this type. This is essential in such a small boiler if it is to be used for marine work, as it will help prevent priming when pitching and rolling. The second is that the casing is double-walled. The air for combustion is taken through inlet holes on top of the outer casing, then passes between the outer and inner casings, down to the bottom of the firebox. In this manner, the temperature of the outer casing is kept down and the air for combustion is preheated before entering the firebox. No asbestos lagging is required. Finally, a water column is fitted, thereby permitting a longer gauge glass to be fitted. The water column will also dampen the water level in the glass, giving a more accurate reading.

The boiler drum is made of a 54mm diameter copper tube, with 1.5mm wall thickness, which is the thinnest wall thickness available here. This roughly





FRONT VIEW



WATER TUBE BOILER ASSEMBLY

equals 16 SWG and will allow a safe maximum working pressure of well over 150 psi or 10.5kg/cm², with a safety factor of 8. As the boiler only will be called upon to give steam at 30 psi, or 2.1kg/cm², it may seem rather on the heavy side. As I said, it is the thinnest tube available here, but if you can get ahold of a tube with 1 or 1.2mm wall thickness (18 or 20 SWG), use it, as it will reduce the requirements for heating when brazing and still have more than ample strength. Likewise, the barrel diameter can be varied within reason, say, between 2" and 2½", if your supply is inch size. If you do this, remember to adjust such components as the endplates and the dome accordingly.

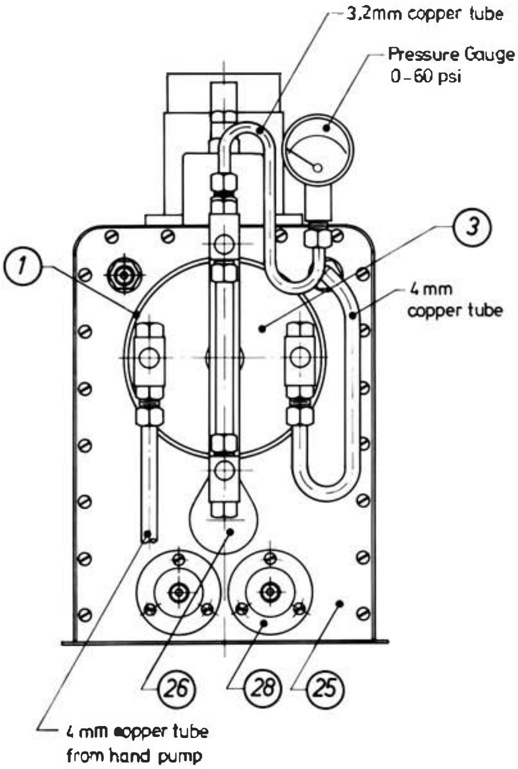
For fuel, butane gas is used, as this lends itself to easy remote control in case the steam plant is to be used for a radio-controlled ship model. The burners have a twin control valve, one of them acting as a pilot valve, to be set for a small flame for stand-by. This will prevent the burner from accidentally being turned off when manipulating the main valve. There are two burners, giving a large bed of fire under the boiler. They never will have to be operated at full output and thus will work very quietly.

The first part to tackle is the **Boiler Barrel** (1) tube. If your lathe will swing the 54mm tube over the cross-slide, cut the tube a little over-length, say 155mm, with a hacksaw. Unless you have a fixed steady, turn up a wooden bung to a force fit in the tube. Center drill deeply in one end of the bung and knock it into one end of the tube. Grip the other end in the three-jaw chuck. Support the outer end with a center held in the tailstock. True up the outer end and then remove the sharp edges, using file and scraper, running at low speed.

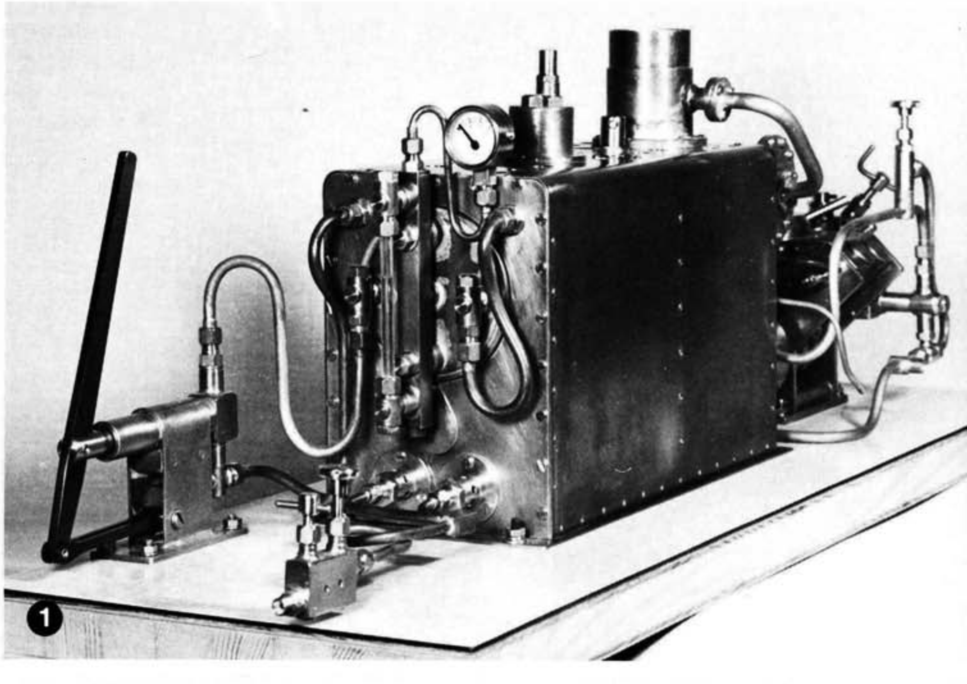
Remove from the chuck and knock out the bung. Insert it in the other end and repeat the process, this time bringing the tube to the final length, 150mm. Before removing the tube from the lathe, scribe the top center-line on the tube. To do this, lock the headstock mandrel by engaging the backgear and traverse the tool over the whole length of the tube, with the tool just touching the tube. This should be done *very* lightly as we do not want to weaken the tube with a deep scribed line, however high the safety factor is. Remove the tube from the lathe.

If your lathe is too small, the tube will have to be finished by hand filing. Finish one end before cutting the tube to length. In order to file the end square, wrap a narrow strip of thin sheet brass around the end of the tube so the ends of the strip overlap and the outer edge lines up at the overlap. The edge of the strip must, of course, be straight. Scribe a line on the tube against the brass strip. Remove the strip and file to the line. Using a scribing gauge or a rule, mark out the length, 150mm. Again, using the brass strip, scribe around the tube at the mark. Cut off with the hacksaw. Hold the tube in a bench vise when doing this and turn the tube as the sawing progresses. This way you can saw close to the scribed line, so there will be little filing work to clean up. The vise should have plastic or sheet lead jaw protectors to avoid damaging the tube.

Next, mark out the top centerline on the tube, if this hasn't already been done in the lathe. Do this by laying the tube on a surface plate or any reasonable flat surface and butting it up against a block (wood will do) to prevent it moving. Use a scribing block to scribe the line. Lacking this, a small block of wood will do. The height is not at all critical. Just hold a scriber against the block and slide it over the whole length of the tube. Then find the bottom centerline. A simple trick for doing this is to wrap a strip of paper around the tube and make pencil marks on both ends of the strip, where it passes over the scribed line. Now remove the strip and fold it so the two pencil marks coincide.



REAR VIEW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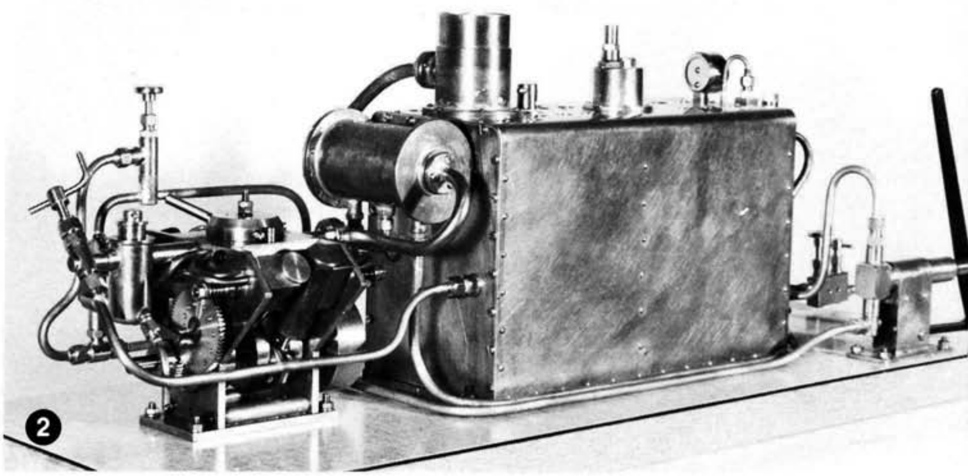
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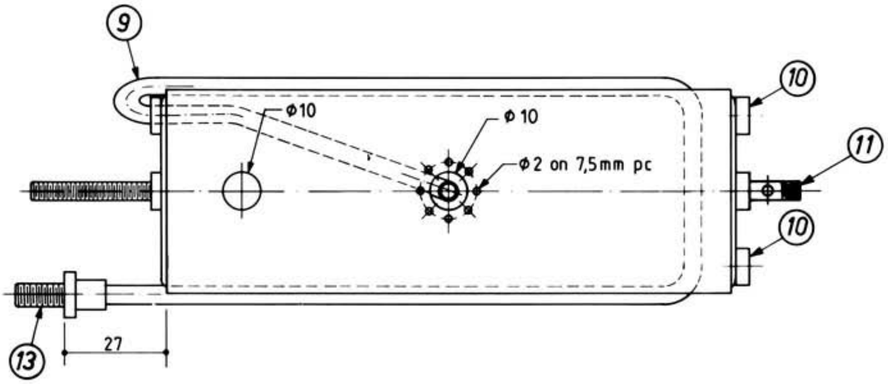
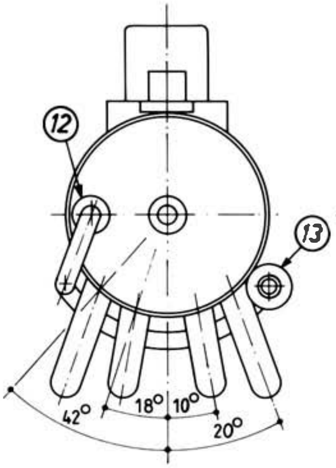
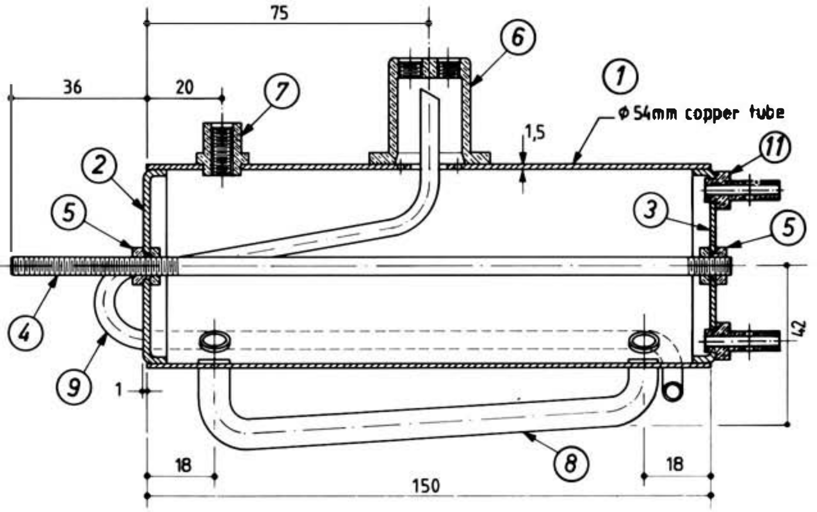
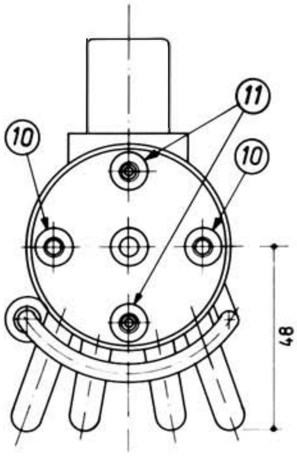




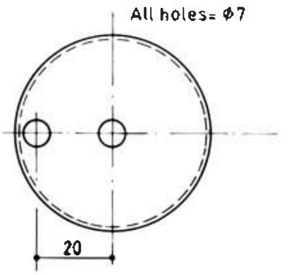
FRONT VIEW



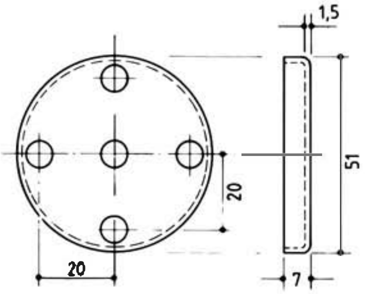
BOILER SHELL



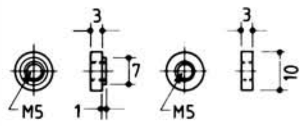
REAR VIEW



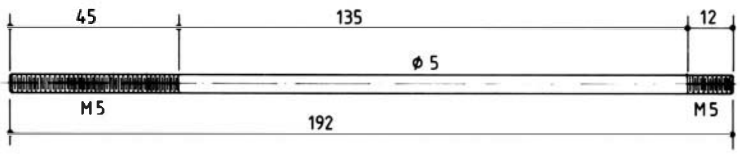
2 FRONT ENDPLATE
1.5 mm Copper, 1 required



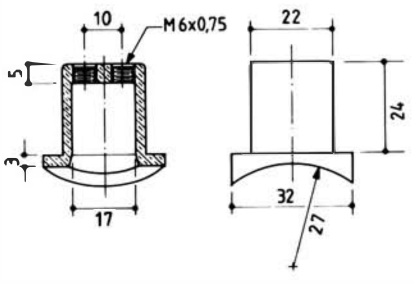
3 REAR ENDPLATE
1.5 mm Copper, 1 required



5 STAY NUTS
Brass, 2 each required



4 CENTER STAY
1.5 mm dia. Copper, 1 required



6 STEAM DOME
Brass, 1 required

Unfold and wrap around one end of the tube again, taking care that the pencil marks again coincide with the scribed top centerline. Make a scribe mark on the tube at the fold. This obviously must be halfway around the tube from the top centerline and thus is the bottom centerline. Repeat at the other end of the tube. Join the two marks, using scriber and straightedge.

On the top centerline, mark out the centers for the dome hole and the filling plug. Now the centers for the water tubes have to be found. Set your scribing gauge to 18mm and make a long scribe mark across the bottom centerline 18mm from each end. Use a divider set to 8mm to mark out the two inner tube centers, measuring from the bottom centerline. Reset the divider to 20mm for the two outer tubes, still measuring from the bottom centerline. Center pop at all hole locations (note: not on the bottom centerline) and drill, say, 1mm. Drill out to the proper size, using drills modified for sheet metal. Drills with standard tips will produce holes in thin stock which are anything but round and to size; besides, they are likely to catch the material and do nasty things to one's hands.

Drill the small holes at the dome location. Their position is not critical. Deburr all holes.

The **Water Tubes (8)** are bent up from 8mm copper tube with a wall thickness of around 0.8mm. If you are using inch-size stock, 5/16" 20 or 22 SWG should be used. Do not make the mistake of cutting the tubes to size before bending them. Instead, take a length of tube as long as can be conveniently handled, say around 1 meter, and fill with fine, dry sand. Close one end by squeezing it flat in the bench vise. Fill it well and ram down the sand. Close the other end the same way. Now, heat the spot where you want to make the first bend to a dull red. As you need something to hold onto while bending, the first bend should be made about 75 to 100mm from the tube's end. When it has cooled down, start bending it by hand. You will find that the sharp bend cannot be done at one go. As soon as the tube begins to feel stiff and hard, you will have to repeat the heating before continuing with the bending. If the tube tends to flatten out at the bend, this can be counteracted by gently squeezing it in a vise with smooth jaws. When satisfied with the bend, make the second bend. Spot the position of this bend by eyesight, checking against the holes in the barrel tube. Make sure the tube will fit in the barrel before trimming the ends to length. If necessary, adjust with further bending. After the ends have been cut, shake out the sand, trim the ends and do not forget to deburr the inside of the ends. Repeat the proceedure for the other tube.

In order to flange the **Endplates (2 and 3)**, a former is needed. It can be made of metal, hardwood or plexiglas rod. I used a scrap piece of 50mm diameter aluminum. Just face it and turn down to 47mm diameter. (If your boiler barrel diameter is larger or smaller than 54mm, adjust the size of the former accordingly, taking the barrel tube thickness into account.) Round off the edge to about 1mm radius.

Mark out and cut two disks of 2mm copper, 57mm diameter, using a hacksaw and a coarse file. Anneal them by heating to dull red. Find the wooden bung used when truing up the barrel tube ends, or make up something similar of wood or plastic. Sandwich the copper disk between the bung and the former **(photo 4)**. Make sure the disk protrudes an equal amount all around and clamp the assembly in the bench vise. Use a plastic or wooden mallet (never a hammer) to knock the copper down around the former. Do not, on any account, try to make it in one go; if this is done, the copper will become brittle and crack. Instead, start by knocking it over about 30° **(photo 5)**, working around the disk, turning the whole assembly in the vise as you proceed. When the copper begins to feel hard and dead, remove the disk and anneal it before proceeding. About three or four annealings probably will be required. When the flanging of the first endplate is finished, repeat for the second one **(photo 6)**.

It will be found that the endplatee are just a trifle too large to enter the barrel tube. This is due to the fact that the metal has thickened somewhat when bent over to a smaller diameter. To correct this, set the endplates up in the lathe, one at a time, and skim off the flange to a loose sliding fit in the barrel tube. At the same time, make a small center dot at the end, for the stay bushing hole. Remove from the lathe and mark out the centers for the remaining holes, using the center dot as reference. Note the difference between the front and back endplate. Drill all holes, first using a small drill and then a 6mm drill with a modified tip. A drop of cutting oil will do wonders. When the holes are deburred, your endplates are finished **(photo 7)**.

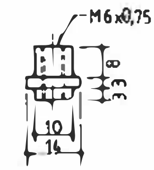
The **Feed Valve Bushings (10)**, the **Water Column Bushings (11)** and the **Superheater Bushings (12)** are simple turning jobs, which calls for no comment, except that the threading should be done in the lathe using taps in the tailstock. Make the **Center Stay (4)** of 5mm phosphor bronze or copper and its **Stay Nuts (5)** at the same time. You may wonder why the stay on the photos of my boiler looks thinner. The reason is that I used much stronger monel metal, being out of stock of 5mm phosphor bronze and copper. By the way, if you plan to use commercially available non-return feed valves, the threads of their bushings must, of course, be adjusted accordingly.

The **Steam Dome (6)** and the **Filling Bushing (7)** are the last two parts to make before the boiler can be brazed up. The filling bushing is another simple turning job, requiring no description. You will notice that it is missing in my photographs of the boiler at this stage, the reason being, I added the filling plug as an after-thought. I had intended to use the plug in the dome for filling up, but found out that this way, the superheater also got filled with water.

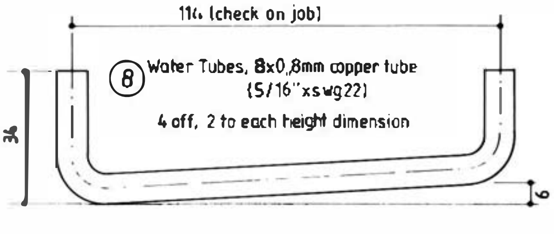
The dome is made of 32mm brass rod, about 35mm long to start with. Set it up in the three-jaw, face and turn down to 22mm diameter for 24mm length. Chamfer the corners, reverse in the chuck and bore out **(photo 8)**.

The base has to be curved to fit the barrel tube **(photo 9)**. This can be done either by hand filing or milling. If you have access to a milling machine, the set-up in **photo 10** will do the job. The swing tool is set to describe a circle of the same diameter as that of the boiler barrel tube. Unfortunately, the trusty Unimat will not do this job as a vertical miller, as its vertical feed is limited to 20mm, so the Unimatists will have to resort to hand filing.

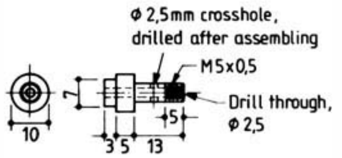
All joints of the boiler pressure vessel should be silver soldered, using a good quality silver solder such as Easy-Flo Number 2. Admittedly, this is one of the more expensive varieties of silver solder, but a very small quantity will be needed, less than one half-meter stick of 1.5 or 2mm



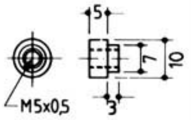
7 FILLING BUSHING
Brass, 1 required



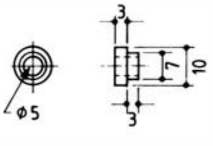
8 WATER TUBES
Copper, 4 required



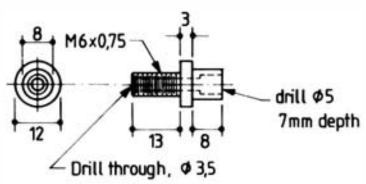
11 WATER COLUMN BUSHINGS
Brass, 2 required



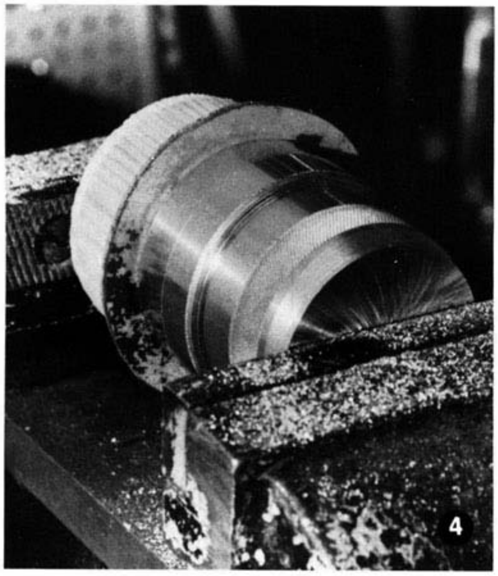
10 FEED VALVE BUSHINGS
Brass, 2 required



12 SUPERHEATER BUSHING
Brass, 1 required



13 SUPERHEATER UNION
Brass, 1 required



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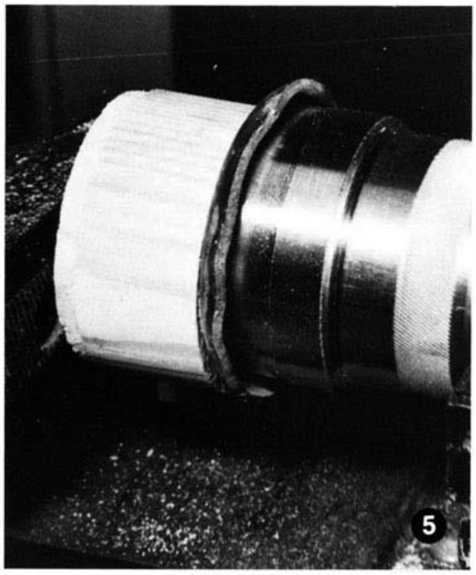

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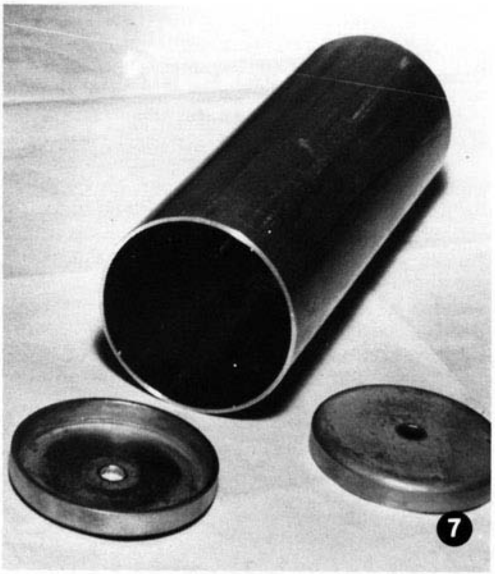

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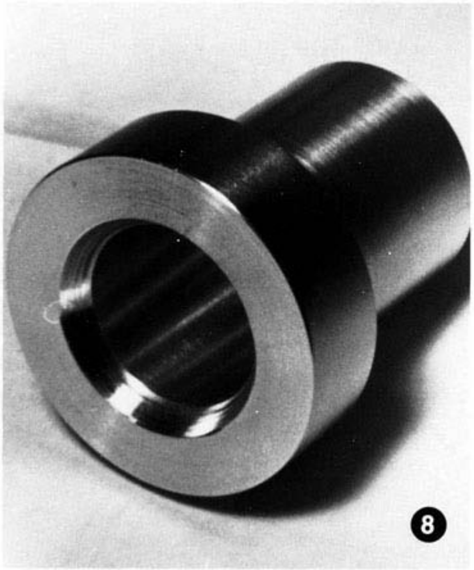

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thickness. It is one of the easiest solders to use, flowing as its name implies. Whatever make or type you use, make sure you use a flux intended for use with it.

The heating equipment needed is quite modest, a bottled gas outfit being preferred. If you have an oxy-acetylene outfit, you probably will know how to use it and can skip these notes. I used a Sievert bottledgas set with burner support number B2 and burner type 3941, the latter having a flame tube of 22mm diameter, just to give an idea of size. As a brazing hearth, I use an old baking oven pan with a pair offire bricks to put the workpiece on.

Finally, a pickle bath is needed. The pickle bath is used to remove the oxides and the flux remaining after each soldering operation. It consists of a 10% solution of sulfuric acid and is made by adding one part of concentrated sulfuric acid to nine parts of water. The acid must be added to the water, never the other way around or a violent reaction will occur, causing the acid to splatter about. It must be done outdoors because of the fumes. Keep the bath in a plastic bucket of about 5 liter capacity, making it about 2/3 full. The bucket must have a really close-fitting lid. All pickling should be done outdoors, and the lid kept closed when the bath is not used, as the fumes will cause rusting of tools and other steel items. Keep it out of reach of children. All this may sound formidable, however, the acid bath is quite weak and is perfectly safe if handled with intellegence. If you happen to get splatters on your skin, just flush with water and it will do no harm.

The first soldering operation will be to attach the water tubes to the barrel tube **(photo 11)**. Put the parts in the pickle bath for a few minutes in order to remove oxides and degrease them. Rinse in water and let dry. Put the water tubes into their holes in the barrel. The ends should protrude about 1mm into the barrel tube. If the tubes are a loose fit in the holes, they must be prevented from slipping during soldering. To do this, tie the two inner tubes together at the middle, using brass or copper wire. Then do likewise with the outer tubes **(photo 12)**.

Apply flux paste to all joints, both on the inside and outside. Lay the assembly on its back in the brazing hearth. Apply heat to one end of the tubes and barrel by playing the flame on it. Do not attempt to apply the solder until the proper temperature has been reached. This can be judged from the behavior of the flux. When it has molten to an almost clear liquid, the temperature is about right. Touch the joint with the solder stick and it will melt and run around the joint. Don't keep the stick in the flame for more than a second or two orit will melt and deposit a large blob of solder on your workpiece. The solder should melt by the contact to the workpiece, not by heat from theflame. When all four tubes are soldered to the barrel, turn the attention to the joints at the other end **(photo 13)**.

When finished, put it in the pickle bath. Tie a length of brass wire to it for holding the assembly while it is lowered into the bath. The bath will act faster if the workpiece is put in while still warm, but do not overdo it. Let the workpiece cool down a bit first, or there is a great risk that the acid will splatter all around. If pickling warm, always wear protective glasses for your eyes and have a bucket of water close at hand. After a couple of minutes, remove from the bath and rinse in water. Inspect the joints to make sure that the solder has penetrated and can be seen on the inside of the barrel.

We now can go on and attach the front endplate. Put the center stay into position by means of the stay bushing and the backing nut. Adjust the bushing and nut on the stay so that, when the back plate is in its proper position in the barrel tube, the other end of the stay will protrude 5mm out of the barrel's other end. Stand the assembly vertically on the brazing hearth, with the front plate uppermost. The barrel tube must rest on a pair of packing pieces to prevent the stay from pushing out the endplate. In order to reduce the number of heating operations needed to complete the boiler, the **Superheater (9)** should be put in now. Simply cut a 5mm copper tube to 0.75m length. Anneal one end and make the bend that will enter the steam dome. Poke it through the hole in the front endplate and through the hole at the steam dome's location. Apply flux to the joint between the endplate and the barrel tube, also at the stay and superheater bushings. In order to protect the already-soldered jointa between the barrel tube and the water tubes (in case they are re-melted) apply flux to them also. Silver solder the joints at the endplate, pickle and wash **(photo 14).** Before the next soldering operation, the superheater should be bent to shape, to get it out of the way **(photo 15).** Anneal the tube where it is to be bent.

Now do the rear end, including its bushings. Before putting on flux, adjust the nut on the stay to give the proper position of the endplate in the barrel **(photo 16).** After pickling and washing, all joints done thus far should be carefully inspected. If there is any doubts about soundness, re-solder it, not forgetting to protect nearby joints with flux.

To hold the dome in position during the soldering, drill a small hole through its flange and the boiler barrel tube and knock in a tight-fitting brass pin. Set the filler plug bushing in its hole. Apply flux to it and to the dome. Solder up and pickle, this time giving it some extra time in the bath **(photo 17).**

There is one small thing to be made before the boiler is ready for the hydro test and that is the **Superheater Union (13).** Turn this part up from brass and also make a cap nut of 8mm hex brass for it. This nut will be used as the steam pipe union nut later on, but do not drill through it yet as it will be used to blank off the superheater during the hydro-test. Cut the super-heater tube to proper length, silver solder the union fitting to it and you are ready for the test.

The purpose of the test is to check to see that the boiler is leak-free and, much more important, that it is able to withstand a pressure far exceeding the intended working pressure. It is an absolutely safe testing method. Should the boiler fail, which is extremely unlikely, there will be no explosion, only a squirt of water.

First, make and fit threaded plugs of hex brass to all openings in the boiler, except one in the dome, which will be used for the pressure gauge. To insure absolute tightness, wrap a strip of plumber's teflon (PTFE) tape in the threads of all plugs before screwing them in. Next, you need a pressure gauge with a maximum reading of around 8kg/cm², say, 100 psi. Make and fit

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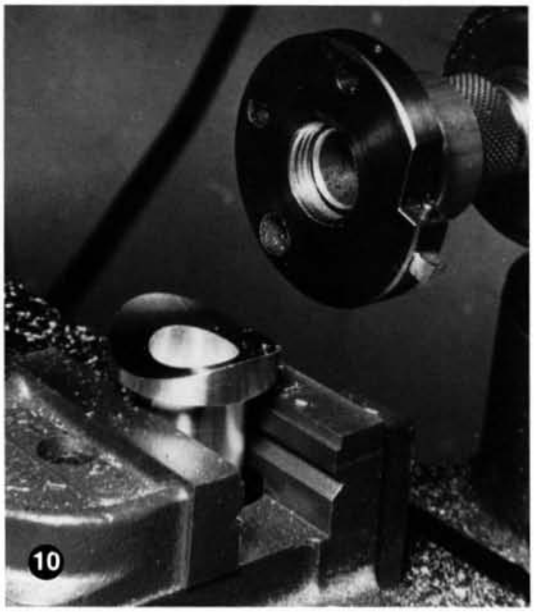

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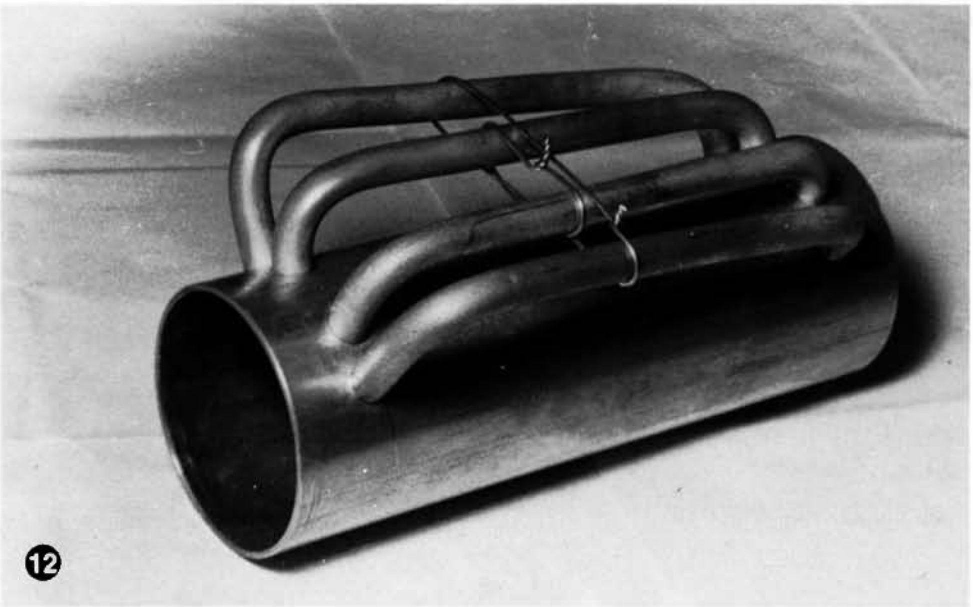

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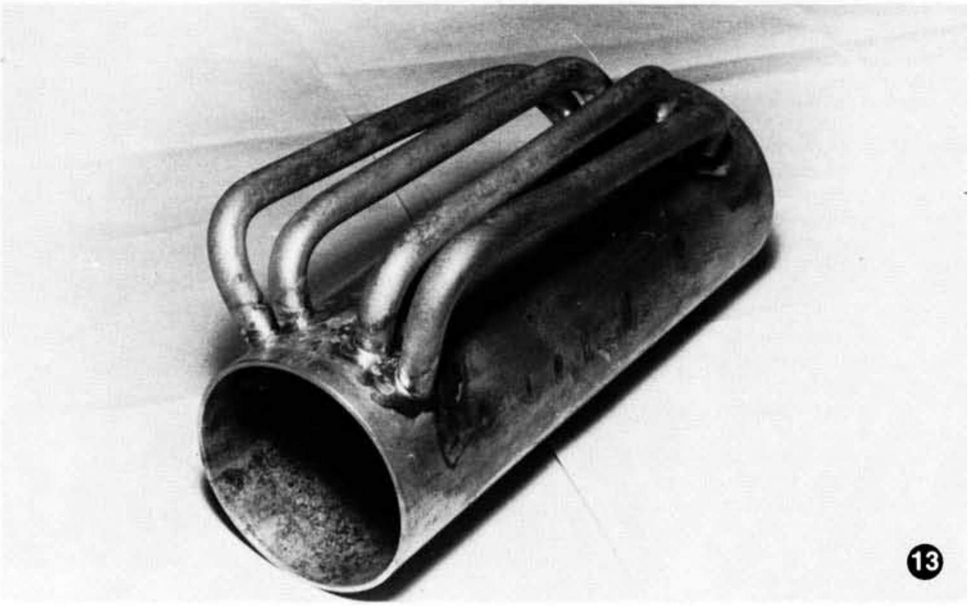

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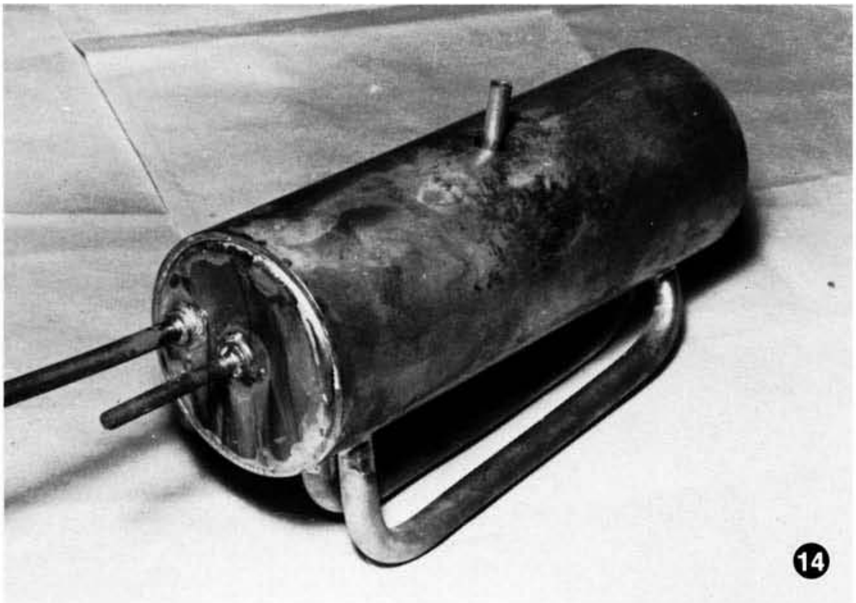

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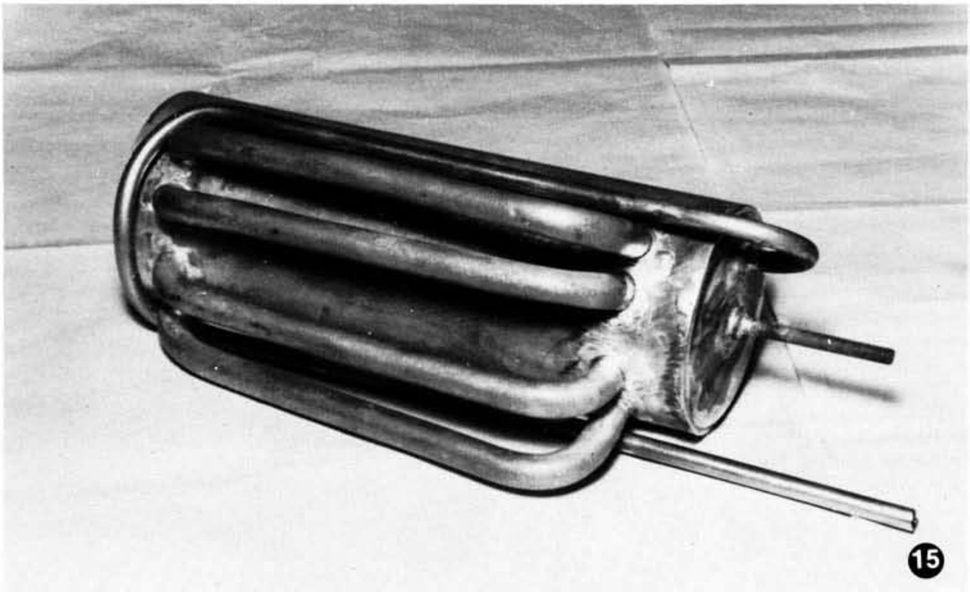
an adapter to it, so itcan bescrewedintothe safety valve hole in the dome, but do not screw the gauge in yet.

The boiler must next be completely filled with water; no air bubbles can remain in it. Unscrew the cap nut on the superheater to let out the air in itand then tighten it. When the boiler has been completely filled, screw in the pressure gauge with teflon tape on its threads. It is important that all threads are completely pressure tight during the test, otherwise the pressure cannot be raised.

To raise the pressure, just heat the boiler, using a gas burner. As the water will expand more than the copper when heated, the pressure will go up. No large amount of heat is needed. Watch the pressure gauge, and remove the flame when twice the working pressure is reached (4.2kg/cm^2 or 60 psi) (**photo 18**). Keep the pressure there



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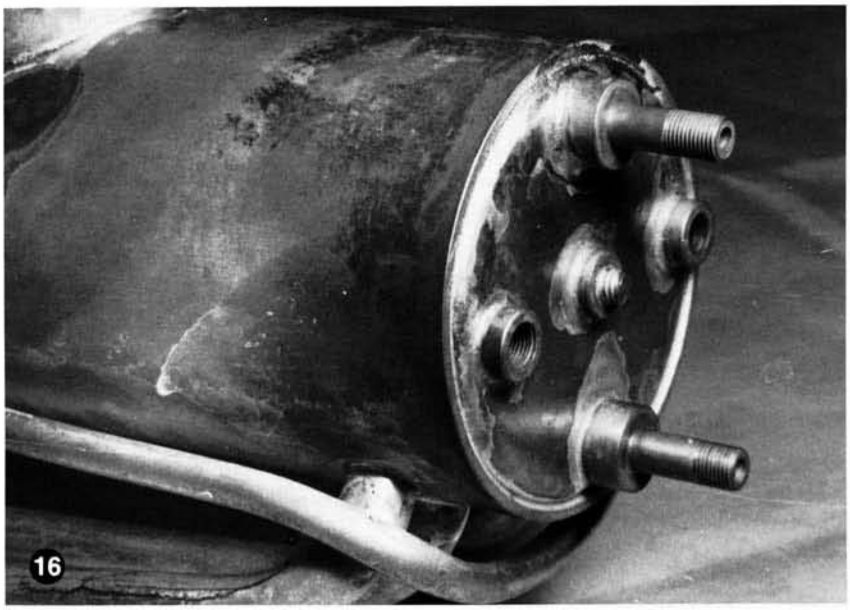

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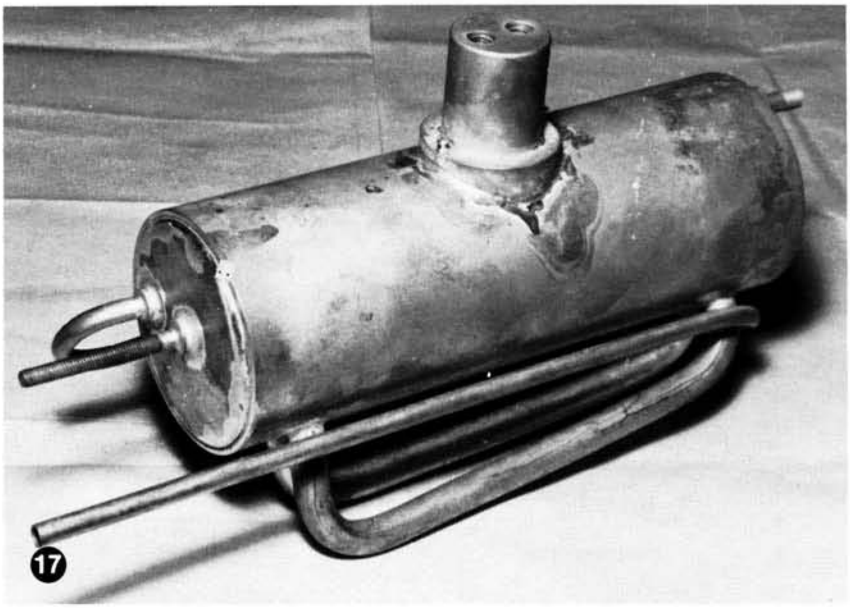
for about 10 minutes. If this can be done without heating the boiler to more than 50-60°C, it has passed the test. If there is a leak, the pressure will not raise. The leak can be located by the appearance of water trickling through it. The boiler must then be emptied and the faulty joint re-soldered. The plugs also must be removed during the soldering, to prevent burning the teflon tape. Then re-do the test. Note that during the test, the boiler must on no account be heated above 100°C (212°F), as the test will then cease to be a hydraulic test. In such case, should a burst occur, the escaping water will flash into steam and result in an explosion.

Having successfully completed the hydro-test, the boiler can be emptied and put aside. With the boiler itself completed, we will continue construction by making the casing and the armature for our Miniature Boiler Works, which are described next.



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The casing may seem a bit complicated at the first look. It is double walled in order to keep the temperature of the outer surface down to enable it to be installed safely in a small wooden hull. The air required for combustion in the firebox is made to pass between the outer and the inner casings. That way the outer casing will be kept cool and the air will be pre-heated before entering the firebox. No asbestos insulation is used.

The best material for the **Inner Casing (22)** undoubtedly is stainless steel, but brass also would do in a pinch. In the latter case, increase the thickness to 1mm.

Start by cutting the sheet to size, 178 x 284mm. Scribe lines to represent the centers of the bends. If you have access to a bending brake, use it to bend the sheet to a U-shape **(photo 19)**. The radius of the bend is not important, I have shown it fairly large in the drawing because most builders will have to do the bending by hand, resulting in larger radius than when a proper bending brake is used. If the bending has to be done by hand, do as follows: clamp a pair of flat steel bars to the sheet, about 1mm from the scribed line and on the center part of the sheet. Use a pair of heavy clamps for this. Position the protruding part of the sheet on the workbench, butt up the steel bar against the edge of the bench, and then use the clamps as handles for making the bend. (See **Figure 20.**) Then repeat for the second bend.

Now, check the dimensions. It does not matter a bean if the height and width do not check exactly with those shown on the drawing; only remember to adjust the dimensions of the outer casing and the endplates when making them, later on. The heights of the legs of the inner casing wrapper must be equal, of course. If not, trim off the longer leg.

Mark out and drill the 8mm diameter air inlet holes along the bottom edges. Use a drill bit modified for sheet metal drilling **(photo 21)**.

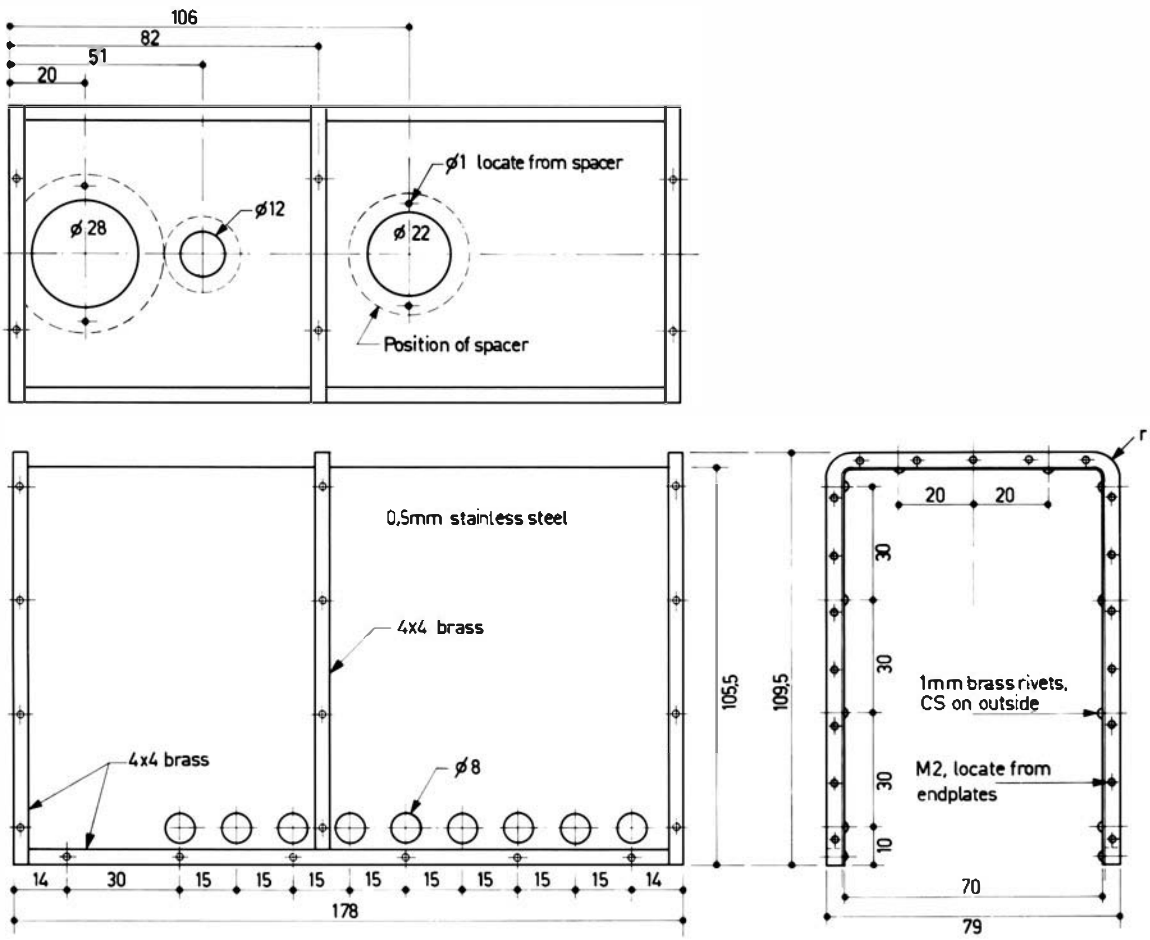
Mark out the centers for the three holes on the top surface **(photo 22)**. Note that the center distance of the holes for the steam dome and the filling plug bushing must agree with the same dimension on the boiler barrel, so check on that first. If you have a hole cutter and a stout enough drilling machine, fine, use it to make the large holes. Otherwise, scribe the contours of the holes with a divider, then drill a row of small holes just inside the scribed line, close together. Break out the center piece and finish by filing.

Now make the framework of 4 x 4mm brass. If you feel it difficult to bend the vertical end pieces to fit the inner casing, there is no objection to making them in three pieces and finishing the top corner radius by filing. Mark out the position for the rivets on the framework pieces, drill 1mm diameter and use them as drilling fixtures for drilling the corresponding holes in the inner casing. Countersink the holes on the outside of the framework members and rivet them to the inner casing **(photo 23)**. Be careful with the position of the rivets, so that they will not interfere with the screw holes for the endplates or the rivets for the outer casing, later on.

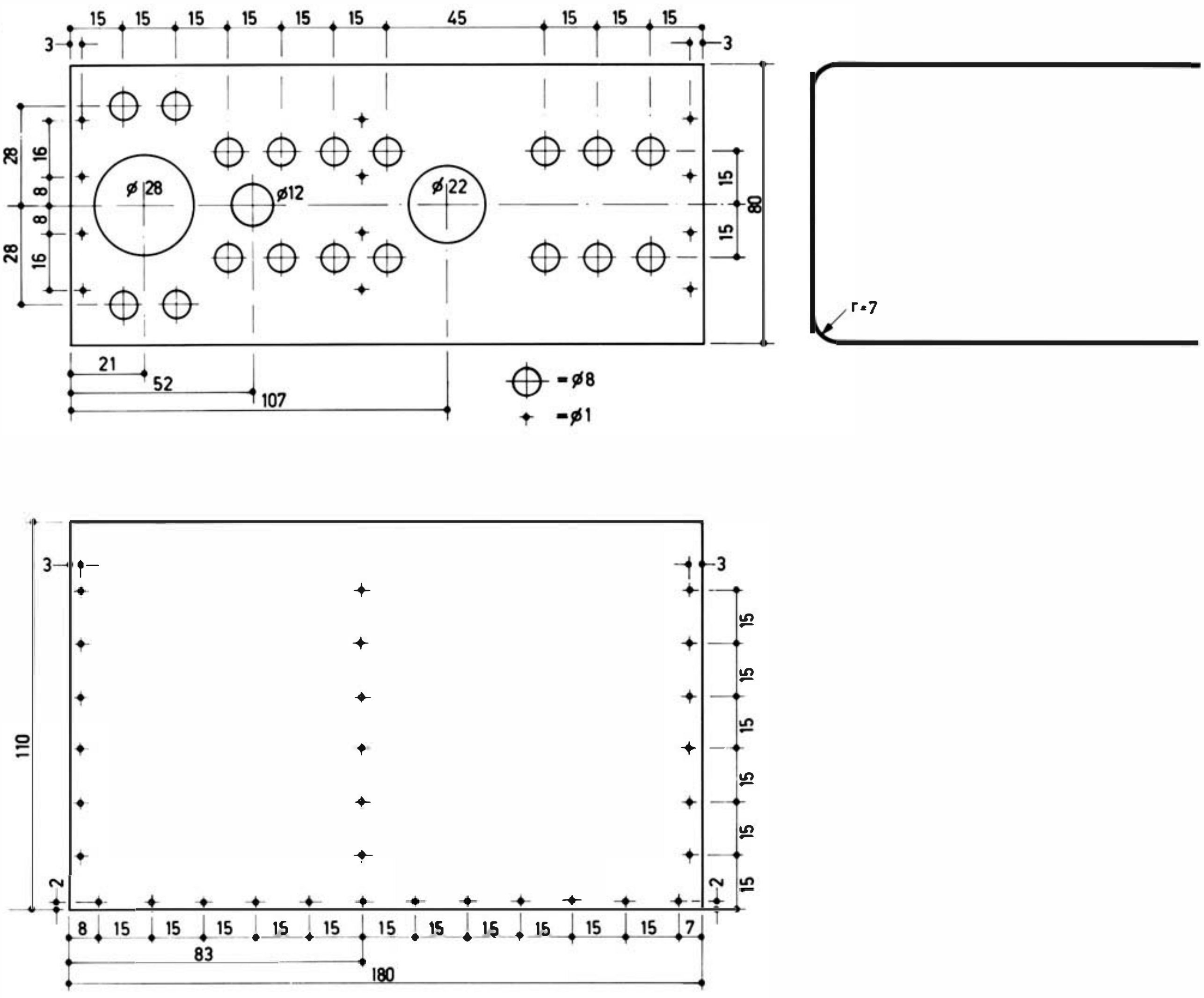
If you make the framework in three pieces, save the filing of the top corner radius until after the outer casing is made, so it may be made to fit that of the outer casing.

The **Outer Casing (23)** is bent up from 0.5mm sheet brass in the same way as the inner casing. To obtain the radius at the top corners, substitute a piece of wood for one of the steel bars. The wood should have one of its edges rounded off. If desired, the outer casing can, of course, be made of stainless steel, though brass is much easier to bend and drill. Note that the outer casing should be 2mm longer than the inner casing.

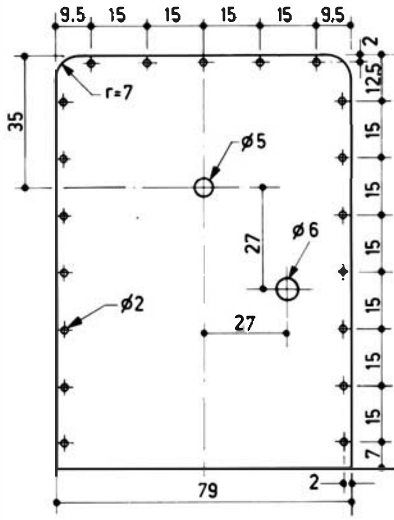
Mark out and drill all holes, except the three large ones on the top **(photo 24)**. Before the casing can be permanently assembled, spacers 27A, 27B and 27C are needed. These parts are turned up from brass stock. Insert **Filler Spacer (27C)** in its hole in the inner casing. Slide the outer casing on to its proper position. Note that the outer casing should protrude 1mm past the ends of the inner casing. Using a scriber, mark out the hole for the filling bushing on the inside of the outer casing. Remove the wrapper, drill and file the hole.



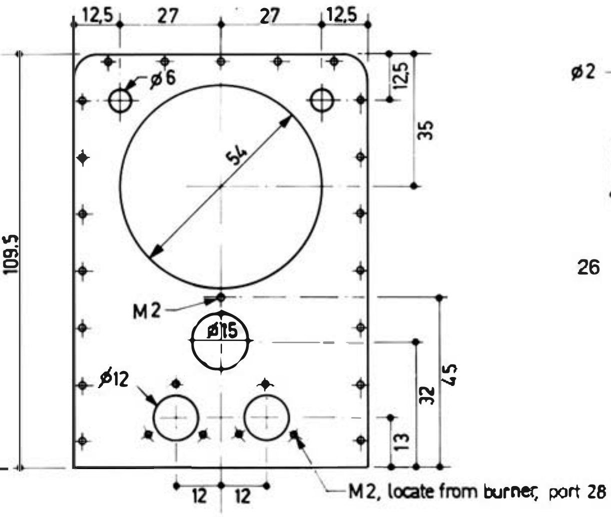
22 INNER CASING



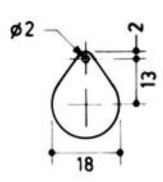
23 OUTER CASING
0.5mm Brass



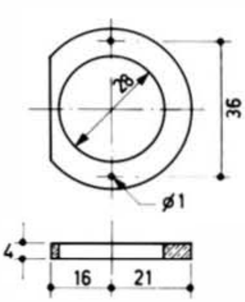
24 FRONT ENDPLATE
1 mm Brass



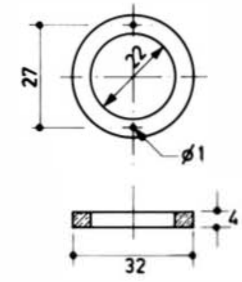
25 REAR ENDPLATE
1mm Brass



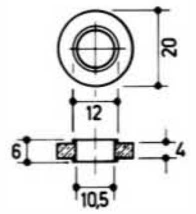
26 FIRE DOOR
1mm Brass



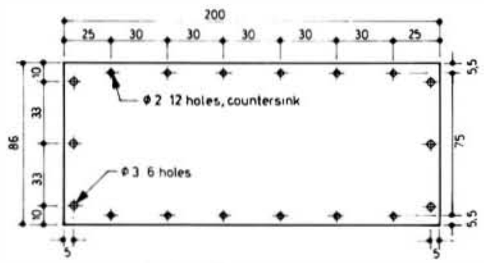
27A STACK SPACER
Brass



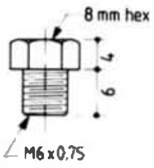
27B DOME SPACER
Brass



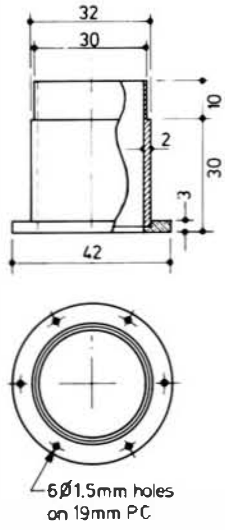
27C FILLER SPACER
Brass



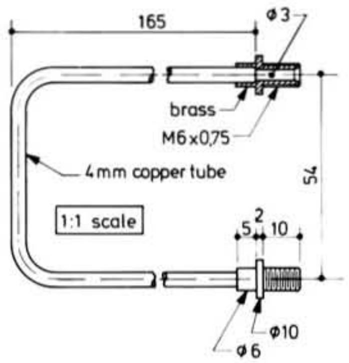
BOTTOM PLATE
1mm Brass, 1 required
shown ¼ size



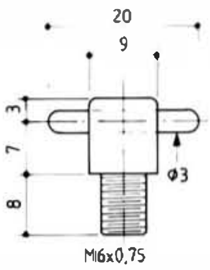
15 DOME PLUG
Brass



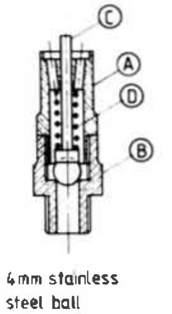
19 STACK BASE
Brass



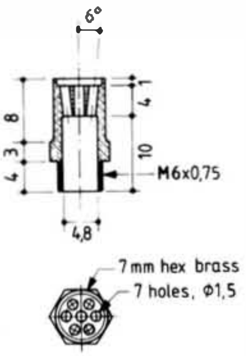
20 FEEDWATER HEATER



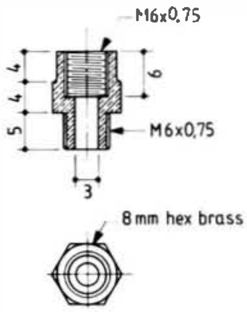
16 FILLING PLUG
Brass



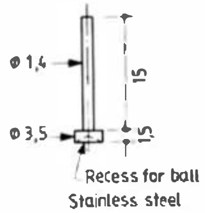
ASSEMBLY



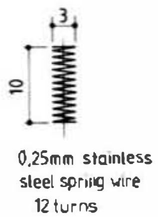
14A HOUSING



14B VALVE SEAT

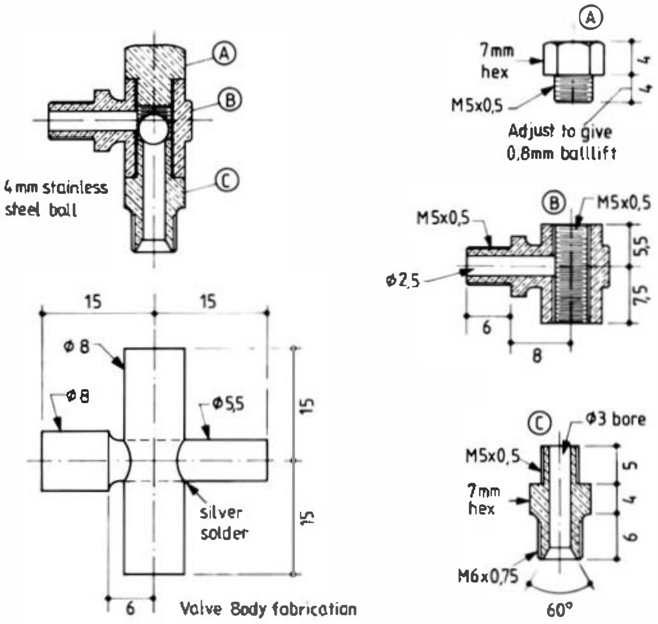


14C SPINDLE

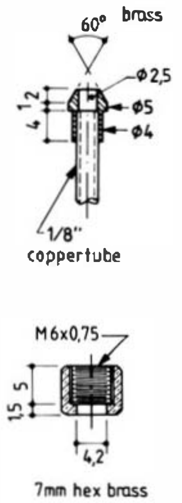


14D SPRING

14 SAFETY VALVE



17 FEED VALVES
Brass. 2 required



18 PIPE UNION
Brass

Rivet the **Stack Spacer (27A)** and **Dome Spacer (27B)** to the inner casing with two rivets for each of the spacers. The rivet heads should be on the inside.

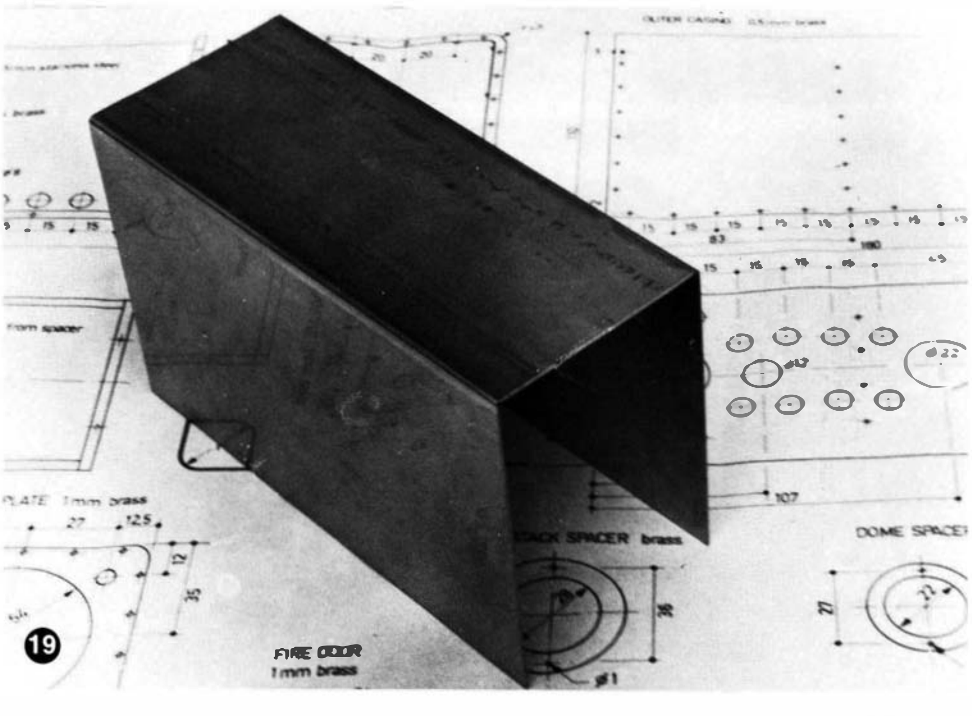
Now, slide the outer casing into position again and mark out the stack and dome holes with the scriber. Remove and drill and file out the holes.

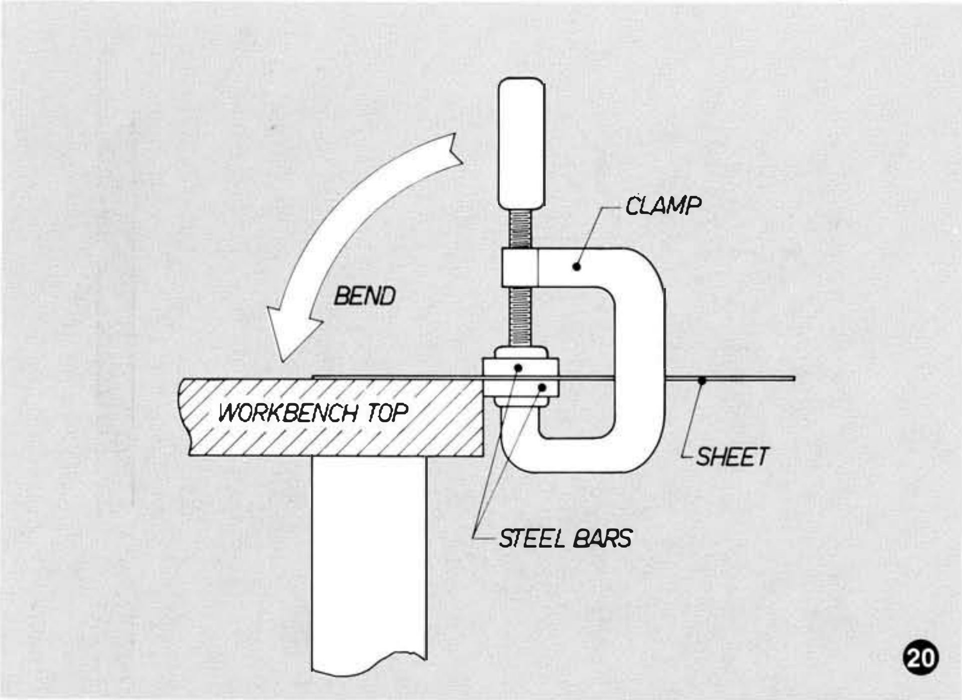
The outer casing now can be attached permanently. Do not forget to insert the filler spacer when doing this. Hold the outer casing in position with a couple of toolmaker's clamps. Peen over the flanges of the filler spacer with a ball peen hammer on both inside and outside.

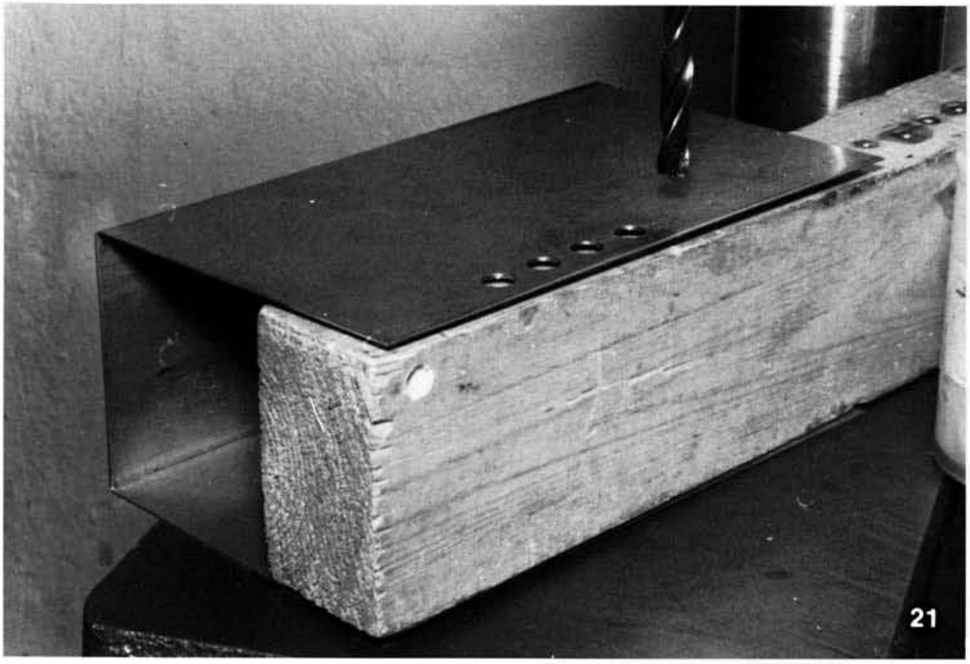
There are two ways to rivet the casing together. The first is to drill the holes for the rivets, countersink on the outside and insert the rivets from the inside, then rivet up on the outside. The other way, which I used, is to drill the rivet holes a tight press fit for the rivets and then hammer the rivets in from the outside, relying on the press fit of the rivets. The rivets should, in this case, be cut to 4mm length before being knocked in. Incidentally, for 1mm rivets I use 1mm brass nails with round heads. They just happen to be a tight press fit in holes drilled with a 1mm drill bit.

Whichever method you choose, start with the twelve rivets on the top of the casing. Then do the middle vertical row on the sides, from the top and down. After this, do the outer vertical rows and the bottom rows. Hold the wrappers together with a few toolmaker's clamps when riveting and keep on the alert, so the outer casing does not slip out of position. If you drive the rivets in from the outside, use a rivet snap to prevent damage to the rivet heads. Finally, put four rivets through the dome spacer from the outside and rivet into countersunk holes on the inside (**photo 25**). The two rivet heads on the inside of the dome spacer must be filed or chiseled away, as they would otherwise interfere with the steam dome seat.

The **Front Endplate (24)** and **Rear Endplate (25)** are made of 1mm sheet brass, or if you prefer, 1mm stainless steel. Start by cutting two pieces to 79 x 109.5mm (remember to check from the job). Mark out all holes shown on the drawing for the front endplate. Center pop and drill 1mm diameter. Clamp together with the other piece







and drill through all holes (**photo 26**), except the hole marked 6mm diameter on the drawing. Separate and open up all holes on the front endplate to final size. Round off the top corners to fit the casing and clamp the endplate into place at the stack end of the casing. Spot the screw holes in the end of the wrapper. Drill through with a 1.7mm drill bit and tap M2. Put in screws and tighten up.

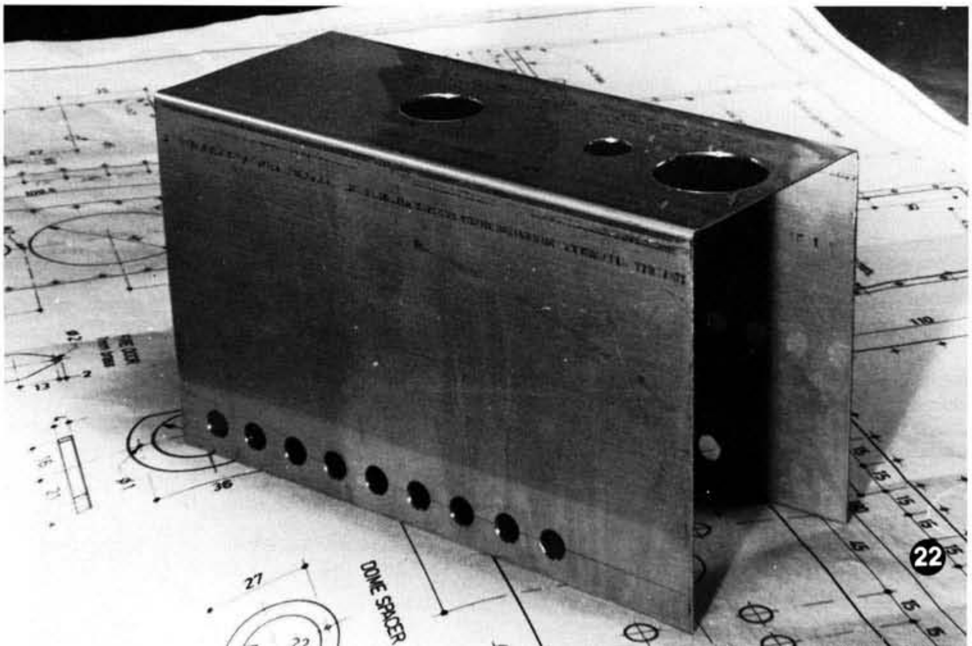
Now for the rear endplate. Locate and drill (1mm diameter) the remaining hole centers. Use a divider to scribe the outline of the boiler barrel opening. Drill a row of small holes, say 3mm diameter, just inside the scribed line, close together (**photo 27**). Break out the center and file the opening to a close fit for the boiler barrel (**photo 28**). Open out the remaining holes to final size and round off the top corners. Attach to the wrapper as before.

Make the **Fire Door (26)** from 1mm brass. Attach it to the rear endplate with an M2 screw and a locknut on the inside of the endplate.

The **Stack Base (19)** is made of a piece of 32mm diameter brass tube, and a bottom flange (**photo 29**), also of brass. The diameter of the tube can be varied within reason, to suit whatever you have on hand. Silver solder the joint. The step at the top is intended to fit an extension stack, if desired. Use the Unimat dividing head to spot the mounting holes. Drill the mounting holes in the casing, using the stack base as drilling fixture. Rivet the stack base in place(**photo 30**).

To begin the **Feed Water Heater (20)**, turn up the two end fittings from 10mm diameter brass rod. Use a large centerdrill to make the 60° mating surfaces for the unions. Silver solder the fittings to a 375mm length of 4mm diameter copper tube. Anneal by heating and bend to shape. Make two nuts from 8mm hexagonal brass stock and two washers from 10mm diameter brass rod (**photo 31**). Mount the feed water heater in the casing.

The boiler barrel now can be assembled into the casing. Remove the end plates from the casing. Put an M5 nut on the boiler's center stay, then hold the barrel in place in the casing and re-install the end plates. Put another M5 nut on the center stay and



adjust the two nuts so that the boiler barrel is protruding 1mm outside the rear end plate (**photos 32 and 33**), then tighten up the nuts. Make and fit a brass nut to the superheater outlet.

The boiler **Bottom Plate** is only a sheet of 1mm brass, attached with countersunk screws to the boiler casing's bottom edges. Make it up and attach to the boiler.

The **Safety Valve Seat (14B)** is made of 8mm hexagonal brass stock. Set it up in the three-jaw, with about 10mm protruding from the jaws. Face the outer end, centerdrill and drill 5.3mm to 5mm depth. Chamfer the entrance to the bore lightly and tap M6 x 0.75. Using a 3mm drill bit, drill to about 20mm depth. To form the valve seat, a 5mm endmill is used in the tailstock chuck (**photo 34**). Feed the endmill in exactly 6mm. Then use a 3mm reamer to remove any burrs in the 3mm hole. Turn the outside contour and then part off to 13mm length. Reverse in the chuck and turn and thread the bottom end (**photo 35**).

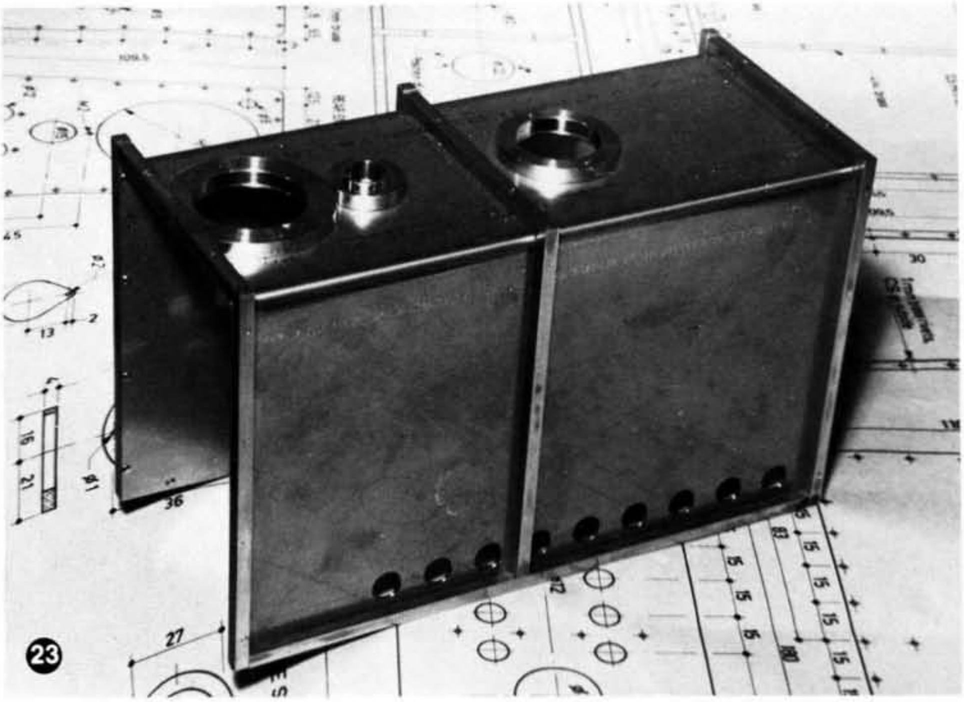
Now the spindle **Housing (14A).** Set up a piece of 7mm hexagonal brass rod in the three-jaw and turn the top outline. Centerdrill and drill 1.5mm to 10mm depth. Then make the recess in the top and break the edges. Part off to 15mm length.

To spot the steam outlet holes in the top, use the Unimat dividing head (**photo 36**). Just spot the holes with a centerdrill, then change to a 1.5mm drill bit and drill to about 7mm depth. Note that the holes should slope slightly towards the center. The drawing indicates an angle of 6°, but this is not at all critical. The easiest way to do this is to prop up one side of the dividing head when drilling.

Now set the workpiece up in the lathe again. This time, grip it by the already-finished top end. Face, turn down to 6mm diameter for 4mm length. Thread M6 x0.75. Centerdrill and drill to 10mm depth, using a 4.8mm drill bit. Chamfer the entrance to the bore slightly and poke a 1.4mm drill bit through all the small holes to remove any burrs.

The **Spindle (14C)** is turned up from a piece of 3.5 or 4mm stainless steel rod. Note the recess in the lower end. It is done with a centerdrill, followed by a 3.5mm drill bit.

The **Spring (14D)** must be made either



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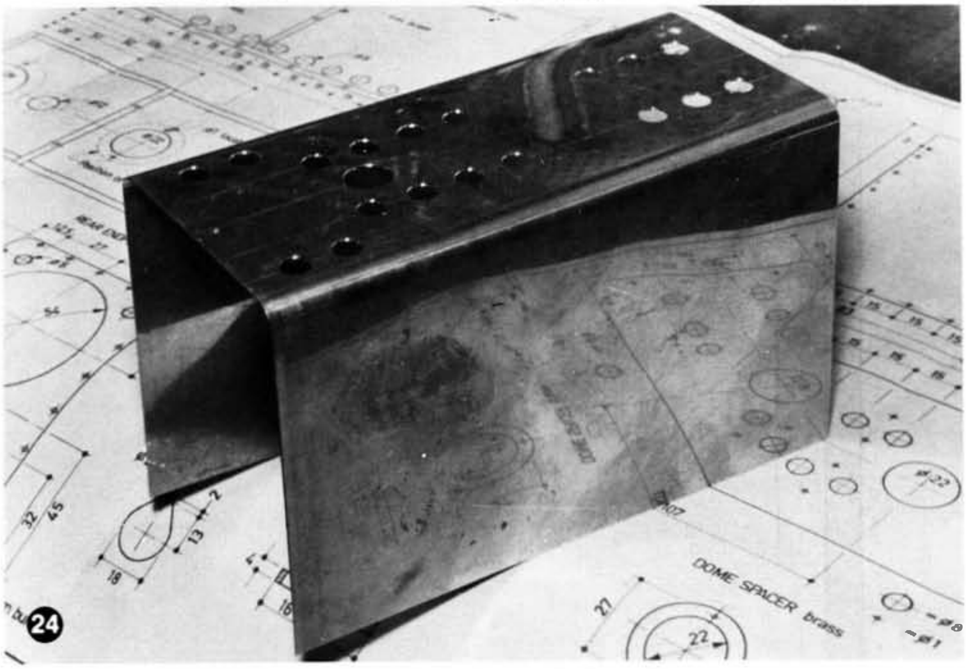

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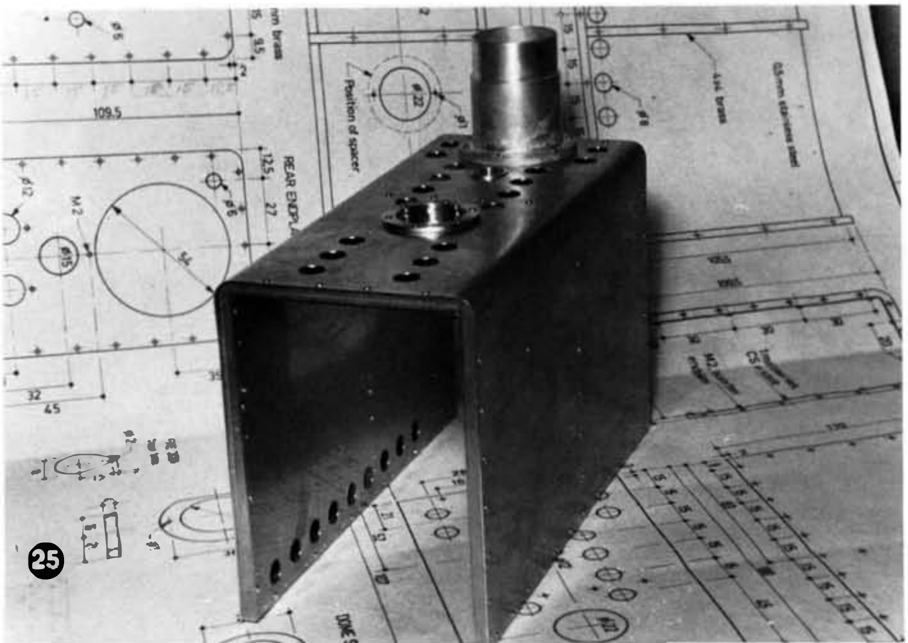

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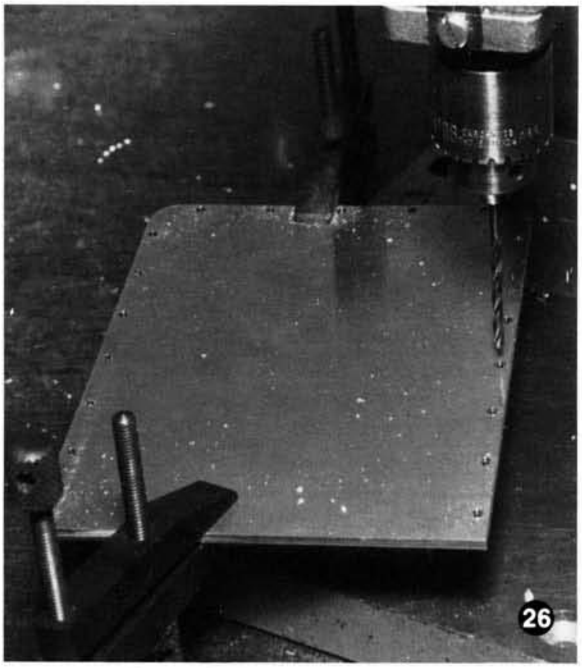

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of stainless steel spring wire or phosphor bronze wire; ordinary music wire would rust away quickly. The spring can be wound up in the lathe, using a 1.5mm rod for a mandrel. Its length, and maybe also the number of turns, will probably have to be adjusted at the boiler's steam trial, as the stiffness of the wire will vary between different sources.

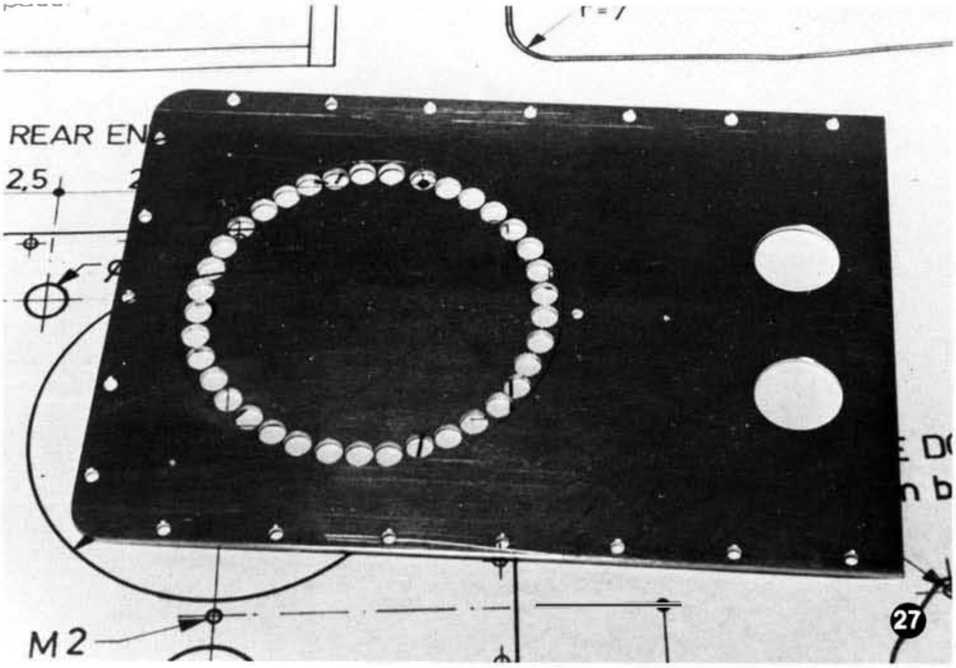
The 4mm ball can be either stainless steel or phosphor bronze, the former being preferred. To make sure that the ball will seal on its seat, do as follows: stand the valve seat on a hard surface. Drop the ball into place. Stand a short pieceof 4mm brass rod on top of the ball and give it a light but distinct blow with a small hammer. If your ball is phosphor bronze, substitute a steel ball of the same diameter while doing this, as the bronze ball is too soft.

Assemble the safety valve and screw it into place on the steam dome (**photo 37**).

The **Dome Plug (15)** and **Filling Plug (16)** simply can be turned up from brass. The cross-pin on the filling plug (**photo 38**) either can be a press fit, or secured with Loctite.

Two **Feed Valves (17)** are required, one for the engine-driven feed pump and one for the hand pump. The latter is not really necessary, but is very handy for filling the boiler when starting from empty, or in case the engine-driven pump should fail. If you decide not to fit the hand pump, fit a threaded plug in its bushing and make only one feed valve. The boiler will, of course, run without the engine pump also, but the operating time will be limited to about 20 minutes.

To make the valves, start by making up the required number of **Valve Body Fabrications (photo 39).** Actually, make two extra while at it, as they will be needed for the water gauge, later on. Part off as many 30mm lengths of 8mm diameter brass rod as will be needed (eight, if you are to make two valves and the water gauge). Crossdrill half of them at the middle, using a 5.5mm drill bit. While doing this, hold the rods in a machine vise, and start the hole with a centerdrill. The exact location of the hole is not at all critical, eye-sighting will do. Turn down the remaining pieces to a sliding fit in



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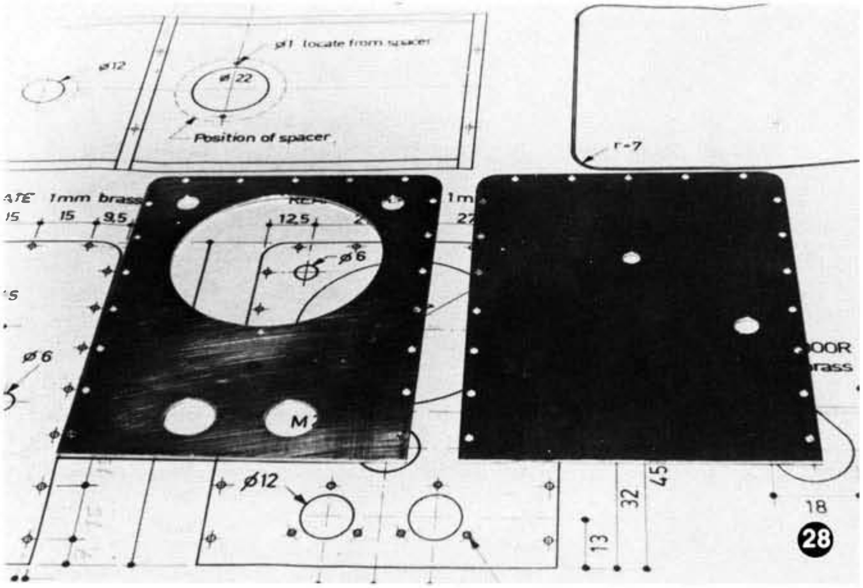

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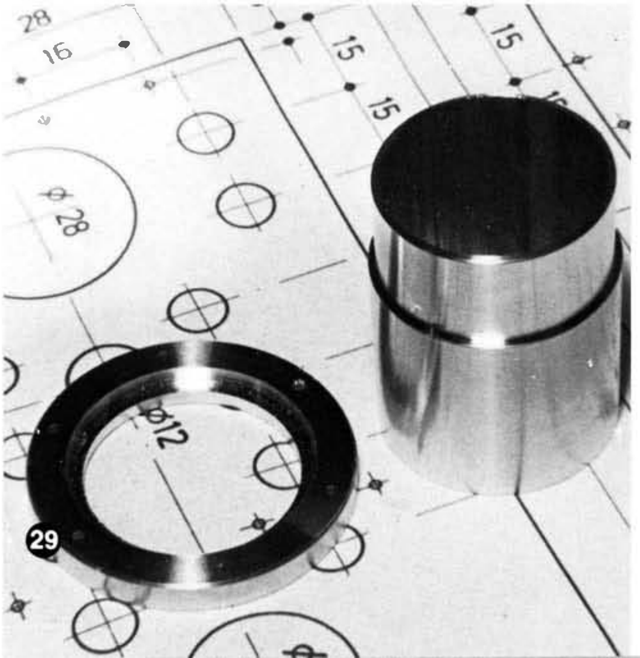

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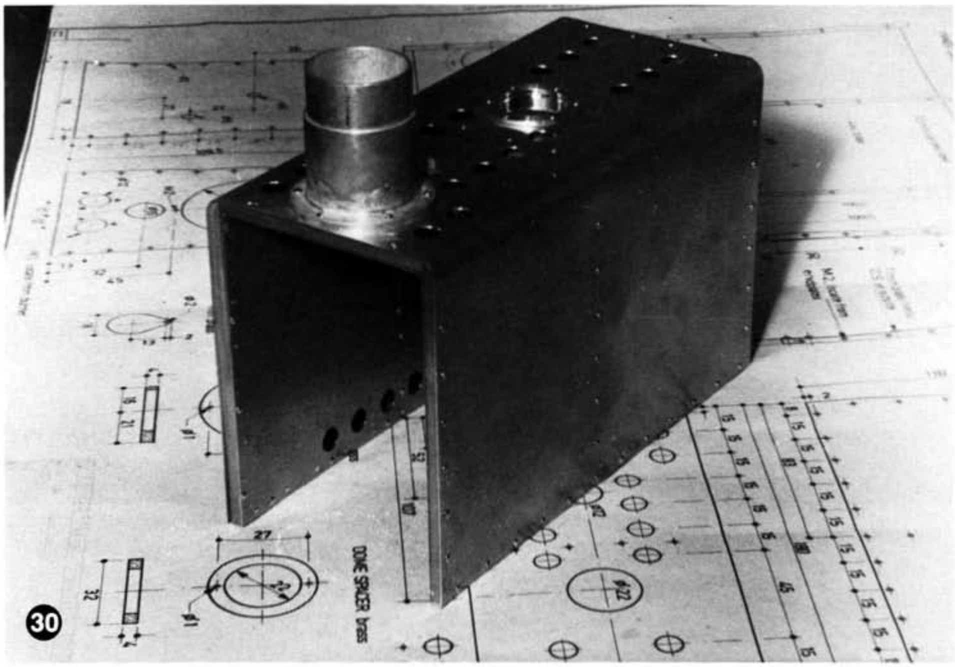
the 5.5mm hole. Use a tool with a rounded-off nose to get the radius between the 5.5mm and 8mm diameter parts. Silver solder the parts together.

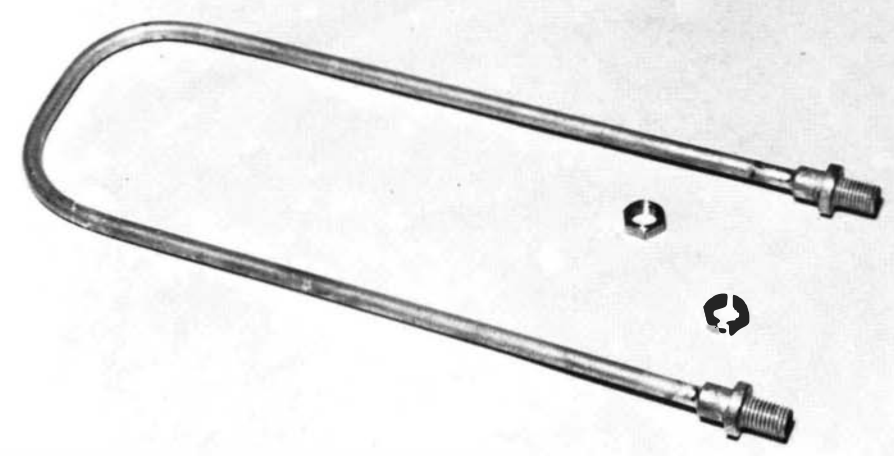
While soldering, be careful not to apply too much solder to the joint, which would spoil the neat appearance of the finished fitting. It should suffice to touch one end of the joint with the solder stick. If the joint is properly fluxed the solder will flow through to the other side and form a nice fillet. Be careful to avoid overheating, as the flux then will be burned and hard to remove. Pickle while still hot. Use a pair of tweezers to tie a brass wire around the valve body to hold it in the pickle bath. After the pickling, rinse well in water and polish up with a brass brush.

Now we are ready for the machining. Grip one of the embryo valves by one end of the vertical 8mm diameter stem, using the three-jaw chuck. Part off and face the outer end so that it protrudes 7.5mm from the centerline of the crosspiece. Round off the edges with a small file. Center drill and drill to about 20mm depth with a 4.5mm drill bit. Change to a 5mm drill bit and drill to about 1.5mm depth. This will allow the bottom fitting (the valve seat) to bed down properly when assembling the valve. Now, tap the hole M5 x0.5mm, all the way. Remove from the chuck and repeat the process for the other valve.

For the following operations we need a few simple chucking fixtures. Part off four stubs of 10mm brass rod; they should be about 25mm long. Chuck one in the three-jaw, with about 10mm sticking out. Turn down to 5mm diameter for about 6mm length. Thread M5 x 0.5mm. Use a small file to make an identification mark just outside chuck jaw number 1. This will enable you to set it up the same way from time to time. Using a narrow parting tool, make a groove at the very end of the thread. This will enable a threaded object to be screwed onto the stub all the way, against the shoulder.

Now, chuck the next stub, but this time only about 3mm should stick out from the jaws. Face it and remove the edges. Center drill and drill 4.5mm diameter, to 12mm depth. Counterdrill 5mm diameter to 2mm depth and then tap M5 x 0.5mm to the





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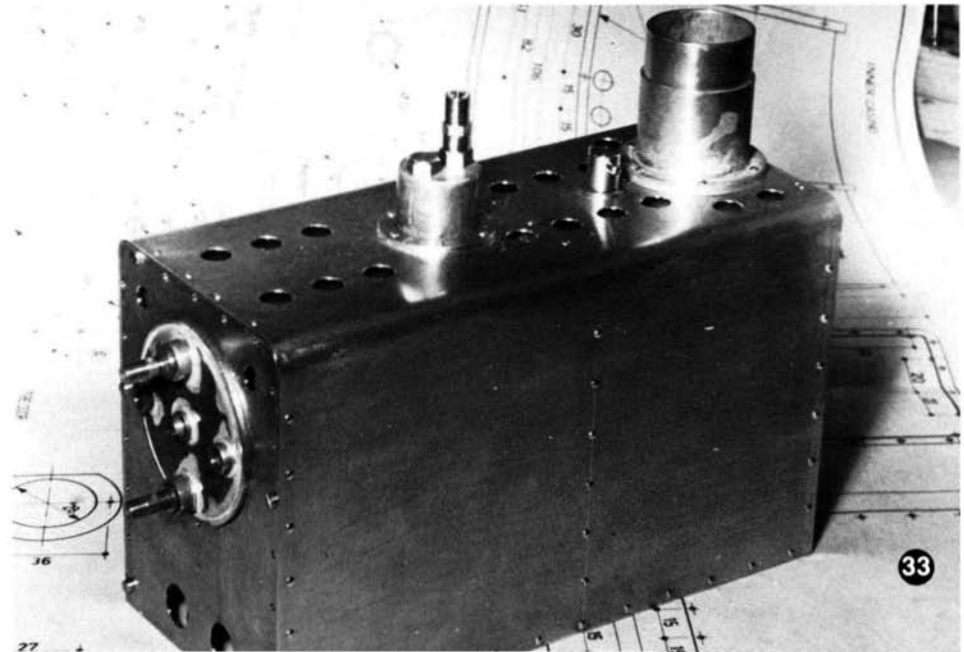

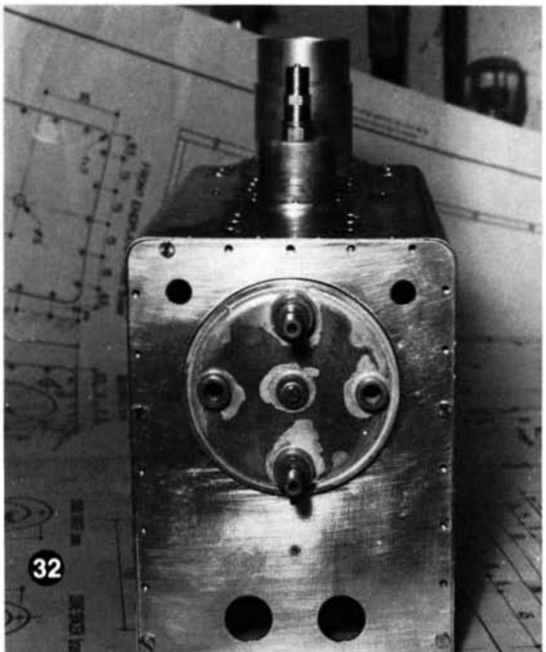

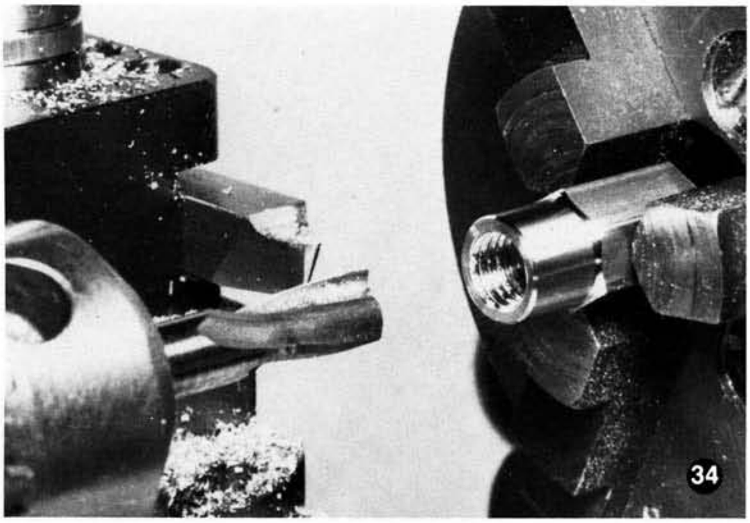

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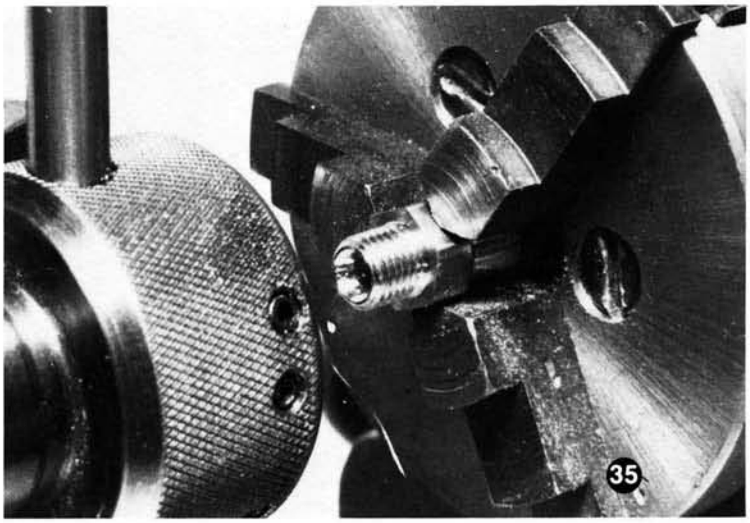

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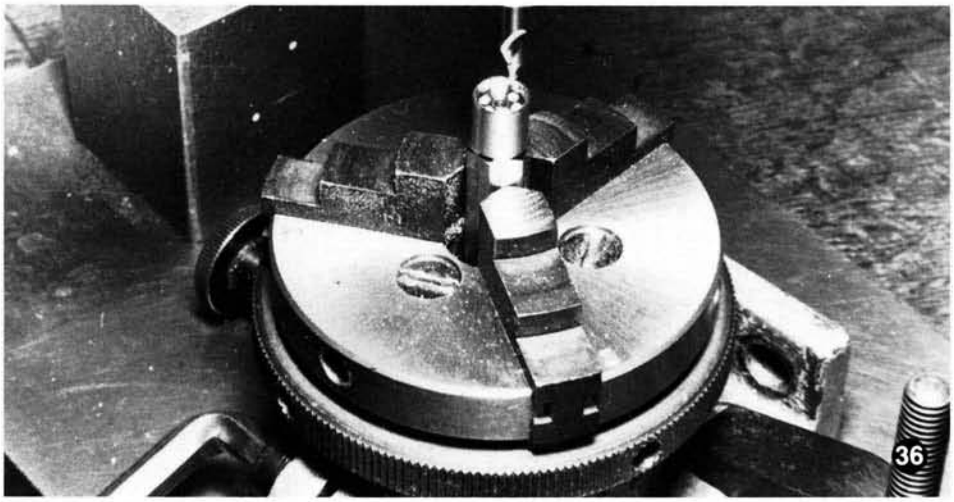

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bottom. Make a witness mark as before.

Repeat the process for the other two stubs, but this time make it M6 x 0.75mm. Keep these stubs with your taps and dies, as they will be needed frequently.

Back to the feed valves. Chuck the M5 x 0.5mm male-threaded fixture in the three-jaw and screw one of the valves onto it, with the already-finished end towards the chuck. Part off and face the outer end to 5.5mm length from the centerline of the cross-piece. Counterbore to about 1.5mm depth, using a 5mm diameter drill bit. Repeat for the other valve.

Remove the fixture from the chuck and grip one of the valves by its 5.5mm stem in the chuck. Face the end to 14mm length from the body's centerline and turn down to 5mm diameter for 6mm length (**photo 40**). Chamfer the end and thread M5 x 0.5mm (**photo 41**). Center drill and drill through to the tapped hole with a 2.5mm diameter drill bit. Repeat for the remaining valve.

Now, use the female-threaded fixture to hold the valve in the chuck. Part off the 5.5mm diameter stem about 1mm from the valve body (**photo 42**). Face and round off the edge. Treat the other valve the same way.

The top caps (17A) are made of 7mm hex brass rod. Use the tapped fixture for holding them while rounding off the top face. This can be done either with a suitably ground lathe tool or, quicker, a small file. I always keep a small file, of the type intended for dressing up auto engine breaker contacts, handy at the lathe for this kind of job.

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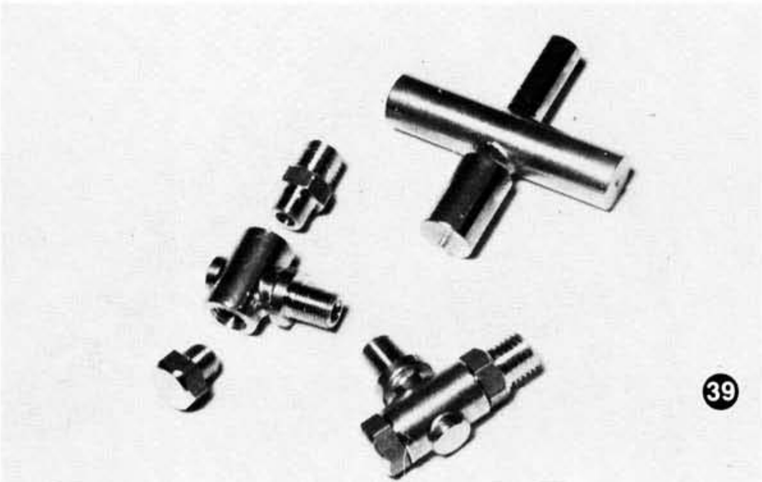

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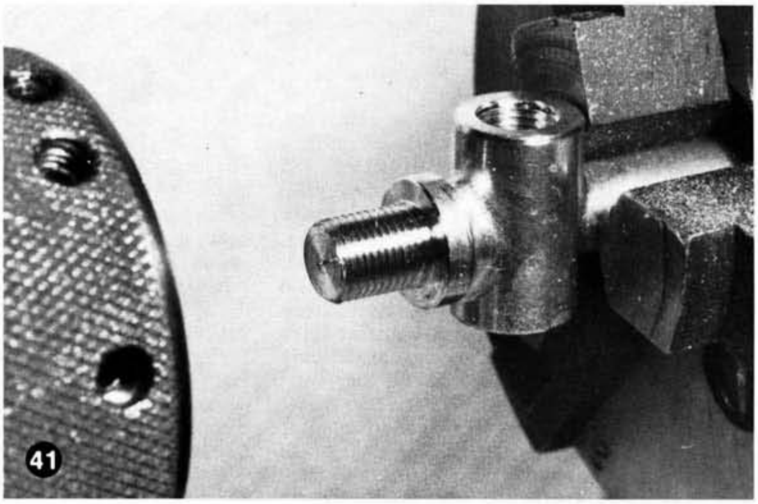

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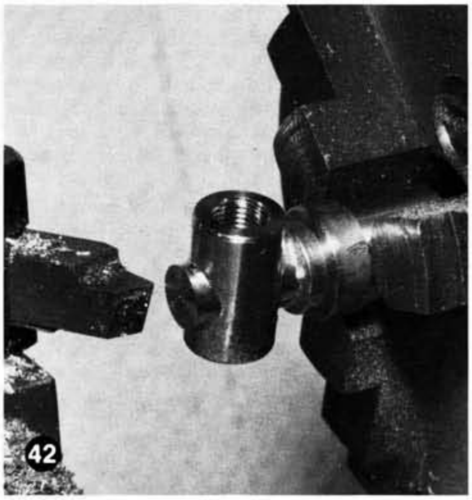
The valve seat (17C) is made from the same stock. Note that the bottom end of the 7mm hex portion should be rounded off, to remove the sharp edges. To this end, use a round-nosed tool while turning the 6mm diameter end before threading **(photo 43)**. Use a large centerdrill to form the 60° seat for the union **(photo 44)**. Part off to 15mm length, then set up in the chuck using the tapped fixture **(photo 45)**. Turn down and thread the top end. Drill through 3mm diameter and face the valve seat. As the last operation, skim off the valve seat (the top surface) to remove the burrs formed when drilling through.

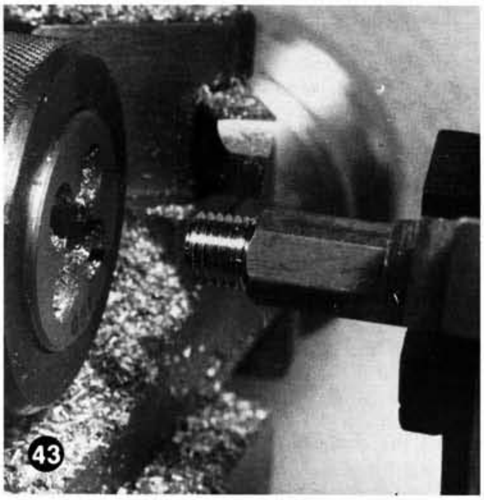
Screw the valve seat into the body and drop the ball into place. Use the method prescribed for the safety valve to seat the ball. Then screw in the top cap. Check the lift of the ball by poking a small drill bit or rod up through the bore in the seat, lifting the ball off the seat. The 0.8mm figure is not at all critical, eye measurement will do. If necessary, adjust the length ofthe top cap's threaded portion, then your valves are finished **(photo 46)** and can be screwed into their bushings on the boiler.

Your Miniature Boiler Works is starting to take shape now and should look quite presentable. There is still much to be done, though, and our next step will be the construction of some of the fittings and valves.

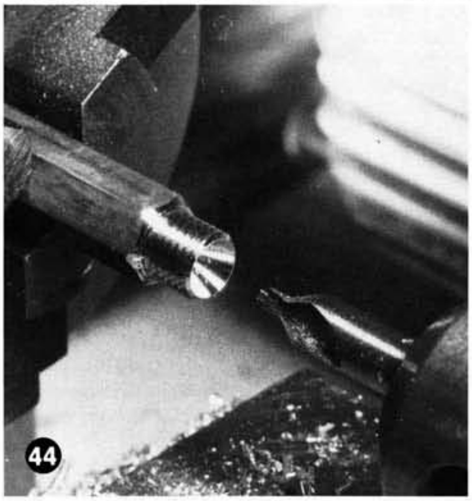
The main reason for fitting a Water **Column (21A)** to this boiler is to increase the distance between the water gauge's top and bottom fittings, so a longer glass can be used, to allow a larger variation ofthe water



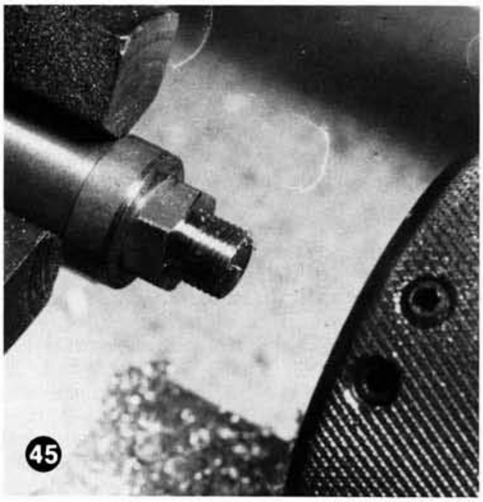
42



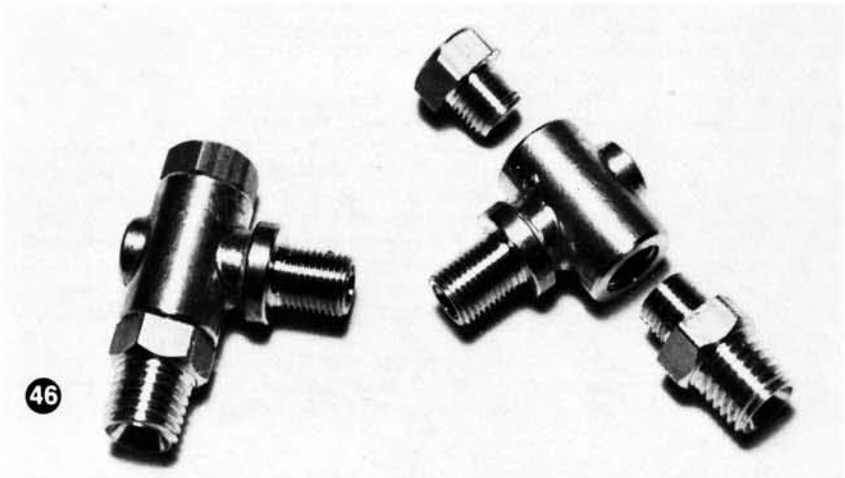
43



44



45



46

level. Secondly, it will help dampening movements of the water level in the glass.

The column is made of a piece of 8mm square brass stock, its length being 76mm. Set it up in the lathe, this time using the four-jaw chuck. Adjust the jaws until the workpiece runs true. Center drill and drill roughly half-way through, 4.5mm diameter. Tap the hole M5 x 0.5mm to 6mm depth. Reverse in the chuck. When doing this, loosen only the number one and two jaws, reverse the workpiece and re-tighten the same jaws. Re-centering will not be required now. Again, center drill and drill 4.5mm until the drill breaks through into the hole from the other end. Tap this end too.

Mark out the centers for the two water gauge bushings on the front surface. Center pop and drill 6mm diameter, breaking into the center passage. Use a small drill first and then change to a 6mm drill bit with the tip modified for brass as otherwise, it would very likely catch when breaking through to the center passage.

Now measure, on your boiler barrel, the exact distance between the two water column bushing studs. Mark out on the water column in accordance, using the scribing gauge. Center pop carefully, then drill through, starting with a 2.5mm drill bit; follow up with a 5 mm drill bit, again modified for brass. Deburr all holes. Try the column for fit on the boiler. If it just will not go on, enlarge the holes slightly until it will fit. Make the two water gauge **Bushings (21E)** and silver solder them to the column **(photo 47)**. Then make the **Bottom Plug (21G)** and also the **Pressure Gauge Connection (21H)** at the top. Then finish off the four **Washers (21F)** and the two **Cap Nuts (21I)** after which the column is fitted to the boiler for drilling the crossholes in the bushing studs. Make a drill bushing for this operation (see **Figure 48**). Insert the drill bushing in the pressure gauge hole and drill through the stud, using a 2.5mm drill bit. Do likewise at the lower end connection.

The bodies for the water gauge top and bottom fittings **(photo 49)** are fabricated the same way as those for the feed valves, if you have not already done that. Begin the machining by setting up one of the bodies in the three-jaw. Grip it in one end of the 8mm diameter part. Part off to 8mm length, measured from the centerline of the cross piece. Turn down the 6mm diameter for 4mm length. Then use a parting-off tool, set diagonally in the toolpost, to chamfer the edge of the 8mm diameter part lightly **(photo 50)** as it would be difficult to reach it with a file. Chamfer the outer edge too, for starting thread. Thread M6 x0.75mm **(photo 51)**. Repeat for the other gauge body.

Note that there is a small difference between the gauge bodies. The lower one has a short restriction in the bore. This will give the glass tube a shelf to stand on when assembling the parts, to insure that the tube will stay in the right position when tightening the gland nuts.

Back to the machining. Use one of the tapped chuck fixtures (which were described last month with the feed valves) to hold one of the bodies in the three-jaw. Part off to final length, face and remove the edges. Center drill and drill through with a 3.5mm drill bit **(photo 52)**. Change to 4.5mm drill bit and drill to 5mm depth. Tap M5 x 0.5mm **(photo 53)**. Now, change the holding fixture to the one with the M5 x 0.5mm male thread and screw the body into it. Drill out to 4.5mm diameter, 2mm deep.

Repeat for the top body, with the only exception being that it is drilled 4.5mm diameter all the way through.

The cross pieces are finished in exactly the same manner as the same operation on the feed valves **(photo 54)**. The only remaining parts are the plugs and the **Gland Nuts (21C) (photo 55)**. They are made from 7mm hex stock. Chamfer the edges for appearance.

To begin the **Burner (28)**, part off two pieces of 22mm diameter brass rod to 25mm length for the **Burner Base (28B)**. Face both ends to make the pieces 24mm long. Chuck one of them in the three-jaw, with about 15mm sticking out. Reduce the outer 12mm diameter. Repeat for the other piece.

Grip one of the pieces by the 12mm diameter end. Turn down the outer 10mm to 10mm diameter. This will leave a flange 22mm diameter and 2mm thick. Center drill and drill through, say, 5mm diameter. Follow up with a 7.3mm drill bit, all the way through. Change to a 8mm drill bit and drill to just 1mm depth. Tap M8 x 0.75mm, to about 10mm depth **(photo 56)**. Repeat for the other piece.

Use the Unimat dividing head to spot and drill the six air holes around the periphery of the tapped end **(photo 57)**. Spot and drill the mounting holes, also with the aid of the dividing head. Again, repeat for the other piece.

Now, grip one of the pieces in the three-jaw, with the 12mm diameter end facing the tailstock. Using an 8mm drill bit, drill to 19mm depth—just past the air holes, that is. Remove from the chuck and poke a 2.5 mm drill bit through the air holes to remove the burrs, then finish off the other piece.

Next comes the **Burner Bars (28A)**. Each one simply is a 95mm length of 10mm brass tube, 1mm wall thickness, with 20 thin slots. The slots should be about 0.25mm wide and go halfway through the tube **(photo 58)**. The easiest way to make the slots is to cut them with a thin razor saw. If you wonder why the slots on my burner are slanted, it is because I cut them in the milling machine. That took most of an evening's work, including the set-up, while hand-sawing should take less than half an hour; take your choice.

Make the **Plugs (28D)** that close the outer ends of the burner bars. Their flanges are 1.5mm larger in diameter than the burner bars, simply because it is easier to solder a joint which has a step in it than a butt joint.

There remains one thing to be done on the burner bases. That is to bore them out to a sliding fit on the burner bars, to 10mm depth. Then silver solder the parts together and put them in the pickle bath for a few minutes **(photo 59)**.

The **Orifices (28C)** are made from 10mm hexagonal brass stock. Part off two pieces, 16mm long. Grip one of them in the three-jaw, with about 10mm sticking out. Turn down to 5mm diameter for 5mm length. Chamfer the edge and tap M5 x 0.5mm. Chamfer the edges of the hexagonal part, too **(photo 60)**. Center drill deeply, to form the seat for the union and drill with a 2mm drill bit to 14mm depth. Repeat for the other part.

Now, use one of the tapped chucking fixtures to hold one of the orifices in the three-jaw. Turn the outer end to the outline shown in the drawing, and thread M8 x 0.75 mm **(photo 61)**. Center drill very lightly with the smallest possible center drill **(photo 62)**. Change to a 0.3mm drill bit and drill through. As there is only 2mm of material left before the drill enters the 2mm diameter bore from the other end, the drilling is easy despite the very small drill bit.

Face off the outer end to remove all traces left by the centerdrill **(photo 63)**. Repeat the process for the remaining orifice. The burners now can be assembled and put into place in the boiler casing. Use the burners themselves as drilling templates for spotting the mounting holes in the casing, then drill 1.7mm and tap M2.

The **Burner Valve (31) (photo 64)** really is a twin valve in a common block. One of them, the pilot valve, is used to adjust the burner to a suitable minimum output to prevent blow-off when the engine is stopped. The main valve is used to regulate steam output under load. This way, there is no risk of the burner accidentally being put out when operating the main valve.

Begin with the **Valve Body (31A)**. It is made from 8 x 15mm flat brass bar, 25mm long. Square up the ends in the lathe, holding it in the four-jaw chuck. Use the scribing gauge to mark out the centers of the two valve seats and the input and output connections. Center-pop all of them, then drill the holes for the valve seats, say, 2.5mm first. Change to a 5.5mm drill bit and drill through. Use a drill bit modified for brass and hold the workpiece in a machine vise, otherwise there is risk that the drill will catch when breaking through.

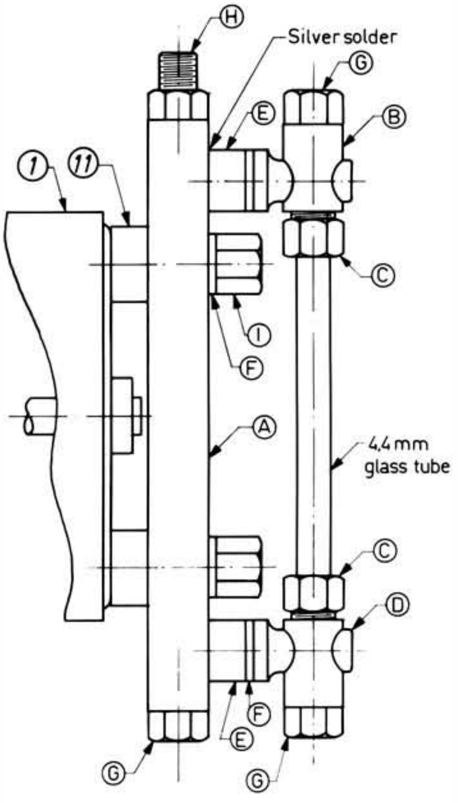
Now, make the **Valve Seats (31B)** from 6mm diameter brass rod. Chuck a length in the three-jaw, with about 18mm sticking out. Turn down the outer 16mm of the rod to a loose fit in the holes of the valve body. Part off to 23mm length and repeat for the other valve seat.

Grip one of the pieces in the three-jaw on the turned-down portion. With a round-nose tool, turn down the outer 6mm to 5mm diameter. Chamfer the edge and thread M5 x 0.5mm, 4mm length. Center drill and drill 2.5mm diameter to 15mm depth, then change to a 1.2mm drill bit and continue to 21mm depth. Change again, to a 3.1mm drill bit and drill to 7mm depth. Finally, tap M3 to the bottom of the 2.5 diameter bore, using a bottom tap. Repeat for the other valve seat **(photo 65)**.

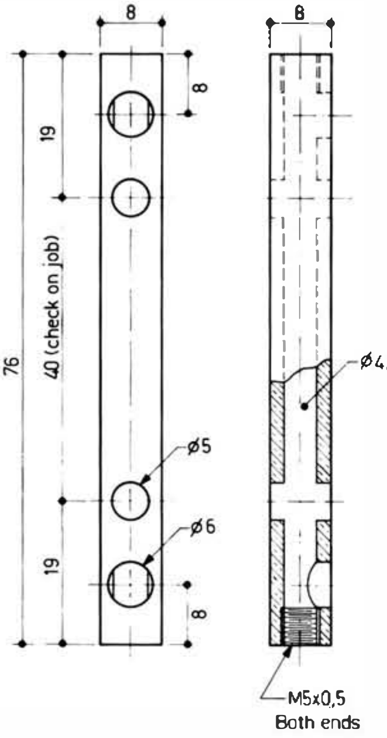
Silver solder the seats to the body. It is important that there are *no* leaks in the solder joints. Therefore, apply flux to the bores of the body before inserting the valve seats and flux the visible joints liberally. Heat and apply silver solder to the upper joints only. Play the flame on the lower end until a smooth fillet of silver appears, indicating that the silver has flowed all the way through the body, insuring a sound joint.

The passages through the body now can be drilled **(photo 66)**. First, drill 4.5mm diameter to 4mm depth and tap M5 x 0.5mm. Then drill 1.5mm diameter to connect the valve seats. Poke a 1.2mm drill bit through the valve seats to remove the burrs. Finally, drill the 2mm diameter mounting holes.

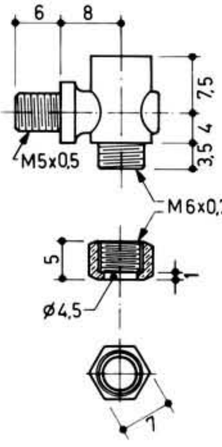
The **Connection (31C)** fittings are turned up from 6mm hexagonal stock. Make the two spacer washers to go with them and screw the fittings into the valve body.



21 WATER GAUGE

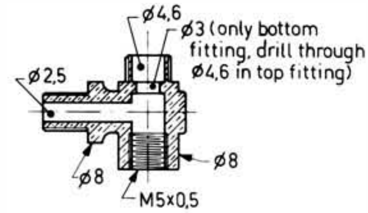


21A WATER COLUMN

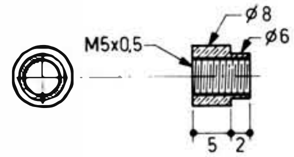


21B TOP FITTING
1 required

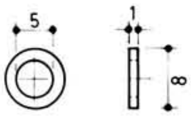
21C GLAND NUT
2 required



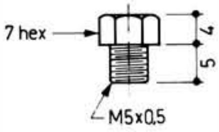
21D BOTTOM FITTING



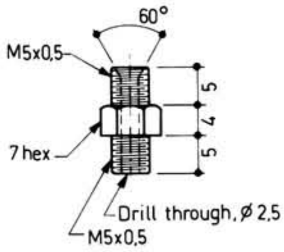
21E BUSHING
2 required



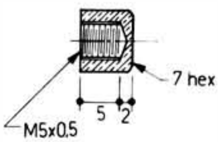
21F WASHER
4 required



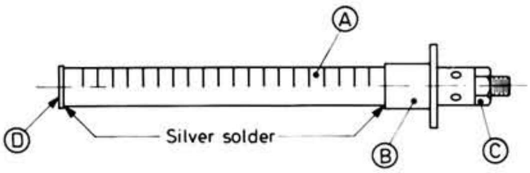
21G PLUG
3 required



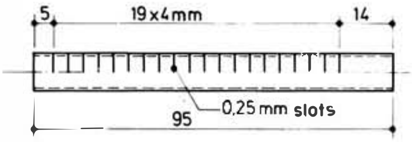
21H PRESSURE GAUGE CONNECTION



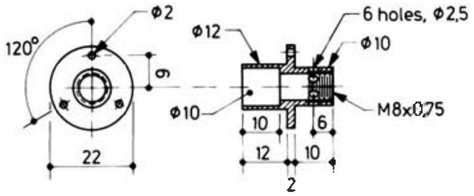
21 I CAP NUT
2 required



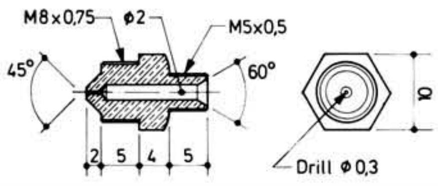
28 BURNER
2 required



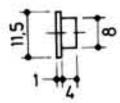
28A BURNER BAR
10 x 1 mm Brass Tube. 2 required



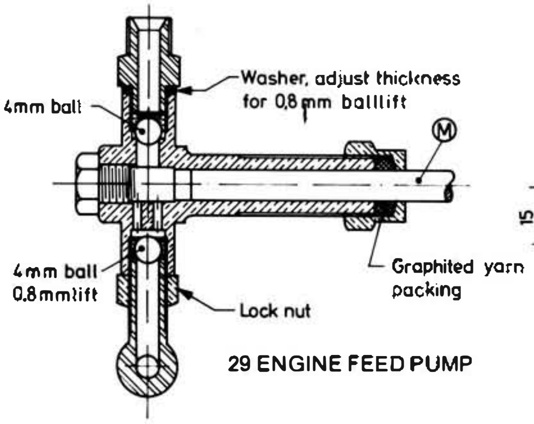
28B BURNER BASE
Brass, 2 required



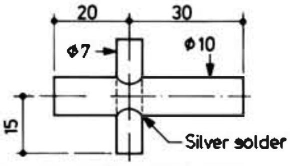
28C ORIFICE
Brass, 2 required



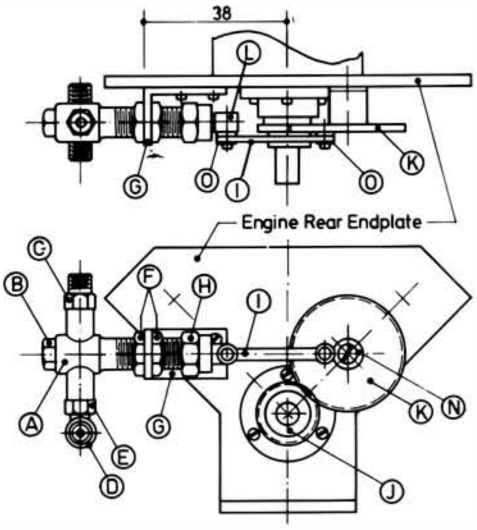
28D PLUG
Brass, 1 required



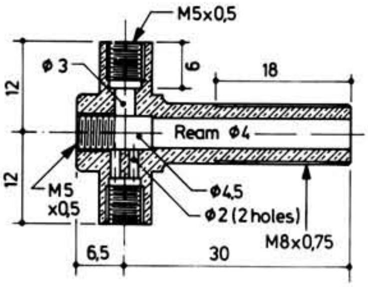
29 ENGINE FEED PUMP



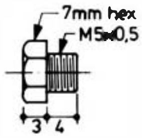
Pump Body fabrication
Brass



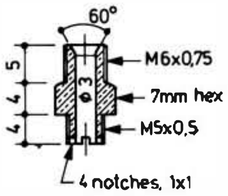
29 ENGINE FEED PUMP INSTALLATION



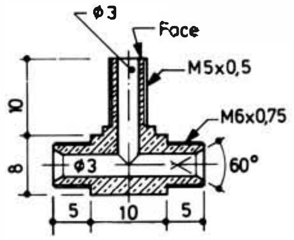
29A PUMP BODY
Brass, 1 required



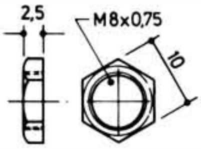
29B CAP/SCREW
Brass, 1 required



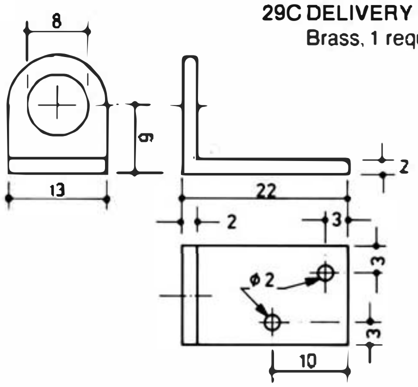
29C DELIVERY VALVE
Brass, 1 required



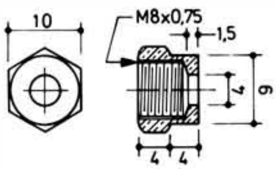
29D INLET VALVE
Brass, 1 required



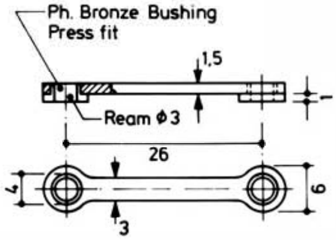
29F NUT
Brass, 1 required



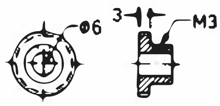
29G PUMP BRACKET
Brass, 1 required



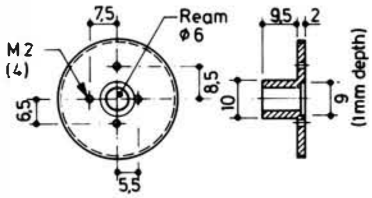
29H GLAND NUT
Brass, 1 required



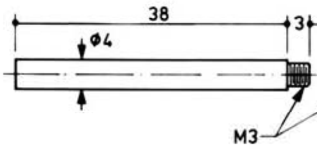
29I CONNECTION ROD
Steel, 1 required

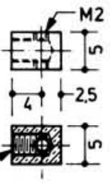


29J GEAR WHEEL
3OT, module 0.5,
1 required



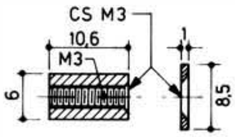
29K GEAR WHEEL
6OT, module 0.5,
1 required



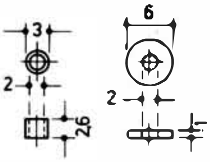


29M PUMP RAM
Stainless steel,
1 required

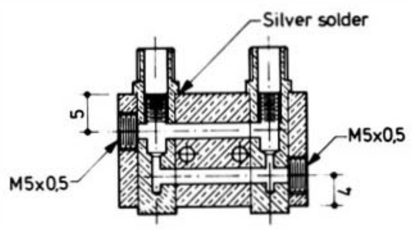
29L CROSSHEAD
5 x 5mm, Brass,
1 required



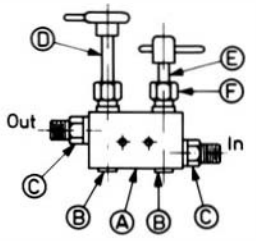
29O GUDGEON PIN
AND WASHER
Steel, 2 required
each



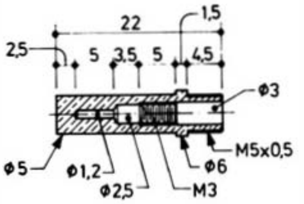
29N GEARSTUD AND
WASHER
Steel, 1 required



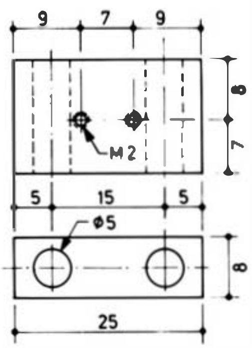
Valve Body fabrication.
Drill passages (ø2) after soldering.



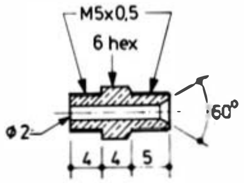
31 BURNER VALVE
1 required



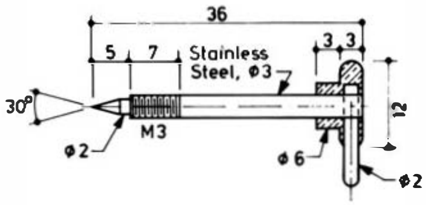
31B VALVE SEAT
Brass, 2 required



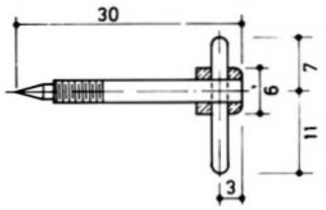
31A VALVEBODY
Brass, 1 required



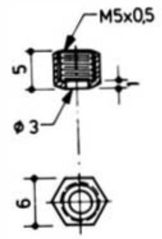
31C CONNECTION
Brass, 2 required



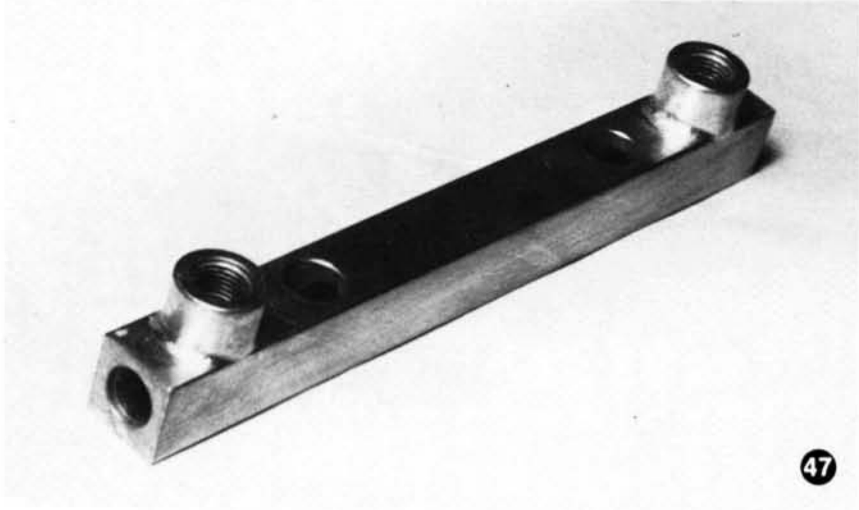
31D VALVESPINDLE
1 required



31E VALVE SPINDLE
1 required



31F GLANDNUT
Brass, 2 required



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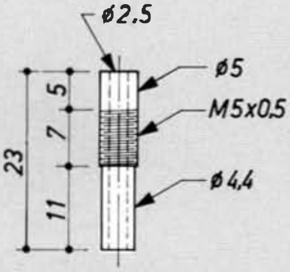
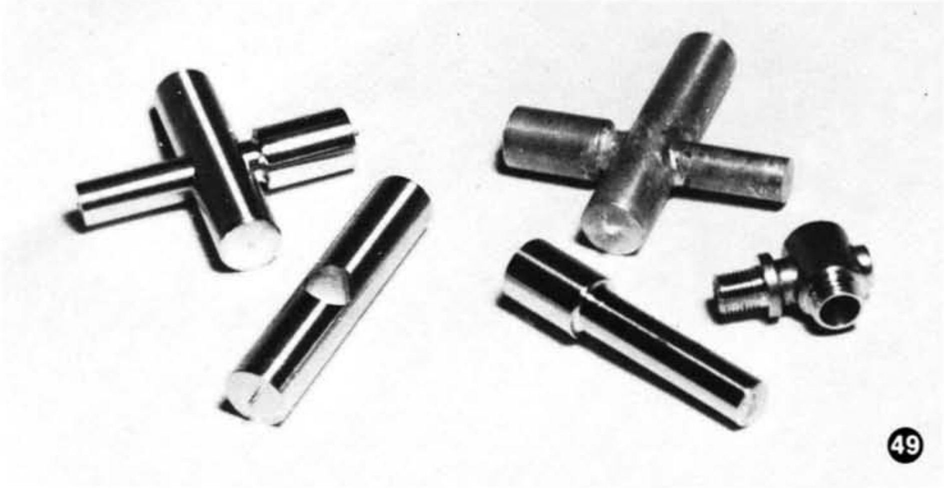


Drill bushing

Figure 48



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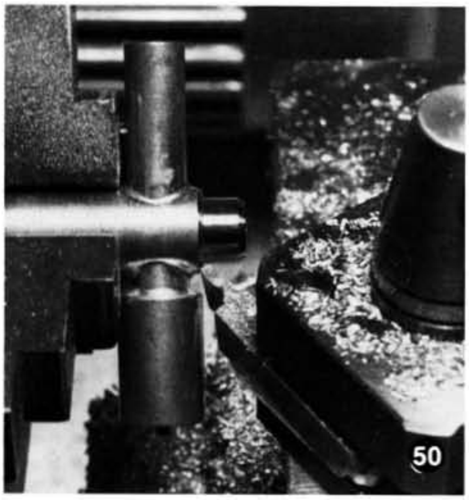

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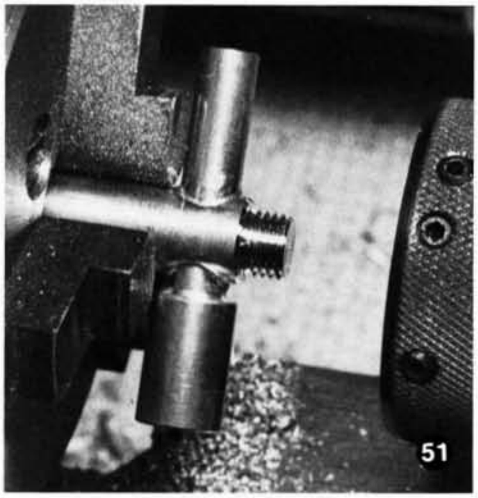

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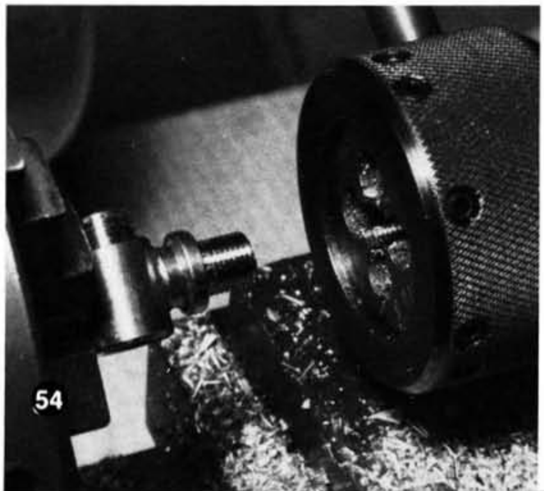

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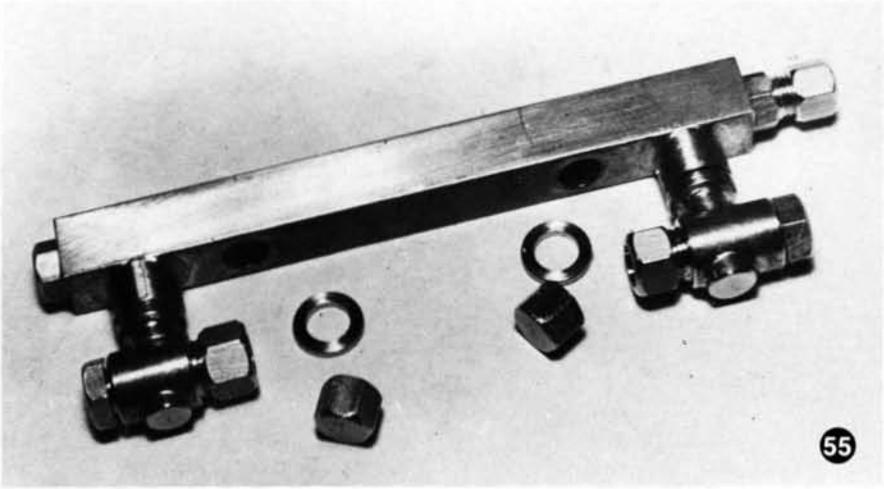

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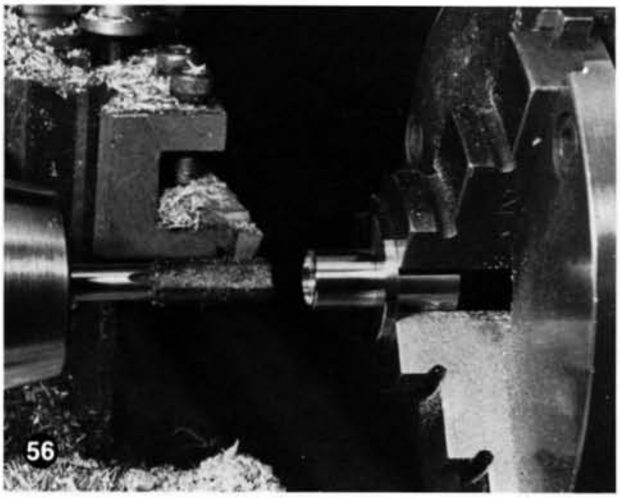

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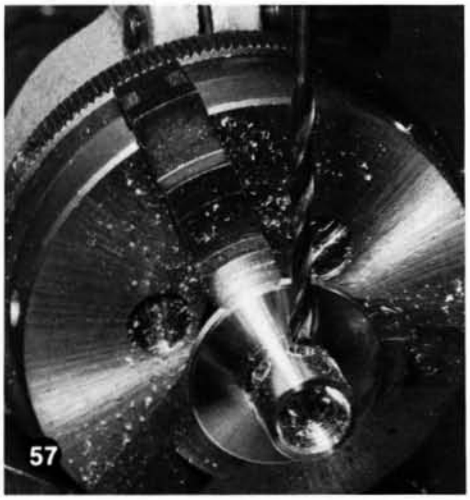

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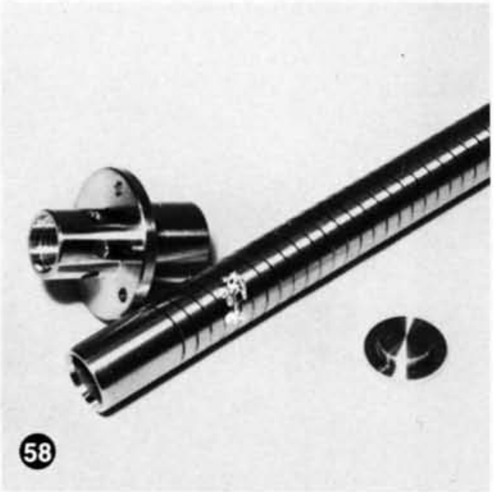

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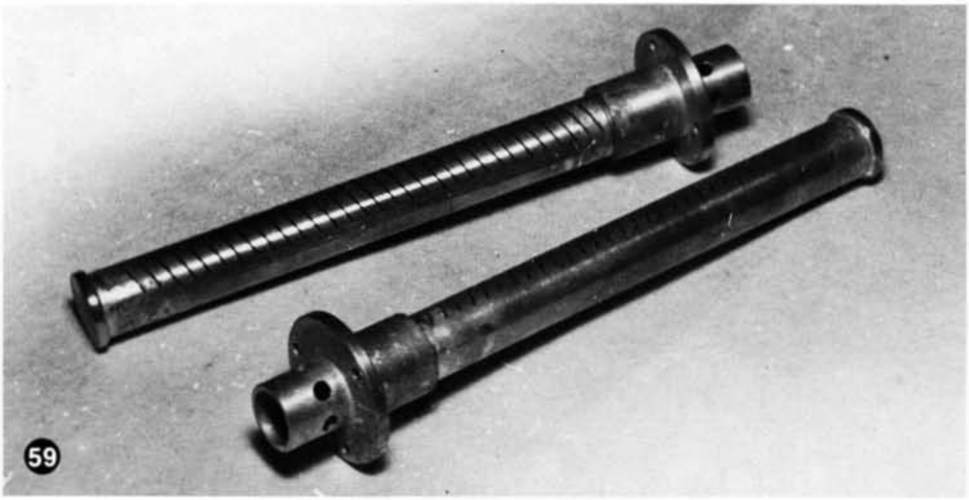

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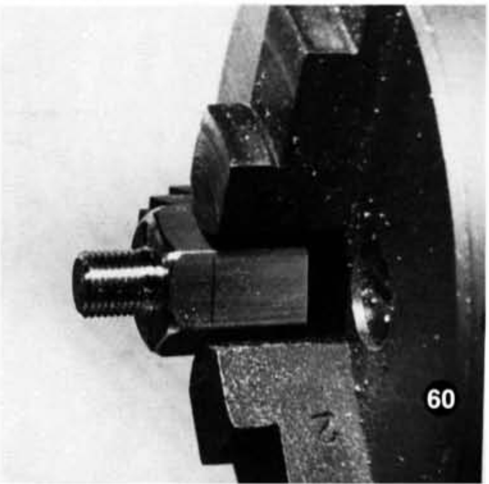

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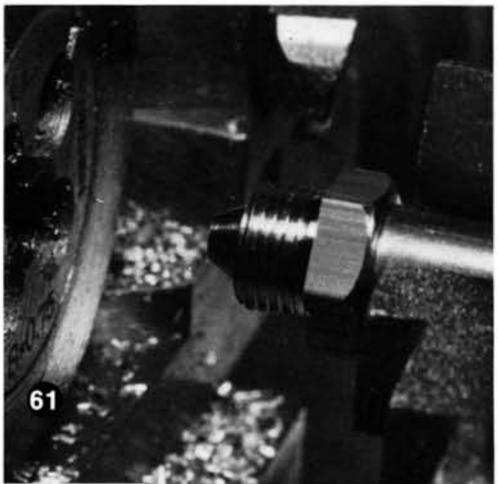

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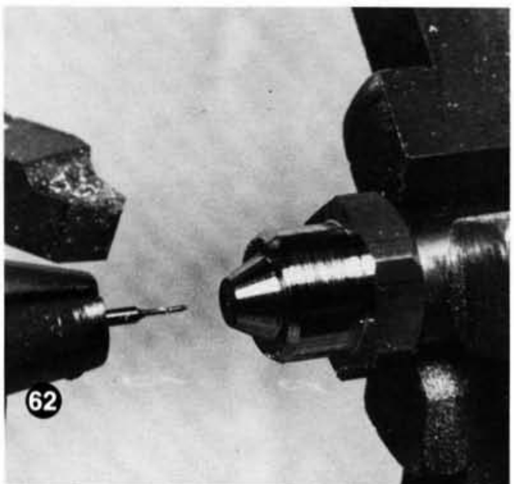

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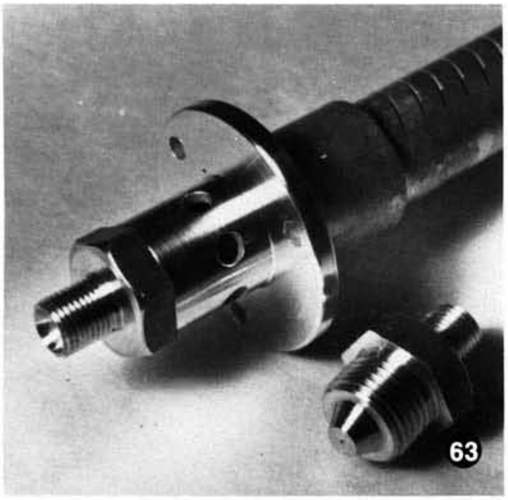
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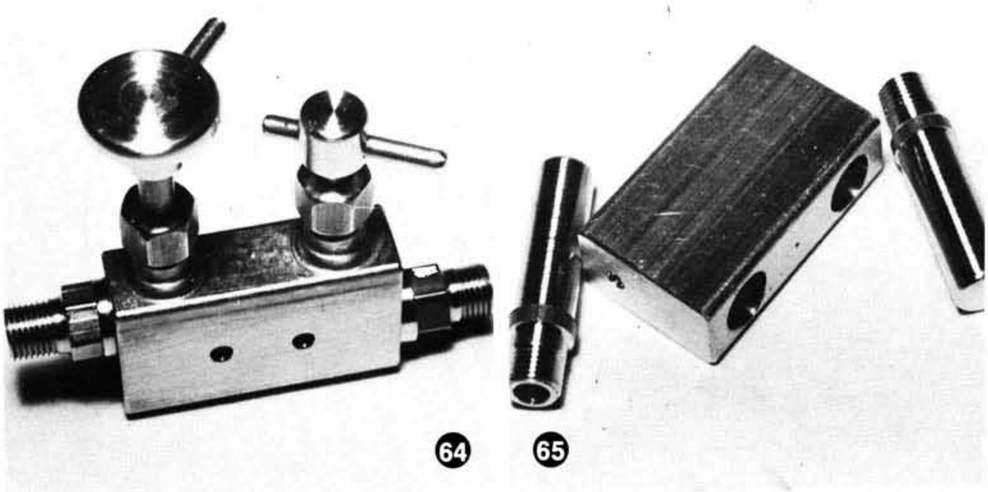
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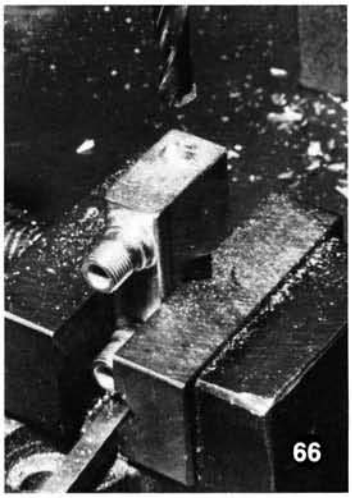
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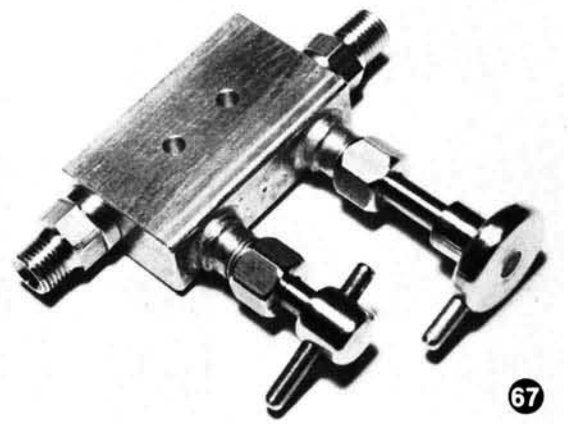
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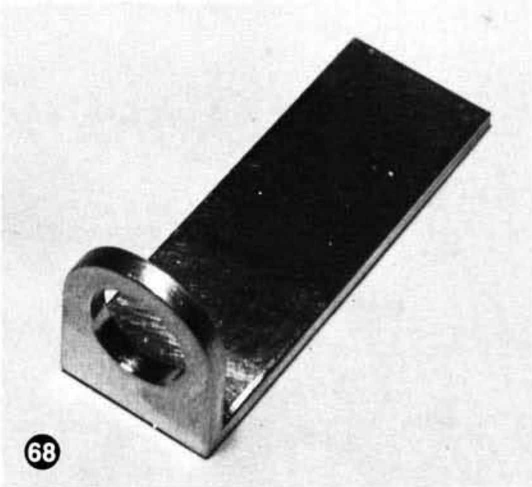
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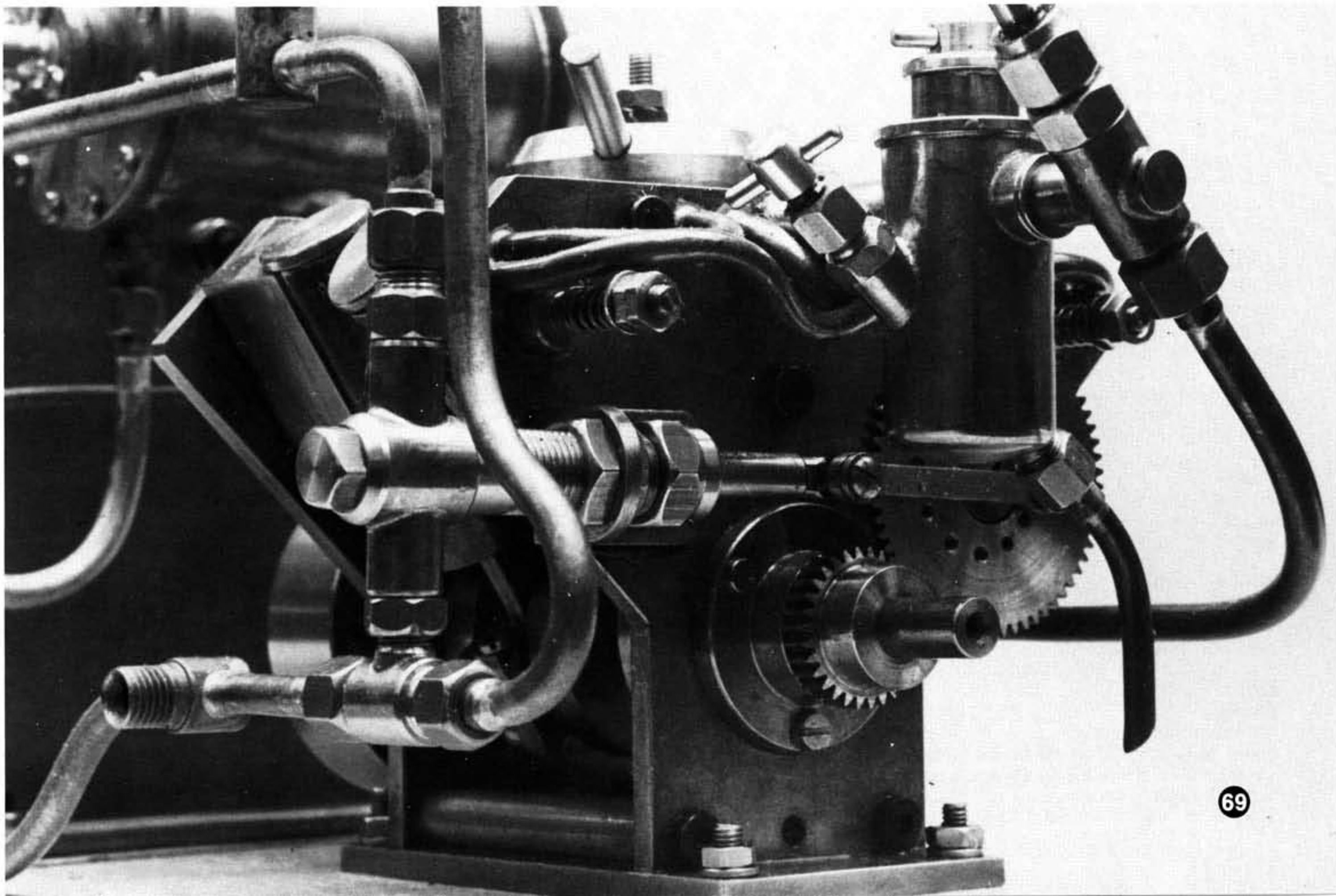
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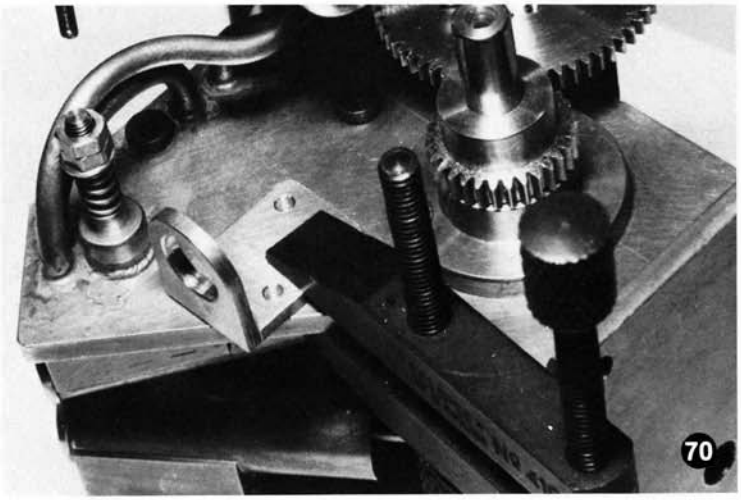
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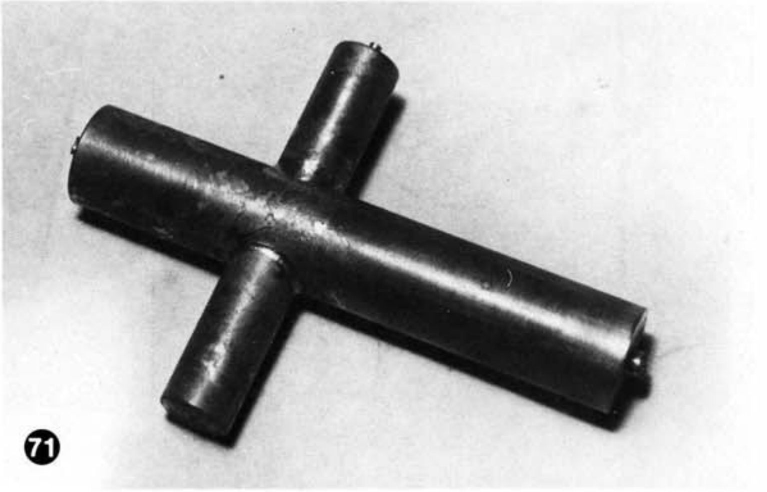

71

The **Valve Spindles (31D)** are made from 3mm diameter stainless steel. Turn down the outer 6mm to2mm diameter. Then use a fine-cut file to form the point. Polish the point with fine emery cloth. Thread M3 to 13mm from the tip. Part offto the required length and repeat forthe other spindle. Note that the two spindles are of different length.

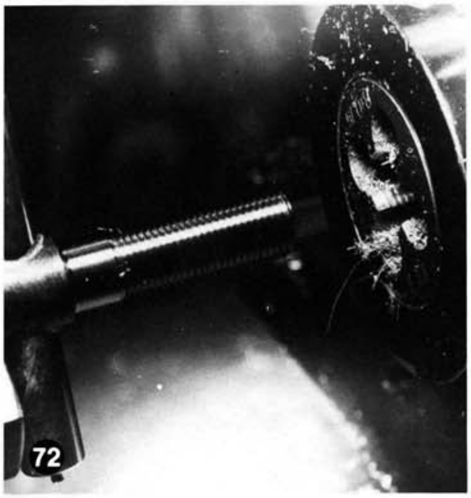
The handwheels are turned up from brass scraps. They are secured to the stems with Loctite. For additional secutiry, the pins go through the spindles.

Make the**Gland Nuts (31F)** from 6mm hexagonal brass stock. The packing can consist either of graphited yarn or plumber's teflon tape, twined to a string. Wind a few turns of it on the stem in the opposite direction to that of the gland's thread, tighten the gland nut and your burner valve is complete **(photo 67).**

The engine-driven **Feed Pump (29) (photo 69)** will feed water into the boiler whenever the engine is running, in either forward or reverse. It is geared to the crankshaft, running at half engine speed. The capacity of the pump can be altered by repositioning the connection rod in any of the tapped holes in the large gear, thus altering the throw of the ram. Further adjustment of the pumpoutputis made with the bypass valve. The drawings show metric gears of module 0.5 size, but any type of gear can be used, as long as they are of roughly the same size. Neither the number of teeth or the gear ratio are critical, as long as the gear ratio is in the neighborhood of 2:1.

First select the gears. The small one should have a boss for the setscrew and be a good fit on the engine shaft. If not, bore and ream and fit the setscrew. The large gear should also have a boss, 9.5mm long. Bore out and ream the boss to 6mm. If the gear's bore is already larger than that, fit a bushing to reduce the bore to 6mm. If needed, machine the gear to 2mm thickness. Part off a length of 6mm silver steel rod to the same length as the gear's total thickness and drill through it, 3mm diameter. Insert the stud in the gear and clamp to the engine's rear endplate with a tool-maker's clamp.

To obtain the proper mesh between the gears, puta piece of very thin paper between them before tightening the clamp. A piece of airmail paper will be about the right thickness. The exact horizontal location of the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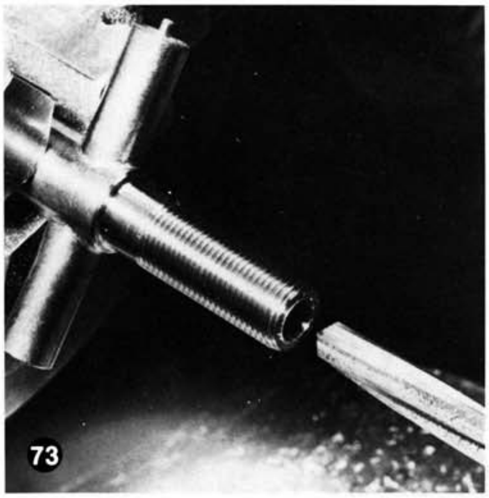
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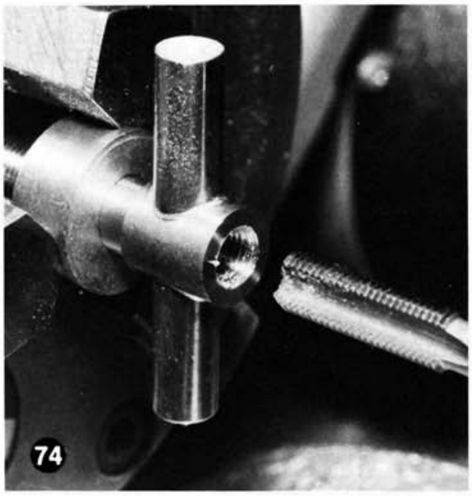
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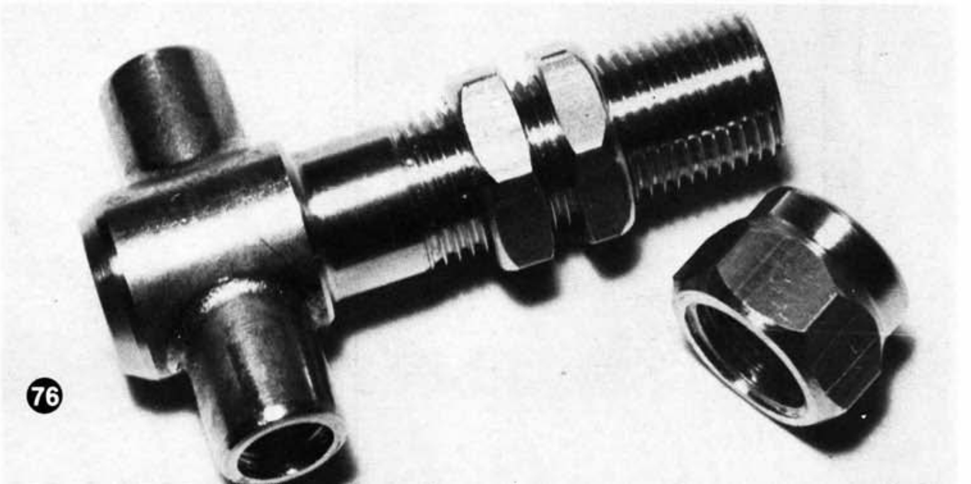
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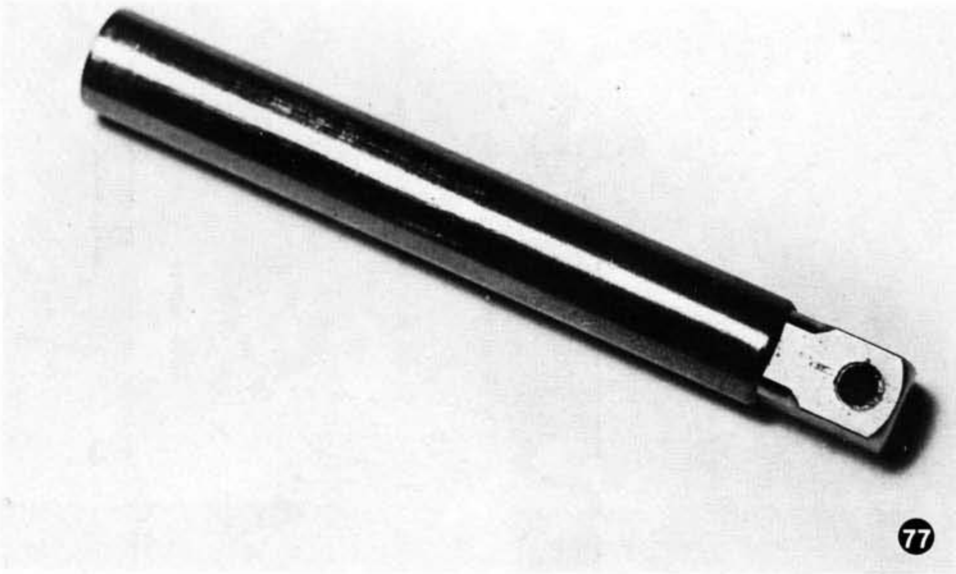

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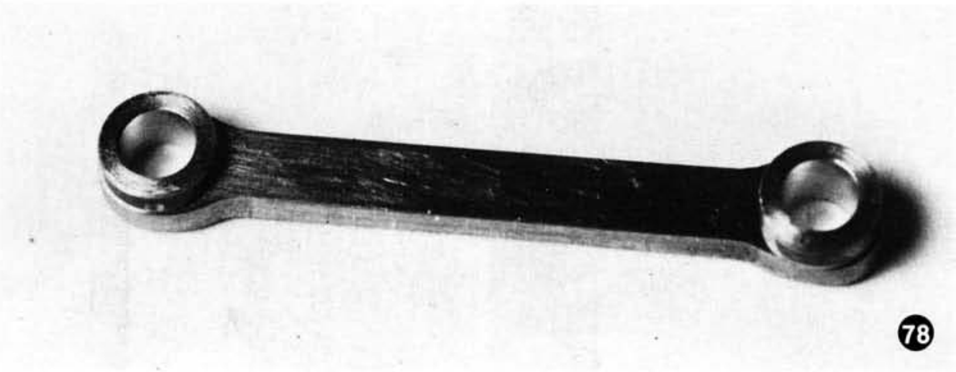

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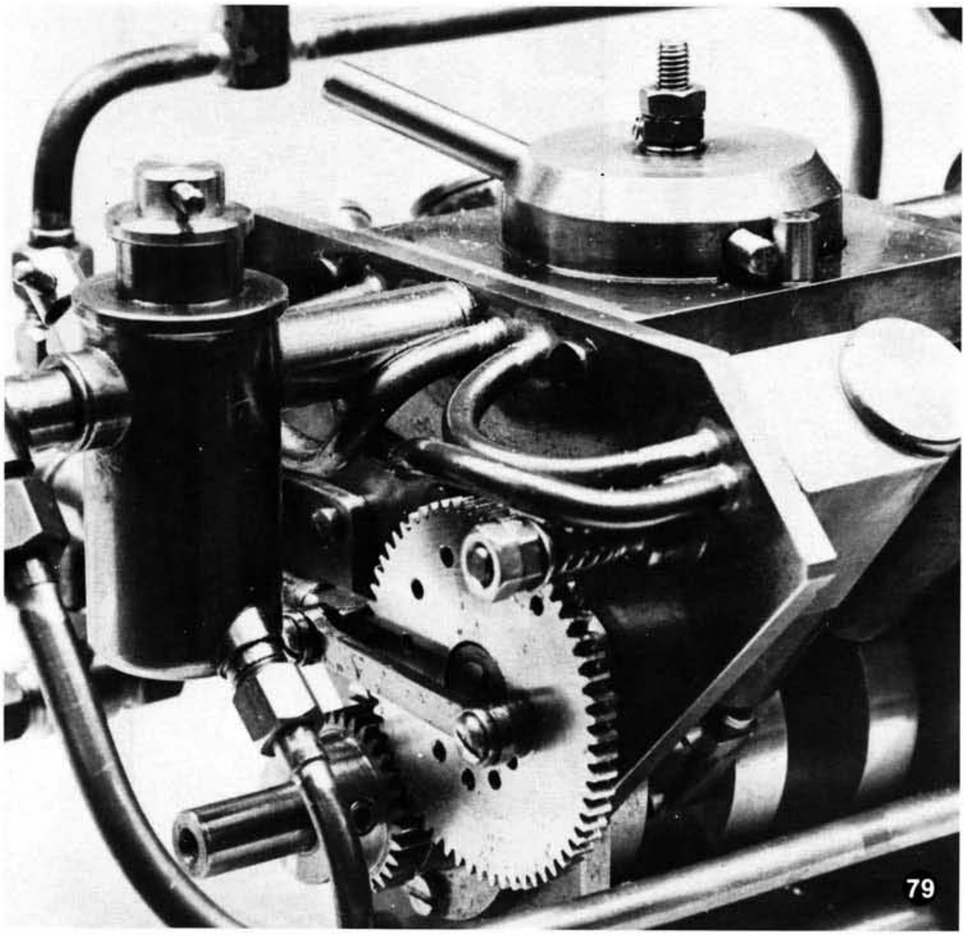


79

large gear is not critical; eyeballing will do. Tighten up the clamp and spot the screw hole, using a 3mm drill bit. Remove the gear and drill through the endplate, 2.5mm diameter. Tap M3. While drilling and tapping, stuff a wad of household paper behind the endplate to collect the chips.

Make the retaining washer from steel. The washer must be recessed in the gear in order to clear the connection rod, so turn the recess in the gear, 1mm deep. Shorten the stud correspondingly, also countersink it lightly at one end. Drill and tap the crankpin holes in the large gear. Their positions are not critical, the easiest way is to locate them by eye-sighting. In my photos, you will notice that there are more crank pin holes than indicated in the drawings. This is because the gear had been used previously for an experimental, long-stroke pump. When the holes have been tapped, mount the gear on its stud on the engine endplate.

Next comes the **Pump Bracket (29G) (photo 68).** It can either be sawn out of a piece of brass angle, or bent up from 2mm flat brass. If you do the latter, first cut a strip 13mm wide and about45mm long. The bend must have fairly small internal radius. Therefore, file ormill a bevelled recess at the line of bend, just leaving a small amount of metal to keep the pieces together, then bend 90° and silver solder. Trim to size, mark out and drill the holes. Round off the outer end of the short leg. Clamp the bracket to the engine rear end plate with a clamp and spot the mounting holes (**photo 70).** The bracket should be located on the same horizontal centerline as the large gear. Drill the mounting holes 1.7mm diameter and tap M2. Attach the pump bracket with M2 screws.

The **Pump Body (29A)** is made of brass or bronze rod. Part off a piece of 10mm rod to 50mm length. Drill a 7mm cross hole 30mm from one end. Put a 30mm long 7mm rod in this hole and silver solder (**photo 71).** After pickling and cleaning, grip the assembly in the three-jaw, by the shorter 10mm diameter end. Using a round-nose tool, turn down the outer end to 8mm diameter for 25mm length. Chamfer the end and thread M8 x 0.75mm. The thread should be 18mm long (**photo 72).** Center drill and drill all the way through, using progressively larger drills, to 3.9mm diameter. Ream 4mm diameter (**photo 73).** Reverse in the chuck. Use a tapped bush fixture to hold the cylinder, to avoid damaging the thread. Part off to final length and round off the corner. Drill out to 4.5mm diameter for 10mm depth and tap M5 x0.5mm (**photo 74).**

Now, grip the embryo pump cylinder by one of the 7mm diameter ends. Part off the projecting end at 12mm from the cylinder centerline. Center drill and drill to 5mm depth with a 4.5mm drill bit. Change to a 3mm drill bit and drill through into the cylinder bore. Tap the hole M5 x 0.5mm. Form the valve seat with a 4mm endmill, held in the drill chuck (**photo 75).** Reverse the pump cylinder in the chuck and repeat for the other end, the only difference being that no connecting hole should be drilled to the bore. Instead, drill two 2mm passages using a bench drill. This way, the valve ball cannot block the water entry to the cylinder.

Make the two **Nuts (29F)** and the **Gland Nut (29H).** The **Delivery Valve (29C)** is made of a piece of 7mm hex brass. The 60° taper at the top end is formed with a centerdrill. File the four notches at the bottom end; their exact form and size is not critical, their purpose, again, is to prevent the ball from blocking the water's passage.

The **Inlet Valve (29D)** is made by soldering together two pieces of brass rod in the same way as was done for the pump cylinder, the only difference being that the 10mm diameter rod should be 30mm long, with the crosshole in the middle. The machining is done much in the same way as that of the pump cylinder. Note that the top end should be faced after drilling and threading to provide a proper seat for the valve ball. Make a locknut (29E on the assembly drawing) from 7mm hex brass **(photo 76).**

The parts so far made can be assembled now. Put a 4mm stainless steel ball in the top (delivery) valve box. In order to form a seat for the ball, stand the pump cylinder on the work table, resting on the bottom valve box. Then hold a short piece of 4mm brass rod against the ball and give it a light, but distinct, blow with a hammer. Screw in the delivery valve. The ball should be able to lift about 0.8mm from its seat, so make a brass washer of the proper thickness required to obtain this goal.

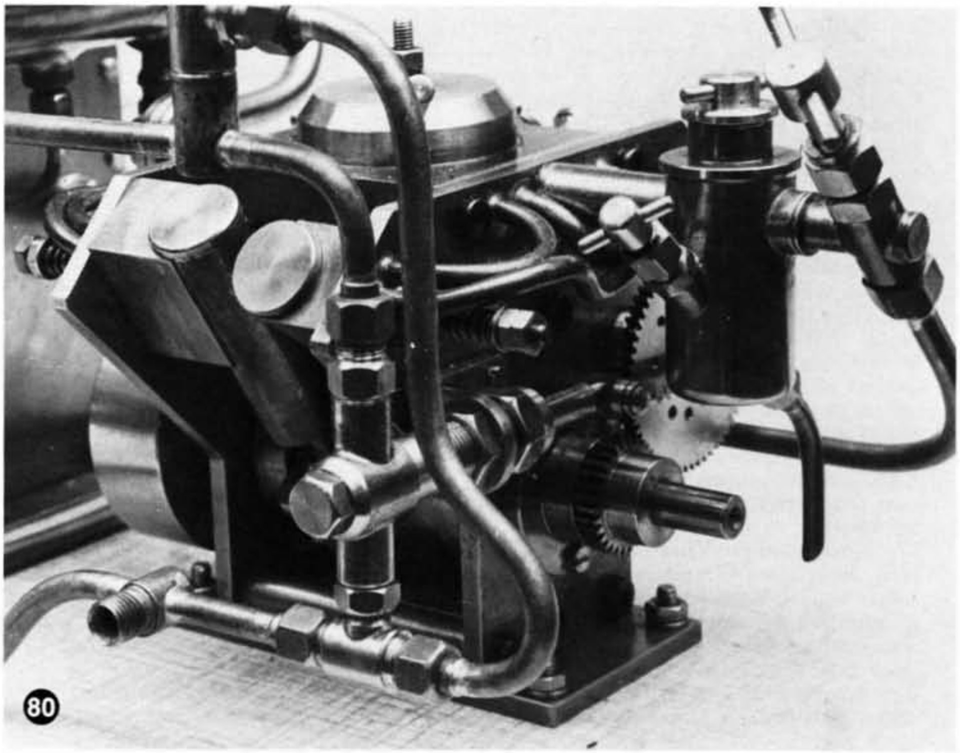
Install the inlet valve and ball. This ball can be seated by screwing the inlet valve hard up, until it bottoms on the ball, then backing off about one and a half turns, which will give the proper balllift. Finally, tighten up the locknut. Also, make the **Cap Screw (29B)** and fit it to the cylinder.

Next comes the **Pump Ram (29M)** which simply is a piece of 4mm stainless steel rod, turned down and threaded M3 at one end. It must be smooth and free from scratches, so polish it with a fine polishing paper. Make and fit the **Crosshead (29L).** Pump ram shown in **photo 77** differs slightly in proportions, as you may detect; my pump has a 5mm bore. As I found out, this gave the pump an unnecessarily large capacity, so I reduced the bore to 4mm in the drawings. Mount the pump cylinder in the pump bracket on the engine.

The **Connection Rod (29I),** is milled or, simpler, filed out of a scrap of 1.5mm mild steel or brass sheet. Drill the bushing holes first. Turn up the two phosphor bronze bushings and press them into the con-rod. Ream the bores after fitting them to the con-rod, as they will probably shrink a fraction due to the press fitting **(photo 78).**

Finally, make the two **Gudgeon Pins and Washers (29O).** The pins are short lengths of 3mm silver steel rod, drilled through 2mm diameter. Their length should be just a fraction over the width of the con-rod bushings. Then assemble the con-rod to the pump. Set the crank end in the hole in the gear wheel giving the shortest stroke **(photo 79).** Adjust the position of the pump cylinder in the bracket to give about 0.5mm clearance between the ram and the cap screw when the ram is fully in. Whenever the stroke of the pump is changed, this clearance must be adjusted to prevent the possibility of the pump becoming air-locked. Put a few turns of graphited yarn around the ram and tighten up the gland nut lightly; finger tight will suffice.

Your engine-driven pump is now complete **(photos 80 and 81),** requiring only the connection of plumbing to make it operational. Before we consider it finished, though, let's take a look at a couple of optional features.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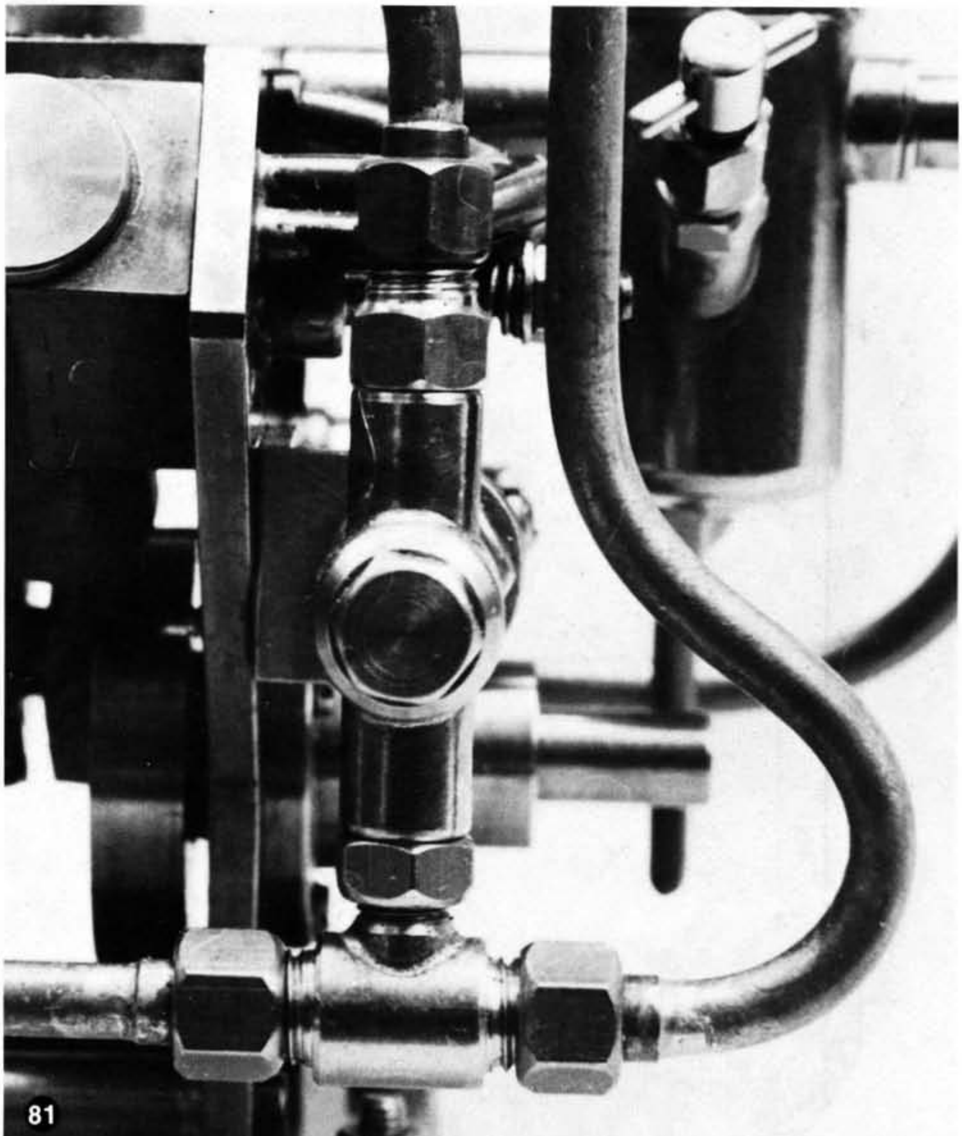

81

The **Hand Pump (30)** is an optional accessory, which is not needed for the power plant's function. It is, however, a very handy means of filling up the boiler from empty and for hydraulic testing of the boiler, which should be done from time to time. In a stationary plant it is also useful for keeping up the water level in the boiler if the engine pump should fail. In a ship model it will be a bit awkward to manipulate, but it will enable hydraulic testing to be done without removing the boiler from the hull.

The **Pump Stand (30A)** is made of two pieces of sheet brass, 1mm and 2mm thick, respectively, and silver soldered together **(photo 82)**. When riveting the 3mm thick spacer in place, put a 12mm diameter brass rod in the opening for the pump cylinder to obtain the proper space for the latter. Although not shown in the drawing, the base should have four 3mm holes for mounting screws.

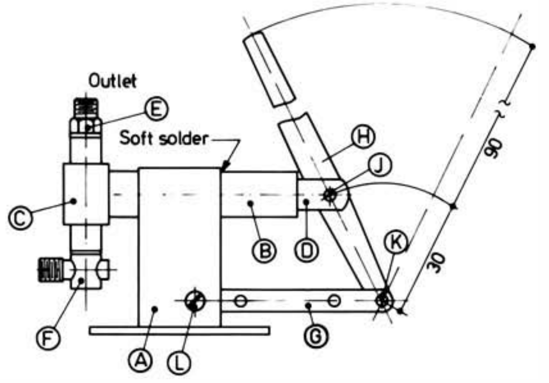
Next, make the **Valve Box (30C)** from 12 x 12mm brass. Cut off and face a piece to 30mm length. Mark out and center pop the position for the three bores. Set up in the four-jaw as shown in **photo 83.** Adjust the jaws until the center pop runs reasonably true. Center drill and drill to 10mm depth with a 3mm drill bit. Drill out to, say, 9.5mm diameter. Then bore to final size, using an internal boring tool **(photo 84).** Now, set the work lengthwise in the chuck and adjust the jaws until the center pop mark runs true. Turn down to 8mm diameter for 7mm length **(photo 85)**. Center drill and drill 4.5mm diameter to 6mm depth. Tap M5 x 0.5mm **(photo 86)**. Then drill through to the 10mm bore with a 3mm drill bit. Exchange the drill bit for a 4mm endmill. Feed it in 7mm to form the valve ball seat. Poke the 3mm drill bit through once again to remove the burrs.

Repeat for the other end of the valve box, only this time do not drill through to the center bore. Remove from the chuck and chamfer all sharp edges with a file and scraper. Drill the two communicating holes to the center bore with a drillpress and the valve box is completed.

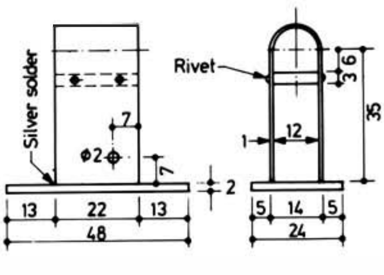
The **Cylinder (30B)** simply is a 6mm length of 12mm diameter bronze or brass rod, which is drilled through and reamed 8mm diameter **(photo 87)**. Turn down 10mm of one end to a press fit in the valve box and press the parts together **(photo 88)** in a bench vise. Should you miss the press fit, no harm is done, simply use Loctite to stick them together.

Drill the three communicating holes into the bore of the cylinder, then soft solder the cylinder to the stand **(photo 89)** (Of course, if the cylinder has to be Loctited to the valve box, this has to wait until after the soldering has been done, as the heat would destroy the Loctite bond.) The **Delivery Valve (30E)** and the **Inlet Valve (30F)** are very similar to their counterparts on the engine pump, so I will save repeating a description of their manufacture. Likewise, their valve balls should be seated in the same manner.

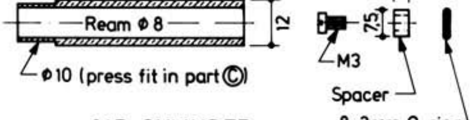
For the **Pump Ram (30D)** a piece of 8mm diameter stainless steel rod is needed. Part off to 72mm length. Turn down one end to 4mm diameter, 6mm length. Drill 2.5mm diameter to about 8mm depth and tap M3. The cross drilling and slotting of the other end should be done at the same set-up in the Unimat (as a vertical milling machine) to make sure that the cross hole is at right angle to the slot. Use a slitting saw for cutting the slot. As a 3mm wide cut in stainless steel will be a bit on the heavy side for the Unimat, a thinner saw, say, 1.5mm can be used and the slot be made in several cuts. When finished, remove all sharp edges and polish the ram with fine polishing paper. Make the spacer from brass and fit it and the O-ring to the ram **(photo 90)**. The length of the spacer may need some adjust-



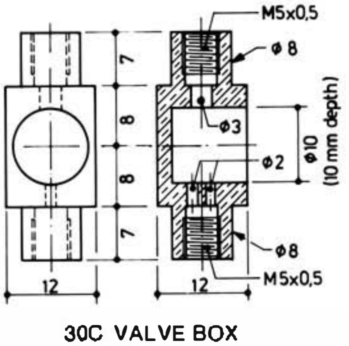
30 HAND PUMP



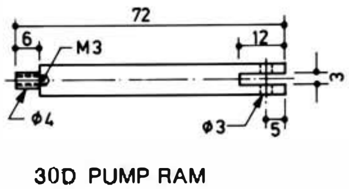
30A PUMPSTAND
Brass, 1 required



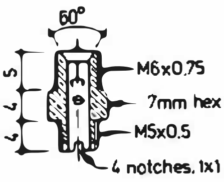
30B CYLINDER
Brass, 1 required



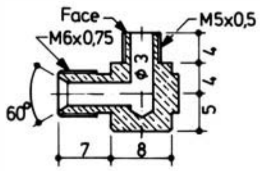
30C VALVE BOX
Brass, 1 required



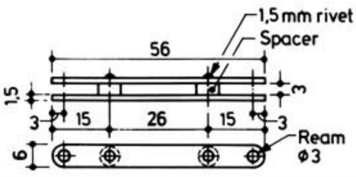
30D PUMP RAM
8mm dia. Stainless Steel, 1 required



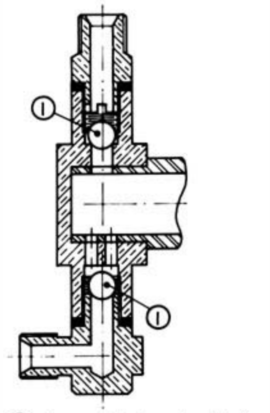
30E DELIVERY VALVE
Brass, 1 required



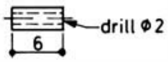
30F INLET VALVE
Brass, 1 required



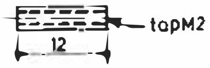
30G LINK
Steel, 1 required



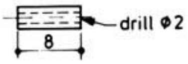
(1)=4mm stainless steel balls



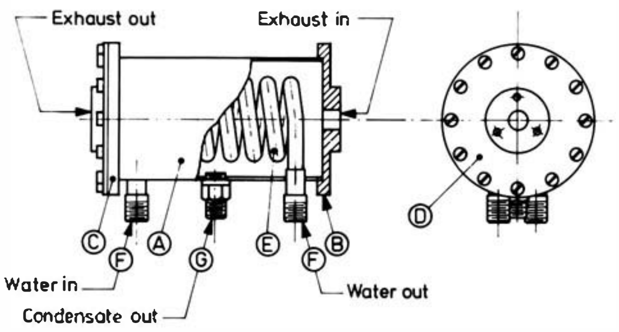
30K PIN
3mm dia. Silver Steel,
1 required



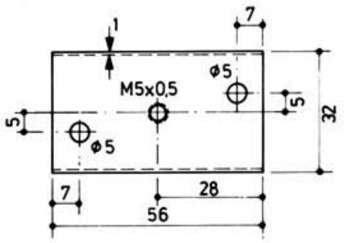
30L PIN
3mm dia. Silver Steel,
1 required



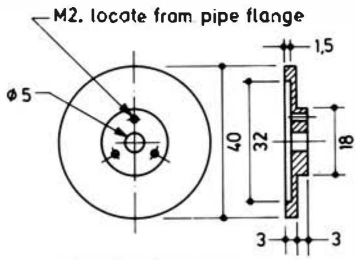
30J PIN
3mm dia. Silver Steel,
1 required



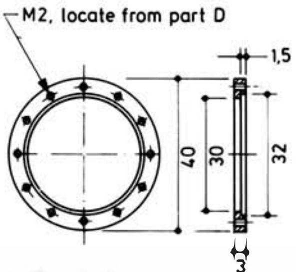
32 EXHAUST STEAM FEEDWATER HEATER
1 required



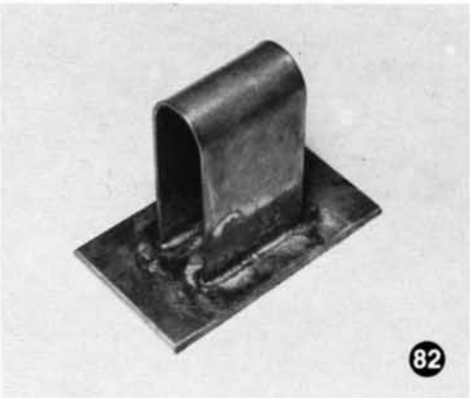
32A BARREL
Brass, 1 required



32B END PLATE
Brass, 1 required



32C END FLANGE
Brass, 1 required



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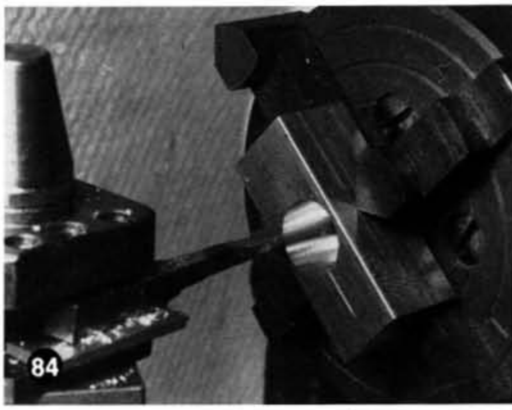

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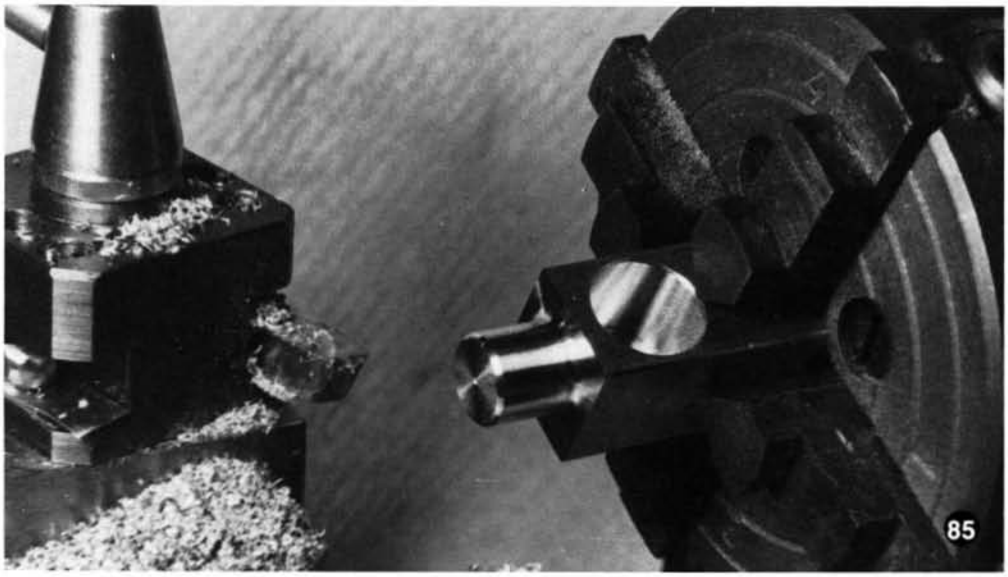

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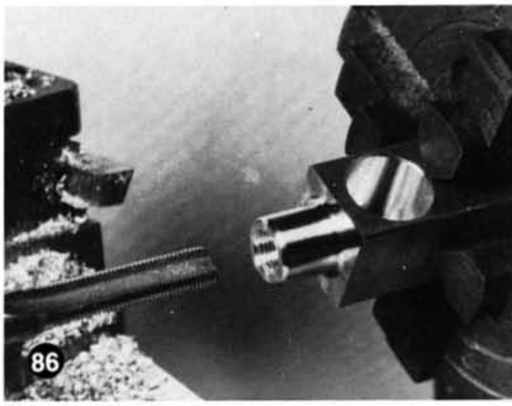

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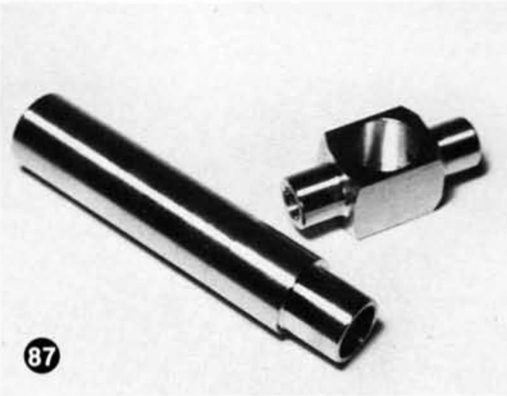

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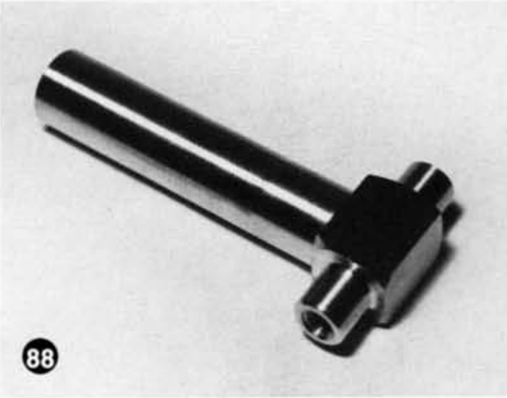

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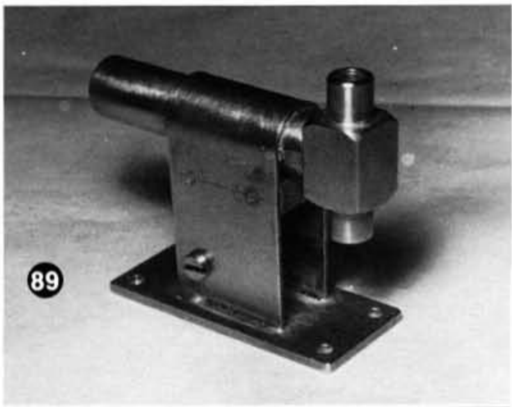

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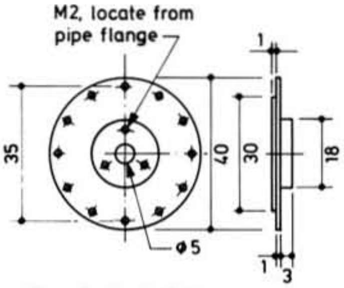
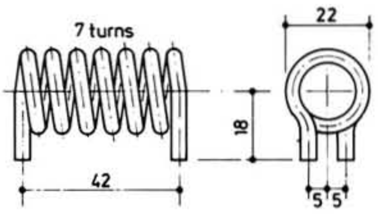
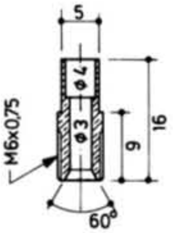


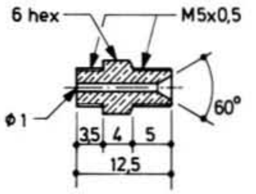
32D END PLATE
Brass, 1 required



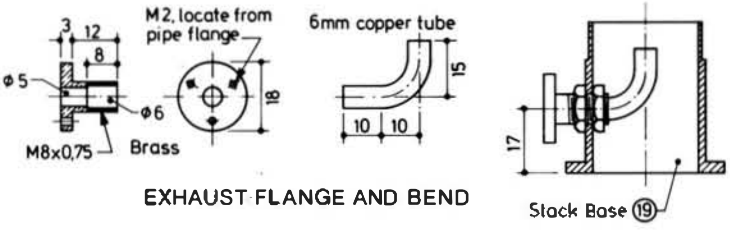
32E WATER TUBE COIL
4mm Copper Tube,
1 required



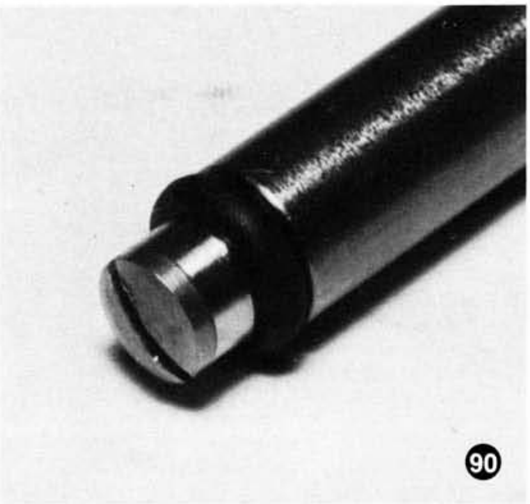
32F WATER CONNECTION
Brass, 2 required



32G DRAIN CONNECTION
Brass, 1 required



EXHAUST FLANGE AND BEND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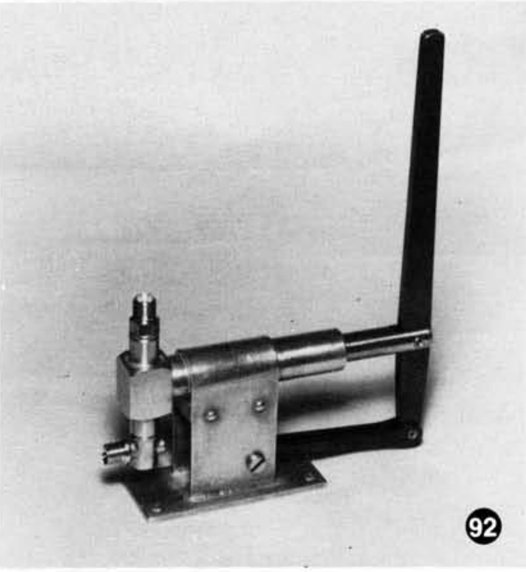
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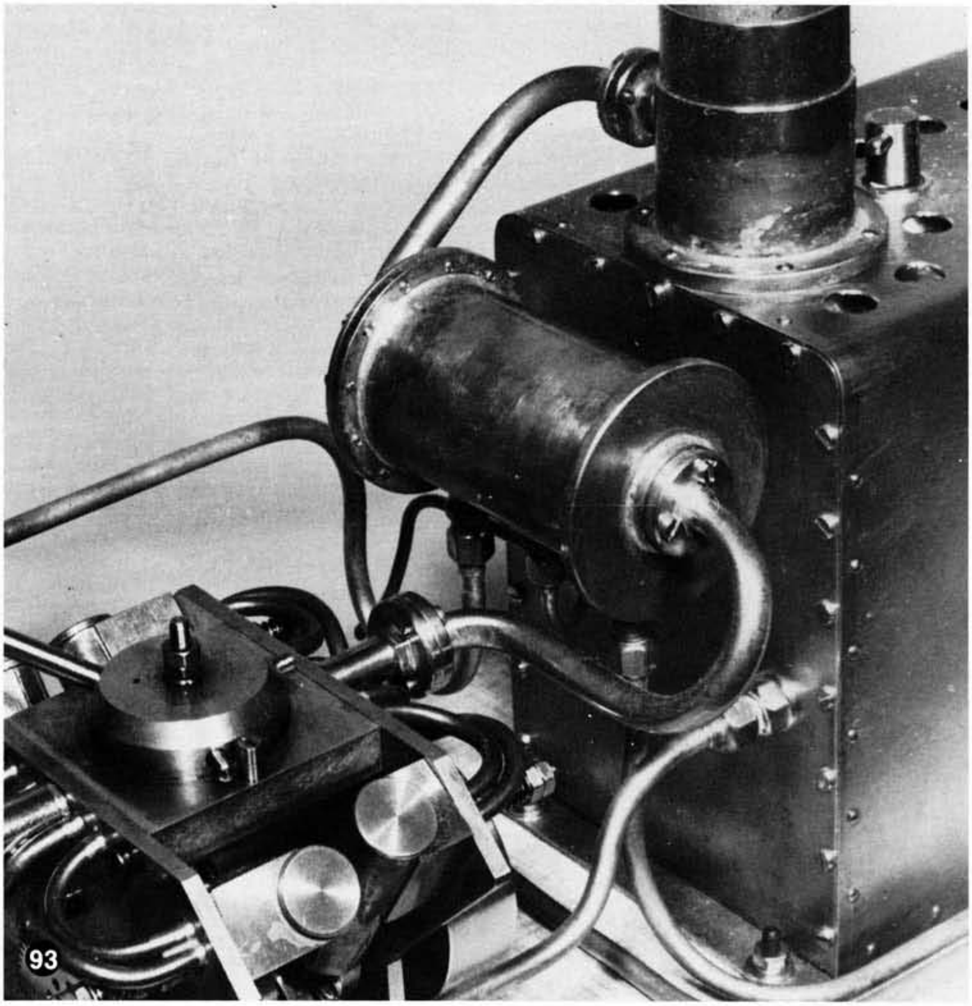
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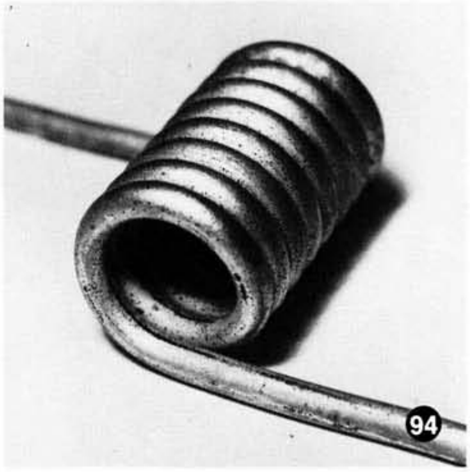
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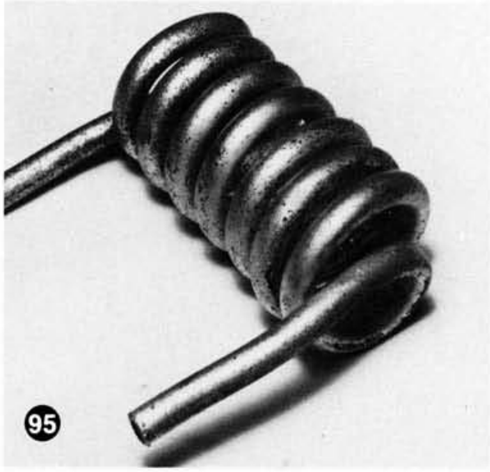
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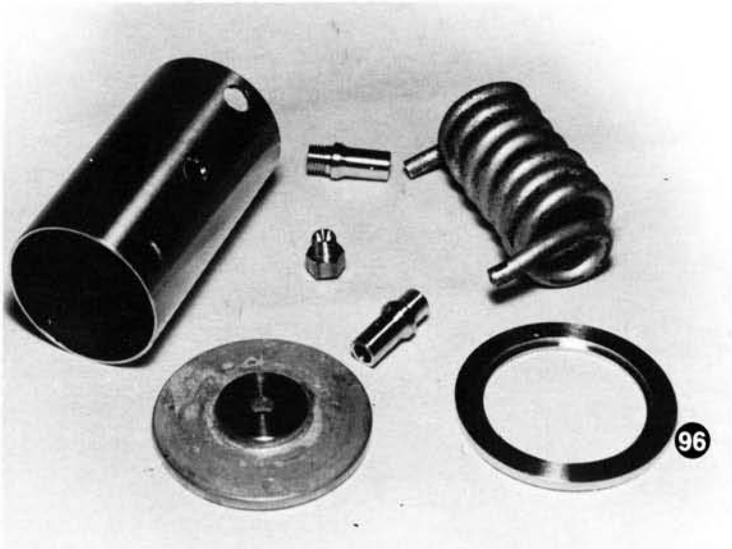
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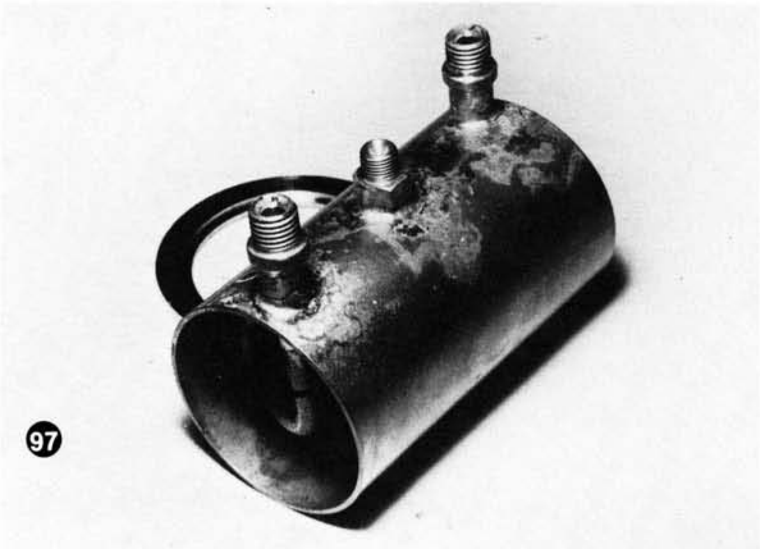

97

ing, until it squeezes out the O-ring to a proper fit in the cylinder bore.

The **Link (30G)** is made from scraps of 1.5mm thick sheet steel or brass. Clamp them together when drilling the holes. Also, make the two spacers, and rivet the parts together. Actually, I did not follow my own drawings here, as might be seen in **photo 91.** I milled the link out of solid steel, just for the fun of it.

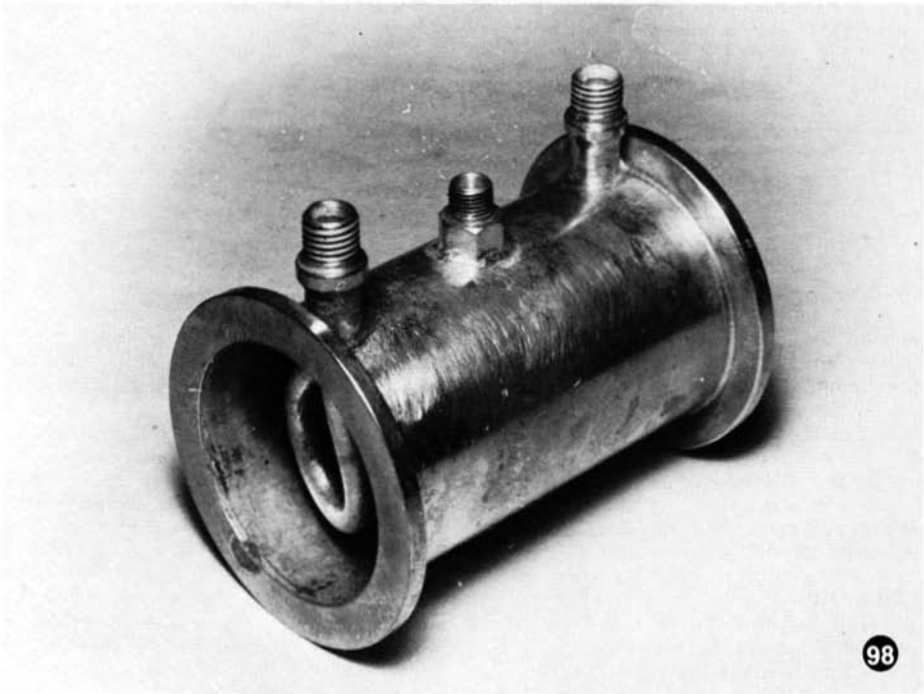
Saw and file the **Handle (30H)** out of 3mm steel or brass. Ream the pin holes 3mm diameter. If the link and handle are made of steel, they can be protected from rusting by blackening them, either with chemical gun blue or by heating and dipping in oil.

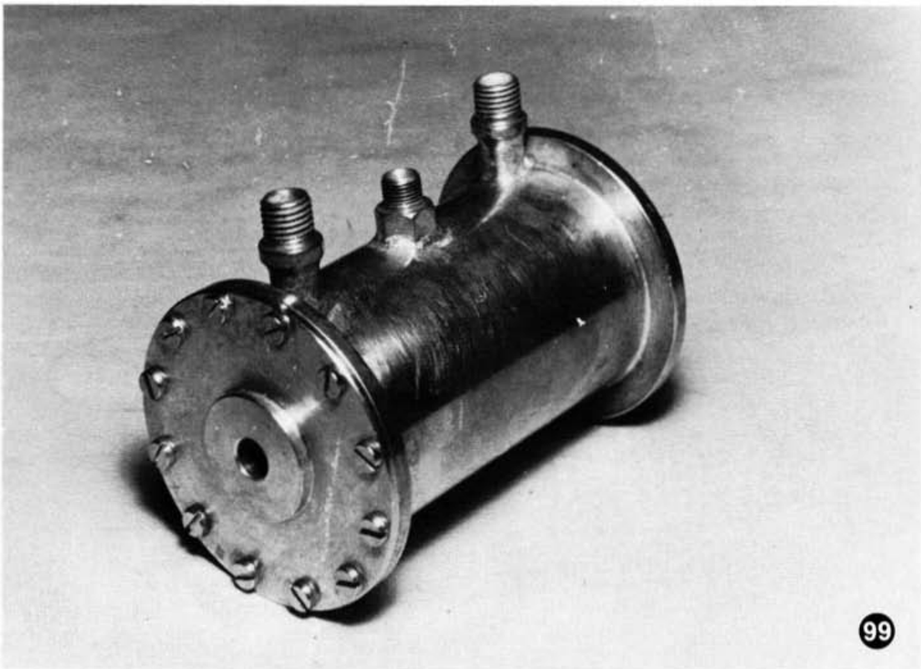
Finally, make the three **Pins (30J, K and L)** from 3mm diameter drill rod. Assemble the pump **(photo 92)**. The two short pins are kept in place by expanding their ends, using a center punch in the holes drilled through them.

The **Exhaust Steam Feed Water Heater (32) (photo 93)** is a purely optional item since the engine will run equally well without it. If you are in a hurry, you may wish to delete it, or add it later on. It will, however, increase the boiler's steam-raising capacity slightly, and save a small percent on fuel. My reason for including it is more ecological than economical. It will separate most of the oil and condensed water from the exhaust. This is very desirable if your plant is to be used to power a model ship, as it will otherwise leave an oil film in its wake and also shower itself with oil and water droplets. Besides, it is very simple to make, so take your choice.

The first part on the agenda is the **Barrel (32A).** It is a 56mm length of 32mm copper or brass tube, 1mm wall thickness. Its diameter can, of course, be varied within reason, to suit whatever material is on hand, only remember to adjust the dimensions of the end plates accordingly. Square up the ends of the tube in the lathe. Markout and drill the holes. Wind up the **Water Tube Coil (32E)** thin-walled copper tube. Anneal the tube, and fill it well with fine sand to prevent flattening. Wind it around a 14mm rod in order to get the proper diameter of the coil **(photo 94).** Note the direction of the winding. Again, anneal the outer ends of the coil, bend to proper shape, trim to length and shake out the sand **(photo 95).** Deburr the ends.

Make the **Water Connections (32F)**





from brass rod. They should fit stiffly in their holes in the barrel.

The **End Plates (32B and D)** and the **End Flange (32C)** are turned up from 40mm diameter brass rod. Spot the twelve screw holes near the periphery of 32D with the aid of the dividing head. Do not drill the screw holes in the end flange yet; that is better left until after the parts have been soldered together. Also, leave the screw holes for the pipe flanges until the plumbing stage. Make the **Drain Connection (32G)** and a washer for it. (The latter is only shown in the assembly drawing.) You now have the parts shown in **photo 96**, ready for silver soldering together.

Assemble the parts, except the end flange and the end plates, apply flux on all joints, including those between the water tube coil and the water connection fittings. Silver solder all joints in one heat, then pickle and rinse (**photo 97**). Then attach the end flange and the end plate and solder them to the barrel. When doing this, the previously-soldered joints should be protected by flux, in case they might be melted again. Pickle again, this time for at least ten minutes and rinse thoroughly (**photo 98**).

Now, clamp the loose end plate to the end flange and drill the screw holes, 1.7mm diameter. Remove the end plate and tap the holes in the flange M2. Attach the end plate to the feed water heater with M2 screws. To make sure that the joint will be leak-free, apply some plumber's jointing compound to it before putting the parts together. The exhaust feed water heater is now completed (**photo 99**) and can be put aside, awaiting the plumbing stage.

While we are in this area we might as well finish off the **Exhaust Flange and Bend.** This item will be needed only if you decide to let your engine exhaust up the stack. The alternative is to run a separate exhaust pipe parallel to the stack. Anyhow, the exhaust flange is a simple thing to make, needing no further description (**photo 100**).

The **Bypass Valve (33)** is used to regulate the amount of water forced into the boiler by the engine feed pump. It is set to maintain a steady water level in the boiler, the pump's excess discharge being bled back to the inlet side of the pump.

The **Valve Body (33A)** is made of two pieces of brass rod, silver soldered together. First, part off a piece of 8mm diameter rod, say, 30mm long. Drill a 6mm diameter cross hole, 9mm from one end. Then part off a 6mm diameter rod to 30mm length. Insert this in the hole in the thicker rod and adjust until it protrudes equally on both sides. Silver solder in position. Grip the valve body by the longer 8mm diameter end in the three-jaw. Face the other end until it extends 8mm from the soldered joint. Center drill and drill to 13mm depth, using a 4.5mm drill bit. Change the drill bit to 2mm and drill through. Chamfer the entrance to the hole slightly and tap M5 x 0.5 to 6mm depth.

Reverse the valve body in the chuck and part off to the correct length, 21mm. Do this carefully, as there is not much to grip on. Then turn down to 6mm diameter for 5mm length. Chamfer the end and thread M6 x 0.75.

Now grip the valve body by one end of the 6mm rod. Face the outer end until it sticks 10mm out from the body (14mm to the centerline). Center drill and drill through to the other hole with a 3mm drill bit. Thread the outside M6 x 0.75 for 6mm length and put in the 60° cone.

Make the **Gland (33B)** and **Gland Nut (33C)** from 7mm hex stock. These call for no further description.

The **Valve Spindle (33D)** is made from a piece of 3mm diameter stainless steel rod. Be careful about the length of the thread. Make the handwheel of brass and secure it with a drop of Loctite. Drill a cross hole of 2mm diameter and fit a handle of 2mm diameter drill rod. It, too, could be secured with Loctite.

Note that I have filed away the stub left by machining away the chucking spigot opposite the outlet. It makes the valve look a bit neater.

The exact length and routing of the various pipes will, of course, depend on the engine and boiler room layout if the plant is to be used for marine work. The hand pump and the burner control valve can be positioned wherever convenient. Even if your plant is to end up in a ship's hull, it will simplify the plumbing work if you mount the engine and boiler temporarily on a piece of board, preferably faced with Formica or some other water-resistant surface. The boiler and engine should be located in the same relative positions as they will have in the hull.

Make the flanges for the exhaust pipe. Four will be needed, three **Exhaust Flanges** and one **Engine Exhaust Flange,** if you have made the exhaust feedwater heater. Drill the screw holes in the dividing head. Fill a 6mm copper pipe of, say, 0.5m length with fine sand and anneal it. Bend to form the pipe connecting the engine to the exhaust feed water heater. Several annealings will be necessary. When satisfied with its shape, cut and trim to size. Silver solder the flanges to it. Note that the screw holes in the flanges should be so oriented that they are accessible (**photo 101**). Drill the corresponding screw holes in the engine exhaust flange and the feedwater heater and tap M2. Install the feedwater heater in place, then make and install the exhaust pipe between the feedwater heater and the stack base (**photo 102**).

Now, make all the required **Union Nipples and Union Nuts (photo 103).** These components lend themselves to mass production (**photos 104, 105, 106 and 107**).

The pipe from the engine pump to the feedwater heater is made of two pieces of 4mm copper tube. Make the right-angle bend in the shorter piece first, then silver solder to the **Bypass valve socket**. Trim the pump end of the pipe to length, then solder on the union (not forgetting to slip the union nut on first).

Bend the feedwater heater end of the pipe to shape, trim to length and attach its union and nut. Pickle and wash carefully, and it is ready to install (**photo 108**).

The bypass valve now can be installed. A washer may be needed under it in order to orient its outlet properly. Make and install the return pipe between the valve and the pump inlet valve.

Next comes the pipe between the engine pump inlet valve and the hand pump inlet valve. This pipe has a supply connection near the engine pump. It is also made of 4mm copper pipe.

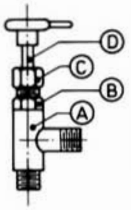
The output from the exhaust feedwater heater is connected to the boiler feedwater heater (**photo 109**), running parallel to the hand pump supply pipe. Then make the short pipe connecting the boiler feed water heater with the feed valve (**photo 111;** also seen in **photo 109**). As this pipe has sharp bends, it needs filling with sand during forming. Also, make and fit the pipe from the hand pump to the other feed valve.

The pressure gauge is connected by a 2.4mm copper pipe, which also supports it. It is important that this pipe has an S-bend in it, where condensate will collect and protect the gauge from direct contact with steam.

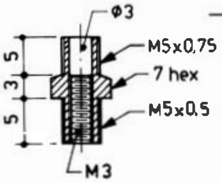
The drain outlet of the feedwater heater should be connected to a drain tank when the plant is installed in a hull. For test running, it is sufficient to make up a short length of 3mm copper tube to bring the condensate to the side of the plant, where it can be collected in a small can.

The superheater is connected to the throttle valve by a 4mm copper pipe (**photo 110**).

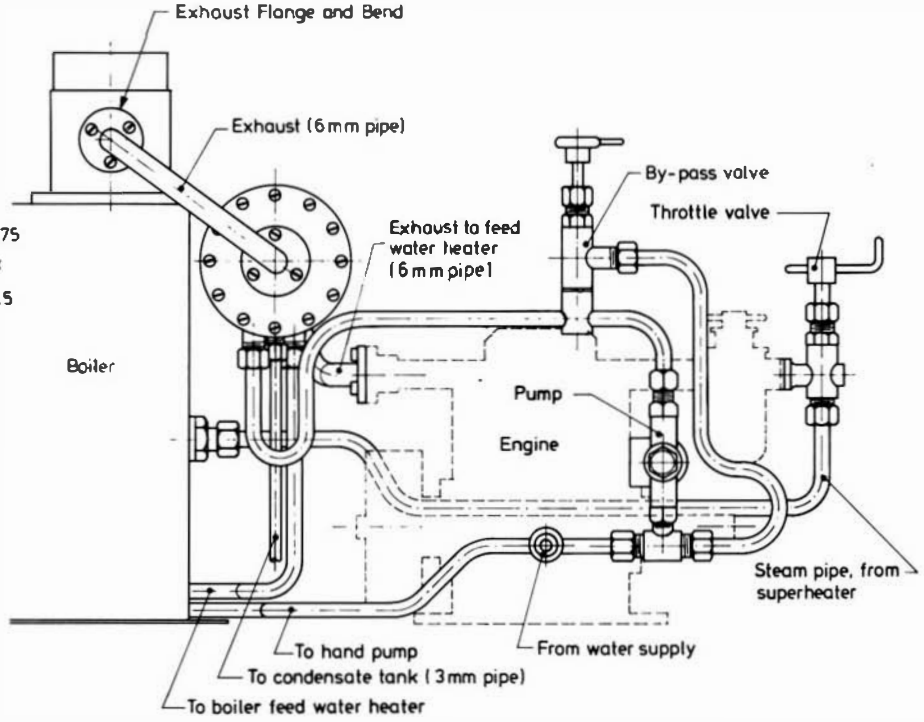
100



33 BY-PASS VALVE

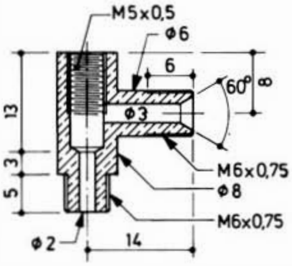


33A VALVE BODY
Brass, 1 required

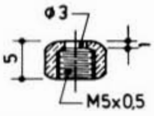


Note: all pipework 4mm copper tube unless otherwise specified

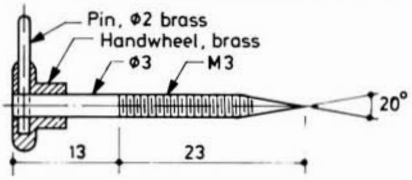
ENGINE PUMP PIPEWORK



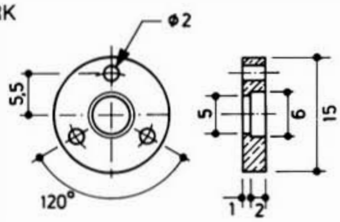
33B GLAND
Brass, 1 required



33C GLAND NUT
Brass, 1 required

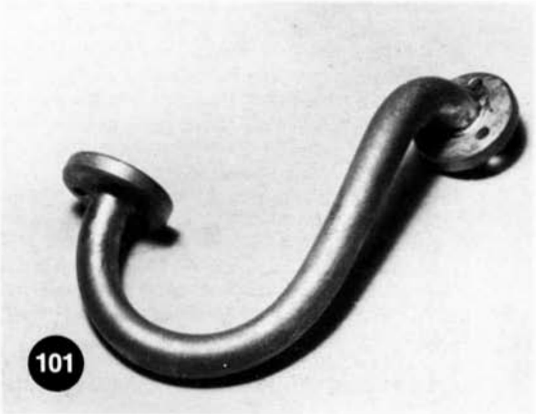


33D VALVE SPINDLE
Stainless Steel, 1 required



ENGINE EXHAUST FLANGE
Brass, 1 required

The final pipe work is that feeding the burners. It is all done with 3mm copper pipe. The **Fan-out Fitting** between the valve and the burners is made of a small block of 6mm square brass, drilled out to take the three pipes. The complete pipe is shown in **photo 112.** Make the pipe connecting to the control valve as long as will be needed in your boiler room layout; the excess can be coiled up temporarily when testing, as in the photos. The same applies to the pipe between the gas container and the control valve. I have not specified the connection fitting for the gas container end of the pipe, as that will depend on the kind of gas



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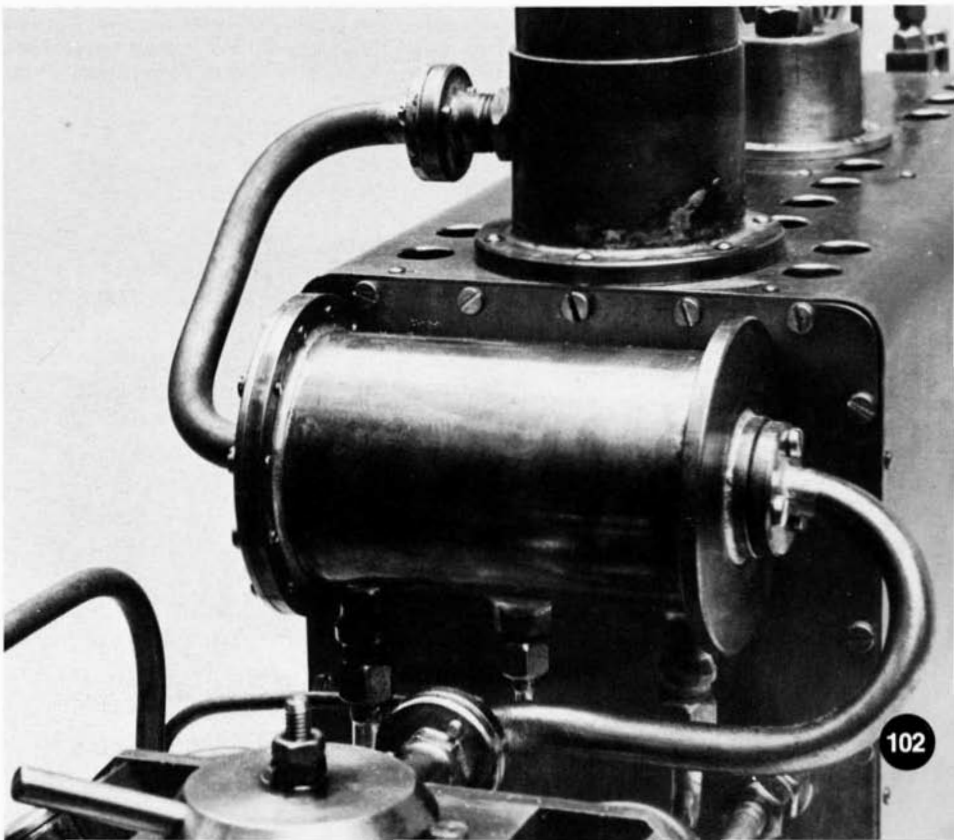

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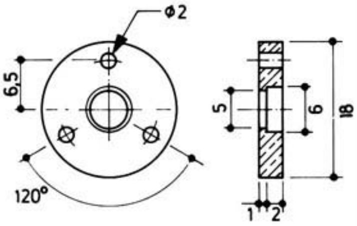
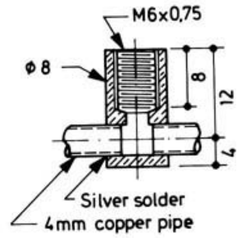
container. For marine work, the disposable type is preferred, because of its much lower weight. The gas used should be Butane, as the burner orifices are dimensioned for that. If you should want to use Propane gas, orifices with much smaller bores have to be substituted, as that gas has much higher pressure.

The miniature pressure gauge shown in the photos is a commercial item, the only ready-made part used in the steam plant. Ideally, it should have a range of 0-60 psi. Not being able to locate such a range, I fitted one reading 0-120 psi.

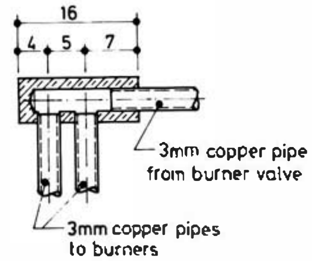
Before the steam test, a second hydraulic test should be made with all boiler fittings except the safety valve in place. Remove the safety valve. Also, remove the steam pipe at the superheater union and fit a cap nut in its place. Do the same with the pipe from the exhaust feedwater heater, at the boiler feedwater heater. Make a fitting which will take a plastic tube and fit on the water supply fitting at the engine pump. Put the other end of the plastic tube into a can of clean water and fill the boiler completely by operating the hand pump. Now fit your test pressure gauge in place of the safety valve. Again, operate the hand pump to raise the pressure to twice the working pressure, 60 psi or 4.2 kg/cm^2. If there are no leaks in the armature fittings, an occasional stroke on the pump will suffice to keep the pressure for a few minutes. If, on the other hand, a leak is found, the boiler will have to be emptied and the leak attended to. Use plumber's teflon tape or jointing compound to cure leaking threads, preferably the former on threads which will have to be taken apart for installation or maintenance. When satisfied with the test, the boiler has to be partly emptied for the steam test. This has to be



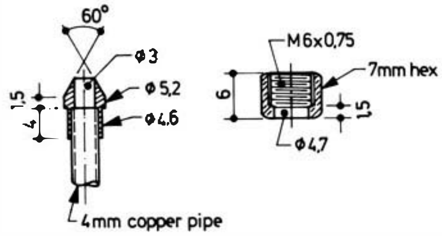
EXHAUST FLANGE
Brass, 3 required



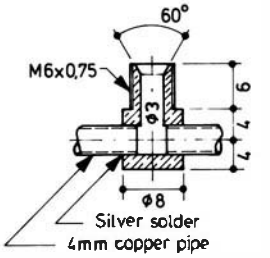
BY-PASS VALVE SOCKET
Brass, 1 required



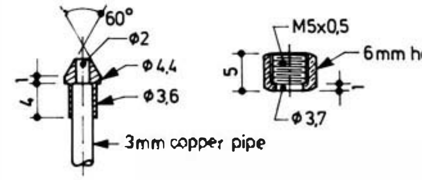
GAS PIPE FAN-OUT FITTING
Brass, 6 x 6mm, 1 required



UNION NIPPLE AND UNION NUT
M6 x 0.75, Brass, 14 required each

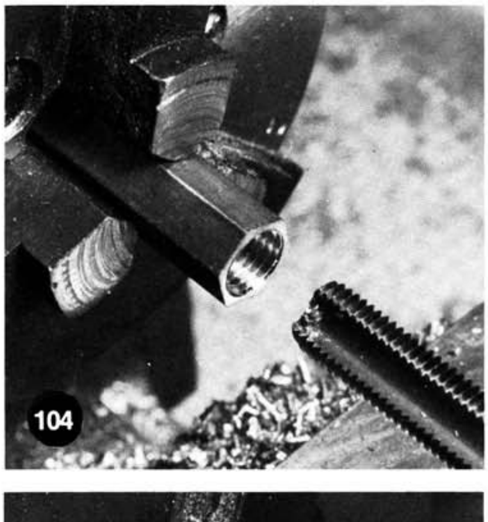


FEED WATER CONNECTION
Brass, 1 required



UNION NIPPLE AND UNION NUT
M5 x 0.5, Brass, 5 required each


103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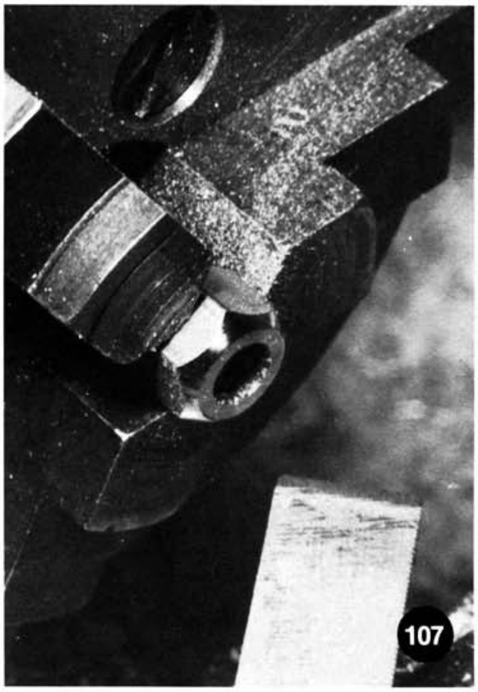
106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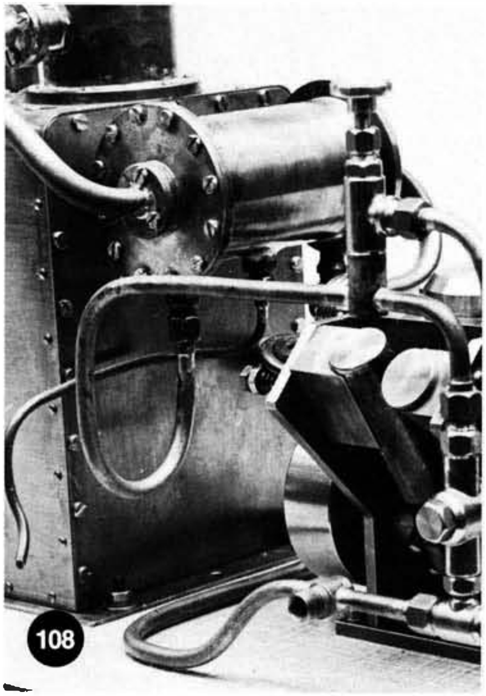

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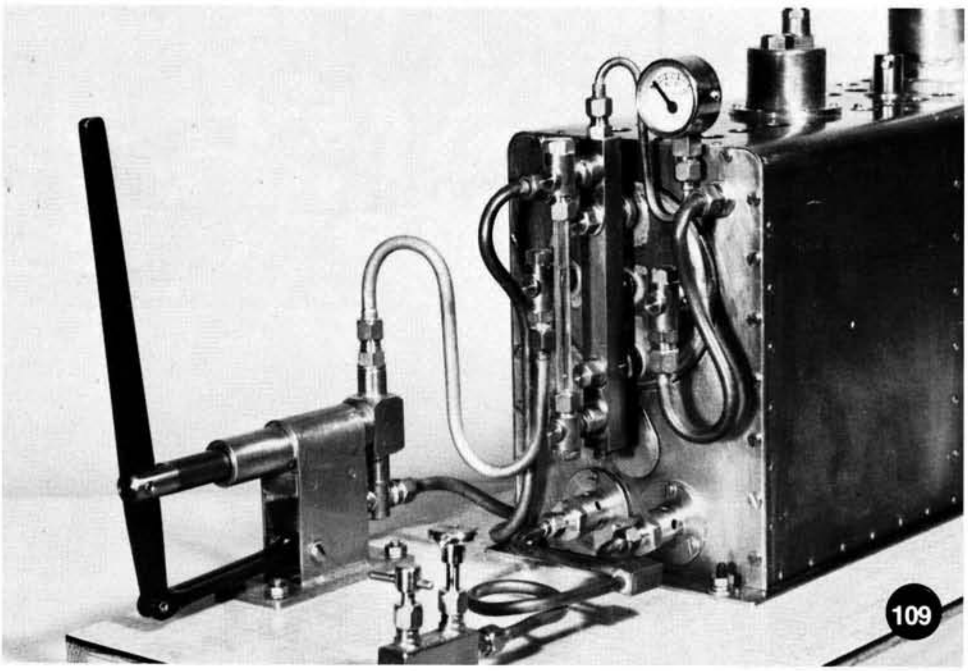
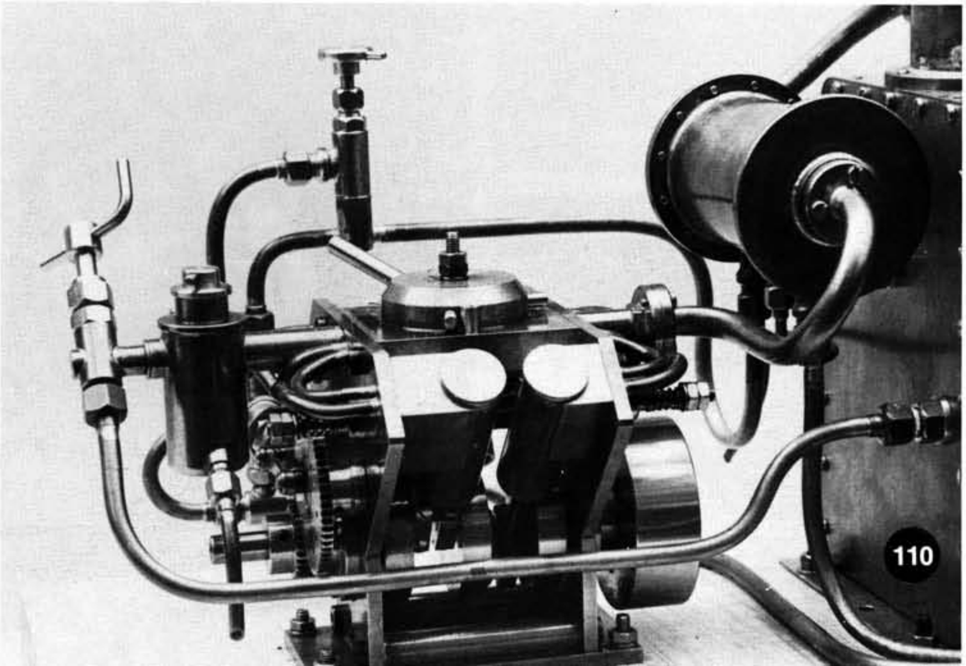


109



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done in a most undignified manner, by removing the filler plug and the test gauge and holding the whole steam plant upside down. Leave the water level at about two-thirds on the water level gauge. Replace the filler plug.

Re-install the safety valve. Remove the dome plug and put the pressure test gauge in its place. Re-connect the feedwater pipe to the boiler feedwater heater. Also, connect the steam pipe to the superheater. Connect the gas supply to the burner valve. Fill the engine's lubricator tank, up to the small hole in the steam passage, with cylinder oil. Note that ordinary oil should never be used in the lubricator, only cylinder oil (some times called valve oil) works in conjunction with steam. Oil all moving parts of the engine with machine oil. Check that the throttle valve is closed and open up the bypass valve threeorfourturns. Also, check that the lubricator's drain valve is closed.

Now, light the burners. Do this by inserting a burning match through the fire door, and then opening the pilot valveabout an eighth of a turn—never the other way around, as in that case, the firebox would be filled with a gas-air mixture before the match is introduced, with an obvious result. Do not be alarmed by this warning, I have tried it purposely several times, to make sure there is no danger.

Leave the burner at this low setting for about two minutes, as the draft is very poor when the boiler is cold; any increase in the gas supply would only result in incomplete combustion, causing the burners to choke themselves. After about two minutes, close the fire door and open up the burner main valve. Within a couple of minutes, the pressure should begin to rise. Go slowly, by moderating the fire if necessary, until the pressure reaches 40 psi or 2.8 kg/cm². That is, if the safety valve does not open, of course. If the safety valve opens at a lower pressure, the fire has to be put out and the safety valve spring adjusted, or a very small brass washer put between the valve stem and the spring. It does not matter if the valve does not open exactly at 40 psi during the test, as the boiler has a very high safety factor. Anything up to50 psi would do. Keep the pressure near the blowing-off point for about a quarter of an hour and check that there are no steam or water leaks. If no leaks are found, the boiler has passed the steam pressure test, if not, the fire must be dropped and the leak tended before the test is redone.

When the test is completed, the safety valve must be reset tothe proper blowing-off pressure, 30 psior 2.1 kg/cm². Todothis, put out the fire and let the boiler cool off until all pressure is gone. Remove the plastic feed-water tube from the water supply can or remove the filler plug, otherwise the boiler will fill itself completely with water, due to the vacuum which will form in it when the steam condenses.

Lower the blowing-off point of the safety valve by inserting a washer of appropriate thickness between the valve spindle housing and the valve seat. In this way, the boiler can be given periodic steam tests simply by temporarily removing the washer.

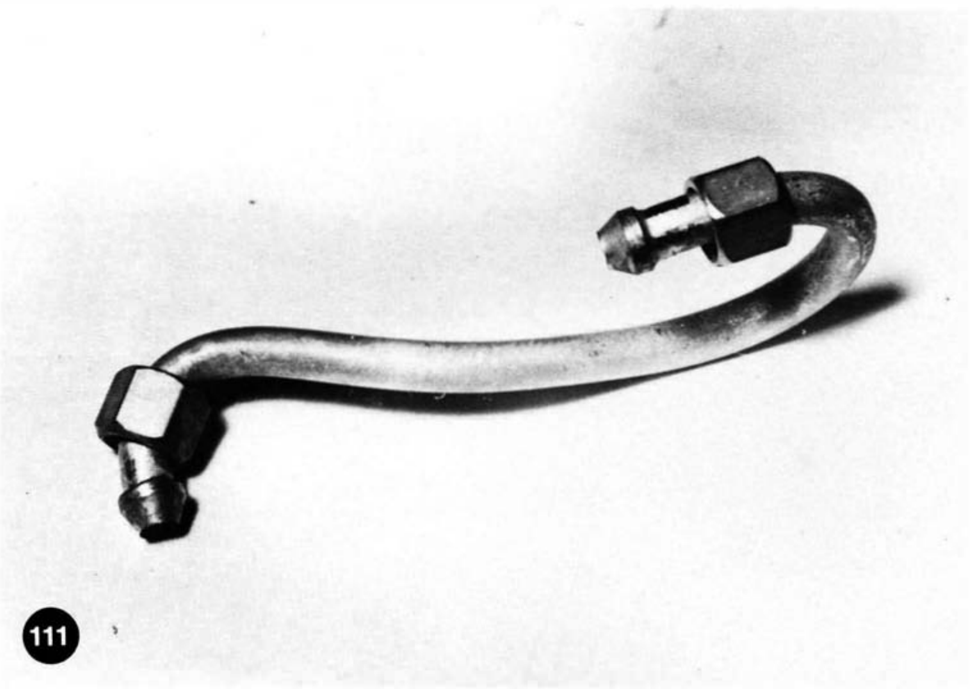
When the valve is working at the proper pressure, try the hand pump, tomake sure that it is working properly. Keep an eye on the water gauge; the level should be kept at about half to two-thirds of a glass.

Now, at last, the engine can be tried out. Place a small can or tray under the drain pipe, as there will be plenty of condensate from the feedwater when the engine is running. Crack the throttle valve open, just a very small amount. As the engine is stone cold, all the steam will condense in it in the beginning, and it will act more like a hydraulic motor than a steam engine to begin with. Keep the speed down to crawling until the cylinders have warmed up and the cylinders have been cleared of condensate, then the speed can be increased.

Watch the boiler pressure and try to keep it just below the blowing-off point by means of the burner main valve. Keep an eye on the water gauge; when it has fallen to about a third on the glass, put the engine pump into action by closing the bypass valve. By careful regulation, it is possible to find a valve setting which will keep the water level constant over long periods. The engine pump may need to have its stroke adjusted in order to obtain this. Remember, whenever the pump's stroke is changed, the pump cylinder's position in the bracket must be adjusted for minimum clearance to prevent the possibility of the pump being airlocked. Should there be an irregular rattling noise from the pump when running, it indicates that the valve balls are bouncing on their seats, due to the high lift. The valve lift should then be reduced.

In a small boiler like this, it is important to use clean feedwater. If the feedwater is stored in a tank, it will pay off to use distilled water, as it will only use small amounts. In marine work, however, it might be convenient to take the feedwater directly from the pond or lake which the vessel is running in. There is no objection to this, provided the water is clean. The boiler will then need to be washed out at regular intervals. In severe cases, the boiler can be cleaned out by filling it with a weak solution of vinegar and leaving it for a couple of hours. Flush very carefully with clean water afterwards.

After each running session, wipe down the engine and oil it. Drain the lubricator of condensate, top off the oil, and the steam plant will be ready for the next run **(photo 113).**



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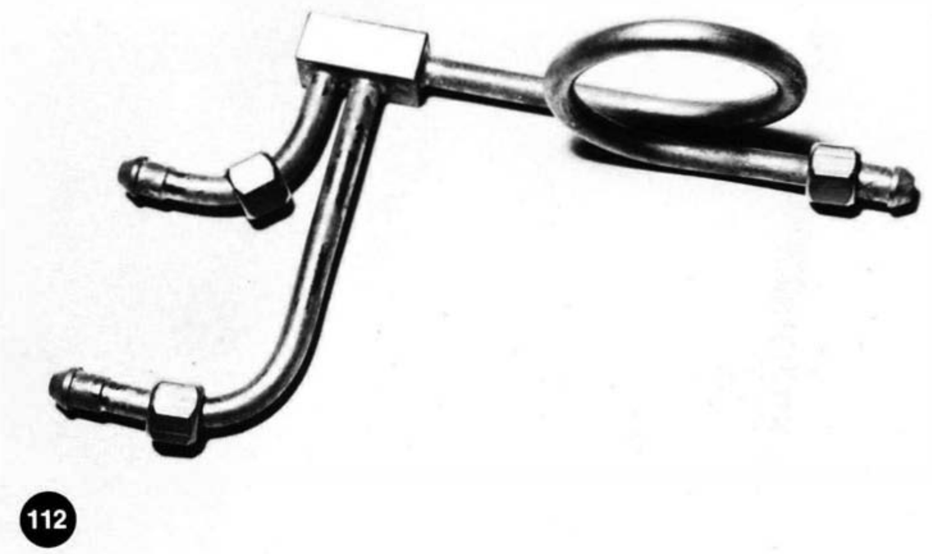

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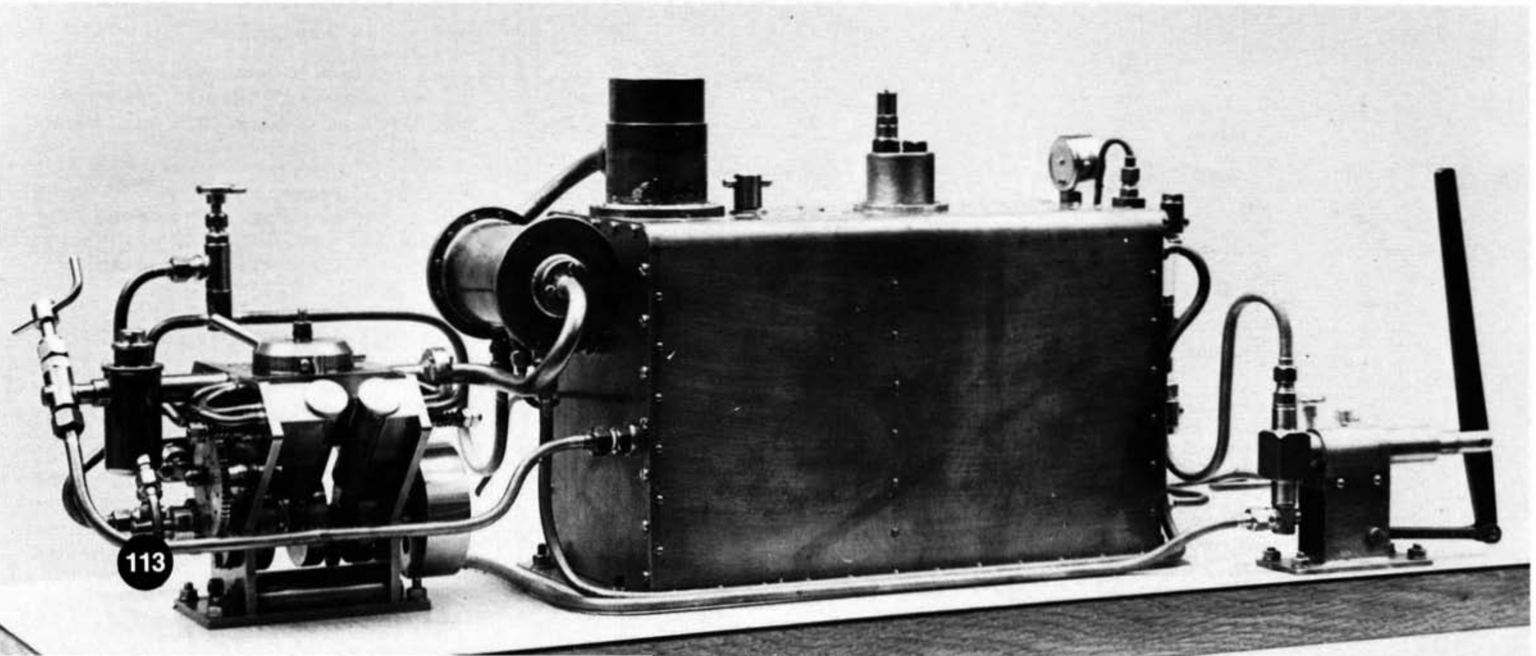

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Appendix

Metric to Decimal Inch Conversion Chart

by William C. Fitt

0-0.509mm
0-0.02004 inches

	millimeters (mm)									
	0	.001	.002	.003	.004	.005	.006	.007	.008	.009
mm	inches									
0	0.00000	0.00004	0.00008	0.00012	0.00016	0.00020	0.00024	0.00028	0.00031	0.00035
.010	0.00039	0.00043	0.00047	0.00051	0.00055	0.00059	0.00063	0.00067	0.00071	0.00075
.020	0.00079	0.00083	0.00087	0.00091	0.00094	0.00098	0.00102	0.00106	0.00110	0.00114
.030	0.00118	0.00122	0.00126	0.00130	0.00134	0.00138	0.00142	0.00146	0.00150	0.00154
.040	0.00157	0.00161	0.00165	0.00169	0.00173	0.00177	0.00181	0.00185	0.00189	0.00193
.050	0.00197	0.00201	0.00205	0.00209	0.00213	0.00217	0.00220	0.00224	0.00228	0.00232
.060	0.00236	0.00240	0.00244	0.00248	0.00252	0.00256	0.00260	0.00264	0.00268	0.00272
.070	0.00276	0.00280	0.00283	0.00287	0.00291	0.00295	0.00299	0.00303	0.00307	0.00311
.080	0.00315	0.00319	0.00323	0.00327	0.00331	0.00335	0.00339	0.00343	0.00346	0.00350
.090	0.00354	0.00356	0.00362	0.00388	0.00370	0.00374	0.00378	0.00362	0.00386	0.00390
.100	**0.00384**	**0.00398**	**0.00402**	**0.00406**	**0.00400**	**0.00413**	**0.00417**	**0.00421**	**0.00425**	**0.00429**
.110	0.00433	0.00437	0.00441	0.00445	0.00449	0.00453	0.00457	0.00461	0.00465	0.00469
.120	0.00472	0.00476	0.00480	0.00484	0.00488	0.00492	0.00496	0.00500	0.00504	0.00508
.130	0.00512	0.00516	0.00520	0.00524	0.00528	0.00531	0.00535	0.00539	0.00543	0.00547
.140	0.00551	0.00555	0.00559	0.00583	0.00587	0.00571	0.00575	0.00579	0.00583	0.00587
.150	0.00591	0.00594	0.00598	0.00602	000606	0.00610	0.00614	0.00618	0.00622	0.00626
.180	0.00630	0.00634	0.00638	0.00642	0.00646	0.00650	0.00654	0.00657	0.00661	0.00665
.170	0.00669	0.00673	0.00677	0.00681	0.00685	0.00689	0.00693	0.00697	0.00701	0.00705
.180	0.00709	0.00713	0.00717	0.00720	0.00724	0.00728	0.00732	0.00736	0.00740	0.00744
.190	0.00748	0.00752	0.00756	0.00760	0.00764	0.00768	0.00772	0.00776	0.00780	0.00783
.200	**0.00787**	**0.00781**	**0.00795**	**0.00799**	**0.00803**	**0.00807**	**0.00811**	**0.00815**	**0.00919**	**0.00823**
.210	0.00827	0.00831	0.00835	0.00839	0.00842	0.00848	0.00850	0.00854	0.00858	0.00862
.220	0.00886	0.00870	0.00874	0.00878	0.00882	0.00888	0.00890	0.00894	0.00898	0.00902
.230	0.00905	0.00909	0.00913	0.00917	0.00921	0.00925	0.00929	0.00933	0.00937	0.00941
.240	0.00945	0.00949	0.00953	0.00957	0.00961	0.00965	0.00968	0.00972	0.00976	0.00980
.250	0.00984	0.00988	0.00992	0.00996	0.01000	0.01004	0.01008	0.01012	0.01016	0.01020
.280	0.01024	0.01028	0.01031	0.01035	0.01039	0.01042	0.01047	0.01051	0.01055	0.01059
.270	0.01063	0.01067	0.01071	0.01075	0.01079	0.01083	0.01087	0.01091	0.01094	0.01098
.280	0.01102	0.01106	0.01110	0.01114	0.01118	0.01122	0.01126	0.01130	0.01134	0.01138
.290	0.01142	0.01146	0.01150	0.01154	0.01158	0.01181	0.01165	0.01169	0.01173	0.01177
.300	**0.01181**	**0.01185**	**0.01189**	**0.01193**	**0.01197**	**0.01201**	**0.01205**	**0.01209**	**0.01213**	**0.01217**
.310	0.01220	0.01224	0.01228	0.01232	0.01236	0.01240	0.01244	0.01248	0.01252	0.01256
.320	0.01260	0.01264	0.01268	0.01272	0.01276	0.01279	0.01283	0.01287	0.01291	0.01295
.330	0.01299	0.01303	0.01307	0.01311	0.01315	0.01319	0.01323	0.01327	0.01331	0.01335
.340	0.01339	0.01342	0.01346	0.01350	0.01354	0.01358	0.01362	0.01366	0.01370	0.01374
.350	0.01378	0.01382	0.01386	0.01390	0.01394	0.01398	0.01402	0.01405	0.01409	0.01413
.360	0.01417	0.01421	0.01425	0.01429	0.01433	0.01437	0.01441	0.01445	0.01449	0.01453
.370	0.01457	0.01461	0.01465	0.01468	0.01472	0.01478	0.01480	0.01484	0.01488	0.01492
.380	0.01496	0.01500	0.01504	0.01508	0.01512	0.01518	0.01520	0.01524	0.01528	0.01531
.390	0.01535	0.01539	0.01543	0.01547	0.01551	0.01555	0.01559	0.01563	0.01567	0.01571
.400	**0.01575**	**0.01579**	**0.01583**	**0.01587**	**0.01591**	**0.01594**	**0.01598**	**0.01602**	**0.01606**	**0.01610**
.410	0.01814	0.01818	0.01822	0.01626	0.01630	0.01634	0.01638	0.01642	0.01646	0.01650
.420	0.01653	0.01657	0.01661	0.01665	0.01669	0.01673	0.01877	0.01661	0.01665	0.01669
.430	0.01893	0.01697	0.01701	0.01705	0.01709	0.01713	0.01716	0.01720	0.01724	0.01728
.440	0.01732	0.01736	0.01740	0.01744	0.01748	0.01752	0.01758	0.01760	0.01764	0.01768
.450	0.01772	0.01776	0.01779	0.01763	0.01787	0.01791	0.01795	0.01799	0.01803	0.01807
.480	0.01811	0.01815	0.01819	0.01823	0.01827	0.01831	0.01835	0.01839	0.01842	0.01846
.470	0.01850	0.01854	0.01858	0.01862	0.01868	0.01870	0.01874	0.01878	0.01882	0.01886
.480	0.01890	0.01894	0.01898	0.01902	0.01905	0.01909	0.01913	0.01917	0.01921	0.01925
.490	0.01929	0.01933	0.01937	0.01941	0.01945	0.01949	0.01952	0.01957	0.01961	0.01965
.500	**0.01968**	**0.01972**	**0.01976**	**0.01980**	**0.01984**	**0.01988**	**0.01982**	**0.01996**	**0.02000**	**0.02004**

0.510 - 0.009mm
0.02008 - 0.03972 inches

mm	0	.001	.002	.003	.004	.005	.006	.007	.008	.009
.510	0.02008	0.02012	0.02016	0.02020	0.02024	0.02028	0.02031	0.02035	0.02039	0.02043
.520	0.02047	0.02051	0.02055	0.02059	0.02063	0.02067	0.02071	0.02075	0.02079	0.02083
.530	0.02087	0.02090	0.02094	0.02098	0.02102	0.02106	0.02110	0.02114	0.02118	0.02122
.540	0.02126	0.02130	0.02134	0.02138	0.02142	0.02148	0.02150	0.02153	0.02157	0.02161
.550	0.02165	0.02169	0.02173	0.02177	0.02181	0.02185	0.02189	0.02193	0.02197	0.02201
.560	0.02205	0.02209	0.02213	0.02216	0.02220	0.02224	0.02228	0.02232	0.02236	0.02240
.570	0.02244	0.02248	0.02252	0.02256	0.02260	0.02264	0.02268	0.02272	0.02276	0.02279
.580	0.02283	0.02287	0.02291	0.02295	0.02299	0.02303	0.02307	0.02311	0.02315	0.02319
.590	0.02323	0.02327	0.02331	0.02335	0.02339	0.02342	0.02346	0.02350	0.02354	0.02358
.600	**0.02362**	**0.02366**	**0.02370**	**0.02374**	**0.02378**	**0.02382**	**0.02386**	**0.02390**	**0.02394**	**0.02398**
.610	0.02402	0.02405	0.02409	0.02413	0.02417	0.02421	0.02425	0.02429	0.02433	0.02437
.620	0.02441	0.02445	0.02449	0.02453	0.02457	0.02461	0.02464	0.02468	0.02472	0.02476
.630	0.02480	0.02484	0.02488	0.02492	0.02496	0.02500	0.02504	0.02508	0.02512	0.02516
.640	0.02520	0.02524	0.02527	0.02531	0.02535	0.02539	0.02543	0.02547	0.02551	0.02555
.650	0.02559	0.02563	0.02567	0.02571	0.02575	0.02579	0.02583	0.02587	0.02590	0.02594
.660	0.02598	0.02602	0.02606	0.02610	0.02614	0.02618	0.02622	0.02626	0.02630	0.02634
.670	0.02638	0.02642	0.02646	0.02650	0.02653	0.02657	0.02661	0.02665	0.02669	0.02673
.680	0.02677	0.02681	0.02685	0.02689	0.02693	0.02697	0.02701	0.02705	0.02709	0.02713
.690	0.02716	0.02720	0.02724	0.02728	0.02732	0.02736	0.02740	0.02744	0.02748	0.02752
.700	**0.02756**	**0.02780**	**0.02764**	**0.02788**	**0.02772**	**0.02776**	**0.02779**	**0.02763**	**0.02767**	**0.02791**
.710	0.02795	0.02799	0.02803	0.02807	0.02811	0.02815	0.02819	0.02823	0.02827	0.02831
.720	0.02835	0.02839	0.02842	0.02846	0.02850	0.02854	0.02858	0.02862	0.02866	0.02870
.730	0.02874	0.02878	0.02882	0.02886	0.02890	0.02894	0.02898	0.02901	0.02905	0.02909
.740	0.02913	0.02917	0.02921	0.02925	0.02929	0.02933	0.02937	0.02941	0.02945	0.02949
.750	0.02953	0.02957	0.02961	0.02964	0.02968	0.02972	0.02976	0.02980	0.02984	0.02988
.760	0.02992	0.02996	0.03000	0.03004	0.03008	0.03012	0.03016	0.03020	0.03024	0.03027
.770	0.03031	0.03035	0.03039	0.03043	0.03047	0.03051	0.03055	0.03059	0.03063	0.03067
.780	0.03071	0.03075	0.03079	0.03083	0.03087	0.03090	0.03094	0.03098	0.03102	0.03106
.790	0.03110	0.03114	0.03118	0.03122	0.03126	0.03130	0.03134	0.03138	0.03142	0.03146
.800	**0.03150**	**0.03153**	**0.03157**	**0.03161**	**0.03165**	**0.03169**	**0.03173**	**0.03177**	**0.03181**	**0.03165**
.810	0.03189	0.03193	0.03197	0.03201	0.03205	0.03209	0.03213	0.03216	0.03220	0.03224
.820	0.03228	0.03232	0.03236	0.03240	0.03244	0.03248	0.03252	0.03256	0.03260	0.03264
.630	0.03268	0.03272	0.03276	0.03279	0.03283	0.03287	0.03291	0.03295	0.03299	0.03303
.840	0.03307	0.03311	0.03315	0.03319	0.03323	0.03327	0.03331	0.03335	0.03338	0.03342
.850	0.03346	0.03350	0.03354	0.03358	0.03362	0.03366	0.03370	0.03374	0.03378	0.03382
.860	0.03386	0.03390	0.03394	0.03398	0.03401	0.03405	0.03409	0.03413	0.03417	0.03421
.870	0.03425	0.03429	0.03433	0.03437	0.03441	0.03445	0.03449	0.03453	0.03457	0.03461
.860	0.03464	0.03468	0.03472	0.03476	0.03480	0.03484	0.03488	0.03492	0.03496	0.03500
.890	0.03504	0.03506	0.03512	0.03516	0.03520	0.03524	0.03527	0.03531	0.03535	0.03539
.900	**0.03543**	**0.03547**	**0.03551**	**0.03555**	**0.03558**	**0.03563**	**0.03567**	**0.03571**	**0.03575**	**0.03579**
.910	0.03583	0.03587	0.03590	0.03594	0.03598	0.03602	0.03606	0.03610	0.03614	0.03618
.920	0.03822	0.03626	0.03630	0.03634	0.03638	0.03642	0.03646	0.03650	0.03653	0.03657
.930	0.03661	0.03665	0.03669	0.03873	0.03677	0.03681	0.03685	0.03669	0.03893	0.03697
.940	0.03701	0.03705	0.03709	0.03712	0.03716	0.03720	0.03724	0.03728	0.03732	0.03738
.950	0.03740	0.03744	0.03748	0.03752	0.03756	0.03760	0.03764	0.03768	0.03772	0.03775
.960	0.03779	0.03783	0.03787	0.03791	0.03795	0.03799	0.03803	0.03807	0.03811	0.03815
.970	0.03819	0.03823	0.03827	0.03831	0.03835	0.03838	0.03842	0.03846	0.03850	0.03854
.980	0.03858	0.03862	0.03866	0.03870	0.03874	0.03878	0.03882	0.03886	0.03890	0.03894
.990	0.03898	0.03901	0.03905	0.03909	0.03913	0.03917	0.03921	0.03925	0.03929	0.03933
1.000	**0.03937**	**0.03941**	**0.03945**	**0.03949**	**0.03953**	**0.03957**	**0.03961**	**0.03964**	**0.03968**	**0.03972**

Note: There are some minor discrepancies in the following figures because the equipment used did not distinguish the accepted practice beyond the third decimal point. As a result, 1mm reads 0.040 inches rather than 0.039(0.039369). In any instance, the error is less than 0.001 inch.

Metric to Decimal Inch Conversion Chart

by Larry Koehl

1 - 100.9mm
0.040-3.973
inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	0.040	0.044	0.048	0.052	0.056	0.060	0.063	0.067	0.071	0.075
2	0.079	0.083	0.087	0.091	0.095	0.099	0.103	0.107	0.111	0.115
3	0.119	0.123	0.126	0.130	0.134	0.138	0.142	0.146	0.150	0.154
4	0.158	0.162	0.166	0.170	0.174	0.178	0.182	0.186	0.189	0.193
5	0.197	0.201	0.205	0.209	0.213	0.217	0.221	0.225	0.229	0.233
6	0.237	0.241	0.245	0.249	0.252	0.256	0.260	0.264	0.268	0.272
7	0.276	0.280	0.284	0.288	0.292	0.296	0.300	0.304	0.308	0.312
8	0.315	0.319	0.323	0.327	0.331	0.335	0.339	0.343	0.347	0.351
9	0.355	0.359	0.363	0.367	0.371	0.375	0.378	0.382	0.386	0.390
10	**0.394**	**0.398**	**0.402**	0.406	0.410	0.414	0.418	**0.422**	0.426	0.430
11	0.434	0.438	0.441	0.445	0.449	0.453	0.457	0.461	0.465	0.469
12	0.473	0.477	0.481	0.485	0.489	0.493	0.497	0.500	0.504	0.508
13	0.512	0.516	0.520	0.524	0.528	0.532	0.536	0.540	0.544	0.548
14	0.552	0.556	0.560	0.563	0.567	0.571	0.575	0.579	0.583	0.587
15	0.591	0.595	0.599	0.603	0.607	0.611	0.615	0.619	0.623	0.626
16	0.630	0.634	0.638	0.642	0.646	0.650	0.654	0.658	0.662	0.666
17	0.670	0.674	0.678	0.682	0.686	0.689	0.693	0.697	0.701	0.705
18	0.709	0.713	0.717	0.721	0.725	0.729	0.733	0.737	0.741	0.745
19	0.749	0.752	0.756	0.760	0.764	0.768	0.772	0.776	0.780	0.784
20	0.788	**0.792**	0.796	0.800	**0.804**	**0.808**	**0.812**	0.815	**0.819**	0.823
21	0.827	0.831	0.835	0.839	0.843	0.847	0.851	0.855	0.859	0.863
22	0.867	0.871	0.875	0.878	0.882	0.886	0.890	0.894	0.898	0.902
23	0.906	0.910	0.914	0.918	0.922	0.926	0.930	0.934	0.938	0.941
24	0.945	0.949	0.953	0.957	0.961	0.965	0.969	0.973	0.977	0.981
25	0.985	0.989	0.993	0.997	1.000	1.004	1.008	1.012	1.016	1.020
26	1.024	1.028	1.032	1.036	1.040	1.044	1.048	1.052	1.056	1.060
27	1.063	1.067	1.071	1.075	1.079	1.083	1.087	1.091	1.095	1.099
28	1.103	1.107	1.111	1.115	1.119	1.123	1.126	1.130	1.134	1.138
29	1.142	1.146	1.150	1.154	1.158	1.162	1.166	1.170	1.174	1.178
30	**1.182**	**1.186**	**1.189**	**1.193**	**1.197**	**1.201**	**1.205**	**1.209**	**1.213**	**1.217**
31	1.221	1.225	1.229	1.233	1.237	1.241	1.245	1.249	1.252	1.256
32	1.260	1.264	1.268	1.272	1.276	1.280	1.284	1.288	1.292	1.296
33	1.300	1.304	1.308	1.312	1.315	1.319	1.323	1.327	1.331	.1335
34	1.339	1.343	1.347	1.351	1.355	1.359	1.363	1.367	1.371	1.375
35	1.378	1.382	1.386	1.390	1.394	1.398	1.402	1.406	1.410	1.414
36	1.418	1.422	1.426	1.430	1.434	1.437	1.441	1.445	1.449	1.453
37	1.457	1.461	1.465	1.469	1.473	1.477	1.481	1.485	1.489	1.493
38	1.497	1.500	1.504	1.508	1.512	1.516	1.520	1.524	1.528	1.532
39	1.536	1.540	1.544	1.548	1.552	1.556	1.560	1.563	1.567	1.571
40	**1.575**	**1.579**	**1.583**	**1.587**	**1.591**	**1.595**	**1.599**	**1.603**	**1.607**	1.611
41	1.615	1.619	1.623	1.626	1.630	1.634	1.638	1.642	1.646	1.650
42	1.654	1.658	1.662	1.666	1.670	1.674	1.678	1.682	1.686	1.689
43	1.693	1.697	1.701	1.705	1.709	1.713	1.717	1.721	1.725	1.729
44	1.733	1.737	1.741	1.745	1.749	1.752	1.756	1.760	1.764	1.768
45	1.772	1.776	1.780	1.784	1.788	1.792	1.796	1.800	1.804	1.808
46	1.812	1.815	1.819	1.823	1.827	1.831	1.835	1.839	1.843	1.847
47	1.851	1.855	1.859	1.863	1.867	1.871	1.875	1.878	1.882	1.886
48	1.890	1.894	1.898	1.902	1.906	1.910	1.914	1.918	1.922	1.926
49	1.930	1.934	1.937	1.941	1.945	1.949	1.953	1.957	1.961	1.965
50	**1.969**	**1.973**	**1.977**	**1.981**	**1.985**	**1.989**	**1.993**	**1.997**	**2.000**	2.004

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
51	2.008	2.012	2.016	2.020	2.024	2.028	2.032	2.036	2.040	2.044
52	2.048	2.052	2.056	2.060	1.063	1.067	2.071	2.075	2.079	2.083
53	2.087	2.091	2.095	2.099	2.103	2.107	2.111	2.115	2.119	2.123
54	2.126	2.130	2.134	2.138	2.142	2.146	2.150	2.154	2.158	2.162
55	2.166	2.170	2.174	2.178	2.182	2.186	2.189	2.193	2.197	2.201
56	2.205	2.209	2.213	2.217	2.221	2.225	2.229	2.233	2.237	2.241
57	2.245	2.249	2.252	2.256	2.260	2.264	2.268	2.272	2.276	2.280
58	2.284	2.288	2.292	2.296	2.300	2.304	2.308	2.312	2.315	2.319
59	2.323	2.327	2.331	2.335	2.339	2.343	2.347	2.351	2.355	2.359
60	**2.363**	**2.367**	**2.371**	**2.374**	**2.378**	**2.382**	**2.386**	**2.390**	**2.394**	**2.398**
61	2.402	2.406	2.410	2.414	2.418	2.422	2.426	2.430	2.434	2.437
62	2.441	2.445	2.449	2.453	2.457	2.461	2.465	2.469	2.473	2.477
63	2.481	2.485	2.489	2.493	2.497	2.500	2.504	2.508	2.512	2.516
64	2.520	2.524	2.528	2.532	2.536	2.540	2.544	2.548	2.552	2.556
65	2.560	2.563	2.567	2.571	2.575	2.579	2.583	2.587	2.591	2.595
66	2.599	2.603	2.607	2.611	2.615	2.619	2.623	2.626	2.630	2.634
67	2.638	2.642	2.646	2.650	2.654	2.658	2.662	2.666	2.670	2.674
68	2.678	2.682	2.686	2.689	2.693	2.697	2.701	2.705	2.709	2.713
69	2.717	2.721	2.725	2.729	2.733	2.737	2.741	2.745	2.749	2.752
70	**2.756**	**2.760**	**2.764**	**2.768**	**2.772**	**2.776**	**2.780**	**2.784**	**2.788**	**2.792**
71	2.796	2.800	2.804	2.808	2.811	2.815	2.819	2.823	2.827	2.831
72	2.835	2.839	2.843	2.847	2.851	2.855	2.859	2.863	2.867	2.871
73	2.874	2.878	2.882	2.886	2.890	2.894	2.898	2.902	2.906	2.910
74	2.914	2.918	2.922	2.926	2.930	2.934	2.937	2.941	2.945	2.949
75	2.953	2.957	2.961	2.965	2.969	2.973	2.977	2.981	2.985	2.989
76	2.993	2.997	3.000	3.004	3.008	3.012	3.016	3.020	3.024	3.028
77	3.032	3.036	3.040	3.044	3.048	3.052	3.056	3.060	3.063	3.067
78	3.071	3.075	3.079	3.083	3.087	3.091	3.095	3.099	3.103	3.107
79	3.111	3.115	3.119	3.123	3.126	3.130	3.134	3.138	3.142	3.146
80	**3.150**	**3.154**	3.158	**3.162**	**3.166**	**3.170**	3.174	3.178	**3.182**	3.186
81	3.189	3.193	3.197	3.201	3.205	3.209	3.213	3.217	3.221	3.225
82	3.229	3.233	3.237	3.241	3.245	3.248	3.252	3.256	3.260	3.264
83	3.268	3.272	3.276	3.280	3.284	3.288	3.292	3.296	3.300	3.304
84	3.308	3.311	3.315	3.319	3.323	3.327	3.331	3.335	3.339	3.343
85	3.347	3.351	3.355	3.359	3.363	3.367	3.371	3.374	3.378	3.382
86	3.386	3.390	3.394	3.398	3.402	3.406	3.410	3.414	3.418	3.422
87	3.426	3.430	3.434	3.437	3.441	3.445	3.449	3.453	3.457	3.461
88	3.465	3.469	3.473	3.477	3.481	3.485	3.489	3.493	3.497	3.500
89	3.504	3.508	3.512	3.516	3.520	3.524	3.528	3.532	3.536	3.540
90	**3.544**	**3.548**	**3.552**	**3.556**	**3.560**	3.563	3.567	3.571	3.575	3.579
91	3.583	3.587	3.591	3.595	3.599	3.603	3.607	3.611	3.615	3.619
92	3.623	3.626	3.630	3.634	3.638	3.642	3.646	3.650	3.654	3.658
93	3.662	3.666	3.670	3.674	3.678	3.682	3.686	3.689	3.693	3.697
94	3.701	3.705	3.709	3.713	3.717	3.721	3.725	3.729	3.733	3.737
95	3.741	3.745	3.748	3.752	3.756	3.760	3.764	3.768	3.772	3.776
96	3.780	3.784	3.788	3.792	3.796	3.800	3.804	3.808	3.811	3.815
97	3.819	3.823	3.827	3.831	3.835	3.839	3.843	3.847	3.851	3.855
98	3.859	3.863	3.867	3.871	3.874	3.878	3.882	3.886	3.890	3.894
99	3.898	3.902	3.906	3.910	3.914	3.918	3.922	3.926	3.930	3.934
100	**3.937**	**3.941**	**3.945**	**3.949**	**3.953**	**3.957**	**3.961**	**3.965**	**3.969**	3.973

101 - 200.9mm
3.977 - 7.910
inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
101	3.977	3.981	3.985	3.989	3.993	3.997	4.000	4.004	4.008	4.012
102	4.016	4.020	4.024	4.028	4.032	4.036	4.040	4.044	4.048	4.052
103	4.056	4.060	4.063	4.067	4.071	4.075	4.079	4.083	4.087	4.091
104	4.095	4.099	4.103	4.107	4.111	4.115	4.119	4.123	4.126	4.130
105	4.134	4.138	4.142	4.146	4.150	4.154	4.158	4.162	4.166	4.170
106	4.174	4.178	4.182	4.185	4.189	4.193	4.197	4.201	4.205	4.209
107	4.213	4.217	4.221	4.225	4.229	4.233	4.237	4.241	4.245	4.248
108	4.252	4.256	4.260	4.264	4.268	4.272	4.276	4.280	4.284	4.288
109	4.292	4.296	4.300	4.304	4.308	4.311	4.315	4.319	4.323	4.327
110	4.331	4.335	4.339	4.343	4.347	4.351	4.355	4.359	4.363	4.367
111	4.371	4.374	4.378	4.382	4.386	4.390	4.394	4.398	4.402	4.406
112	4.410	4.414	4.418	4.422	4.426	4.430	4.434	4.437	4.441	4.445
113	4.449	4.453	4.457	4.461	4.465	4.469	4.473	4.477	4.481	4.485
114	4.489	4.493	4.497	4.500	4.504	4.508	4.512	4.516	4.520	4.524
115	4.528	4.532	4.536	4.540	4.544	4.548	4.552	4.556	4.560	4.563
116	4.567	4.571	4.575	4.579	4.583	4.587	4.591	4.595	4.599	4.603
117	4.607	4.611	4.615	4.619	4.622	4.626	4.630	4.634	4.638	4.642
118	4.646	4.650	4.654	4.658	4.662	4.666	4.670	4.674	4.678	4.682
119	4.685	4.669	4.693	4.697	4.701	4.705	4.709	4.713	4.717	4.721
120	4.725	4.729	4.733	4.737	4.741	4.745	4.748	4.752	4.756	4.760
121	4.764	4.768	4.772	4.776	4.780	4.784	4.788	4.792	4.796	4.800
122	4.804	4.808	4.811	4.815	4.819	4.823	4.827	4.831	4.835	4.839
123	4.843	4.847	4.851	4.855	4.859	4.863	4.867	4.871	4.874	4.878
124	4.882	4.886	4.890	4.894	4.898	4.902	4.906	4.910	4.914	4.918
125	4.922	4.926	4.930	4.934	4.937	4.941	4.945	4.949	4.953	4.957
126	4.961	4.965	4.969	4.973	4.977	4.981	4.985	4.989	4.993	4.997
127	5.000	5.004	5.008	5.012	5.016	5.020	5.024	5.028	5.032	5.036
128	5.040	5.044	5.048	5.052	5.056	5.059	5.063	5.067	5.071	5.075
129	5.079	5.083	5.087	5.091	5.095	5.099	5.103	5.107	5.111	5.115
130	5.119	5.122	5.126	5.130	5.134	5.138	5.142	5.146	5.150	5.154
131	5.158	5.162	5.166	5.170	5.174	5.178	5.182	5.185	5.189	5.193
132	5.197	5.201	5.205	5.209	5.213	5.217	5.221	5.225	5.229	5.233
133	5.237	5.241	5.245	5.248	5.252	5.256	5.260	5.264	5.268	5.272
134	5.276	5.280	5.284	5.288	5.292	5.296	5.300	5.304	5.308	5.311
135	5.315	5.319	5.323	5.327	5.331	5.335	5.339	5.343	5.347	5.351
136	5.355	5.359	5.363	5.367	5.371	5.374	5.378	5.382	5.386	5.390
137	5.394	5.398	5.402	5.406	5.410	5.414	5.418	5.422	5.426	5.430
138	5.434	5.437	5.441	5.445	5.449	5.453	5.457	5.461	5.465	5.469
139	5.473	5.477	5.481	5.485	5.489	5.493	5.497	5.500	5.504	5.508
140	5.512	5.516	5.520	5.524	5.528	5.532	5.536	5.540	5.544	5.548
141	5.552	5.556	5.559	5.563	5.567	5.571	5.575	5.579	5.583	5.587
142	5.591	5.595	5.599	5.603	5.607	5.611	5.615	5.619	5.622	5.626
143	5.630	5.634	5.638	5.642	5.646	5.650	5.654	5.658	5.662	5.666
144	5.670	5.674	5.678	5.682	5.685	5.689	5.693	5.697	5.701	5.705
145	5.709	5.713	5.717	5.721	5.725	5.729	5.733	5.737	5.741	5.745
146	5.748	5.752	5.756	5.760	5.764	5.768	5.772	5.776	5.780	5.784
147	5.788	5.792	5.796	5.800	5.804	5.808	5.811	5.815	5.819	5.823
148	5.827	5.831	5.835	5.839	5.843	5.847	5.851	5.855	5.859	5.863
149	5.867	5.871	5.874	5.878	5.882	5.886	5.890	5.894	5.898	5.902
150	5.906	5.910	5.914	5.918	5.922	5.926	5.930	5.934	5.937	5.941

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
151	5.945	5.949	5.953	5.957	5.961	5.965	5.969	5.973	5.977	5.981
152	5.985	5.989	5.993	5.996	6.000	6.004	6.008	6.012	6.016	6.020
153	6.024	6.028	6.032	6.036	6.040	6.044	6.048	6.052	6.056	6.059
154	6.063	6.067	6.071	6.075	6.079	6.083	6.087	6.091	6.095	6.099
155	6.103	6.107	6.111	6.115	6.119	6.122	6.126	6.130	6.134	6.138
156	6.142	6.146	6.150	6.154	6.158	6.162	6.166	6.170	6.174	6.178
157	6.182	6.185	6.189	6.193	6.197	6.201	6.205	6.209	6.213	6.217
158	6.221	6.225	6.229	6.233	6.237	6.241	6.245	6.248	6.252	6.256
159	6.260	6.264	6.268	6.272	6.276	6.280	6.284	6.288	6.292	6.296
160	6.300	6.304	6.308	6.311	6.315	6.319	6.323	6.327	6.331	6.335
161	6.339	6.343	6.347	6.351	6.355	6.359	6.363	6.367	6.371	6.374
162	6.378	6.382	6.386	6.390	6.394	6.398	6.402	6.406	6.410	6.414
163	6.418	6.422	6.426	6.430	6.433	6.437	6.441	6.445	6.449	6.453
164	6.457	6.461	6.465	6.469	6.473	6.477	6.481	6.485	6.489	6.493
165	6.496	6.500	6.504	6.508	6.512	6.516	6.520	6.524	6.528	6.532
166	6.536	6.540	6.544	6.548	6.552	6.556	6.559	6.563	6.567	6.571
167	6.575	6.579	6.583	6.587	6.591	6.595	6.599	6.603	6.607	6.611
168	6.615	6.619	6.622	6.626	6.630	6.634	6.638	6.642	6.646	6.650
169	6.654	6.658	6.662	6.666	6.670	6.674	6.678	6.682	6.685	6.689
170	6.693	6.697	6.701	6.705	6.709	6.713	6.717	6.721	6.725	6.729
171	6.733	6.737	6.741	6.745	6.748	6.752	6.756	6.760	6.764	6.768
172	6.772	6.776	6.780	6.784	6.788	6.792	6.796	6.800	6.804	6.808
173	6.811	6.815	6.819	6.823	6.827	6.831	6.835	6.839	6.843	6.847
174	6.851	6.855	6.859	6.863	6.867	6.871	6.874	6.878	6.882	6.886
175	6.890	6.894	6.898	6.902	6.906	6.910	6.914	6.918	6.922	6.926
176	6.930	6.933	6.937	6.941	6.945	6.949	6.953	6.957	6.961	6.965
177	6.969	6.973	6.977	6.981	6.985	6.989	6.993	6.996	7.000	7.004
178	7.008	7.012	7.016	7.020	7.024	7.028	7.032	7.036	7.040	7.044
179	7.048	7.052	7.056	7.059	7.063	7.067	7.071	7.075	7.079	7.083
180	7.087	7.091	7.095	7.099	7.103	7.107	7.111	7.115	7.119	7.122
181	7.126	7.130	7.134	7.138	7.142	7.146	7.150	7.154	7.158	7.162
182	7.166	7.170	7.174	7.178	7.182	7.185	7.189	7.193	7.197	7.201
183	7.205	7.209	7.213	7.217	7.221	7.225	7.229	7.233	7.237	7.241
184	7.245	7.248	7.252	7.256	7.260	7.264	7.268	7.272	7.276	7.280
185	7.284	7.288	7.292	7.296	7.300	7.304	7.308	7.311	7.315	7.319
186	7.323	7.327	7.331	7.335	7.339	7.343	7.347	7.351	7.355	7.359
187	7.363	7.367	7.370	7.374	7.378	7.382	7.386	7.390	7.394	7.398
188	7.402	7.406	7.410	7.414	7.418	7.422	7.426	7.430	7.433	7.437
189	7.441	7.445	7.449	7.453	7.457	7.461	7.465	7.469	7.473	7.477
190	7.481	7.485	7.489	7.493	7.496	7.500	7.504	7.508	7.512	7.516
191	7.520	7.524	7.528	7.532	7.536	7.540	7.544	7.548	7.552	7.556
192	7.559	7.563	7.567	7.571	7.575	7.579	7.583	7.587	7.591	7.595
193	7.599	7.603	7.607	7.611	7.615	7.619	7.622	7.626	7.630	7.634
194	7.638	7.642	7.646	7.650	7.654	7.658	7.662	7.666	7.670	7.674
195	7.678	7.682	7.685	7.669	7.693	7.697	7.701	7.705	7.709	7.713
196	7.717	7.721	7.725	7.729	7.733	7.737	7.741	7.745	7.748	7.752
197	7.756	7.760	7.764	7.768	7.772	7.776	7.780	7.784	7.788	7.792
198	7.796	7.800	7.804	7.807	7.811	7.815	7.819	7.823	7.827	7.831
199	7.835	7.839	7.843	7.847	7.851	7.855	7.859	7.863	7.867	7.870
200	7.874	7.878	7.882	7.886	7.890	7.894	7.898	7.902	7.906	7.910

201 - 300.9mm
7.914 - 11.847
inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
201	7.914	7.918	7.922	7.926	7.930	7.933	7.937	7.941	7.945	7.949
202	7.953	7.957	7.961	7.965	7.969	7.973	7.977	7.981	7.985	7.989
203	7.993	7.996	8.000	8.004	8.008	8.012	8.016	8.020	8.024	8.028
204	8.032	8.036	8.040	8.044	8.048	8.052	8.056	8.059	8.063	8.067
205	8.071	8.075	8.079	8.083	8.087	8.091	8.095	8.099	8.103	8.107
206	8.111	8.115	8.119	8.122	8.126	8.130	8.134	8.138	8.142	8.146
207	8.150	8.154	8.158	8.162	8.166	8.170	8.174	8.178	8.182	8.185
208	8.189	8.193	8.197	8.201	8.205	8.209	8.213	8.217	8.221	8.225
209	8.229	8.233	8.237	8.241	8.244	8.248	8.252	8.256	8.260	8.264
210	**8.268**	**8.272**	**8.276**	**8.280**	**8.284**	**8.288**	**8.292**	**8.296**	**8.300**	**8.304**
211	8.307	8.311	8.315	8.319	8.323	8.327	8.331	8.335	8.339	8.343
212	8.347	8.351	8.355	8.359	8.363	8.367	8.370	8.374	8.378	8.382
213	8.386	8.390	8.394	8.398	8.402	8.406	8.410	8.414	8.418	8.422
214	8.426	8.430	8.433	8.437	8.441	8.445	8.449	8.453	8.457	8.461
215	8.465	8.469	8.473	8.477	8.481	8.485	8.489	8.493	8.496	8.500
216	8.504	8.508	8.512	8.516	8.520	8.524	8.528	8.532	8.536	8.540
217	8.544	8.548	8.552	8.556	8.559	8.563	8.567	8.571	8.575	8.579
218	8.583	8.587	8.591	8.595	8.599	8.603	8.607	8.611	8.615	8.619
219	8.622	8.626	8.630	8.634	8.638	8.642	8.646	8.650	8.654	8.658
220	**8.662**	**8.666**	**8.670**	**8.874**	**8.678**	**8.682**	**8.685**	**8.689**	**8.693**	**8.697**
221	8.701	8.705	8.709	8.713	8.717	8.721	8.725	8.729	8.733	8.737
222	8.741	8.744	8.748	8.752	8.756	8.760	8.764	8.768	8.772	8.776
223	8.780	8.784	8.788	8.792	8.796	8.800	8.804	8.807	8.811	8.815
224	8.819	8.823	8.827	8.831	8.835	8.839	8.843	8.847	8.851	8.855
225	8.859	8.863	8.867	8.870	8.874	8.878	8.882	8.886	8.890	8.894
226	8.898	8.902	8.906	8.910	8.914	8.918	8.922	8.926	8.930	8.933
227	8.937	8.941	8.945	8.949	8.953	8.957	8.961	8.965	8.969	8.973
228	8.977	8.981	8.985	8.989	8.993	8.996	9.000	9.004	9.008	9.012
229	9.016	9.020	9.024	9.028	9.032	9.036	9.040	9.044	9.048	9.052
230	**9.056**	**9.059**	**9.063**	**9.067**	**9.071**	**9.075**	**9.079**	**9.083**	**9.087**	**9.091**
231	9.095	9.099	9.103	9.107	9.111	9.115	9.119	9.122	9.126	9.130
232	9.134	9.138	9.142	9.146	9.150	9.154	9.158	9.162	9.166	9.170
233	9.174	9.178	9.181	9.185	9.189	9.193	9.197	9.201	9.205	9.209
234	9.213	9.217	9.221	9.225	9.229	9.233	9.237	9.241	9.244	9.248
235	9.252	9.256	9.260	9.264	9.268	9.272	9.276	9.280	9.284	9.288
236	9.292	9.296	9.300	9.304	9.307	9.311	9.315	9.319	9.323	9.327
237	9.331	9.335	9.339	9.343	9.347	9.351	9.355	9.359	9.363	9.367
238	9.370	9.374	9.378	9.382	9.386	9.390	9.394	9.398	9.402	9.406
239	9.410	9.414	9.418	9.422	9.426	9.430	9.433	9.437	9.441	9.445
240	**9.449**	**9.453**	**9.457**	**9.461**	**9.465**	**9.469**	**9.473**	**9.477**	**9.481**	**9.485**
241	9.489	9.493	9.496	9.500	9.504	9.508	9.512	9.516	9.520	9.524
242	9.528	9.532	9.536	9.540	9.544	9.548	9.552	9.556	9.559	9.563
243	9.567	9.571	9.575	9.579	9.583	9.587	9.591	9.595	9.599	9.603
244	9.607	9.611	9.615	9.618	9.622	9.626	9.630	9.634	9.638	9.642
245	9.646	9.650	9.654	9.658	9.662	9.666	9.870	9.674	9.678	9.681
246	9.685	9.689	9.693	9.697	9.701	9.705	9.709	9.713	9.717	9.721
247	9.725	9.729	9.733	9.737	9.741	9.744	0.748	9.752	9.756	9.760
248	9.764	9.768	9.772	9.778	9.780	9.784	9.788	9.792	9.796	9.800
249	9.804	9.807	9.811	9.815	9.819	9.823	9.827	9.831	9.835	9.839
250	**9.843**	**9.847**	**9.851**	**9.855**	**9.859**	**9.863**	**9.867**	**9.870**	**9.874**	**9.878**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
251	9.882	9.886	9.890	9.894	9.898	9.902	9.906	9.910	9.914	9.918
252	9.922	9.926	9.930	9.933	9.937	9.941	9.945	9.949	9.953	9.957
253	9.961	9.965	9.969	9.973	9.977	9.981	9.985	9.989	9.993	9.996
254	10.000	10.004	10.008	10.012	10.016	10.020	10.024	10.028	10.032	10.036
255	10.040	10.044	10.048	10.052	10.056	10.059	10.063	10.067	10.071	10.075
256	10.079	10.083	10.087	10.091	10.095	10.099	10.103	10.107	10.111	10.115
257	10.118	10.122	10.126	10.130	10.134	10.138	10.142	10.146	10.150	10.154
258	10.158	10.162	10.166	10.170	10.174	10.178	10.181	10.185	10.189	10.193
259	10.197	10.201	10.205	10.209	10.213	10.217	10.221	10.225	10.229	10.233
260	**10.237**	**10.241**	**10.244**	**10.248**	**10.252**	**10.256**	**10.260**	**10.264**	**10.268**	**10.272**
261	10.276	10.280	10.284	10.288	10.292	10.296	10.300	10.304	10.307	10.311
262	10.315	10.319	10.323	10.327	10.331	10.335	10.339	10.343	10.347	10.351
263	10.355	10.359	10.363	10.367	10.370	10.374	10.378	10.382	10.386	10.390
264	10.394	10.398	10.402	10.406	10.410	10.414	10.418	10.422	10.426	10.430
265	10.433	10.437	10.441	10.445	10.449	10.453	10.457	10.461	10.465	10.469
266	10.473	10.477	10.481	10.485	10.489	10.493	10.496	10.500	10.504	10.508
267	10.512	10.516	10.520	10.524	10.528	10.532	10.536	10.540	10.544	10.548
268	10.552	10.555	10.559	10.563	10.567	10.571	10.575	10.579	10.583	10.587
269	10.591	10.595	10.599	10.603	10.607	10.611	10.615	10.618	10.622	10.626
270	**10.630**	**10.634**	**10.638**	**10.642**	**10.646**	**10.650**	**10.654**	**10.658**	**10.662**	**10.666**
271	10.670	10.674	10.678	10.681	10.685	10.689	10.693	10.697	10.701	10.705
272	10.709	10.713	10.717	10.721	10.725	10.729	10.733	10.737	10.741	10.744
273	10.748	10.752	10.756	10.760	10.764	10.768	10.772	10.776	10.780	10.784
274	10.788	10.792	10.796	10.800	10.804	10.807	10.811	10.815	10.819	10.823
275	10.827	10.831	10.835	10.839	10.843	10.847	10.851	10.855	10.859	10.863
276	10.867	10.870	10.874	10.878	10.882	10.886	10.890	10.894	10.898	10.902
277	10.906	10.910	10.914	10.918	10.922	10.926	10.930	10.933	10.937	10.941
278	10.945	10.949	10.953	10.957	10.961	10.965	10.969	10.973	10.977	10.981
279	10.985	10.989	10.992	10.996	11.000	11.004	11.008	11.012	11.016	11.020
280	**11.024**	**11.028**	**11.032**	**11.036**	**11.040**	**11.044**	**11.048**	**11.052**	**11.055**	**11.059**
281	11.063	11.067	11.071	11.075	11.079	11.083	11.087	11.091	11.095	11.099
282	11.103	11.107	11.111	11.115	11.118	11.122	11.126	11.130	11.134	11.138
283	11.142	11.146	11.150	11.154	11.158	11.162	11.166	11.170	11.174	11.178
284	11.181	11.185	11.189	11.193	11.197	11.201	11.205	11.209	11.213	11.217
285	11.221	11.225	11.229	11.233	11.237	11.241	11.244	11.248	11.252	11.256
286	11.260	11.264	11.268	11.272	11.276	11.280	11.284	11.288	11.292	11.296
287	11.300	11.304	11.307	11.311	11.315	11.319	11.323	11.327	11.331	11.335
288	11.339	11.343	11.347	11.351	11.355	11.359	11.363	11.367	11.370	11.374
289	11.378	11.382	11.386	11.390	11.394	11.398	11.402	11.406	11.410	11.414
290	**11.418**	**11.422**	**11.426**	**11.429**	**11.433**	**11.437**	**11.441**	**11.445**	**11.449**	**11.453**
291	11.457	11.461	11.465	11.469	11.473	11.477	11.481	11.485	11.489	11.492
292	11.496	11.500	11.504	11.508	11.512	11.516	11.520	11.524	11.528	11.532
293	11.536	11.540	11.544	11.548	11.552	11.555	11.559	11.563	11.567	11.571
294	11.575	11.579	11.583	11.587	11.591	11.595	11.599	11.603	11.607	11.611
295	11.615	11.618	11.622	11.826	11.630	11.634	11.638	11.642	11.646	11.650
296	11.654	11.658	11.662	11.666	11.670	11.674	11.678	11.681	11.685	11.689
297	11.693	11.697	11.701	11.705	11.709	11.713	11.717	11.721	11.725	11.729
298	11.733	11.737	11.741	11.744	11.748	11.752	11.756	11.760	11.764	11.768
299	11.772	11.776	11.780	11.784	11.788	11.792	11.796	11.800	11.804	11.807
300	**11.811**	**11.815**	**11.819**	**11.823**	**11.827**	**11.831**	**11.835**	**11.839**	**11.843**	**11.847**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
301	11.851	11.855	11.859	11.863	11.867	11.870	11.874	11.878	11.882	11.886
302	11.890	11.894	11.898	11.902	11.906	11.910	11.914	11.918	11.922	11.926
303	11.929	11.933	11.937	11.941	11.945	11.949	11.953	11.957	11.961	11.965
304	11.969	11.973	11.977	11.981	11.985	11.989	11.992	11.996	12.000	12.004
305	12.008	12.012	12.016	12.020	12.024	12.028	12.032	12.036	12.040	12.044
306	12.048	12.052	12.055	12.059	12.063	12.067	12.071	12.075	12.079	12.083
307	12.087	12.091	12.095	12.099	12.103	12.107	12.111	12.115	12.118	12.122
308	12.126	12.130	12.134	12.138	12.142	12.146	12.150	12.154	12.158	12.162
309	12.166	12.170	12.174	12.178	12.181	12.185	12.189	12.193	12.197	12.201
310	**12.206**	**12.209**	**12.213**	**12.217**	**12.221**	**12.225**	**12.229**	**12.233**	**12.237**	**12.241**
311	12.244	12.248	12.252	12.256	12.260	12.264	12.268	12.272	12.276	12.280
312	12.284	12.288	12.292	12.296	12.300	12.304	12.307	12.311	12.315	12.319
313	12.323	12.327	12.331	12.335	12.339	12.343	12.347	12.351	12.355	12.359
314	12.363	12.366	12.370	12.374	12.378	12.382	12.386	12.390	12.394	12.398
315	12.402	12.406	12.410	12.414	12.418	12.422	12.426	12.429	12.433	12.437
316	12.441	12.445	12.449	12.453	12.457	12.461	12.465	12.469	12.473	12.477
317	12.481	12.485	12.489	12.492	12.496	12.500	12.504	12.508	12.512	12.516
318	12.520	12.524	12.528	12.532	12.536	12.540	12.544	12.548	12.552	12.555
319	12.559	12.563	12.567	12.571	12.575	12.579	12.583	12.587	12.591	12.595
320	**12.599**	**12.603**	**12.607**	**12.611**	**12.615**	**12.618**	**12.622**	**12.626**	**12.630**	**12.634**
321	12.638	12.642	12.646	12.650	12.654	12.658	12.662	12.666	12.670	12.674
322	12.678	12.681	12.685	12.689	12.693	12.697	12.701	12.705	12.709	12.713
323	12.717	12.721	12.725	12.729	12.733	12.737	12.741	12.744	12.748	12.752
324	12.756	12.760	12.764	12.768	12.772	12.776	12.780	12.784	12.788	12.792
325	12.796	12.800	12.803	12.807	12.811	12.815	12.819	12.823	12.827	12.831
326	12.835	12.839	12.843	12.847	12.851	12.855	12.859	12.863	12.866	12.870
327	12.874	12.878	12.882	12.886	12.890	12.894	12.898	12.902	12.906	12.910
328	12.914	12.918	12.922	12.926	12.929	12.933	12.937	12.941	12.945	12.949
329	12.953	12.957	12.961	12.965	12.969	12.973	12.977	12.981	12.985	12.989
330	**12.992**	**12.996**	**13.000**	**13.004**	**13.008**	**13.012**	**13.016**	**13.020**	**13.024**	**13.028**
331	13.032	13.036	13.040	13.044	13.048	13.052	13.055	13.059	13.063	13.067
332	13.071	13.075	13.079	13.083	13.087	13.091	13.095	13.099	13.103	13.107
333	13.111	13.115	13.118	13.122	13.126	13.130	13.134	13.138	13.142	13.146
334	13.150	13.154	13.158	13.162	13.166	13.170	13.174	13.178	13.181	13.185
335	13.189	13.193	13.197	13.201	13.205	13.209	13.213	13.217	13.221	13.225
336	13.229	13.233	13.237	13.240	13.244	13.248	13.252	13.256	13.260	13.264
337	13.268	13.272	13.276	13.280	13.284	13.288	13.292	13.296	13.300	13.303
338	13.307	13.311	13.315	13.319	13.323	13.327	13.331	13.335	13.339	13.343
339	13.347	13.351	13.355	13.359	13.363	13.366	13.370	13.374	13.378	13.382
340	**13.386**	**13.390**	**13.394**	**13.398**	**13.402**	**13.406**	**13.410**	**13.414**	**13.418**	**13.422**
341	13.426	13.429	13.433	13.437	13.441	13.445	13.449	13.453	13.457	13.461
342	13.465	13.469	13.473	13.477	13.481	13.485	13.489	13.492	13.496	13.500
343	13.504	13.508	13.512	13.516	13.520	13.524	13.528	13.532	13.536	13.540
344	13.544	13.548	13.552	13.555	13.559	13.563	13.567	13.571	13.575	13.579
345	13.583	13.587	13.591	13.595	13.599	13.603	13.607	13.611	13.615	13.618
346	13.622	13.626	13.630	13.634	13.638	13.642	13.646	13.650	13.654	13.658
347	13.662	13.666	13.670	13.674	13.678	13.681	13.685	13.689	13.693	13.697
348	13.701	13.705	13.709	13.713	13.717	13.721	13.725	13.729	13.733	13.737
349	13.740	13.744	13.748	13.752	13.756	13.760	13.764	13.768	13.772	13.776
350	**13.780**	**13.784**	**13.788**	**13.792**	**13.796**	**13.800**	**13.803**	**13.807**	**13.811**	**13.815**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
351	13.819	13.823	13.827	13.831	13.835	13.839	13.843	13.847	13.851	13.855
352	13.859	13.863	13.866	13.870	13.874	13.878	13.882	13.886	13.890	13.894
353	13.898	13.902	13.906	13.910	13.914	13.918	13.922	13.926	13.929	13.933
354	13.937	13.941	13.945	13.949	13.953	13.957	13.961	13.965	13.969	13.973
355	13.977	13.981	13.985	13.989	13.992	13.996	14.000	14.004	14.008	14.012
356	14.016	14.020	14.024	14.028	14.032	14.036	14.040	14.044	14.048	14.052
357	14.055	14.059	14.063	14.067	14.071	14.075	14.079	14.083	14.087	14.091
358	14.095	14.099	14.103	14.107	14.111	14.115	14.118	14.122	14.126	14.130
359	14.134	14.138	14.142	14.146	14.150	14.154	14.158	14.162	14.166	14.170
360	**17.174**	**14.177**	**14.181**	**14.185**	**14.189**	**14.193**	**14.197**	**14.201**	**14.205**	**14.209**
361	14.213	14.217	14.221	14.225	14.229	14.233	14.237	14.240	14.244	14.248
362	14.252	14.256	14.260	14.264	14.268	14.272	14.276	14.280	14.284	14.288
363	14.292	14.296	14.300	14.303	14.307	14.311	14.315	14.319	14.323	14.327
364	14.331	14.335	14.339	14.343	14.347	14.351	14.355	14.359	14.363	14.366
365	14.370	14.374	14.378	14.382	14.386	14.390	14.394	14.398	14.402	14.406
366	14.410	14.414	14.418	14.422	14.426	14.429	14.433	14.437	14.441	14.445
367	14.449	14.453	14.457	14.461	14.465	14.469	14.473	14.477	14.481	14.485
366	14.489	14.492	14.496	14.500	14.504	14.508	14.512	14.516	14.520	14.524
369	14.528	14.532	14.536	14.540	14.544	14.548	14.552	14.555	14.559	14.563
370	**14.667**	**14.571**	**14.575**	**14.679**	**14.583**	**14.587**	**14.591**	**14.595**	**14.599**	**15.603**
371	14.607	14.611	14.614	14.618	14.622	14.626	14.630	14.634	14.638	14.642
372	14.646	14.650	14.654	14.658	14.662	14.666	14.670	14.674	14.677	14.681
373	14.685	14.689	14.693	14.697	14.701	14.705	14.709	14.713	14.717	14.721
374	14.725	14.729	14.733	14.737	14.740	14.744	14.748	14.752	14.756	14.760
375	14.764	14.768	14.772	14.776	14.780	14.784	14.788	14.792	14.796	14.800
375	14.803	14.807	14.811	14.815	14.819	14.823	14.827	14.831	14.835	14.839
377	14.843	14.847	14.851	14.855	14.859	14.863	14.866	14.870	14.874	14.878
378	14.882	14.886	14.890	14.894	14.898	14.902	14.906	14.910	14.914	14.918
379	14.922	14.926	14.929	14.933	14.937	14.941	14.945	14.949	14.953	14.957
380	**14.961**	**14.965**	**14.969**	**14.973**	**14.977**	**14.981**	**14.985**	**14.989**	**14.992**	**14.996**
381	15.000	15.004	15.008	15.012	15.016	15.020	15.024	15.028	15.032	15.036
382	15.040	15.044	15.048	15.052	15.055	15.059	15.063	15.067	15.071	15.075
383	15.079	15.083	15.087	15.091	15.095	15.099	15.103	15.107	15.111	15.114
384	15.118	15.122	15.126	15.130	15.134	15.138	15.142	15.146	15.150	15.154
385	15.158	15.162	15.166	15.170	15.174	15.177	15.181	15.185	15.189	15.193
386	15.197	15.201	15.205	15.209	15.213	15.217	15.221	15.225	15.229	15.233
387	15.237	15.240	15.244	15.248	15.252	15.256	15.260	15.264	15.268	15.272
388	15.276	15.280	15.284	15.288	15.292	15.296	15.300	15.303	15.307	15.311
389	15.315	15.319	15.323	15.327	15.331	15.335	15.339	15.343	15.347	15.351
390	**15.356**	**15.359**	**15.363**	**15.366**	**15.370**	**15.374**	**15.378**	**15.382**	**15.386**	**15.390**
391	15.394	15.398	15.402	15.406	15.410	15.414	15.418	15.422	15.426	15.429
392	15.433	15.437	15.441	15.445	15.449	15.453	15.457	15.461	15.465	15.469
393	15.473	15.477	15.481	15.485	15.489	15.492	15.496	15.500	15.504	15.508
394	15.512	15.516	15.520	15.524	15.528	15.532	15.536	15.540	15.544	15.548
395	15.551	15.555	15.559	15.563	15.567	15.571	15.575	15.579	15.583	15.587
396	15.591	15.595	15.599	15.603	15.607	15.611	15.614	15.618	15.622	15.626
397	15.630	15.634	15.638	15.642	15.646	15.650	15.654	15.658	15.662	15.666
398	15.670	15.674	15.677	15.681	15.685	15.689	15.693	15.697	15.701	15.705
399	15.709	15.713	15.717	15.721	15.725	15.729	15.733	15.737	15.740	15.744
400	**15.748**	**15.752**	**15.756**	**15.760**	**15.764**	**15.768**	**15.772**	**15.776**	**16.780**	**15.784**

401 - 500.9mm
15.788 - 19.721
inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
401	15.788	15.792	15.796	15.800	15.803	15.807	15.811	15.815	15.819	15.823
402	15.827	15.831	15.835	15.839	15.843	15.847	15.851	15.855	15.859	15.863
403	15.866	15.870	15.874	15.878	15.882	15.886	15.890	15.894	15.898	15.902
404	15.906	15.910	15.914	15.918	15.922	15.926	15.929	15.933	15.937	15.941
405	15.945	15.949	15.953	15.957	15.961	15.965	15.969	15.973	15.977	15.981
406	15.985	15.988	15.992	15.996	16.000	16.004	16.008	16.012	16.016	16.020
407	16.024	16.028	16.032	16.036	16.040	16.044	16.048	16.051	16.055	16.059
408	16.063	16.067	16.071	16.075	16.079	16.083	16.087	16.091	16.095	16.099
409	16.103	16.107	16.111	16.114	16.118	16.122	16.126	16.130	16.134	16.138
410	**16.142**	**16.146**	**16.150**	**16.154**	**16.158**	**16.182**	**16.166**	**16.170**	**16.174**	**16.177**
411	16.181	16.185	16.189	16.193	16.197	16.201	16.205	16.209	16.213	16.217
412	16.221	16.225	16.229	16.233	16.236	16.240	16.244	16.248	16.252	16.256
413	16.260	16.264	16.268	16.272	16.276	16.280	16.284	16.288	16.292	16.296
414	16.299	16.303	16.307	16.311	16.315	16.319	16.323	16.327	16.331	16.335
415	16.339	16.343	16.347	16.351	16.355	16.359	16.362	16.366	16.370	16.374
416	16.378	16.382	16.386	16.390	16.394	16.398	16.402	16.406	16.410	16.414
417	16.418	16.422	16.425	16.429	16.433	16.437	16.441	16.445	16.449	16.453
418	16.457	16.461	16.465	16.469	16.473	16.477	16.481	16.485	16.488	16.492
419	16.496	16.500	16.504	16.508	16.512	16.516	16.520	16.524	16.528	16.532
420	**16.536**	**16.540**	**16.544**	**16.548**	**16.551**	**16.555**	**16.559**	**16.563**	**16.567**	**16.571**
421	16.575	16.579	16.583	16.587	16.591	16.595	16.599	16.603	16.607	16.610
422	16.614	16.618	16.622	16.626	16.630	16.634	16.638	16.642	16.646	16.650
423	16.654	16.658	16.862	16.666	16.670	16.673	16.677	16.681	16.685	16.689
424	16.693	16.697	16.701	16.705	16.709	16.713	16.717	16.721	16.725	16.729
425	16.733	16.736	16.740	16.744	16.748	16.752	16.756	16.760	16.764	16.768
426	16.772	16.776	16.780	16.784	16.788	16.792	16.796	16.799	16.803	16.807
427	16.811	16.815	16.819	16.823	16.827	16.831	16.835	16.839	16.843	16.847
428	16.851	16.855	16.859	16.862	16.866	16.870	16.874	16.878	16.882	16.886
429	16.890	16.894	16.898	16.902	16.906	16.910	16.914	16.918	16.921	16.925
430	**16.929**	**16.933**	**16.937**	**16.941**	**16.945**	**16.949**	**16.953**	**16.957**	**16.961**	**16.965**
431	16.969	16.973	16.977	16.981	16.984	16.988	16.992	16.996	17.000	17.004
432	17.008	17.012	17.016	17.020	17.024	17.028	17.032	17.036	17.040	17.044
433	17.047	17.051	17.055	17.059	17.063	17.067	17.071	17.075	17.079	17.083
434	17.087	17.091	17.095	17.099	17.103	17.107	17.110	17.114	17.118	17.122
435	17.126	17.130	17.134	17.138	17.142	17.146	17.150	17.154	17.158	17.162
436	17.166	17.170	17.173	17.177	17.181	17.185	17.189	17.193	17.197	17.201
437	17.205	17.209	17.213	17.217	17.221	17.225	17.229	17.232	17.236	17.240
438	17.244	17.248	17.252	17.256	17.260	17.264	17.268	17.272	17.276	17.280
439	17.284	17.288	17.292	17.295	17.299	17.303	17.307	17.311	17.315	17.319
440	**17.323**	**17.327**	**17.331**	**17.335**	**17.339**	**17.343**	**17.347**	**17.351**	**17.355**	**17.358**
441	17.362	17.366	17.370	17.374	17.378	17.382	17.386	17.390	18.394	17.398
442	17.402	17.406	17.410	17.414	17.418	17.421	17.425	17.429	17.433	17.437
443	17.441	17.445	17.449	17.453	17.457	17.461	17.465	17.469	17.473	17.477
444	17.481	17.484	17.488	17.492	17.496	17.500	17.504	17.508	17.512	17.516
445	17.520	17.524	17.528	17.532	17.536	17.540	17.544	17.547	17.551	17.555
446	17.559	17.563	17.567	17.571	17.575	17.579	17.583	17.587	17.591	17.595
447	17.599	17.603	17.606	17.610	17.614	17.618	17.622	17.626	17.630	17.634
448	17.638	17.642	17.646	17.650	17.654	17.658	17.662	17.666	17.669	17.673
449	17.677	17.681	17.685	17.689	17.693	17.697	17.701	17.705	17.709	17.713
450	**17.717**	**17.721**	**17.725**	**17.729**	**17.732**	**17.736**	**17.740**	**17.744**	**17.748**	**17.752**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
451	17.756	17.760	17.764	17.768	17.772	17.776	17.780	17.784	17.788	17.792
452	17.795	17.799	17.803	17.807	17.811	17.815	17.819	17.823	17.827	17.831
453	17.835	17.839	17.843	17.847	17.851	17.855	17.858	17.862	17.866	17.870
454	17.874	17.878	17.882	17.886	17.890	17.894	17.898	17.902	17.906	17.910
455	17.914	17.917	17.921	17.925	17.929	17.933	17.937	17.941	17.945	17.949
456	17.953	17.957	17.961	17.965	17.969	17.973	17.977	17.980	17.984	17.988
457	17.992	17.996	18.000	18.004	18.008	18.012	18.016	18.020	18.024	18.028
458	18.032	18.036	18.040	18.043	18.047	18.051	18.055	18.059	18.063	18.067
459	18.071	18.075	18.079	18.083	18.087	18.091	18.095	18.099	18.103	18.106
460	**18.110**	**18.114**	**18.118**	**18.122**	**18.126**	**18.130**	**18.134**	**18.138**	**18.142**	**18.146**
461	18.150	18.154	18.158	18.162	18.166	18.169	18.173	18.177	18.181	18.185
462	18.189	18.193	18.197	18.201	18.205	18.209	18.213	18.217	18.221	18.225
463	18.229	18.232	18.236	18.240	18.244	18.248	18.252	18.256	18.260	18.264
464	18.268	18.272	18.276	18.280	18.284	18.288	18.291	18.295	18.299	18.303
465	18.307	18.311	18.315	18.319	18.323	18.327	18.331	18.335	18.339	18.343
466	18.347	18.351	18.354	18.358	18.362	18.366	18.370	18.374	18.378	18.382
467	18.386	18.390	18.394	18.398	18.402	18.406	18.410	18.414	18.417	18.421
468	18.425	18.429	18.433	18.437	18.441	18.445	18.449	18.453	18.457	18.461
469	18.465	18.469	18.473	18.477	18.480	18.484	18.488	18.492	18.496	18.500
470	**18.504**	**18.508**	**18.512**	**18.516**	**18.520**	**18.524**	**18.528**	**18.532**	**18.536**	**18.540**
471	18.543	18.547	18.551	18.555	18.559	18.563	18.567	18.571	18.575	18.579
472	18.583	18.587	18.591	18.595	18.599	18.602	18.606	18.610	18.614	18.618
473	18.622	18.626	18.630	18.634	18.638	18.642	18.646	18.650	18.654	18.658
474	18.662	18.665	18.669	18.673	18.677	18.681	18.685	18.689	18.693	18.697
475	18.701	18.705	18.709	18.713	18.717	18.721	18.725	18.728	18.732	18.736
476	18.740	18.744	18.748	18.752	18.756	18.760	18.764	18.768	18.772	18.776
477	18.780	18.784	18.788	18.791	18.795	18.799	18.803	18.807	18.811	18.815
478	18.819	18.823	18.827	18.831	18.835	18.839	18.843	18.847	18.851	18.854
479	18.868	18.862	18.866	18.870	18.874	18.878	18.882	18.886	18.890	18.894
480	**18.898**	**18.902**	**18.906**	**18.910**	**18.913**	**18.917**	**18.921**	**18.925**	**18.929**	**18.933**
481	18.937	18.941	18.945	18.949	18.953	18.957	18.961	18.965	18.969	18.973
482	18.976	18.980	19.984	19.988	18.992	18.996	19.000	19.004	19.008	19.012
483	19.016	19.020	19.024	19.028	19.032	19.036	19.039	19.043	19.047	19.051
484	19.055	19.059	19.063	19.067	19.071	19.075	19.079	19.083	19.087	19.091
485	19.095	19.099	19.102	19.106	19.110	19.114	19.118	19.122	19.126	19.130
486	19.134	19.138	19.142	19.146	19.150	19.154	19.158	19.162	19.165	19.169
487	19.173	19.177	19.181	19.185	19.189	19.193	19.197	19.201	19.205	19.209
488	19.213	19.217	19.221	19.225	19.228	19.232	19.236	19.240	19.244	19.248
489	19.252	19.256	19.260	19.264	19.268	19.272	19.276	19.280	19.284	19.287
490	**19.291**	**18.295**	**19.299**	**19.303**	**19.307**	**19.311**	**19.315**	**19.319**	**19.323**	**19.327**
491	19.331	19.335	19.339	19.343	19.347	19.350	19.354	19.358	19.362	19.366
492	19.370	19.374	19.378	19.382	19.386	19.390	19.394	19.398	19.402	19.406
493	19.410	19.413	19.417	19.421	19.425	19.429	19.433	19.437	19.441	19.445
494	19.449	19.453	19.457	19.461	19.465	19.469	19.473	19.476	19.480	19.484
495	19.488	19.492	19.496	19.500	19.504	19.508	19.512	19.516	19.520	19.524
496	19.528	19.532	19.536	19.539	19.543	19.547	19.551	19.555	19.559	19.563
497	19.567	19.571	19.575	19.579	19.583	19.587	19.591	19.595	19.598	19.602
498	19.606	19.610	19.614	19.618	19.622	19.626	19.630	19.634	19.638	19.642
499	19.646	19.650	19.654	19.658	19.661	19.665	19.669	19.673	19.677	19.681
500	**19.685**	**19.689**	**19.693**	**19.697**	**19.701**	**19.705**	**19.709**	**19.713**	**19.717**	**19.721**

501 - 600.9mm
19.724 - 23.657 inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
501	19.724	19.728	19.732	19.736	19.740	19.744	19.748	19.752	19.756	19.760
502	19.764	19.768	19.772	19.776	19.780	19.784	19.787	19.791	19.795	19.799
503	19.803	19.807	19.811	19.815	19.819	19.823	19.827	19.831	19.835	19.839
504	19.843	19.847	19.850	19.854	19.858	19.862	19.866	19.870	19.874	19.878
505	19.882	19.886	19.890	19.894	19.898	19.902	19.906	19.910	19.913	19.917
506	19.921	19.925	19.929	19.933	19.937	19.941	19.945	19.949	19.953	19.957
507	19.961	19.965	19.969	19.972	19.976	19.980	19.984	19.988	19.992	19.996
508	20.000	20.004	20.008	20.012	20.016	20.020	20.024	20.028	20.032	20.035
509	20.039	20.043	20.047	20.051	20.055	20.059	20.063	20.067	20.071	20.075
510	**20.079**	**20.083**	**20.087**	**20.091**	**20.095**	**20.098**	**20.102**	20.106	20.110	20.114
511	20.118	20.122	20.126	20.130	20.134	20.138	20.142	20.146	20.150	20.154
512	20.158	20.161	20.165	20.169	20.173	20.177	20.181	20.185	20.189	20.193
513	20.197	20.201	20.205	20.209	20.213	20.217	20.221	20.224	20.228	20.232
514	20.236	20.240	20.244	20.248	20.252	20.258	20.260	20.264	20.268	20.272
515	20.276	20.280	20.283	20.287	20.291	20.295	20.299	20.303	20.307	20.311
516	20.315	20.319	20.323	20.327	20.331	20.335	20.339	20.343	20.346	20.350
517	20.354	20.358	20.362	20.366	20.370	20.374	20.378	20.382	20.386	20.390
518	20.394	20.398	20.402	20.406	20.409	20.413	20.417	20.421	20.425	20.429
519	20.433	20.437	20.441	20.445	20.449	20.453	20.457	20.461	20.465	20.469
520	**20.472**	20.476	**20.480**	**20.484**	**20.488**	**20.492**	**20.496**	**20.500**	**20.504**	**20.508**
521	20.512	20.516	20.520	20.524	20.528	20.532	20.535	20.539	20.543	20.547
522	20.551	20.555	20.559	20.563	20.567	20.571	20.575	20.579	20.583	20.587
523	20.591	20.594	20.598	20.602	20.606	20.610	20.614	20.618	20.622	20.626
524	20.630	20.634	20.638	20.642	20.646	20.650	20.654	20.657	20.661	20.665
525	20.669	20.673	20.677	20.681	20.685	20.689	20.693	20.697	20.701	20.705
526	20.709	20.713	20.717	20.720	20.724	20.728	20.732	20.736	20.740	20.744
527	20.748	20.752	20.756	20.760	20.764	20.768	20.772	20.776	20.780	20.783
528	20.787	20.791	20.795	20.799	20.803	20.807	20.811	20.815	20.819	20.823
529	20.827	20.831	20.835	20.839	20.843	20.846	20.850	20.854	20.858	20.862
530	**20.866**	**20.870**	**20.874**	**20.878**	**20.882**	**20.886**	**20.890**	**20.894**	**20.898**	**20.902**
531	20.906	20.909	20.913	20.917	20.921	20.925	20.929	20.933	20.937	20.941
532	20.945	20.949	20.953	20.957	20.961	20.965	20.968	20.972	20.976	20.980
533	20.984	20.988	20.992	20.996	21.000	21.004	21.008	21.012	21.016	21.020
534	21.024	21.028	21.031	21.035	21.039	21.043	21.047	21.051	21.055	21.059
535	21.063	21.067	21.071	21.075	21.079	21.083	21.087	21.091	21.094	21.098
536	21.102	21.106	21.110	21.114	21.118	21.122	21.126	21.130	21.134	21.138
537	21.142	21.146	21.150	21.154	21.157	21.161	21.165	21.169	21.173	21.177
538	21.181	21.185	21.189	21.193	21.197	21.201	21.205	21.209	21.213	21.217
539	21.220	21.224	21.228	21.232	21.236	21.240	21.244	21.248	21.252	21.256
540	**21.260**	**21.264**	**21.268**	**21.272**	**21.276**	**21.279**	**21.283**	**21.287**	**21.291**	**21.295**
541	21.299	21.303	21.307	21.311	21.315	21.319	21.323	21.327	21.331	21.335
542	21.339	21.342	21.346	21.350	21.354	21.358	21.362	21.386	21.370	21.374
543	21.378	21.382	21.386	21.390	21.394	21.398	21.402	21.405	21.409	21.413
544	21.417	21.421	21.425	21.429	21.433	21.437	21.441	21.445	21.449	21.453
545	21.457	21.461	21.465	21.468	21.472	21.476	21.480	21.484	21.488	21.492
546	21.496	21.500	21.504	21.508	21.512	21.516	21.520	21.524	21.528	21.531
547	21.535	21.539	21.543	21.547	21.551	21.555	21.559	21.563	21.567	21.571
548	21.575	21.579	21.583	21.587	21.590	21.594	21.598	21.602	21.606	21.610
549	21.614	21.618	21.622	21.626	21.630	21.634	21.638	21.642	21.646	21.650
550	**21.653**	**21.657**	**21.661**	**21.665**	**21.669**	21.673	**21.677**	**21.681**	**21.685**	21.689

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
551	21.693	21.697	21.701	21.705	21.709	21.713	21.716	21.720	21.724	21.728
552	21.732	21.736	21.740	21.744	21.748	21.752	21.756	21.760	21.764	21.768
553	21.772	21.776	21.779	21.783	21.787	21.791	21.795	21.799	21.803	21.807
554	21.811	21.815	21.819,	21.823	21.827	21.831	21.835	21.839	21.842	21.846
555	21.850	21.854	21.858	21.862	21.866	21.870	21.874	21.878	21.882	21.886
556	21.890	21.894	21.898	21.902	21.905	21.909	21.913	21.917	21.921	21.925
557	21.929	21.933	21.937	21.941	21.945	21.949	21.953	21.957	21.961	21.964
558	21.968	21.972	21.976	21.980	21.984	21.988	21.992	21.996	22.000	22.004
559	22.008	22.012	22.016	22.020	22.024	22.027	22.031	22.035	22.039	22.043
560	**22.047**	**22.051**	**22.055**	**22.059**	22.063	22.067	22.071	**22.075**	**22.079**	**22.083**
561	22.087	22.090	22.094	22.098	22.102	22.106	22.110	22.114	22.118	22.122
562	22.126	22.130	22.134	22.138	22.142	22.146	22.150	22.153	22.157	22.161
563	22.165	22.169	22.173	22.177	22.181	22.185	22.189	22.193	22.197	22.201
564	22.205	22.209	22.213	22.216	22.220	22.224	22.228	22.232	22.236	22.240
565	22.244	22.248	22.252	22.256	22.260	22.264	22.268	22.272	22.275	22.279
566	22.283	22.287	22.291	22.295	22.299	22.303	22.307	22.311	22.315	22.319
567	22.323	22.327	22.331	22.335	22.338	22.342	22.346	22.350	22.354	22.358
568	22.362	22.366	22.370	22.374	22.378	22.282	22.386	22.390	22.394	22.398
569	22.401	22.405	22.409	22.413	22.417	22.421	22.425	22.429	22.433	22.437
570	**22.441**	**22.445**	**22.449**	**22.453**	**22.457**	22.461	**22.464**	**22.468**	**22.472**	**22.476**
571	22.480	22.484	22.488	22.492	22.496	22.500	22.504	22.508	22.512	22.516
572	22.520	22.524	22.527	22.531	22.535	22.539	22.543	22.547	22.551	22.555
573	22.559	22.563	22.567	22.571	22.575	22.579	22.583	22.587	22.590	22.594
574	22.598	22.602	22.606	22.610	22.614	22.618	22.622	22.626	22.630	22.634
575	22.638	22.642	22.646	22.649	22.653	22.657	22.661	22.665	22.669	22.673
576	22.677	22.681	22.685	22.689	22.693	22.697	22.701	22.705	22.709	22.712
577	22.716	22.720	22.724	22.728	22.732	22.736	22.740	22.744	22.748	22.752
578	22.756	22.760	22.764	22.768	22.772	22.775	22.779	22.783	22.787	22.791
579	22.795	22.799	22.803	22.807	22.811	22.815	22.819	22.823	22.827	22.831
580	**22.835**	**22.838**	**22.842**	**22.846**	**22.850**	**22.854**	**22.858**	**22.862**	**22.866**	**22.870**
581	22.874	22.878	22.882	22.886	22.890	22.894	22.898	22.901	22.905	22.909
582	22.913	22.917	22.921	22.925	22.929	22.933	22.937	22.941	22.945	22.949
583	22.953	22.957	22.960	22.964	22.968	22.972	22.976	22.980	22.984	22.988
584	22.992	22.996	23.000	23.004	23.008	23.012	23.016	23.020	23.023	23.027
585	23.031	23.035	23.039	23.043	23.047	23.051	23.055	23.059	23.063	23.067
586	23.071	23.075	23.079	23.083	23.086	23.090	23.094	23.098	23.102	23.106
587	23.110	23.114	23.118	23.122	23.126	23.130	23.134	23.138	23.142	23.146
588	23.149	23.153	23.157	23.161	23.165	23.169	23.173	23.177	23.181	23.185
589	23.189	23.193	23.197	23.201	23.205	23.209	23.212	23.216	23.220	23.224
590	**23.228**	**23.232**	**23.236**	**23.240**	**23.244**	**23.248**	**23.252**	**23.256**	23.260	**23.264**
591	23.268	23.271	23.275	23.279	23.283	23.287	23.291	23.295	23.299	23.303
592	23.307	23.311	23.315	23.319	23.323	23.327	23.331	23.334	23.338	23.342
593	23.346	23.350	23.354	23.358	23.362	23.366	23.370	23.374	23.378	23.382
594	23.386	23.390	23.394	23.397	23.401	23.405	23.409	23.413	23.417	23.421
595	23.425	23.429	23.433	23.437	23.441	23.445	23.449	23.453	23.457	23.460
596	23.464	23.468	23.472	23.476	23.480	23.484	23.488	23.492	23.496	23.500
597	23.504	23.508	23.512	23.516	23.520	23.523	23.527	23.531	23.535	23.539
598	23.543	23.547	23.551	23.555	23.559	23.563	23.567	23.571	23.575	23.579
599	23.583	23.586	23.590	23.594	23.598	23.602	23.606	23.610	23.614	23.618
600	23.622	23.626	23.630	**23.634**	**23.638**	**23.642**	**23.645**	**23.649**	23.653	**23.657**

601 - 700.9mm
23.661 - 27.594 inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
601	23.661	23.665	23.669	23.673	23.677	23.681	23.685	23.689	23.693	23.697
602	23.701	23.705	23.708	23.712	23.716	23.720	23.724	23.728	23.732	23.736
603	23.740	23.744	23.748	23.752	23.756	23.760	23.764	23.768	23.771	23.775
604	23.779	23.783	23.787	23.791	23.795	23.799	23.803	23.807	23.811	23.815
605	23.819	23.823	23.827	23.831	23.834	23.838	23.842	23.846	23.850	23.854
606	23.858	23.862	23.866	23.870	23.874	23.878	23.882	23.886	23.890	23.894
607	23.897	23.901	23.905	23.909	23.913	23.917	23.921	23.925	23.929	23.933
608	23.937	23.941	23.945	23.949	23.953	23.956	23.960	23.964	23.968	23.972
609	23.976	23.980	23.984	23.988	23.992	23.996	24.000	24.004	24.008	24.012
610	**24.016**	**24.019**	**24.023**	**24.027**	**24.031**	**24.035**	**24.039**	**24.043**	**24.047**	**24.051**
611	24.055	24.059	24.063	24.067	24.071	24.075	24.079	24.082	24.086	24.090
612	24.094	24.098	24.102	24.106	24.110	24.114	24.118	24.122	24.126	24.130
613	24.134	24.138	24.142	24.145	24.149	24.153	24.157	24.161	24.165	24.169
614	24.173	24.177	24.181	24.185	24.189	24.193	24.197	24.201	24.205	24.208
615	24.212	24.216	24.220	24.224	24.228	24.232	24.236	24.240	24.244	24.248
616	24.252	24.256	24.260	24.264	24.268	24.271	24.275	24.279	24.283	24.287
617	24.291	24.295	24.299	24.303	24.307	24.311	24.315	24.319	24.323	24.327
618	24.330	24.334	24.338	24.342	24.346	24.350	24.354	24.358	24.362	24.366
619	24.370	24.374	24.378	24.382	24.386	24.390	24.393	24.397	24.401	24.405
620	**24.409**	**24.413**	**24.417**	**24.421**	**24.425**	**24.429**	**24.433**	**24.437**	**24.441**	**24.445**
621	24.449	24.453	24.456	24.460	24.464	24.468	24.472	24.476	24.480	24.484
622	24.488	24.492	24.496	24.500	24.504	24.508	24.512	24.516	24.519	24.523
623	24.527	24.531	24.535	24.539	24.543	24.547	24.551	24.555	24.559	24.563
624	24.567	24.571	24.575	24.579	24.582	24.586	24.590	24.594	24.598	24.602
625	24.606	24.610	24.614	24.618	24.622	24.626	24.630	24.634	24.638	24.641
626	24.645	24.649	24.653	24.657	24.661	24.665	24.669	24.673	24.677	24.681
627	24.685	24.689	24.693	24.697	24.701	24.704	24.708	24.712	24.716	24.720
628	24.724	24.728	24.732	24.736	24.740	24.744	24.748	24.752	24.756	24.760
629	24.764	24.767	24.771	24.775	24.779	24.783	24.787	24.791	24.795	24.799
630	**24.803**	**24.807**	**24.811**	**24.815**	**24.819**	**24.823**	**24.827**	**24.830**	**24.834**	**24.838**
631	24.842	24.846	24.850	24.854	24.858	24.862	24.866	24.870	24.874	24.878
632	24.882	24.886	24.890	24.893	24.897	24.901	24.905	24.909	24.913	24.917
633	24.921	24.925	24.929	24.933	24.937	24.941	24.945	24.949	24.952	24.956
634	24.960	24.964	24.968	24.972	24.976	24.980	24.984	24.988	24.992	24.996
635	25.000	25.004	25.008	25.012	25.015	25.019	25.023	25.027	25.031	25.035
636	25.039	25.043	25.047	25.051	25.055	25.059	25.063	25.067	25.071	25.075
637	25.078	25.082	25.086	25.090	25.094	25.098	25.102	25.106	25.110	25.114
638	25.118	25.122	25.126	25.130	25.134	25.138	25.141	25.145	25.149	25.153
639	25.157	25.161	25.165	25.169	25.173	25.177	25.181	25.185	25.189	25.193
640	**25.197**	**25.201**	**25.204**	**25.208**	**25.212**	**25.216**	**25.220**	**25.224**	**25.228**	**25.232**
641	25.236	25.240	25.244	25.248	25.252	25.256	25.260	25.264	25.287	25.271
642	25.275	25.279	25.283	25.287	25.291	25.295	25.299	25.303	25.307	25.311
643	25.315	25.319	25.323	25.326	25.330	25.334	25.338	25.342	25.346	25.350
644	25.354	25.358	25.362	25.366	25.370	25.374	25.378	25.382	25.386	25.389
645	25.393	25.397	25.401	25.405	25.409	25.413	25.417	25.421	25.425	25.429
646	25.433	25.437	25.441	25.445	25.449	25.452	25.456	25.460	25.464	25.468
647	25.472	25.476	25.480	25.484	25.488	25.492	25.496	25.500	25.504	25.508
648	25.512	25.515	25.519	25.523	25.527	25.531	25.535	25.539	25.543	25.547
649	25.551	25.555	25.559	25.563	25.567	25.571	25.575	25.578	25.582	25.586
650	**25.590**	**25.594**	**25.598**	**25.602**	**25.606**	**25.610**	**25.614**	**25.618**	**25.622**	**25.626**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
651	25.630	25.634	25.637	25.641	25.645	25.649	25.653	25.657	25.661	25.665
652	25.669	25.673	25.677	25.681	25.685	25.689	25.693	25.697	25.700	25.704
653	25.708	25.712	25.716	25.720	25.724	25.728	25.732	25.736	25.740	25.744
654	25.748	25.752	25.756	25.760	25.763	25.767	25.771	25.775	25.779	25.783
655	25.787	25.791	25.795	25.799	25.803	25.807	25.811	25.815	25.819	25.823
656	25.826	25.830	25.834	25.838	25.842	25.846	25.850	25.854	25.858	25.862
657	25.866	25.870	25.874	25.878	25.882	25.886	25.889	25.893	25.897	25.901
658	25.905	25.909	25.913	25.917	25.921	25.925	25.929	25.933	25.937	25.941
659	25.945	25.949	25.952	25.956	25.960	25.964	25.968	25.972	25.976	25.980
660	**25.984**	**25.988**	**25.992**	**25.996**	**26.000**	**26.004**	**26.008**	**28.011**	**26.015**	**26.019**
661	26.023	26.027	26.031	26.035	26.039	26.043	26.047	26.051	26.055	26.059
662	26.063	26.067	26.071	26.074	26.078	26.082	26.086	26.090	26.094	26.098
663	26.102	26.106	26.110	26.114	26.118	26.122	26.126	26.130	26.134	26.137
664	26.141	26.145	26.149	26.153	26.157	26.161	26.165	26.169	26.173	26.177
665	26.181	26.185	26.189	26.193	26.197	26.200	26.204	26.208	26.212	26.216
666	26.220	26.224	26.228	26.232	26.236	26.240	26.244	26.248	26.252	26.256
667	26.260	26.263	26.267	26.271	26.275	26.279	26.283	26.287	26.291	26.295
668	26.299	26.303	26.307	26.311	26.315	26.319	26.322	26.326	26.330	26.334
669	26.338	26.342	26.346	26.350	26.354	26.358	26.362	26.366	26.370	26.374
670	**26.378**	**26.382**	**26.385**	**26.389**	**26.393**	**26.397**	**26.401**	**26.405**	**26.409**	**26.413**
671	26.417	26.421	26.425	26.429	26.433	26.437	26.441	26.445	26.448	26.452
672	26.456	26.460	26.464	26.468	26.472	26.476	26.480	26.484	26.488	26.492
673	26.496	26.500	26.504	26.508	26.511	26.515	26.519	26.523	26.527	26.531
674	26.535	26.539	26.543	26.547	26.551	26.555	26.559	26.563	26.567	26.571
675	26.574	26.578	26.582	26.586	26.590	26.594	26.598	26.602	26.606	26.610
676	26.614	26.618	26.622	26.626	26.630	26.633	26.637	26.641	26.645	26.649
677	26.653	26.657	26.661	26.665	26.669	26.673	26.677	26.681	26.685	26.689
678	26.693	26.696	26.700	26.704	26.708	26.712	26.716	26.720	26.724	26.728
679	26.732	26.736	26.740	26.744	26.748	26.752	26.756	26.759	26.763	26.767
680	**26.771**	**26.775**	**26.779**	**26.783**	**26.787**	**26.791**	**26.795**	**26.799**	**26.803**	**26.807**
681	26.811	26.815	26.819	26.822	26.826	26.830	26.834	26.838	26.842	26.846
682	26.850	26.854	26.858	26.852	26.866	26.870	26.874	26.878	26.882	26.885
683	26.889	26.893	26.897	26.901	26.905	26.909	26.913	26.917	26.921	26.925
684	26.929	26.933	26.937	26.941	26.945	26.948	26.952	26.956	26.960	26.964
685	26.968	26.972	26.976	26.980	26.984	26.988	26.992	26.986	27.000	27.004
686	27.007	27.011	27.015	27.019	27.023	27.027	27.031	27.035	27.039	27.043
687	27.047	27.051	27.055	27.059	27.063	27.067	27.070	27.074	27.078	27.082
688	27.086	27.090	27.094	27.098	27.102	27.106	27.110	27.114	27.118	27.122
689	27.126	27.130	27.133	27.137	27.141	27.145	27.149	27.153	27.157	27.161
690	**27.165**	**27.169**	**27.173**	**27.177**	**27.181**	**27.185**	**27.189**	**27.193**	**27.196**	**27.200**
691	27.204	27.208	27.212	27.216	27.220	27.224	27.228	27.232	27.236	27.240
692	27.244	27.248	27.252	27.256	27.259	27.263	27.267	27.271	27.275	27.279
693	27.283	27.287	27.291	27.295	27.299	27.303	27.307	27.311	27.315	27.316
694	27.322	27.326	27.330	27.334	27.338	27.342	27.346	27.350	27.354	27.358
695	27.362	27.366	27.370	27.374	27.378	27.381	27.385	27.389	27.393	27.397
696	27.401	27.405	27.409	27.413	27.417	27.421	27.425	27.429	27.433	27.437
697	27.441	27.444	27.448	27.452	27.456	27.460	27.464	27.468	27.472	27.476
698	27.480	27.484	27.488	27.492	27.496	27.500	27.504	27.507	27.511	27.515
699	27.519	27.523	27.527	27.531	27.535	27.539	27.543	27.647	27.551	27.555
700	**27.559**	**27.563**	**27.567**	**27.570**	**27.574**	**27.578**	**27.582**	**27.586**	**27.590**	**27.594**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
701	27.598	27.602	27.606	27.610	27.614	27.618	27.622	27.626	27.630	27.633
702	27.637	27.641	27.645	27.649	27.653	27.657	27.661	27.665	27.669	27.673
703	27.677	27.681	27.685	27.689	27.692	27.696	27.700	27.704	27.708	27.712
704	27.716	27.720	27.724	27.728	27.732	27.736	27.740	27.744	27.748	27.752
705	27.755	27.759	27.763	27.767	27.771	27.775	27.779	27.783	27.787	27.791
706	27.795	27.799	27.803	27.807	27.811	27.815	27.818	27.822	27.826	27.830
707	27.834	27.838	27.842	27.846	27.850	27.854	27.858	27.862	27.866	27.870
708	27.874	27.878	27.881	27.885	27.889	27.893	27.897	27.901	27.905	27.909
709	27.913	27.917	27.921	27.925	27.929	27.933	27.937	27.941	27.944	27.948
710	27.952	27.956	27.960	27.964	27.968	27.972	27.976	27.980	27.984	27.988
711	27.992	27.996	28.000	28.003	28.007	28.011	28.015	28.019	28.023	28.027
712	28.031	28.035	28.039	28.043	28.047	28.051	28.055	28.059	28.063	28.066
713	28.070	28.074	28.078	28.082	28.086	28.090	28.094	28.098	28.102	28.106
714	28.110	28.114	28.118	28.122	28.126	28.129	28.133	28.137	28.141	28.145
715	28.149	28.153	28.157	28.161	28.165	28.169	28.173	28.177	28.181	28.185
716	28.189	28.192	28.196	28.200	28.204	28.208	28.212	28.216	28.220	28.224
717	28.228	28.232	28.236	28.240	28.244	28.248	28.252	28.255	28.259	28.263
718	28.267	28.271	28.275	28.279	28.283	28.287	28.291	28.295	28.299	28.303
719	28.307	28.311	28.314	28.318	28.322	28.326	28.330	28.334	28.338	28.342
720	28.346	28.350	28.354	28.358	28.362	28.366	28.370	28.374	28.377	28.381
721	28.385	28.389	28.393	28.397	28.401	28.405	28.409	28.413	28.417	28.421
722	28.425	28.429	28.433	28.437	28.440	28.444	28.448	28.452	28.456	28.460
723	28.464	28.468	28.472	28.476	28.480	28.484	28.488	28.492	28.496	28.500
724	28.503	28.507	28.511	28.515	28.519	28.523	28.527	28.531	28.535	28.539
725	28.543	28.547	28.551	28.555	28.559	28.563	28.566	28.570	28.574	28.578
726	28.582	28.586	28.590	28.594	28.598	28.602	28.606	28.610	28.614	28.618
727	28.622	28.626	28.629	28.633	28.637	28.641	28.645	28.649	28.653	28.657
728	28.661	28.665	28.669	28.673	28.677	28.681	28.685	28.688	28.692	28.696
729	28.700	28.704	28.708	28.712	28.716	28.720	28.724	28.728	28.732	28.736
730	28.740	28.744	28.748	28.751	28.755	28.759	28.763	28.767	28.771	28.775
731	28.779	28.783	28.787	28.791	28.795	28.799	28.803	28.807	28.811	28.814
732	28.818	28.822	28.826	28.830	28.834	28.838	28.842	28.846	28.850	28.854
733	28.858	28.862	28.866	28.870	28.874	28.877	28.881	28.885	28.889	28.893
734	28.897	28.901	28.905	28.909	28.913	28.917	28.921	28.925	28.929	28.933
735	28.937	28.940	28.944	28.948	28.952	28.956	28.960	28.964	28.968	28.972
736	28.976	28.980	28.984	28.988	28.992	28.996	28.999	29.003	29.007	29.011
737	29.015	29.019	29.023	29.027	29.031	29.035	29.039	29.043	29.047	29.051
738	29.055	29.059	29.062	29.066	29.070	29.074	29.078	29.082	29.086	29.090
739	29.094	29.098	29.102	29.106	29.110	29.114	29.118	29.122	29.125	29.129
740	29.133	29.137	29.141	29.145	29.149	29.153	29.157	29.161	29.165	29.169
741	29.173	29.177	29.181	29.185	29.188	29.192	29.196	29.200	29.204	29.208
742	29.212	29.216	29.220	29.224	29.228	29.232	29.236	29.240	29.244	29.248
743	29.251	29.255	29.259	29.263	29.267	29.271	29.275	29.279	29.283	29.287
744	29.291	29.295	29.299	29.303	29.307	29.311	29.314	29.318	29.322	29.326
745	29.330	29.334	29.338	29.342	29.346	29.350	29.354	29.358	29.362	29.366
746	29.370	29.373	29.377	29.381	29.385	29.389	29.393	29.397	29.401	29.405
747	29.409	29.413	29.417	29.421	29.425	29.429	29.433	29.436	29.440	29.444
748	29.448	29.452	29.456	29.460	29.464	29.468	29.472	29.476	29.480	29.484
749	29.488	29.492	29.496	29.499	29.503	29.507	29.511	29.515	29.519	29.523
750	29.527	29.531	29.535	29.539	29.543	29.547	29.551	29.555	29.559	29.562

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
751	29.566	29.570	29.574	29.578	29.582	29.586	29.590	29.594	29.598	29.602
752	29.606	29.610	29.614	29.618	29.622	29.625	29.629	29.633	29.637	29.641
753	29.645	29.649	29.653	29.657	29.661	29.665	29.669	29.673	29.677	29.681
754	29.684	29.688	29.692	29.696	29.700	29.704	29.708	29.712	29.716	29.720
755	29.724	29.728	29.732	29.736	29.740	29.744	29.747	29.751	29.755	29.759
756	29.763	29.767	29.771	29.775	29.779	29.783	29.878	29.791	29.795	29.799
757	29.803	29.807	29.810	29.814	29.818	29.822	29.826	29.830	29.834	29.838
758	29.842	29.846	29.850	29.854	29.858	29.962	29.966	29.870	29.783	29.877
759	29.881	29.885	29.889	29.893	29.897	29.901	29.905	29.909	29.913	29.917
760	29.921	29.925	29.929	29.933	29.936	29.940	29.944	29.948	29.952	29.956
761	29.960	29.964	29.968	29.972	29.976	29.980	29.984	29.988	29.992	29.995
762	29.999	30.003	30.007	30.011	30.015	30.019	30.023	30.027	30.031	30.035
763	30.039	30.043	30.047	30.051	30.055	30.058	30.062	30.066	30.070	30.074
764	30.078	30.082	30.086	30.090	30.094	30.098	30.102	30.106	30.110	30.114
765	30.118	30.121	30.125	30.129	30.133	30.137	30.141	30.145	30.149	30.153
766	30.157	30.161	30.165	30.169	30.173	30.177	30.181	30.184	30.188	30.192
767	30.196	30.200	30.204	30.208	30.212	30.216	30.220	30.224	30.228	30.232
768	30.236	30.240	30.244	30.247	30.251	30.255	30.259	30.263	30.267	30.271
769	30.275	30.279	30.283	30.287	30.291	30.295	30.299	30.303	30.307	30.310
770	30.314	30.318	30.322	30.326	30.330	30.334	30.338	30.342	30.346	30.350
771	30.354	30.358	30.362	30.366	30.369	30.373	30.377	30.381	30.385	30.389
772	30.393	30.397	30.401	30.405	30.409	30.413	30.417	30.421	30.425	30.429
773	30.432	30.436	30.440	30.444	30.448	30.452	30.456	30.460	30.464	30.468
774	30.472	30.476	30.480	30.484	30.488	30.492	30.495	30.499	30.503	30.507
775	30.511	30.515	30.519	30.523	30.527	30.531	30.535	30.539	30.543	30.547
776	30.551	30.555	30.558	30.562	30.566	30.570	30.574	30.578	30.582	30.586
777	30.590	30.594	30.598	30.602	30.606	30.610	30.614	30.618	30.621	30.625
778	30.629	30.633	30.637	30.641	30.645	30.649	30.653	30.657	30.661	30.665
779	30.669	30.673	30.677	30.680	30.684	30.688	30.692	30.696	30.700	30.704
780	30.708	30.712	30.716	30.720	30.724	30.728	30.732	30.736	30.740	30.743
781	30.747	30.751	30.755	30.759	30.763	30.767	30.771	30.775	30.779	30.783
782	30.787	30.791	30.795	30.799	30.803	30.806	30.810	30.814	30.818	30.822
783	30.826	30.830	30.834	30.838	30.842	30.846	30.850	30.854	30.858	30.862
784	30.866	30.869	30.873	30.877	30.881	30.885	30.889	30.893	30.897	30.901
785	30.905	30.909	30.913	30.917	30.921	30.925	30.929	30.932	30.936	30.940
786	30.944	30.948	30.952	30.956	30.960	30.964	30.968	30.972	30.976	30.980
787	30.984	30.988	30.992	30.995	30.999	31.003	31.007	31.011	31.015	31.019
788	31.023	31.027	31.031	31.035	31.039	31.043	31.047	31.051	31.054	31.058
789	31.062	31.066	31.070	31.074	31.078	31.082	31.086	31.090	31.094	31.098
790	31.102	31.106	31.110	31.114	31.117	31.121	31.125	31.129	31.133	31.137
791	31.141	31.145	31.149	31.153	31.157	31.161	31.165	31.169	31.173	31.177
792	31.180	31.184	31.188	31.192	31.196	31.200	31.204	31.208	31.212	31.216
793	31.220	31.224	31.228	31.232	31.236	31.240	31.243	31.247	31.251	31.255
794	31.259	31.263	31.267	31.271	31.275	31.279	31.283	31.287	31.291	31.295
795	31.299	31.303	31.306	31.310	31.314	31.318	31.322	31.326	31.330	31.334
796	31.338	31.342	31.346	31.350	31.354	31.358	31.362	31.365	31.369	31.373
797	31.377	31.381	31.385	31.389	31.393	31.397	31.401	31.405	31.409	31.413
798	31.417	31.421	31.425	31.428	31.432	31.436	31.440	31.444	31.448	31.452
799	31.456	31.460	31.464	31.468	31.472	31.476	31.480	31.484	31.488	31.491
800	31.495	31.499	31.503	31.507	31.511	31.515	31.519	31.523	31.527	31.531

801 - 900.9mm
31.535 - 35.468 inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
801	31.535	31.539	31.543	31.547	31.551	31.554	31.558	31.562	31.566	31.570
802	31.574	31.578	31.582	31.586	31.590	31.594	31.598	31.602	31.606	31.610
803	31.614	31.617	31.621	31.625	31.629	31.633	31.637	31.641	31.645	31.649
804	31.653	31.657	31.661	31.665	31.669	31.673	31.676	31.680	31.684	31.688
805	31.692	31.696	31.700	31.704	31.708	31.712	31.716	31.720	31.724	31.728
806	31.732	31.736	31.739	31.743	31.747	31.751	31.755	31.759	31.763	31.767
807	31.771	31.775	31.779	31.783	31.787	31.791	31.795	31.799	31.802	31.806
808	31.810	31.814	31.818	31.822	31.826	31.830	31.834	31.838	31.842	31.846
809	31.850	31.854	31.858	31.862	31.865	31.869	31.873	31.877	31.881	31.885
810	**31.889**	**31.893**	**31.897**	**31.901**	**31.905**	**31.909**	**31.913**	**31.917**	**31.921**	**31.925**
811	31.928	31.932	31.936	31.940	31.944	31.948	31.952	31.956	31.960	31.964
812	31.968	31.972	31.976	31.980	31.984	31.988	31.991	31.995	31.999	32.003
813	32.007	32.011	32.015	32.019	32.023	32.027	32.031	32.035	32.039	32.043
814	32.047	32.050	32.054	32.058	32.062	32.066	32.070	32.074	32.078	32.082
815	32.086	32.090	32.094	32.098	32.102	32.106	32.110	32.113	32.117	32.121
816	32.125	32.129	32.133	32.137	32.141	32.145	32.149	32.153	32.157	32.161
817	32.165	32.169	32.173	32.176	32.180	32.184	32.188	32.192	32.196	32.200
818	32.204	32.208	32.212	32.216	32.220	32.224	32.228	32.232	32.236	32.239
819	32.243	32.247	32.251	32.255	32.259	32.263	32.267	32.271	32.275	32.279
820	**32.283**	**32.287**	**32.291**	**32.295**	**32.299**	**32.302**	**32.306**	**32.310**	**32.314**	**32.318**
821	32.322	32.326	32.330	32.334	32.338	32.342	32.346	32.350	32.354	32.358
822	32.361	32.365	32.369	32.373	32.377	32.381	32.285	32.389	32.393	32.397
823	32.401	32.405	32.409	32.413	32.417	32.421	32.424	32.428	32.432	32.436
824	32.440	32.444	32.448	32.452	32.456	32.460	32.464	32.468	32.472	32.476
825	32.480	32.484	32.487	32.491	32.495	32.499	32.503	32.507	32.511	32.515
826	32.519	32.523	32.527	32.531	32.535	32.539	32.543	32.547	32.550	32.554
827	32.558	32.562	32.566	32.570	32.574	32.578	32.582	32.586	32.590	32.594
828	32.598	32.602	32.606	32.610	32.613	32.617	32.621	32.625	32.629	32.633
829	32.637	32.641	32.645	32.649	32.653	32.657	32.661	32.665	32.669	32.673
830	32.676	**32.680**	**32.684**	**32.688**	**32.692**	**32.696**	**32.700**	**32.704**	**32.708**	**32.712**
831	32.716	32.720	32.724	32.728	32.732	32.735	32.739	32.743	32.747	32.751
832	32.755	32.759	32.763	32.767	32.771	32.775	32.779	32.783	32.787	32.791
833	32.795	32.798	32.802	32.806	32.810	32.814	32.818	32.822	32.826	32.830
834	32.834	32.838	32.842	32.846	32.850	32.854	32.858	32.861	32.865	32.869
835	32.873	32.877	32.881	32.885	32.889	32.893	32.897	32.901	32.905	32.909
836	32.913	32.917	32.921	32.924	32.928	32.932	32.936	32.940	32.944	32.948
837	32.952	32.956	32.960	32.964	32.968	32.972	32.976	32.980	32.984	32.987
838	32.991	32.995	32.999	33.003	33.007	33.011	33.015	33.019	33.023	33.027
839	33.031	33.035	33.039	33.043	33.046	33.050	33.054	33.058	33.062	33.066
840	**33.070**	**33.074**	**33.078**	**33.082**	**33.086**	**33.090**	**33.094**	33.098	**33.102**	33.106
841	33.109	33.113	33.117	33.121	33.125	33.129	33.133	33.137	33.141	33.145
842	33.149	33.153	33.157	33.161	33.165	33.169	33.172	33.176	33.180	33.184
843	33.188	33.192	33.196	33.200	33.204	33.208	33.212	33.216	33.220	33.224
844	33.228	33.232	33.235	33.239	33.243	33.247	33.251	33.255	33.259	33.263
845	33.267	33.271	33.275	33.279	33.283	33.287	33.291	33.295	33.298	33.302
846	33.306	33.310	33.314	33.318	33.322	33.326	33.330	33.334	33.338	33.342
847	33.346	33.350	33.354	33.357	33.361	33.365	33.369	33.373	33.377	33.381
848	33.385	33.389	33.393	33.397	33.401	33.405	33.409	33.413	33.417	33.420
849	33.424	33.428	33.432	33.436	33.440	33.444	33.448	33.452	33.456	33.460
850	**33.464**	**33.468**	**33.472**	**33.476**	**33.480**	**33.483**	**33.487**	**33.491**	**33.495**	**33.499**

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
851	33.503	33.507	33.511	33.515	33.519	33.523	33.527	33.531	33.535	33.539
852	33.543	33.546	33.550	33.554	33.558	33.562	33.566	33.570	33.574	33.578
853	33.582	33.586	33.590	33.594	33.598	33.602	33.606	33.609	33.613	33.617
854	33.621	33.625	33.629	33.633	33.637	33.641	33.645	33.649	33.653	33.657
855	33.661	33.665	33.669	33.672	33.676	33.680	33.684	33.688	33.692	33.696
856	33.700	33.704	33.708	33.712	33.716	33.720	33.724	33.728	33.731	33.735
857	33.739	33.743	33.747	33.751	33.755	33.759	33.763	33.767	33.771	33.775
858	33.779	33.783	33.787	33.791	33.794	33.798	33.802	33.806	33.810	33.814
859	33.818	33.822	33.826	33.830	33.834	33.838	33.842	33.846	33.850	33.854
860	33.857	33.861	33.865	**33.869**	**33.873**	33.877	**33.881**	33.885	33.889	33.893
861	33.897	33.901	33.905	33.909	33.913	33.917	33.920	33.924	33.928	33.932
862	33.936	33.940	33.944	33.948	33.952	33.956	33.960	33.964	33.968	33.972
863	33.976	33.980	33.983	33.987	33.991	33.995	33.999	34.003	34.007	34.011
864	34.015	34.019	34.023	34.027	34.031	34.035	34.039	34.042	34.046	34.050
865	34.054	34.058	34.062	34.066	34.070	34.074	34.078	34.082	34.086	34.090
866	34.094	34.098	34.102	34.105	34.109	34.113	34.117	34.121	34.125	34.129
867	34.133	34.137	34.141	34.145	34.149	34.153	34.157	34.161	34.165	34.168
868	34.172	34.176	34.180	34.184	34.188	34.192	34.196	34.200	34.204	34.208
869	34.212	34.216	34.220	34.224	34.228	34.231	34.235	34.239	34.243	34.247
870	**34.251**	**34.255**	**34.259**	**34.263**	**34.267**	**34.271**	**34.275**	**34.279**	**34.283**	**34.287**
871	34.291	34.294	34.298	34.302	34.306	34.310	34.314	34.318	34.322	34.326
872	34.330	34.334	34.338	34.342	34.346	34.350	34.354	34.357	34.361	34.365
873	34.369	34.373	34.377	34.381	34.385	34.389	34.393	34.397	34.401	34.405
874	34.409	34.413	34.416	34.420	34.424	34.428	34.432	34.436	34.440	34.444
875	34.448	34.452	34.456	34.460	34.464	34.468	34.472	34.476	34.479	34.483
876	34.487	34.491	34.495	34.499	34.503	34.507	34.511	34.515	34.519	34.523
877	34.527	34.531	34.535	34.539	34.542	34.546	34.550	34.554	34.558	34.562
878	34.566	34.570	34.574	34.578	34.582	34.586	34.590	34.594	34.598	34.602
879	34.605	34.609	34.613	34.617	34.621	34.625	34.629	34.633	34.637	34.641
880	**34.645**	**34.649**	**34.653**	**34.657**	**34.661**	**34.665**	**34.668**	**34.672**	**34.676**	**34.680**
881	34.684	34.688	34.692	34.696	34.700	34.704	34.708	34.712	34.716	34.720
882	34.724	34.727	34.731	34.735	34.739	34.743	34.747	34.751	34.755	34.759
883	34.763	34.767	34.771	34.775	34.779	34.783	34.787	34.790	34.794	34.798
884	34.802	34.806	34.810	34.814	34.818	34.822	34.826	34.830	34.834	34.838
885	34.842	34.846	34.850	34.853	34.857	34.861	34.865	34.869	34.873	34.877
886	34.881	34.885	34.889	34.893	34.897	34.901	34.905	34.909	34.913	34.916
887	34.920	34.924	34.928	34.932	34.936	34.940	34.944	34.948	34.952	34.956
888	34.960	34.964	34.968	34.972	34.976	34.979	34.983	34.987	34.991	34.995
889	34.999	35.003	35.007	35.011	35.015	35.019	35.023	35.027	35.031	35.035
890	**35.038**	**35.042**	35.046	**35.050**	**35.054**	**35.068**	**35.062**	**35.066**	35.070	**35.074**
891	35.078	35.082	35.086	35.090	35.094	35.098	35.101	35.015	35.109	35.113
892	35.117	35.121	35.125	35.129	35.133	35.137	35.141	35.145	35.149	35.153
893	35.157	35.161	35.164	35.168	35.172	35.176	35.180	35.184	35.188	35.192
894	35.196	35.200	35.204	35.208	35.212	35.216	35.220	35.224	35.227	35.231
895	35.235	35.239	35.243	35.247	35.251	35.255	35.259	35.263	35.267	35.271
896	35.275	35.279	35.283	35.287	35.290	35.294	35.298	35.302	35.306	35.310
897	35.314	35.318	35.322	35.326	35.330	35.334	35.338	35.342	35.346	35.350
898	35.353	35.357	35.361	35.365	35.369	35.373	35.377	35.381	35.385	35.389
899	35.393	35.397	35.401	35.405	35.409	35.412	35.416	35.420	35.424	35.428
900	**35.432**	**35.436**	**35.440**	**35.444**	**35.448**	**35.452**	**35.456**	**35.460**	**35.464**	**35.468**

901 - 1000.9mm
35.472 - 39.404 inches

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
901	35.472	35.475	35.479	35.483	35.487	35.491	35.495	35.499	35.503	35.507
902	35.511	35.515	35.519	35.523	35.527	35.531	35.535	35.538	35.542	35.546
903	35.550	35.554	35.558	35.562	35.566	35.570	35.574	35.578	35.582	35.586
904	35.590	35.594	35.598	35.601	35.605	35.609	35.613	35.617	35.621	35.625
905	35.629	35.633	35.637	35.641	35.645	35.649	35.653	35.657	35.661	35.664
906	35.668	35.672	35.676	35.680	35.684	35.688	35.692	35.696	35.700	35.704
907	35.708	35.712	35.716	35.720	35.723	35.727	35.731	35.735	35.739	35.743
908	35.747	35.751	35.755	35.759	35.763	35.767	35.771	35.775	35.779	35.783
909	35.786	35.790	35.794	35.798	35.802	35.806	35.810	35.814	35.818	35.822
910	35.826	35.830	35.834	35.838	35.842	35.846	35.849	35.853	35.857	35.861
911	35.865	35.869	35.873	35.877	35.881	35.885	35.889	35.893	35.897	35.901
912	35.905	35.909	35.912	35.916	35.920	35.924	35.928	35.932	35.936	35.940
913	35.944	35.948	35.952	35.956	35.960	35.964	35.968	35.972	35.975	35.979
914	35.983	35.987	35.991	35.995	35.999	36.003	36.007	36.011	36.015	36.019
915	36.023	36.027	36.031	36.035	36.038	36.042	36.046	36.050	36.054	36.058
916	36.062	36.066	36.070	36.074	36.078	36.082	36.086	36.090	36.094	36.097
917	36.101	36.105	36.109	36.113	36.117	36.121	36.125	36.129	36.133	36.137
918	36.141	36.145	36.149	36.153	36.157	36.160	36.164	36.168	36.172	36.176
919	36.180	36.184	36.188	36.192	36.196	36.200	36.204	36.208	36.212	36.216
920	36.220	36.223	36.227	36.231	36.235	36.239	36.243	36.247	36.251	36.255
921	36.259	36.263	36.267	36.271	36.275	36.279	36.283	36.286	36.290	36.294
922	36.298	36.302	36.306	36.310	36.314	36.318	36.322	36.326	36.330	36.334
923	36.338	36.342	36.346	36.349	36.353	36.357	36.361	36.365	36.369	36.373
924	36.377	36.381	36.385	36.389	36.393	36.397	36.401	36.405	36.408	36.412
925	36.416	36.420	36.424	36.428	36.432	36.436	36.440	36.444	36.448	36.452
926	36.456	36.460	36.464	36.468	36.471	36.475	36.479	36.483	36.487	36.491
927	36.495	36.499	36.503	36.507	36.511	36.515	36.519	36.523	36.527	36.531
928	36.534	36.538	36.542	36.546	36.550	36.554	36.558	36.562	36.566	36.570
929	36.574	36.578	36.582	36.586	36.590	36.594	36.597	36.601	36.605	36.609
930	36.613	36.617	36.621	36.625	36.629	36.633	36.637	36.641	36.645	36.649
931	36.653	36.657	36.660	36.664	36.668	36.672	36.676	36.680	36.684	36.688
932	36.692	36.696	36.700	36.704	36.708	36.712	36.716	36.719	36.723	36.727
933	36.731	36.735	36.739	36.743	36.747	36.751	36.755	36.759	36.763	36.767
934	36.771	36.775	36.779	36.782	36.786	36.790	36.794	36.798	36.802	36.806
935	36.810	36.814	36.818	36.822	36.826	36.830	36.834	36.838	36.842	36.845
936	36.849	36.853	36.857	36.861	36.865	36.869	36.873	36.877	36.881	36.885
937	36.889	36.893	36.897	36.901	36.905	36.908	36.912	36.916	36.920	36.924
938	36.928	36.932	36.936	36.940	36.944	36.948	36.952	36.956	36.960	36.964
939	36.968	36.971	36.975	36.979	36.983	36.987	36.991	36.995	36.999	37.003
940	37.007	37.011	37.015	37.019	37.023	37.027	37.031	37.034	37.038	37.042
941	37.046	37.050	37.054	37.058	37.062	37.066	37.070	37.074	37.078	37.082
942	37.086	37.090	37.093	37.097	37.101	37.105	37.109	37.113	37.117	37.121
943	37.125	37.129	37.133	37.137	37.141	37.145	37.149	37.153	37.156	37.160
944	37.164	37.168	37.172	37.176	37.180	37.184	37.188	37.192	37.196	37.200
945	37.204	37.208	37.212	37.216	37.219	37.223	37.227	37.231	37.235	37.239
9463	37.243	37.247	37.251	37.255	37.259	37.263	37.267	37.271	37.275	37.279
947	37.282	37.286	37.290	37.294	37.298	37.302	37.306	37.310	37.314	37.318
948	37.322	37.326	37.330	37.334	37.338	37.342	37.345	37.349	37.353	37.357
949	37.361	37.365	37.369	37.373	37.377	37.381	37.385	37.389	37.393	37.397
950	37.401	37.404	37.408	37.412	37.416	37.420	37.424	37.428	37.432	37.436

MM	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
951	37.440	37.444	37.448	37.452	37.456	37.460	37.464	37.467	37.471	37.475
952	37.479	37.483	37.487	37.491	37.495	37.499	37.503	37.507	37.511	37.515
953	37.519	37.523	37.527	37.530	37.534	37.538	37.542	37.546	37.550	37.554
954	37.558	37.562	37.566	37.570	37.574	37.578	37.582	37.586	37.590	37.593
955	37.597	37.601	37.605	37.609	37.613	37.617	37.621	37.625	37.629	37.633
956	37.637	37.641	37.645	37.649	37.653	37.656	37.660	27.664	37.668	37.672
957	37.676	37.680	37.684	37.688	37.692	37.696	37.700	37.704	37.708	37.712
958	37.715	37.719	37.723	37.727	37.731	37.735	37.739	37.743	37.747	37.751
959	37.755	37.759	37.763	37.767	37.771	37.775	37.778	37.782	37.786	37.790
960	37.794	37.798	37.802	37.806	37.810	37.814	37.818	37.822	37.826	37.830
961	37.834	37.838	37.841	37.845	37.849	37.853	37.857	37.861	37.865	37.869
962	37.873	37.877	37.881	37.885	37.889	37.893	37.897	37.901	37.904	37.908
963	37.912	37.916	37.920	37.924	37.928	37.932	37.936	37.940	37.944	37.948
964	37.952	37.956	37.960	37.964	37.967	37.971	37.975	37.979	37.983	37.987
965	37.991	37.995	37.999	38.003	38.007	38.011	38.015	38.019	38.023	38.027
966	38.030	38.034	38.038	38.042	38.046	38.050	38.054	38.058	38.062	38.066
967	38.070	38.074	38.078	38.082	38.086	38.089	38.093	38.097	38.101	38.105
968	38.109	38.113	38.117	38.121	38.125	38.129	38.133	38.137	38.141	38.145
969	38.149	38.152	38.156	38.160	38.164	38.168	38.172	38.176	38.180	38.184
970	38.188	38.192	38.196	38.200	38.204	38.208	38.212	38.215	38.219	38.223
971	38.227	38.231	38.235	38.239	38.243	38.247	38.251	38.255	38.259	38.263
972	38.267	38.271	38.275	38.278	38.282	38.286	38.290	38.294	38.298	38.302
973	38.306	38.310	38.314	38.318	38.322	38.326	38.330	38.334	38.338	38.341
974	38.345	38.349	38.353	38.357	38.361	38.365	38.369	38.373	38.377	38.381
975	38.385	38.389	38.393	38.397	38.400	38.404	38.308	38.412	38.416	38.420
976	38.424	38.428	38.432	38.436	38.440	38.444	38.448	38.452	38.456	38.460
977	38.463	38.467	38.471	38.475	38.479	38.483	38.487	38.491	38.495	38.499
978	38.503	38.507	38.511	38.515	38.519	38.523	38.526	38.530	38.534	38.538
979	38.542	38.546	38.550	38.554	38.558	38.562	38.566	38.570	38.574	38.578
980	38.582	38.586	38.589	38.593	38.597	38.601	38.605	38.609	38.613	38.617
981	38.621	38.625	38.629	38.633	38.637	38.641	38.645	38.649	38.652	38.656
982	38.660	38.664	38.668	38.672	38.676	38.680	38.684	38.688	38.692	38.696
983	38.700	38.704	38.708	38.712	38.715	38.719	38.723	38.727	38.731	38.735
984	38.739	38.743	38.747	38.751	38.755	38.759	38.763	38.767	38.771	38.774
985	38.778	38.782	38.786	38.790	38.794	38.798	38.802	38.806	38.810	38.814
986	38.818	38.822	38.826	38.830	38.834	38.837	38.841	38.845	38.849	38.853
987	38.857	38.861	38.865	38.869	38.873	38.877	38.881	38.885	38.889	38.893
988	38.897	38.900	38.904	38.908	38.912	38.916	38.920	38.924	38.928	38.932
989	38.936	38.940	38.944	38.948	38.852	38.956	38.960	38.963	38.967	38.971
990	38.975	38.979	38.983	38.987	38.991	38.995	38.999	39.003	39.007	39.011
991	39.015	39.019	39.023	39.026	39.030	39.034	39.038	39.042	39.046	39.050
992	39.054	39.058	39.062	39.066	39.070	39.074	39.078	39.082	39.085	39.089
993	39.093	39.097	39.101	39.105	39.109	39.113	39.117	39.121	39.125	39.129
994	39.133	39.137	39.141	39.145	39.148	39.152	39.156	39.160	39.164	39.168
995	39.172	39.176	39.180	39.184	39.188	39.192	39.196	39.200	39.204	39.208
996	39.211	39.215	39.219	39.223	39.227	39.231	39.235	39.239	39.243	39.247
997	39.251	39.255	39.259	39.263	39.267	39.271	39.274	39.278	39.282	39.286
998	39.290	39.294	39.298	39.302	39.306	39.310	39.314	39.318	39.322	39.326
999	39.330	39.334	39.337	39.341	39.345	39.349	39.353	39.357	39.361	39.365
1000	39.369	39.373	39.377	39.381	39.385	39.389	39.393	39.396	39.400	39.404

Consecutive Listing of Regular Drill Sizes

by William C. Fitt

INCH AND METRIC SIZES

Number	Fraction	Letter	Metric	Decimal Inches	mm
80	-	-	-	.0135	.343
-	-	-	0.35	.0138	.350
79	-	-	-	.0145	.368
-	1/64	-	-	.0156	.396
-	-	-	0.40	.0158	.400
78	-	-	-	.0160	.406
-	-	-	0.45	.0177	.450
77	-	-	-	.0180	.457
-	-	-	0.50	.0197	.500
76	-	-	-	.0200	.508
-	-	-	0.52	.0205	.520
75	-	-	-	.0210	.533
-	-	-	0.55	.0217	.550
74	-	-	-	.0225	.572
-	-	-	0.58	.0228	.580
-	-	-	0.60	.0236	.600
73	-	-	-	.0240	.610
-	-	-	0.62	.0244	.620
72	-	-	-	.0250	.635
-	-	-	0.65	.0256	.650
71	-	-	-	.0260	.660
-	-	-	0.70	.0276	.700
70	-	-	-	.0280	.711
69	-	-	-	.0292	.742
-	-	-	0.75	.0295	.750
68	-	-	-	.0310	.787
-	1/32	-	-	.0312	.792
-	-	-	0.80	.0315	.800
67	-	-	-	.0320	.813
66	-	-	-	.0330	.838
-	-	-	0.85	.0335	.850
65	-	-	-	.0350	.889
-	-	-	0.90	.0354	.900
64	-	-	-	.0360	.914
63	-	-	-	.0370	.940
-	-	-	0.95	.0374	.950
62	-	-	-	.0380	.965
61	-	-	-	.0390	.991
-	-	-	1.00	.0394	1.000
60	-	-	-	.0400	1.016
59	-	-	-	.0410	1.041
-	-	-	1.05	.0413	1.050
58	-	-	-	.0420	1.069
57	-	-	-	.0430	1.092
-	-	-	1.10	.0433	1.100
-	-	-	1.15	.0453	1.150
56	-	-	-	.0465	1.181
-	3/64	-	-	.0469	1.191
-	-	-	1.20	.0472	1.200
-	-	-	1.25	.0492	1.250
-	-	-	1.30	.0512	1.300
55	-	-	-	.0520	1.321
-	-	-	1.35	.0531	1.350
54	-	-	-	.0550	1.397
-	-	-	1.40	.0551	1.400
-	-	-	1.45	.0571	1.450
-	-	-	1.50	.0591	1.500
53	-	-	-	.0595	1.511
-	-	-	1.55	.0610	1.550
-	1/16	-	-	.0625	1.587
-	-	-	1.60	.0630	1.600
52	-	-	-	.0635	1.613
-	-	-	1.65	.0650	1.850
-	-	-	1.70	.0669	1.700
51	-	-	-	.0670	1.702
-	-	-	1.75	.0689	1.750
50	-	-	-	.0700	1.778
-	-	-	1.80	.0709	1.800
-	-	-	1.85	.0728	1.850
49	-	-	-	.0730	1.854
-	-	-	1.90	.0748	1.900
48	-	-	-	.0760	1.930
-	-	-	1.95	.0768	1.950
-	5/64	-	-	.0781	1.984
47	-	-	-	.0785	1.994
-	-	-	2.00	.0787	2.000
-	-	-	2.05	.0807	2.050
46	-	-	-	.0810	2.057
45	-	-	-	.0820	2.083
-	-	-	2.10	.0827	2.100
-	-	-	2.15	.0846	2.150
44	-	-	-	.0860	2.184
-	-	-	2.20	.0866	2.200
-	-	-	2.25	.0886	2.250
43	-	-	-	.0890	2.261

Number	Fraction	Letter	Metric	Decimal Inches	mm
-	-	-	2.30	.0906	2.300
-	-	-	2.35	.0925	2.350
42	-	-	-	.0935	2.375
-	3/32	-	-	.0937	2.380
-	-	-	2.40	.0945	2.400
41	-	-	-	.0960	2.438
-	-	-	2.45	.0965	2.450
40	-	-	-	.0980	2.489
-	-	-	2.50	.0984	2.500
39	-	-	-	.0995	2.527
38	-	-	-	.1015	2.578
-	-	-	2.60	.1024	2.600
37	-	-	-	.1040	2.642
-	-	-	2.70	.1063	2.700
36	-	-	-	.1065	2.705
-	-	-	2.75	.1083	2.750
-	7/64	-	-	.1094	2.779
35	-	-	-	.1100	2.794
-	-	-	2.80	.1102	2.800
34	-	-	-	.1110	2.819
33	-	-	-	.1130	2.870
-	-	-	2.90	.1142	2.900
32	-	-	-	.1160	2.946
-	-	-	3.00	.1181	3.000
31	-	-	-	.1200	3.048
-	-	-	3.10	.1220	3.100
-	1/8	-	-	.1250	3.175
-	-	-	3.20	.1260	3.200
-	-	-	3.25	.1280	3.250
30	-	-	-	.1285	3.264
-	-	-	3.30	.1299	3.300
-	-	-	3.40	.1339	3.400
29	-	-	-	.1360	3.454
-	-	-	3.50	.1378	3.500
28	-	-	-	.1405	3.569
-	9/64	-	-	.1406	3.571
-	-	-	3.60	.1417	3.600
27	-	-	-	.1440	3.658
-	-	-	3.70	.1457	3.700
26	-	-	-	.1470	3.734
-	-	-	3.75	.1476	3.750
25	-	-	-	.1495	3.797
-	-	-	3.80	.1496	3.600
24	-	-	-	.1520	3.861
-	-	-	3.90	.1535	3.900
23	-	-	-	.1540	3.912
-	5/32	-	-	.1562	3.967
22	-	-	-	.1570	3.988
-	-	-	4.00	.1575	4.000
21	-	-	-	.1590	4.039
20	-	-	-	.1610	4.089
-	-	-	4.10	.1614	4.100
-	-	-	4.20	.1654	4.200
19	-	-	-	.1660	4.216
-	-	-	4.25	.1673	4.250
-	-	-	4.30	.1693	4.300
18	-	-	-	.1695	4.305
-	11/64	-	-	.1719	4.366
17	-	-	-	.1730	4.394
-	-	-	4.40	.1732	4.400
16	-	-	-	.1770	4.496
-	-	-	4.50	.1772	4.500
15	-	-	-	.1800	4.572
-	-	-	4.60	.1811	4.600
14	-	-	-	.1820	4.623
13	-	-	4.70	.1656	4.700
-	-	-	4.75	.1870	4.750
-	3/16	-	-	.1875	4.762
12	-	-	4.80	.1890	4.800
11	-	-	-	.1910	4.851
-	-	-	4.90	.1929	4.900
10	-	-	-	.1935	4.915
9	-	-	-	.1960	4.978
-	-	-	5.00	.1968	5.000
-	-	-	5.05	.1990	5.050
8	-	-	-	.2000	5.080
-	-	-	5.10	.2008	5.100
7	-	-	-	.2010	5.105
-	13/64	-	-	.2031	5.159
6	-	-	-	.2040	5.182
-	-	-	5.20	.2047	5.200
5	-	-	-	.2055	5.220
-	-	-	5.25	.2067	5.250
-	-	-	5.30	.2087	5.300
4	-	-	-	.2050	5.309
-	-	-	5.40	.2126	5.400
3	-	-	-	.2130	5.410
-	-	-	5.50	.2165	5.500
-	7/32	-	-	.2187	5.555
-	-	-	5.60	.2205	5.600

Number	Fraction	Letter	Metric	Decimal Inches	mm
2	-	-	-	.2210	5.613
-	-	-	5.70	.2244	5.700
-	-	-	5.75	.2264	5.750
1	-	-	-	.2280	5.791
-	-	-	5.80	.2283	5.800
-	-	-	5.90	.2323	5.900
-	-	A	-	.2340	5.944
-	15/64	-	-	.2344	5.954
-	-	-	6.00	.2362	6.000
-	-	B	-	.2380	6.045
-	-	-	6.10	.2402	6.100
-	-	C	-	.2420	6.147
-	-	-	6.20	.2441	6.200
-	-	D	-	.2460	6.248
-	-	-	6.25	.2461	6.250
-	-	-	6.30	.2480	6.300
-	1/4	E	-	.2500	6.350
-	-	-	6.40	.2520	6.400
-	-	-	6.50	.2559	6.500
-	-	F	-	.2570	6.528
-	-	-	6.60	.2598	6.600
-	-	G	-	.2610	6.629
-	-	-	6.70	.2638	6.700
-	17/64	-	-	.2656	6.746
-	-	-	6.75	.2657	6.750
-	-	H	-	.2660	6.756
-	-	-	6.80	.2677	6.800
-	-	-	6.90	.2717	6.900
-	-	I	-	.2720	6.909
-	-	-	7.00	.2756	7.000
-	-	J	-	.2770	7.036
-	-	-	7.10	.2795	7.100
-	-	K	-	.2810	7.137
-	9/32	-	-	.2812	7.142
-	-	-	7.20	.2834	7.200
-	-	-	7.25	.2854	7.250
-	-	-	7.30	.2874	7.300
-	-	L	-	.2900	7.366
-	-	-	7.40	.2913	7.400
-	-	M	-	.2950	7.493
-	-	-	7.50	.2953	7.500
-	19/64	-	-	.2969	7.541
-	-	-	7.60	.2992	7.600
-	-	N	-	.3020	7.671
-	-	-	7.70	.3031	7.700
-	-	-	7.75	.3051	7.750
-	-	-	7.80	.3071	7.800
-	-	-	7.90	.3110	7.900
-	5/16	-	-	.3125	7.937
-	-	-	8.00	.3150	8.000
-	-	O	-	.3160	8.026
-	-	-	8.10	.3189	8.100
-	-	-	8.20	.3228	8.200
-	-	P	-	.3230	8.204
-	-	-	8.25	.3248	8.250
-	-	-	8.30	.3268	8.300
-	21/64	-	-	.3281	8.334
-	-	-	8.40	.3307	8.400
-	-	Q	-	.3320	8.433
-	-	-	8.50	.3346	8.500
-	-	-	8.60	.3386	8.600
-	-	R	-	.3390	8.611
-	-	-	8.70	.3425	8.700
-	11/32	-	-	.3437	8.730
-	-	-	8.75	.3445	8.750
-	-	-	8.80	.3465	8.800
-	-	S	-	.3480	8.839
-	-	-	8.90	.3504	8.900
-	-	-	9.00	.3543	9.000
-	-	T	-	.3580	9.093
-	-	-	9.10	.3583	9.100
-	23/64	-	-	.3594	9.129
-	-	-	9.20	.3622	9.200
-	-	-	9.25	.3642	9.250
-	-	-	9.30	.3661	9.300
-	-	U	-	.3680	9.347
-	-	-	9.40	.3701	9.400
-	-	-	9.50	.3740	9.500
-	3/8	-	-	.3750	9.525
-	-	V	-	.3770	9.576
-	-	-	9.60	.3780	9.600
-	-	-	9.70	.3819	9.700
-	-	-	9.75	.3839	9.750
-	-	-	9.80	.3858	9.800
-	-	W	-	.3860	9.804
-	-	-	9.90	.3898	9.900
-	25/64	-	-	.3906	9.921
-	-	-	10.00	.3937	10.000
-	-	X	-	.3970	10.084
-	-	-	10.10	.3976	10.100

Number	Fraction	Letter	Metric	Decimal Inches	mm
-	-	-	10.25	.4035	10.250
-	-	Y	-	.4040	10.262
-	13/32	-	-	.4062	10.317
-	-	Z	-	.4130	10.490
-	-	-	10.50	.4134	10.500
-	27/64	-	-	.4219	10.716
-	-	-	10.75	.4232	10.750
-	-	-	11.00	.4331	11.000
-	7/16	-	-	.4375	11.112
-	-	-	11.25	.4429	11.250
-	-	-	11.50	.4528	11.500
-	29/64	-	-	.4531	11.509
-	-	-	11.75	.4626	11.750
-	15/32	-	-	.4687	11.905
-	-	-	12.00	.4724	12.000
-	-	-	12.25	.4823	12.250
-	31/64	-	-	.4844	12.304
-	-	-	12.50	.4921	12.500
-	1/2	-	-	.5000	12.700
-	-	-	12.75	.5020	12.750
-	-	-	13.00	.5118	13.000
-	33/64	-	-	.5156	13.096
-	-	-	13.25	.5217	13.250
-	17/32	-	-	.5312	13.492
-	-	-	13.50	.5315	13.500
-	-	-	13.75	.5413	13.750
-	35/64	-	-	.5469	13.891
-	-	-	14.00	.5512	14.000
-	-	-	14.25	.5610	14.250
-	9/16	-	-	.5625	14.287
-	-	-	14.50	.5709	14.500
-	37/64	-	-	.5781	14.684
-	-	-	14.75	.5807	14.750
-	-	-	15.00	.5906	15.000
-	19/32	-	-	.5937	15.080
-	-	-	15.25	.6004	15.250
-	39/64	-	-	.6094	15.479
-	-	-	15.50	.6102	15.500
-	-	-	15.75	.6201	15.750
-	5/8	-	-	.6250	15.875
-	-	-	16.00	.6299	16.000
-	-	-	16.25	.6398	16.250
-	41/64	-	-	.6406	16.271
-	-	-	16.50	.6496	16.500
-	21/32	-	-	.6562	16.667
-	-	-	16.75	.6595	16.750
-	-	-	17.00	.6693	17.000
-	43/64	-	-	.6719	17.066
-	-	-	17.25	.6791	17.250
-	11/16	-	-	.6875	17.462
-	-	-	17.50	.6890	17.500
-	-	-	17.75	.6988	17.750
-	45/64	-	-	.7031	17.859
-	-	-	18.00	.7087	18.000
-	-	-	18.25	.7185	18.250
-	23/32	-	-	.7187	18.255
-	-	-	18.50	.7283	18.500
-	47/64	-	-	.7344	18.654
-	-	-	18.75	.7382	18.750
-	-	-	19.00	.7480	19.000
-	3/4	-	-	.7500	19.050
-	-	-	19.25	.7579	19.250
-	49/64	-	-	.7656	19.446
-	-	-	19.50	.7677	19.500
-	-	-	19.75	.7776	19.750
-	25/32	-	-	.7812	19.842
-	-	-	20.00	.7874	20.000
-	51/64	-	-	.7969	20.241
-	-	-	20.50	.8071	20.500
-	13/16	-	-	.8125	20.637
-	-	-	21.00	.8268	21.000
-	53/64	-	-	.8281	21.034
-	27/32	-	-	.8437	21.430
-	-	-	21.50	.8465	21.500
-	55/64	-	-	.8594	21.829
-	-	-	22.00	.8661	22.000
-	7/8	-	-	.8750	22.225
-	-	-	22.50	.8858	22.500
-	57/64	-	-	.8906	22.621
-	-	-	23.00	.9055	23.000
-	29/32	-	-	.9062	23.017
-	59/64	-	-	.9219	23.416
-	-	-	23.50	.9250	23.500
-	15/16	-	-	.9375	23.812
-	-	-	24.00	.9449	24.000
-	61/64	-	-	.9531	24.209
-	-	-	24.50	.9646	24.500
-	31/32	-	-	.9687	24.605
-	-	-	25.00	.9843	25.000
-	63/64	-	-	.9844	25.004
-	1	-	25.40	1.0000	25.400

Suppliers

To assist those readers who do not live in areas where metal suppliers are readily available and to avoid the need to purchase far greater quantities than required for the projects in this book, the following firms and individuals offer kits of castings and/or bar stock. Because of the fluctuations in prices of material, current quotations may be obtained by writing directly to the address given below.

Clarence Myers
Myers Model Engine Works
15929 5 Point Road
Perrysburg, OH 43551-9797

Hot Air Pumping Engine

Coles' Power Models
839 East Front Street
P.O. Box 788
Ventura, CA 93002
(805) 643-7065
(805) 643-5160 Fax

Model Builders' Supplies

Power Model Supply Co.
13260 Summit Drive
DeSoto, MO 63020
(636) 586-6466

Model Builders' Supplies

Notes