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Rewinding Small Motors

KARL WILKINSON

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Preface

The application of electric motors are numerous and varied and the types in use today range between large and small, simple and complicated. Even with the most efficient maintenance, all these have to be repaired sooner or later.

This book has been written to show in a practical way how rewinding is carried out and it will be of help to fitters, engineers, apprentices, students and all who have access to a workshop with the necessary equipment. The text, which is illustrated with over 100 drawings and photographs, has been simply written but nevertheless includes much valuable information.

The various types of motors covered include split phase, capacitor-start, repulsion, repulsion-induction, repulsion-start, shaded-pole, three-phase induction, universal and d.c. Although the rewinding of motors is specifically dealt with, the technique of rewinding is, of course, applicable to the stators, rotors and armatures of a.c. and d.c. generators.

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I

Introduction

The term *f.h.p. motor* is generally applied to a wide range of small machines up to and including those of 746 W. This generic term embraces motors of various types, which may be listed as follows: split phase; capacitor start; capacitor start and run; repulsion, repulsion induction; repulsion start, induction run; shaded pole; three-phase induction; universal, and d.c.

This list by no means includes every possible variety, but it certainly covers the majority of small motors likely to be encountered. The use of f.h.p. motors in general has increased to a remarkable extent during the last decade; and today they find many applications in industry, in the workshop, in the office and in the home. In view of the diversity of types of f.h.p. motor, it is proposed to explain the winding of representative items, since once the fitter has become accustomed to the basic types he will gradually be able to handle others of increasing complexity.

Rewinding

Rewinding is an operation in which the original winding is accurately copied and replaced with new material. The actual design of any particular motor is nearly always a matter for a highly qualified technician and is, generally speaking, beyond the scope of a normal fitter until he has gained considerable experience and acquired a fund of technical knowledge. The situation is further complicated by the fact that many small motors are the result of a long series of modifications to a prototype.

For present purposes, winding is synonymous with rewinding, because the same technique is usually adopted, though of course the rewinder has the more difficult task. Not only must he determine the winding data but he has also to produce a first-class job without, in many instances, any previous experience of the design in question.

Motor Windings

In order to produce torque, all motors require the interaction of two sets of magnetic fields. The usual arrangement is for these fields to be produced by two sets of windings, both carrying current derived from the supply. One set of windings is situated on the stationary outer member or stator and the other set of windings on the rotating member (rotor or armature).

In a.c. motors of the induction or repulsion type, the stator windings are usually, except in shaded-pole motors, distributed in slots around the stator core. These windings are connected to the supply and the field produced by them induces currents in the rotor windings. In universal and d.c. motors, the field coils are of the salient-pole type and together with the armature coils are connected to the supply.

Split-phase Induction Motors

This type of single-phase motor has a squirrel-cage rotor. The stator core, constructed of laminations, has two windings wound in its slots, a main winding for running and an auxiliary winding for starting. The stator windings are connected in parallel across the mains during the starting period. Immediately the motor reaches full speed, the starting winding must be disconnected. This can be accomplished automatically by centrifugal switch which opens the auxiliary circuit at about 80 per cent of the normal running speed. An alternative is to employ a relay with its coil connected in series with the running winding, the fall of current through the relay as the motor speed rises causing the relay switch in the starting-winding circuit to be opened. The starting winding is short-time rated and must not be left in circuit for more than a few seconds, as it would become severely overheated.

Like all induction motors, split-phase motors have a shunt characteristic, i.e. a fairly constant speed independent of load conditions.

Capacitor Motors

The single-phase *capacitor-start* induction motor is almost identical in construction with the split-phase machine, but to obtain a higher starting torque with less current, a short-time-rated electrolytic capacitor is used in series with the auxiliary winding. The circuit of the auxiliary winding is broken by a centrifugal or other switch before full speed is reached.

In the *capacitor-start capacitor-run* induction motor, two capacitors are employed. This allows a portion of the total capacity to be left in the auxiliary circuit while running, so improving the power factor and consequently reducing the running current and heating.

For light duties, a *capacitor-run* induction motor may be used having a single capacitor which is left in the auxiliary-winding circuit permanently. No switch is required as the auxiliary circuit is in action during starting and running.

Repulsion Motors

These single-phase machines have a stator wound with a single winding. The rotor is very similar to a d.c. armature with commutator. The brushes are permanently short-circuited. Currents induced in the rotor by the magnetic field from the stator give the rotor a magnetic polarity that, with suitable brush position on the commutator, causes repulsion to take place between like poles of the stator and rotor. No rotation results if the brush axis corresponds with the axis of the stator winding, called the neutral position, the magnetic polarity of the rotor then being the same as that of the stator. To get reversed rotation, the brushes must be moved round to a corresponding point on the other side of the neutral position. It is also possible by tapping the stator winding to obtain reversal by switching.

It is usual to short-circuit all the commutator segments by a centrifugally-operated device, thus converting the machine into an induction motor during the period of running. The brushes are also lifted in some cases to reduce wear.

To avoid the complication of the short-circuiting device, the rotor may be arranged with a squirrel-cage winding at the bottom of the slots. This takes over at speed and gives induction-motor characteristics.

Where variable speed is required, a plain repulsion motor (without the short-circuiting and brush-lifting mechanism) can be used, the speed control being obtainable by rocking the brushes, which may be connected to a hand-wheel or lever on the motor end-bracket.

The plain repulsion motor has series characteristics with which speed rises as the load on the motor is reduced; as commutation cannot always be made perfect, fairly frequent replacement of brushes may be necessary.

Shaded-pole Induction Motor

For very small horsepowers on single-phase supplies the shaded-pole induction motor is useful on account of its simplicity and robustness. The rotor is of the squirrel-cage pattern. The stator has salient poles somewhat similar to those of universal motor but with the field coils connected across the supply. Each pole is divided by a slot cut in the laminations and one of these divided portions in each pole is surrounded by a heavy copper band, known as a shading coil or loop.

Three-phase Induction Motors

Where three-phase supply is available a three-phase motor may be preferred to a f.h.p. single-phase motor. The rotor is of the usual squirrel-cage type. Three stator windings corresponding to the number of supply phases are wound in the stator slots (two-phase motors have two stator windings). As there are no auxiliary or starting windings, no special centrifugal or other starting switch is needed.

Universal Motors

Universal motors (operating on a.c. or d.c. supply) usually range from about 10 W to 400 W. They are constructed on similar lines to d.c. machines, but the field core must be laminated. They are series wound, that is the field coils are connected in series with the armature winding. They cannot satisfactorily be made to run at less than about 2000 r.p.m.

If similar performance on a.c. and d.c. is required from motors running at less than about 3000 r.p.m., a tapped field winding is desirable.

Although classed as universal, the voltage range is limited to about plus or minus 5 per cent of the voltage for which the motor is wound and the speed will vary approximately in proportion to the variation of voltage.

Universal motors have a series characteristic so that they run at their rated speed only on the rated load. If the load is reduced the speed will rise. Such motors are suitable for driving fans, vacuum cleaners, domestic sewing machines, portable tools, etc., where the load is constant or where a steadily maintained speed is not important. As brush wear takes place more rapidly in universal motors they are not generally considered suitable for long-hour duty.

D.C. Motors

Although the field core of a d.c. machine need not be laminated, in f.h.p. sizes the field core is generally built up of one-piece laminations riveted together, comprising the poles and yoke. The field poles are of the salient-pole type, each being wound with a single coil. The use of two poles, rather than four, is general. The armature core is built up of laminated sheets on a steel shaft, with the coils inserted in the slots.

Direct-current motors may be series, shunt or compound wound. Series-wound motors are employed where high-starting torque as well as a tendency for the speed to rise on light load is required. Such motors should not be used when a steady speed is necessary unless the load is perfectly constant. Shunt or compound motors meet this requirement under conditions of varying load.

Various methods of regulating the speed of d.c. motors may be employed. In the case of a series-wound motor, regulation is necessarily by series resistance in the main circuit and speeds down to about one-quarter of full speed are generally practicable. Shunt- or compound-wound motors can have the speed reduced by resistance in series with the armature and, provided that the slots are suitably skewed or staggered, speeds down to one-tenth or even less of the full speed are possible and full-load torque is available throughout the range. The speed may be increased by inserting resistance in series with the shunt field and up to about 100 per cent increase is possible, but this depends on the design of the motor. In this case, the available torque will be reduced as the speed rises.

2

Single-phase Stators

Concentric Wind

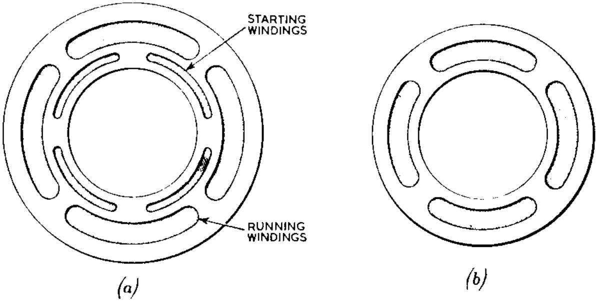
A typical example of a concentric winding is illustrated in Fig. 1(*a*) which represents a type of winding which could equally well be applied to a 75 W or a 746 W motor.

Obtaining the Winding Diagram

The first step is to obtain the original diagram and to determine:

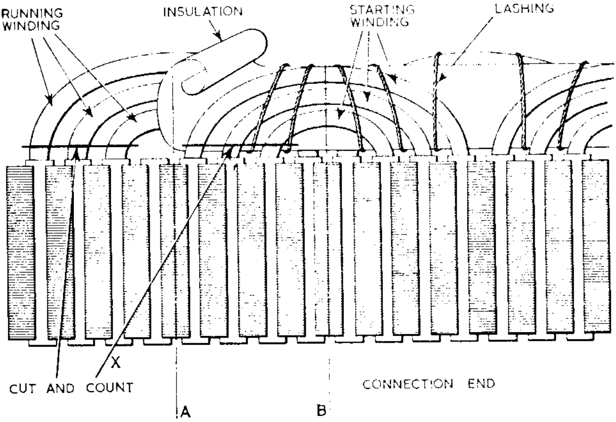
1. The coil connection.
2. The number of turns per coil.
3. The number of coils per pole.
4. The gauge of the wire.
5. The space occupied by the winding. The winding must not foul any other parts such as bolts, end-plates, fans or switchgear.

From Fig. 1(*a*) it will be seen that there are two sets of coils in the stator, and for the common speed of 1440 r.p.m.



1. Concentric windings.

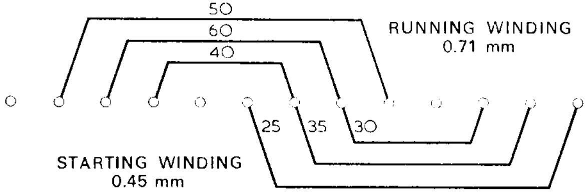
(*a*) Normal arrangement of coils for a single-phase stator; (*b*) similar arrangement, without starting windings, suitable for various types of repulsion and repulsion-induction motors.



2. Internal view of the stator of Fig. 1(a).

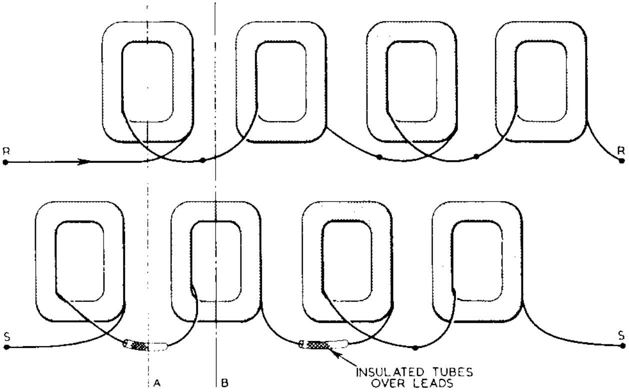
the outer ring has four groups, i.e. poles. Usually the outer ring is the larger; this will be the running circuit while the smaller inner ring will comprise the starting windings. If the stator is cut and opened out flat it appears as in Fig. 2. Only one winding, the starting winding, is fully visible. Each limb of the starting coils is cut at X and the turns of wire in each coil at the end *opposite* to the connection end are counted. This information is recorded as shown in Fig. 3 where the circles represent slots, and the numbers the turns counted.

The next step is to locate the lead entering one of the groups of starting coils, i.e. the lead entering the first pole.



3. Winding diagram showing number of turns.

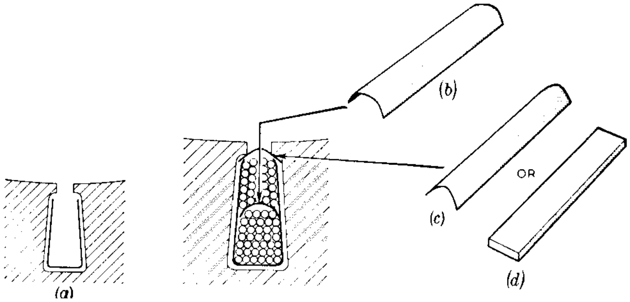
This is usually a single wire, but it may be two or even three wires in parallel. This paralleling of leads is introduced only to obtain the correct cross-sectional area of copper for the current taken by the motor, or to make the coil more flexible. The lead, or leads, must be measured and the covering determined and entered on the diagram of Fig. 3. For all normal motors at the present time, the wire will be enamel-covered or coated with synthetic material; the starting winding may possibly have only cotton and enamel covering. The beginner will find it advisable to trace the connection between each coil group.



4. **Connections of running and starting coils.**

When the starting-winding data have been obtained, the coil can be removed or cut away at one end to show the underlying or running winding, which will be similar to the first, but of larger size, and quite possibly with a different coil distribution. These coils are cut and counted as before and the diagram completed as in Fig. 3. It should be noted that the axes B of the starting poles lie midway between the axes A of the underlying running poles. This is the usual arrangement, but in some motors the position may differ slightly from that shown.

The complete winding diagram has now been obtained and if the lead connections to the coils are also traced the two circuits can be determined. For the standard motor these will appear as in Fig. 4. This point is referred to later.



5. Slot insulation

(*a*) Shows insulation of the slot; (*b*) insulation between two circuits; (*c*) and (*d*) slot wedges.

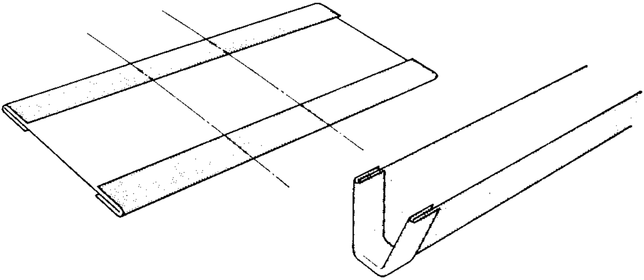
Stripping the Winding

The old winding must now be removed, and as most stators are varnished and baked the winding must be softened to permit the removal of the wire.

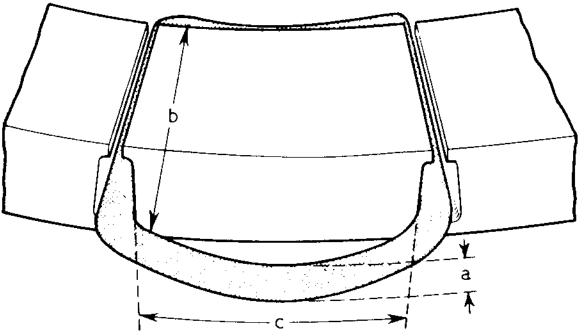
Stripping may be carried out in one of the following ways:

1. Heating the winding by passing current through it, assuming the winding to be continuous.
2. Heating by a gas jet or oven.
3. Shearing off the coils close to the stampings at each end and, after warming, punching the bunch of wires out of the slots, or removing the wedges and unwinding each coil turn by turn.

It is not always easy to strip a stator. This task may in fact take longer than the actual rewinding. Once the old winding has been removed the slots must be cleaned and all old paper removed.



6. Preparation of slot insulation.



7. Dimensions of former.
a **is the thickness,** *b* **the length, and** *c* **the width.**

Insulating the Slots

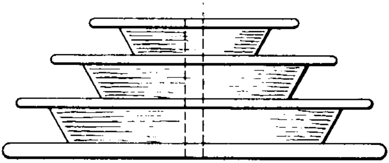
The type of slot lining will vary according to the machine concerned, but generally speaking a lining is made to fit under the lips of the slots and to protrude about 5 mm from each end (see Fig. 5). The insulating material can be a single layer of Presspahn about 0.5 mm thick, or the following alternatives may be used: a composite or sandwich lining of leatheroid and mica, leatheroid and oiled linen, Terylene and leatheroid, two layers of leatheroid, or any combination of the aforementioned materials. As a simple example a single layer of insulation, 0.5 mm or even 0.4 mm thick, would be suitable. The addition of a cuff of Sellotape or adhesive masking cloth is a great advantage as it prevents the paper splitting at the ends of the slots. The paper should be formed into long strips of suitable width and the cuff added before the individual papers are cut off (see Fig. 6).

Making the Formers

The easiest way to wind the stators is to wind the wire on to a wooden former as a first step. In the example shown in Fig. 2 there will be three formers for the starting windings and three for the running, and their dimensions can be obtained in two ways: either by measuring and estimating the length and width of each coil from Fig. 2, or by calculating as in Fig. 7. In Fig. 7 the thickness of the former is represented by the distance *a*, the length by *b*, and the width by *c*. The former is cut with a distinct bevel edge for two reasons: to permit the coil to slip off the former and to allow a longer peripheral length of the coil at the back, i.e. *c* in Fig. 7. These formers are easily cut from plywood, two or more pieces being pinned together to give the correct thickness.

Winding the Coils

The group of formers is next stacked together in the order shown in Fig. 8 with thin barriers separating the formers. A very simple winding head is all that is required for this operation. The coils are then wound using the turns recorded in Fig. 3; since the former is distinctly tapered the lower part of the former is filled first. The coils are wound without cutting the wire, which simply passes from one former to another through a slot in the barrier. When the complete pole is wound, the formers are removed from the machine and each coil is tied on one side by carefully sliding the appropriate barrier away.



8. Stack of formers ready for winding.

Inserting the Coils

When all the coils are made and the stator cleaned and reinsulated, winding can commence. The stator can rest between two battens nailed to the bench. One group of coils is taken and laid flat on the bench to the right of the stator with the wide part of each coil uppermost. Fig. 9 shows this operation where two coils have been inserted and the operator is threading the next coil into its slot. Note that the string tie is away from the operator and that the coil is being 'fanned' to permit the wire to enter the slots, one or two wires at a time.

Once the running windings are in position the mass of wires is dressed to shape to make room for the starting winding. The winding in each slot is covered by a strip of 0.25 mm paper folded as shown in Fig. 5(*b*) and inserted in the slots and pressed down with a piece of brass curtain rail

9. Inserting the coils in a single-phase stator.

Two coils have been inserted and the third is being threaded into its slot.

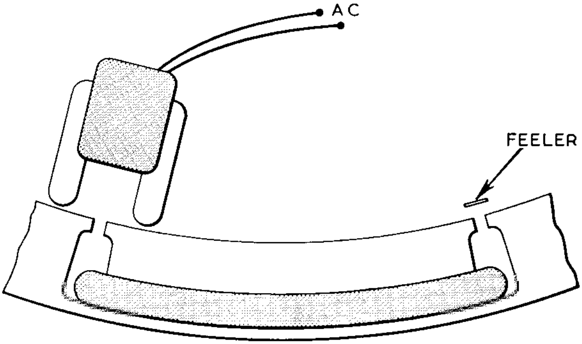
(a most useful tool). After this has been done the complete winding, where it projects beyond the end of the slots, is covered with a layer of insulation. White adhesive marking cloth is excellent for this purpose. This strip of insulation may be seen in Fig. 2. The starting windings are then inserted in a similar manner, and the slots are finally closed by a curved strip as shown in Fig. 5(*c*), or by a parallel strip of fibre as in Fig. 5(*d*).

Lashing and Connecting

With all the winding inserted, the complete stator is dressed with a mallet and one end is lashed with string or cotton tape (see Fig. 2).

The next step is to connect the winding, which so far consists of four running coils and four starting coils or, in other words, 16 loose ends. For the example chosen they are connected according to the diagram in Fig. 4, care being taken to ensure that each lead entering or leaving a coil group is insulated and a similar treatment being adopted for the joints.

The ends of the running and starting wind are now joined to short pieces of flex, preferably using red for the runners and some other colour for the windings. The complete winding is then lashed and dressed into shape—which necessitates a considerable use of the mallet—so that the four flex leads emerge at the correct place. These flex leads should not emerge near any joint, but should be taken round the end of the winding to make sure that the flex is securely anchored.



10. Use of internal growler to test for short circuits in a coil.

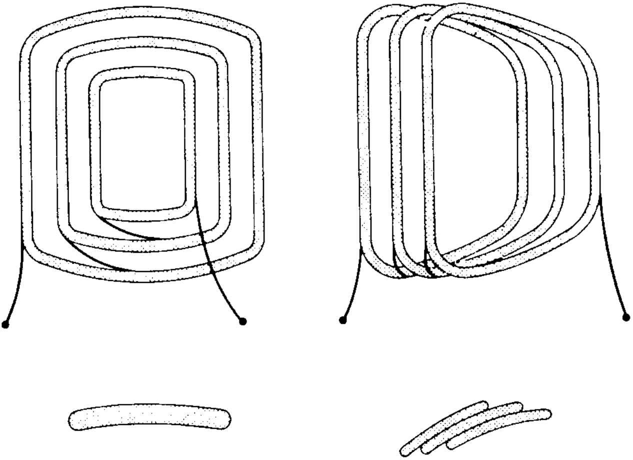
Testing the Concentric Winding

Testing is a straightforward operation in a factory or rewinding shop where adequate equipment is available, but is rather a problem in a job being tackled for the first time.

The first step is to make sure that all windings are insulated from the frame; an ordinary 500 V Megger insulation tester is quite suitable for the motors under consideration. Secondly, the insulation between the two circuits, i.e. between the runners and the starters, must be good. After this the process becomes more complicated; the following conditions should be observed:

1. Each coil must be correctly connected to its neighbour and each pole connected to the next pole according to the data given.
2. The turns and gauge of wire must be correct.
3. The position of the coils and the slots occupied by the coils and poles must be correct also.
4. There must be no shorts between turns or between pole connections.

Of these conditions, the first three are mainly covered by careful initial work, though the number of turns could be assessed by other special test gear. The question of prime importance is that of ensuring that there are no shorts between turns or between coil leads, and the easiest way to do this is to use a simple device known as a growler. This is shown in Fig. 10, and consists simply of a stack of U stampings wound to suit the normal supply voltage.



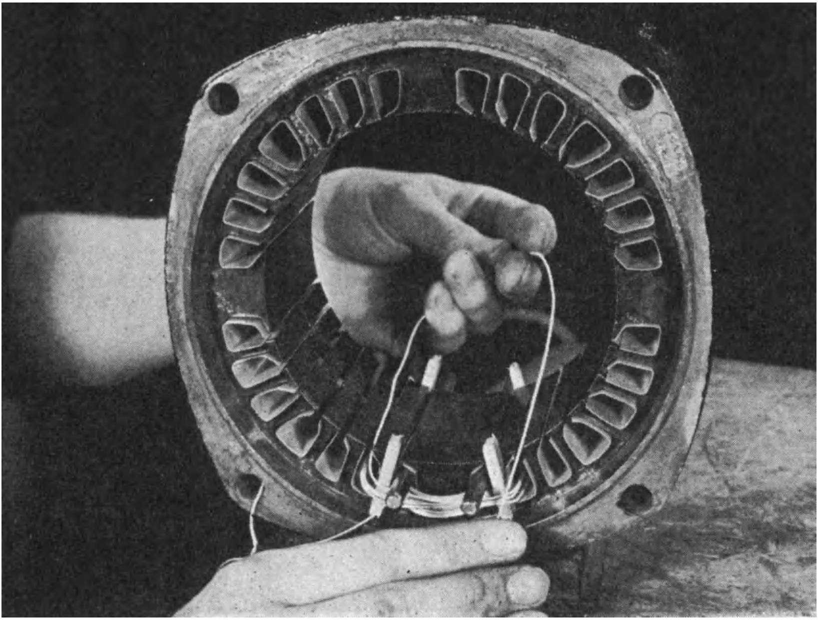
CONCENTRIC COILS
END VIEW

DISTRIBUTED COILS
END VIEW

11. Comparison between distributed wind and concentric wind.

This growler acts as a transformer with no secondary winding. It will induce a flux in stampings of the stator under test, and thus any short in a coil immediately between the poles of the growler, as shown in Fig. 10, will cause a distinct pull on a light steel feeler held over the slot containing the other limb of the coil under test.

The growler is slowly passed over each slot, and each coil is tested in turn. For a normal stator there should be no pull on the feeler. If, however, the stator happens to be parallel connected the feeler will be attracted and so will give a false indication of a short. Therefore when testing parallel-connected stators the parallel connection must be opened before testing begins.



12. The pin wind.

Distributed Wind

There is another way of winding each pole in any stator and this is illustrated in Fig. 11, which shows the first, concentric, example wound distributed. In both cases, in this example, there are three coils for the complete pole winding, and the electrical effect of both is roughly the same. From the winder's point of view the distributed wind has one great advantage: only one former is required on which to wind the coils. It does, however, take up a little more space.

The method of inserting the coils in the stator is very similar to that used for the concentric wind, except that each coil will have to be set down slightly to allow room for the next coil which partly covers it.

Pin Wind

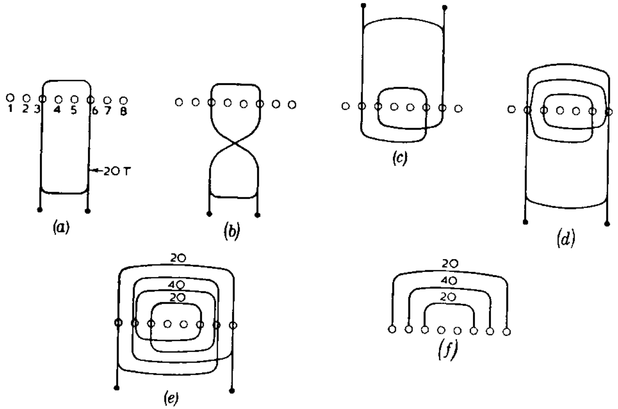
The pin wind is another method of hand winding which, although obsolete for the normal stator, still finds a use in certain types of machine. Indeed, in some examples, it is the only way in which a motor can be wound. The process is illustrated in Fig. 12. It is too simple to warrant an explanation here. It does, nevertheless, require considerable practice in order to obtain a neat winding. It is also obvious that the electric circuit will give the same results as the former concentric-wound pole.

Skein Wind

The skein wind is also a wind which had become obsolete, but which has lately been reintroduced as an economical way of getting a large number of turns of fine wire into a very confined space.

Originally it was used to a great extent in American stators of f.h.p. motors, for both the running and the starting winding. It is very simple, but, like the pin wind, requires practice. Fig. 13 shows the method. Supposing the concentric wind shown in Fig. 13(*f*) is to be converted to a skein wind; a skein of suitable length is wound with 20 turns of wire; it is then laid in slots 3 and 6 and drawn forward to give 20 turns in these two slots. It is now twisted and laid in slots 2 and 7, Fig. 13(*b*) and (*c*).

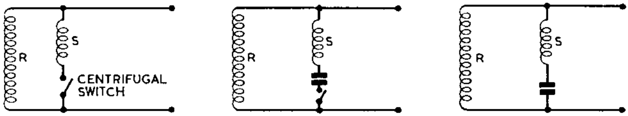
This last process is repeated, thus giving 2 × 20 = 40 turns, as required by the diagram. The process is repeated for a third time and slots 1 and 8 filled with 20 turns. In



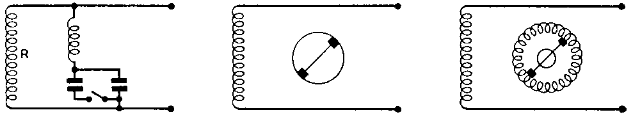
13. **The skein wind.**

The steps are shown in diagrams (*a*) to (*e*) of the procedure for laying a skein wind giving the same result as the concentric coil (*f*). A 20-turn skein is laid in slots 3 and 6 and drawn forward (*a*). It is again twisted and brought back through slots 2 and 7 (*d*), giving 40 turns in these slots. Finally, it is twisted and laid in slots 1 and 8 giving the result shown in (*e*).

point of fact the actual winding is not done exactly as illustrated because it is not necessary to pass the whole skein through the stator for each throw or twist; only a loop from the skein is passed through the stator. The technique will soon be discovered after a few attempts; the illustration represents a simple way of showing it diagrammatically. The difficulties of the process are determining the length of the skein by trial and error (a piece of heavy twine is used as a mock coil of wire), and laying the skein evenly and allowing sufficient loop for the last throw.



SPLIT PHASE (*a*)   CAPACITOR START (*b*)   PERMANENT CAPACITOR (*c*)



CAPACITOR START, CAPACITOR RUN (*d*)   REPULSION, REPULSION START INDUCTION RUN (*e*)   REPULSION INDUCTION (*f*)

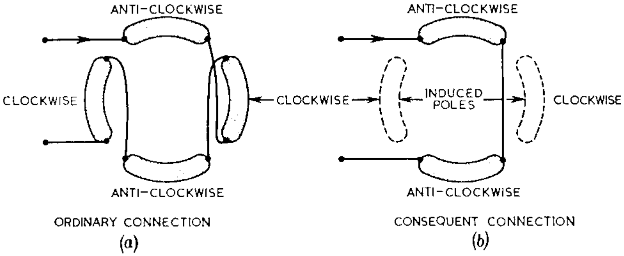
14. Connections of various types of single-phase motor.

This wind is referred to again, later in this chapter, in the section on field-coil winding.

Other Types of Single-phase Stator

The concentric and distributed winds described above are typical of many kinds of single-phase stator, though with variations in the ratio between the runners and starters. Thus if the stator is from a split-phase motor the starting windings will be smaller, both in gauge of wire and in the amount of copper used. If, on the other hand, it is a capacitor start or a capacitor-start and run motor, the starter windings will be approximately equal in volume to the running windings. Fig. 14 shows the connections of various types of single-phase motor.

There are various types of repulsion motor; four varieties are commonly used in industry. They all have what is fundamentally a single stator winding, giving usually four or six poles.



15. The ordinary connection and the consequent connection

The four common types are:

1. The repulsion motor with a wound rotor with two brushes shorted together. Movement of the brush position ± 15° either side of a neutral commutating position will reverse the direction of rotation. Speed can be varied according to brush position. It is seldom used now, except for special applications.
2. The repulsion-start induction-run motor. This starts as a repulsion motor, and once it is up to speed the wound rotor is shorted out to convert it to a squirrel-cage motor of fixed speed.
3. The true repulsion induction motor which incorporates a squirrel-cage rotor beneath the rotor winding. No shorting gear is used and this type can be made reversible and of variable speed as in (1).
4. The compensated repulsion motor. This was once very common, but is now almost obsolete for single-phase working.

Polarity and the Fields

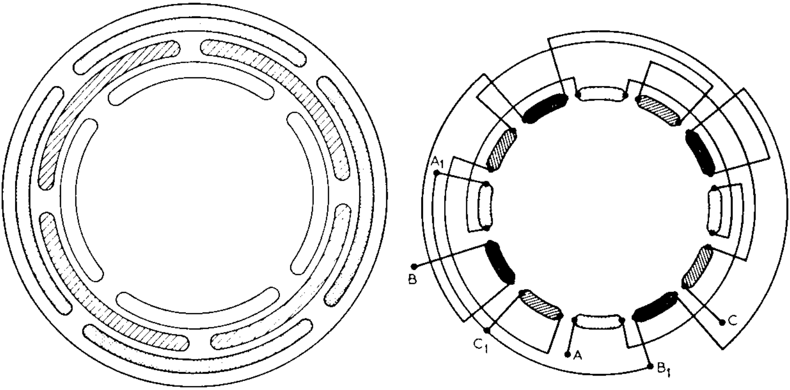
It will be seen that the main winding consists, in the example chosen, of four poles. A similar stator could be wound for two, six or eight poles, giving speeds of 2800, 960 or 720 r.p.m. Speeds below this are very rare in small f.h.p. motors. There will be, for each of the different speeds and for each running pole arrangement, a similar number of starting poles; thus a six-pole motor could have six running poles and six starting poles. Occasionally, in very slow-speed motors, the number of starting coils is half the total of the running coils, and the starting coils are connected 'consequently). This gives an induced pole of the opposite polarity between each wound pole (see Fig. 15). From the figure it is apparent that four poles can be obtained in two ways. This method is occasionally used for the running windings also.

3

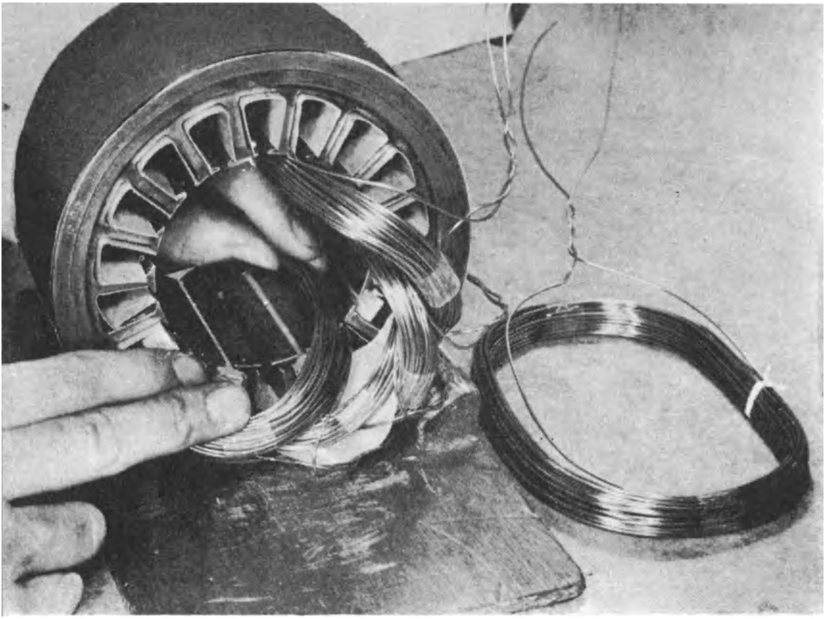
Three-phase Stators

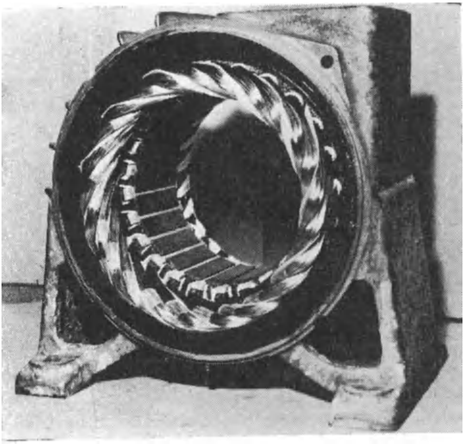
It has been explained that in a single-phase stator there is one set of two, four, six or eight poles communicating directly across the mains.

For a three-phase stator each phase must have its own set of windings and examples are shown in Fig. 16. These represent a three-layer winding and the theoretical connection which is a normal one for f.h.p. motors. As far as the latter is concerned the actual method of winding is very similar to that previously described. The three sets of four poles are similar. Each successive layer is displaced 60 electrical degrees, and each layer can be wound either concentric or distributed. It is most important to have adequate insulation between each phase, i.e. between each of the three layers of coils. In the figure each phase is tinted differently.



16. (*left*) **Three-layer three-phase wind.**
(*right*) **Four-pole three-phase star-connected winding.**





17. Distributed or basket wind.

(*above*) **Inserting the coils.**
(*left*) **The completed wind.**

Distributed or Basket Wind

The previous example, while certainly used in many stators, is not a typical example of a three-phase wind. A more usual arrangement is shown in Fig. 17, which represents the general appearance of a wound three-phase stator. In this arrangement each coil occupies the same relative position in the stator.

The alternative name for the distributed wind is the basket wind and this may be easily understood on reference to Fig. 18, where two varieties are illustrated diagrammatically.

If these two diagrams are examined very carefully they will be self-explanatory. In the single-layer basket wind there will be only one coil in each slot or, to be more exact, one coil side in each slot. In the two-layer basket each slot is shared by two coils.

Winding a Basket Coil

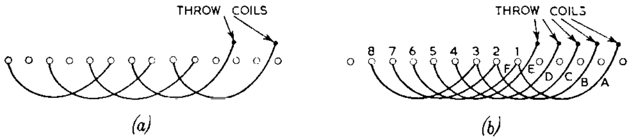
Both the single and double basket are wound in the same manner. The former is first made and will probably be similar to that shown in Fig. 19. Since this chapter is concerned only with small motors the wire will be small in diameter and the wound coil will be reasonably soft and flexible.

Consider first of all the two-layer wind, assuming a winding diagram as shown in Fig. 18(*b*) where the coils are lettered A, B, C, D, etc. With the stator prepared and insulated, winding can commence. One side of coil A is first inserted in any slot (No. 1 in the figure) and the other coil side is left lying loose inside the stator. Coils B, C, D and E are similarly inserted, one side only, in slots 2, 3, 4 and 5, and thus each coil will have one coil side left out.

These coils are called throw coils. The next coil, being F, is the sixth coil inserted, but in this case both sides are laid in a slot with, of course, a strip of insulation where the coil overlies the first limb to be inserted.

The winding proceeds until the last six coils are to be inserted. To do this the first five coil sides left lying in the stator are pulled clear and the last coils are inserted beneath them. Once these last coils have been placed in position, the five coil sides left at the beginning of the winding are laid down and the winding is completed.

In the single-layer wind every other slot is wound. Reference to Fig. 18(*a*) shows that in this case only two coil sides are left lying out for the winding diagram given. The process is shown in Fig. 17.



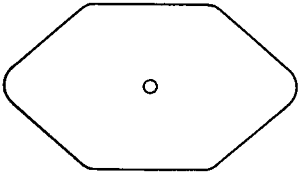
18. Distributed or basket wind.
(*a*) **Single layer;** (*b*) **Two-layer wind.**

It is not particularly easy to describe this process, which is, however, quite simple for a normal four-pole stator, although it must be admitted that this wind can be very trying for a two-pole stator where the coil throw is long, especially when the stator is of narrow bore (e.g. a unit stator used for pumps and woodworking tools). With these tunnel-like stators it is very difficult for the operator to get his hands in underneath the throw coils. Some makers eliminate this difficulty by 'throwing down' the first coils A, B, C, D, E and F instead of leaving them out. This makes the job much easier, but it is more untidy in appearance, and more difficult to insulate.

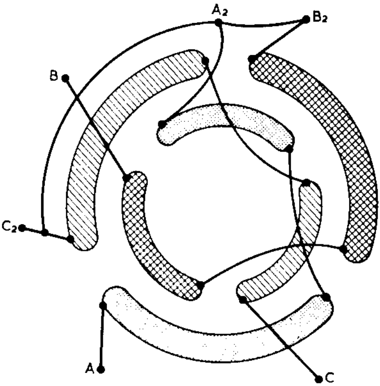
Insulation

It is most important to have adequate insulation between each phase group. In the above example the phase group is only one coil, but for other diagrams there could be anything up to five coils per phase.

For a single-layer basket wind, shown in Fig. 18(*a*), each coil is frequently taped and dressed with a mallet as winding proceeds. Similarly, the two-layer basket can also be cotton taped, but this makes the job much slower, so it is usual to add between each coil, or coil group, a piece of insulated material such as oiled linen, crêpe kraft paper or composite sandwich paper. Alternatively, adhesive masking cloth can be used, a strip being stuck on to each coil before the next coil is added. Masking tape is quite suitable for the small motors described but it is not so suitable for large three-phase stators.



19. Typical former for basket wind.



20. **Four-pole three-phase star connected consequent connection.**

The connection of the normal three-phase stator is shown diagrammatically in Fig. 16. In practice the procedure adopted is similar to that described for single-phase stators, and each lead must be insulated where it leaves or crosses any coil or coils. The star joint is usually buried underneath the lashing.

Although it is seldom used for small three-phase stators, the star/delta connection must be mentioned because it is the normal connection for most larger machines, where the motor starts with the star connection and runs on the delta connection. This connection is, however, used in small stators to effect a voltage change, i.e. a motor with a star/delta connection could be run on either 230 or 400 V, direct on line. For star/delta connection the star joint is omitted and A_1, B_1 and C_1 are brought out to the terminal block.

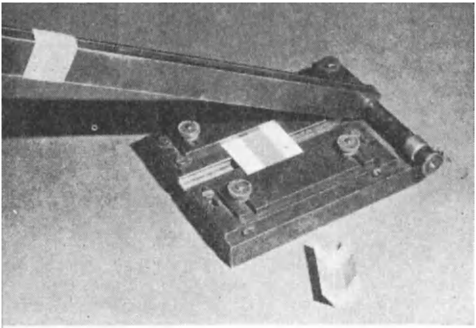
Consequent Connection

The consequent connection for three-phase stators is very similar to that used for single-phase stators and is shown in Fig. 20.

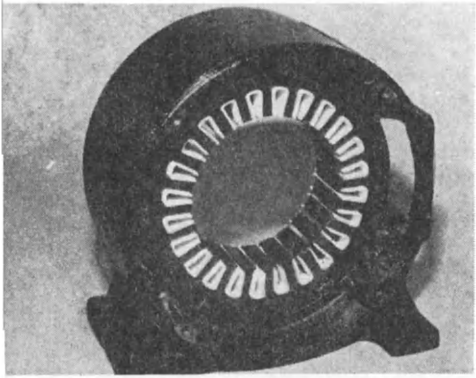
Three-phase Testing

While it follows the basic methods laid down for the single-phase stator, testing for three-phase motors is much more complicated. The first necessity is to ensure that every phase is earth free. Secondly, each phase should be insulated from every other, and in particular the connection between the coils must be according to the data given. Shorts between turns are detected as in the single-phase stator by using a

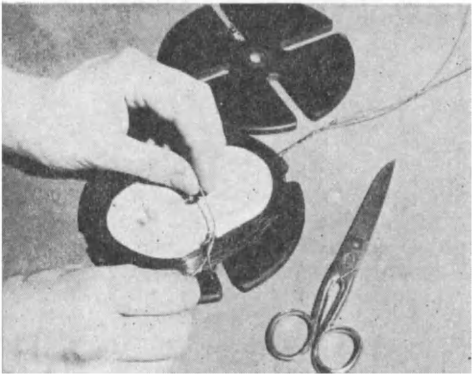
21. Winding a small 3-phase stator 4-pole single-layer basket wind.



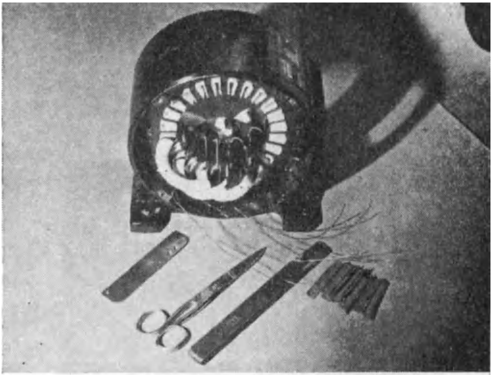
(*top*) Forming the slot linings. In this example the slot papers are reinforced with a 'cuff' of adhesive cotton tape. The simple jig creases the papers to fit the slots.



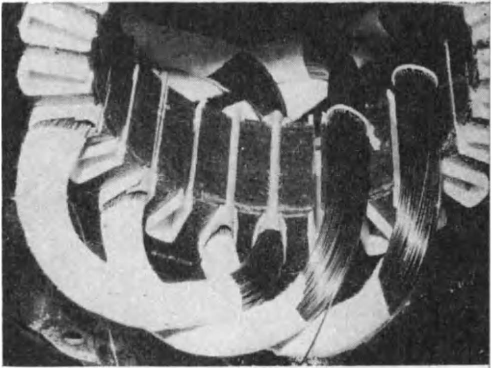
(*centre*) The stator prepared and ready for winding.



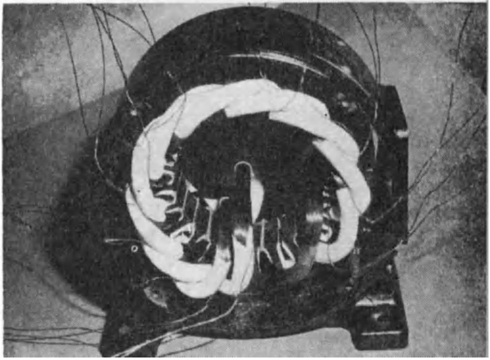
(*bottom*) Making the coils.



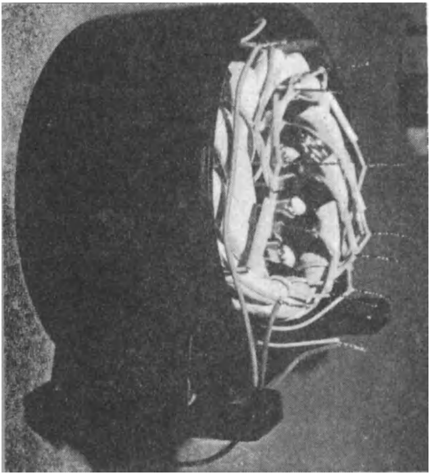
(*top*) **First few coils inserted.**



(*centre*) **Close up of first few coils. Insulation is added to each coil where it will cross and touch other remote coils. The two coils on the right are called 'throw' coils. They are thrown up to allow the last two coils to be inserted. Winding proceeds to the *left*.**

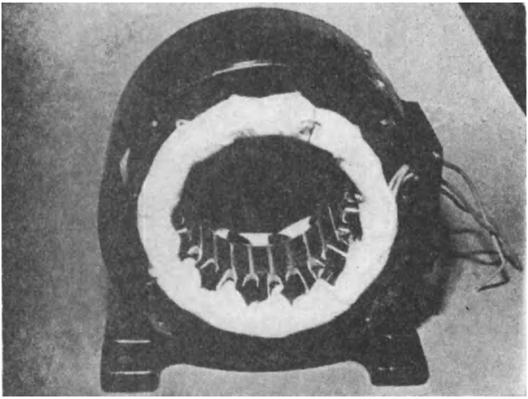


(*bottom*) **Last coil being inserted.**



(*top*) **All coils in. Connections made and stubs left up ready for welding.**

(*bottom*) **Stator complete. Lead end taped over to secure connections.**



growler, testing each slot in turn. Parallel-connected circuits—unusual in small stators—must be disconnected while the test is being carried out.

A wattmeter with a variable supply voltage is excellent for testing three-phase stators. The wattage taken by each phase, either from phase to star or phase to phase, must be equal, except for a very small variation in the three-layer wind. The wattmeter will show faults caused by short circuits or by incorrect coil connection. Thus a stator which is earth free and insulated between phases and also growl free, but which gives unequal wattage reading, is incorrectly connected.

4

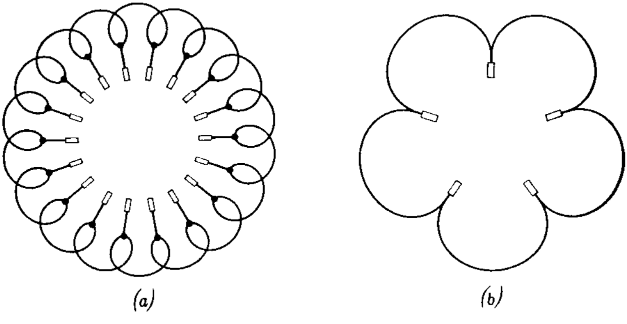
Universal Motors

Winding Small Armatures

It must be understood that nearly all small armatures are machine wound in production shops. Nevertheless they can all, with the exception of the shuttle wind, where all the coils are simultaneously wound, be wound by hand or by means of a very simple machine in contrast to the highly elaborate automatic machines used by manufacturers.

The varieties of wind and the various techniques adopted to obtain the optimum wind for any particular type of armature form an extremely complicated subject. It will be best, therefore, to take as the main example a simple armature which, with slight variations, could be adopted for many purposes.

Before any attempt at winding is made, it is a first requisite that the winder should really understand the elements of the armature circuit and the difference between the lap and the wave wind.



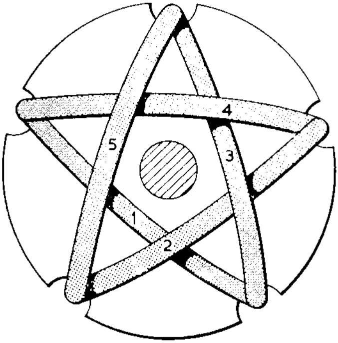
22. Lap-wind armature.
(*a*) **schematic;** (*b*) **simplified.**

These two types of wind are usually described in most textbooks as lap- or wave-wound armatures. In point of fact it is more accurate, as far as small armatures are concerned, to call them lap- or wave-connected armatures because the same armature can in many instances be connected either lap or wave.

As wave winds are quite uncommon in f.h.p. machines, the lap wind will be dealt with first.

Lap Wind

The lap-wind armature is simply a continuous spiral of wire with tappings taken at regular intervals down to the commutator (see Fig. 22(*a*)).



23. End view of simple armature with five slots.

Since the spiral is arranged around the periphery of the armature stampings, the spirals are grouped and laid into slots. Fig. 22(*a*), which is a hypothetical example, can therefore be modified to give Fig. 22(*b*) which gives a schematic diagram of five slots and five commutator bars (CB), with one turn between each tapping. In practice, however, most armatures have a considerable number of turns between each tapping, i.e. between each CB; the number ranges from six for a very low-voltage armature to 200–300 for a small hair-dryer armature. In general, as the number of turns increases so the size of the wire decreases.

Now consider another example where there are, say, 30 turns for each coil. The end view of such a winding could be similar to Fig. 23. Note that these coils are numbered to represent the order in which the coils are placed on the armature. If this simple winding is unrolled and laid flat it will appear as in Fig. 24. In this diagram the CB and connections are shown. Note that each slot has in it two coil sides.

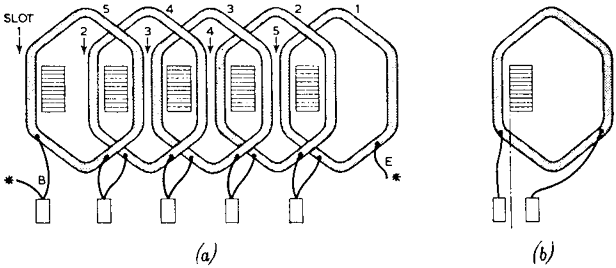
Insulating the Slots

The general method adopted for insulating the slots is very similar to that explained in the section on single-phase stators, but for most hand winds the insulating papers are left projecting above the stampings to protect the wires as these are laid in. This is shown in Fig. 25.

Methods of Lap-winding

There are three ways of winding any lap-connected armature: (1) loop wind; (2) one-, two- or three-in-hand progressive wind; (3) former wind.

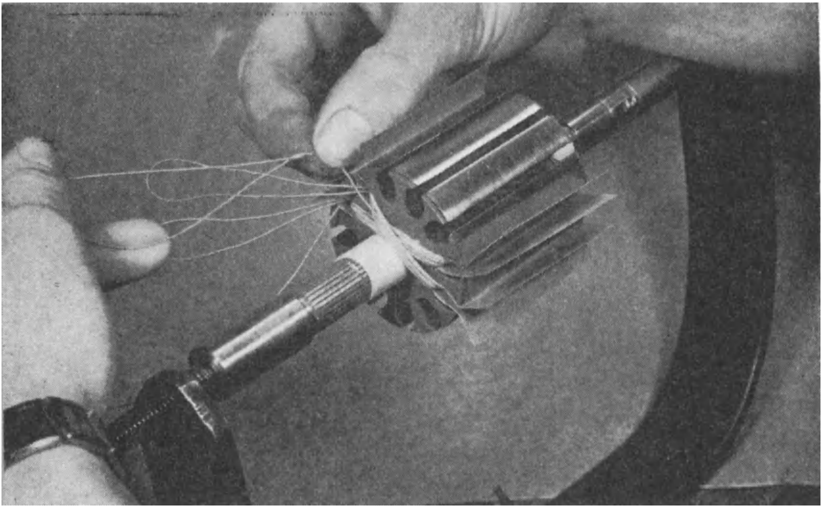
The Loop Wind. For a loop wind the armature is mounted in any convenient stand on the bench with a spool of wire in front of the winder. Referring to the data given in Fig. 24, the end B of the wire is anchored and the wire is passed down slot 1 and back through slot 3. This is one turn. The process is repeated 30 times (for the example given) and a loop is spun in the wire. This is shown clearly in Fig. 25, which, although the armature shows a different number of slots, nevertheless illustrates the technique. The twist of the loop is then laid in slot 2 of Fig. 24 and the wire is taken through slot 2 and back via slot 4. This is done 30 times and another loop spun and the next slot, No. 4, started. Winding proceeds until five coils have been added and each slot has two coil sides in it, with the end of the wire E at the finish twisted to the beginning B. These loops are the taps to the commutator to which they are connected as in Fig. 24(*b*).



24. Armature lap winding.

If the winding in Fig. 25 is unrolled and laid flat it will appear as in (*a*). Each coil is connected to two adjacent bars as in (*b*).

The Two- or Three-in-Hand Wind. The more complicated armature of an electric drill will now be considered. This could have a connecting diagram as shown in Fig. 27.



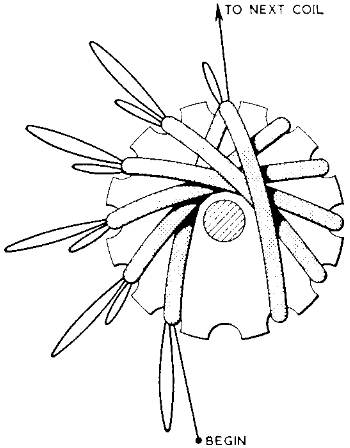
25. The loop wind.

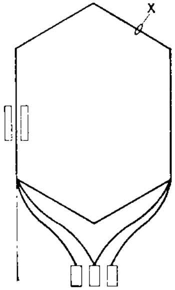
In this case the coil wound in slots 1 and 6 connects to three commutator bars instead of two as in the previous example. This merely means that the spiral has more taps. Now if this armature was wound by the loop method and according to the data given in Fig. 28, 36 turns would be wound and a loop formed, followed by another 36 turns in the same slots.

If Fig. 25 is carefully examined it will be seen that each slot has two loops emerging from it; the second loop is just being spun by the operator before he adds the second lot of 36 turns. Fig. 26 shows the commutator end view of such a wind.

A distinct advantage of the loop wind is that it requires only one spool of wire. For the previous example, however, this type is a disadvantage for a hand wind, because the fact that there are two circuits in each coil means that two lots of 36 turns must be laid in the same slot. This duplication of work can be avoided if the two circuits are wound simultaneously. This method is called the two-in-hand wind because two coils of wire are used, preferably of different colours, and the two circuits are wound in one operation.

Thus, referring to Figs. 26 and 27, two ends of the wires are anchored and 36 turns are wound in slots 1–6. The wires are then cut and the two ends lightly twisted to the two beginnings. In Fig. 28 the coil is illustrated diagrammatically, the two wires being distinguished by their relative thickness.





26. (*left*) **Commutator end view of loop wind.**
27. (*right*) **Connecting diagram of an electric-drill armature.**

This represents the data given in Fig. 27; the coil will contain 72 turns at X, i.e. two circuits of 36 turns each.

Each successive coil is wound in the same way, using two wires, i.e. in slots 1 and 6, 2 and 7, 3 and 8, 4 and 9, 5 and 10, 6 and 11, 7 and 12, 8 and 1, 9 and 2, 10 and 3, 11 and 4, 12 and 5. Each slot will eventually have two coils sharing it, and each slot at the commutator end will have four leads loosely twisted together emerging from it (see Fig. 29).

Twisting Up

When the armature is completely wound the slot papers are trimmed and tucked over the wires, and each slot is wedged with a strip of fibre.

At this juncture there are, for the example chosen, 48 wires lightly twisted into groups of four. These wires must now be sorted out and connected in their correct order to obtain a continuous spiral with tappings at regular intervals. This problem is illustrated diagrammatically in Fig. 28, which shows the operational stages in these connections. In the diagram the coils are represented by loops of twin wire. The first step is to untwist one group and arrange them in the order shown (the beginnings and ends of the two circuits are marked respectively B, B_1 and E, E_1). Reference to Fig. 27 shows that the beginning of the coil must go straight up slot No. 1. This lead is the starting point of the connection and they are retwisted up as in Fig. 28(*c*), that is to say, the end of one circuit connects to the beginning of the next.

In actual practice the order is quite easily located and the twist up is made for only a short way down the leads, the wires being parallel where they enter the commutator.

Fitting the Commutator

The commutator is then added. It is necessary to make sure that:

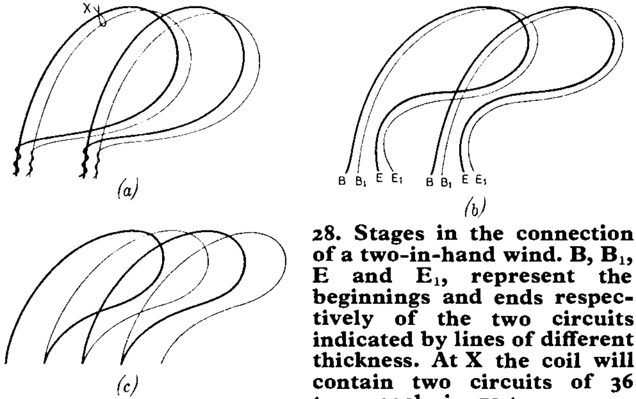
1. The commutator bars are in line with the armature slots according to the data given.
2. The commutator is pressed on to the correct distance.

A felt or fibre disc is frequently added between the back of the commutator and the winding. The winding itself is then dressed to make it smooth and even, and insulation is placed over it to make a bed on which to lay the leads as they run down to the commutator. Any cavity immediately behind the commutator is filled with a few turns of cotton tape.

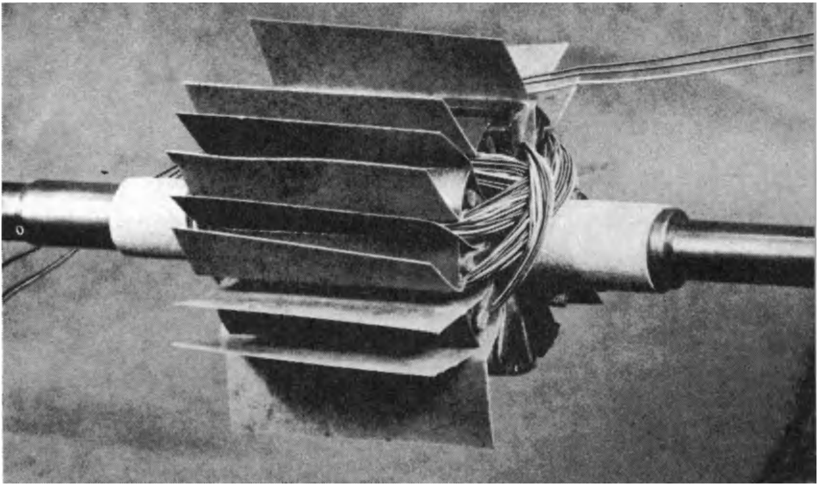
Cleaning the Leads

Since nearly all small armatures are today wound with either artificial silk and enamel or synthetic-enamel covering (double cotton-covered and double silk-insulated wire are now nearly obsolete) it is obvious that the enamel, synthetic or otherwise, must be removed for soldering.

It is possible to use a synthetic-covered wire which is self-soldering. An example of this type is Conyclad, a synthetic



28. Stages in the connection of a two-in-hand wind. B, B_1, E and E_1, represent the beginnings and ends respectively of the two circuits indicated by lines of different thickness. At X the coil will contain two circuits of 36 turns each, *i.e.* 72 turns.

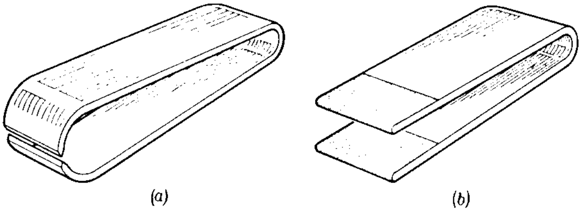


29. **Three-in-hand winding of a lap-connected armature.**

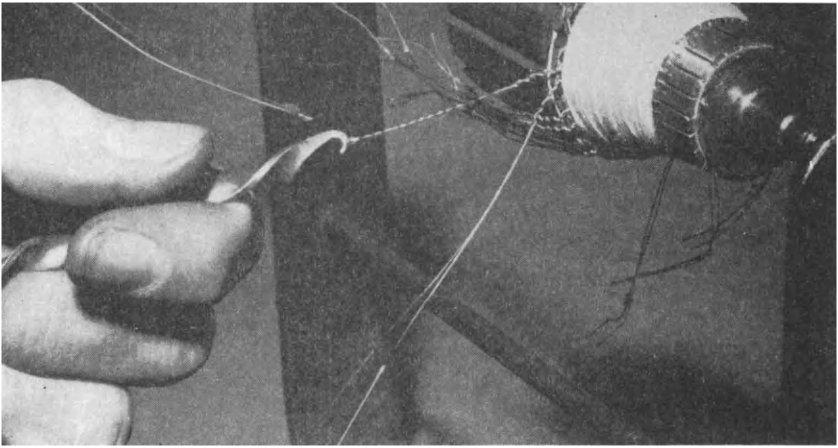
enamel with a layer of nylon on top, the covering being specially treated to allow direct dipping of the wire in high-temperature solder. If such wires are used the twisting can be taken right down the leads.

It is assumed, therefore, that the leads must be cleaned. There are various ways of doing this; most of them necessarily involve the use of abrasives.

The main methods entail either passing the wire between two rotating wire brushes or between two rotating drums of glass fibre, or using a simple stripper similar to those shown in Fig. 30. In some cases it is an advantage to burn off any textile covering as a first step. This will also anneal the wire and partly remove any enamel.



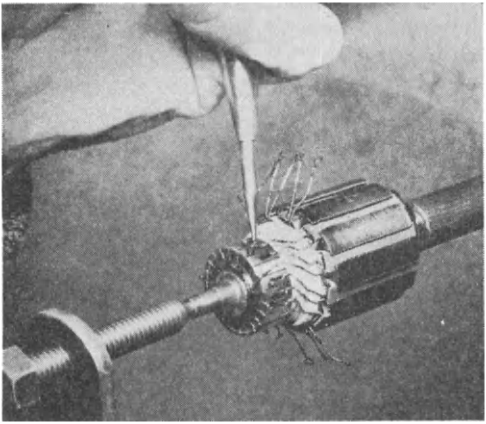
30. **Simple wire strippers.**
(*a*) **metal strippers;** (*b*) **fibre strippers with 'wet-and-dry' stuck on the ends.**



31. Twisting leads together.

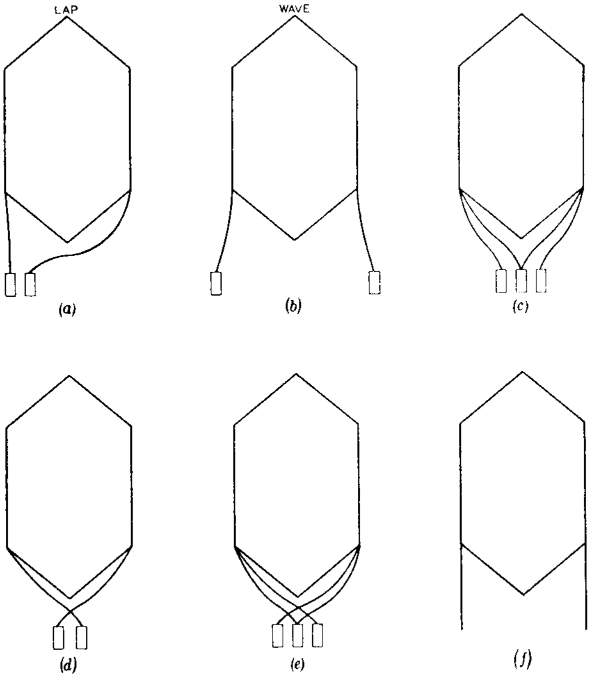
A form of Archimedean screw is employed with a hook at the end which automatically twists the wires as the thumb and finger are pulled down the screw.

When the wires are clean they can be twisted up and laid down to the correct commutator bar, the connection being located from the data. Fig. 31 shows a simple device for twisting the wires together after they have been cleaned. It is a short piece of Archimedean screw with a hook at one end. As the thumb and finger are pulled down the screw the hook automatically twists the wires. Each pair of wires must be snipped into the commutator bar with a small punch (see Fig. 32). This not only holds them in position but also



32. Fixing wires into a commutator.

Each pair of wires is snipped into the commutator bar by means of a small punch. This holds them in position and provides a joint for soldering.



33. Simple armature coil.

(*a*) One circuit is connected to two adjacent commutator bars for a lap wind, (*b*) if the bars are 180° apart mechanically, a wave wind is obtained (*c*) two circuits are connected for a lap wind to two adjacent bars, this is progressive connection. (*d*) and (*e*) show retrogressive connections of one and two circuits. (*f*) simple coil (see text).

helps to make a good joint for soldering. The leads behind the commutator risers are then bound with twine and the armature soldered. Soldering is done in a bath for mass production and with a large iron for short special runs. Heavy-duty tools are usually soldered with high melting-point solder.

Varnishing and Finishing

With very few exceptions all armatures are varnished and baked. This operation is essential because it not only adds insulation between turns, but also secures the whole winding against the action of centrifugal force—which is quite considerable—and prevents any intercoil movement. In addition the whole winding is sealed and the ingress of moisture and dust prevented.

Full treatment of the technique of varnishing would require a chapter to itself, since it is today a highly technical process, requiring temperature-controlled and ventilated ovens. The varnish manufacturers are very willing to advise on suitable varnishes for particular applications.

The varnished armature is then cleaned up, the stampings ground true and the commutator machined and undercut. These last two items are of importance. The commutator face must be true to the journal; some makers achieve an accuracy of ± 0.005 mm. The undercutting must remove the mica between the commutator bars to a depth of 1.5 mm. A few special types of armature are not undercut.

The final process is the dynamic balancing of the armature. Quite elaborate machines, electronically controlled, are now devised for this purpose. They ascertain the position and the amount of unbalance automatically, and the armature is corrected by adding a compensating amount of brass wedging under the lips of the slots in the place indicated. In the latest machines the adjustment is done automatically by milling away the heavy spot on the armature stampings.

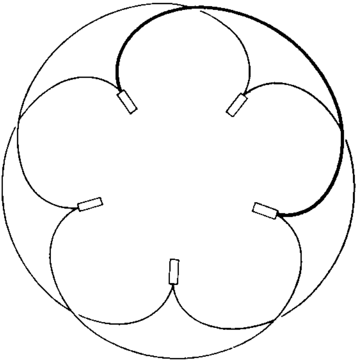
Wave Wind

The simple armature coil illustrated in Fig. 33 will now be considered. If it has one circuit it will be connected to two adjacent commutator bars as in (*a*) for a lap wind. If it has two circuits it will be connected as in (*c*). In every case for a lap wind the ends of a coil are connected to two adjacent bars. This is termed a *progressive connection.* Alternative forms, shown in (*d*) and (*e*) of Fig. 33, are called *retrogressive connections.* The only difference with this type of connection is that it will reverse the direction of rotation of the armature assuming the field connections to be unchanged.

If in Fig. 33(*a*) the end and beginning of the coil are connected to two bars approximately 180 mechanical degrees apart, as in (*b*), a wave wind is obtained. This can be incorporated in the very simple armature with five slots and five commutator bars which was first discussed (see Fig. 23), and serves to illustrate the simplest type of wave wind. The circular diagram will be as in Fig. 34.

At the beginning of this section on armature winding, it was pointed out that for small armatures, and excluding the loop wind, the only difference between the lap and the wave wind is the connection of the ends of each coil of the commutator.

It will be appreciated that with a coil like that in Fig. 33(*f*) the two leads emerging from it could equally well be connected either lap or wave; the only fundamental difference in the technique of winding is that, for wave wind, the leads are left out from the slot end nearest to the commutator bar to which they are to be connected.



34. Simple wave connection.

This circular diagram is of a wave-wound armature with five slots and five bars.

A lap wind must normally have an even number of commutator bars, but the wave wind must have an odd number.

As we are dealing only with typical examples of simple straightforward armatures, it is obviously impossible to treat here all the many variations which are in use. These variations relate in the main to the manner in which coils are placed on an armature, that is, the order or specific arrangement adopted. Even the connections of the armature circuits are subject to a number of variations, mainly due to the relationship between the number of coils and slots and the number of commutator bars.

Further Information on Armature Winding

Refer to Chapter 8 for further information on armature winding.

Armature Testing

It is appropriate to give some idea of armature testing here.

For the simple straightforward example chosen, the testing too is straightforward.

There are three main requirements for every armature:

1. The winding must be earth free.
2. The connection to the commutator must be correct, i.e. the tappings from the windings must be regular and in order.
3. There must be no shorts between any turns in any coil.
4. There must be no shorts between any coil or coils.
5. The joints at the commutator must be sound.

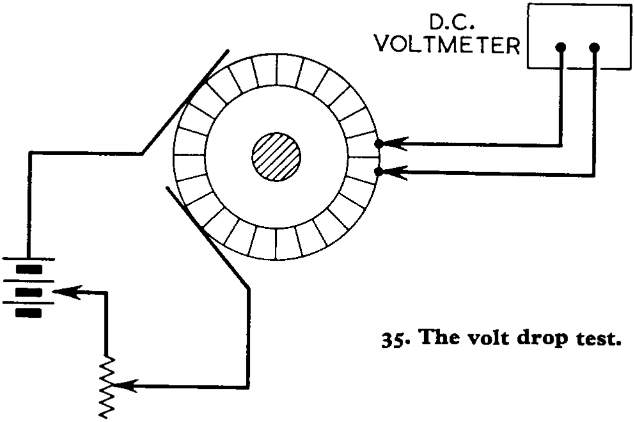
The Earth Test

The earth test is quite normal and needs hardly any explanation. For a 230 V armature an ordinary 500 V Megger earth tester is an obvious choice. But it must be appreciated that if an armature is rated for only 6 V such a test would hardly be warranted, and in these cases a series lamp of 230 V is adequate unless the low-voltage armature concerned comes, for example, from an aircraft machine, in which case the test specifications are much more rigid.

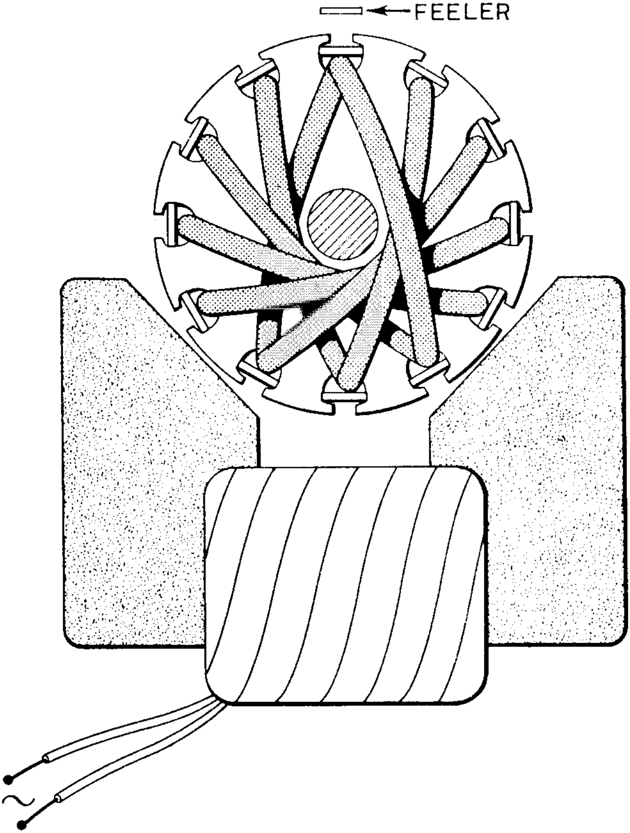
Flash testing is recommended only for newly-wound armatures and not for those that have seen long service.

The Volt-drop Test

The volt-drop test will cover points (2)–(5) listed above. Some kind of simple device is required to hold the armature and to feed current into the commutator while the armature itself is slowly rotated and each pair of commutator bars tested in turn. The test is shown diagrammatically in Fig. 35.



35. The volt drop test.

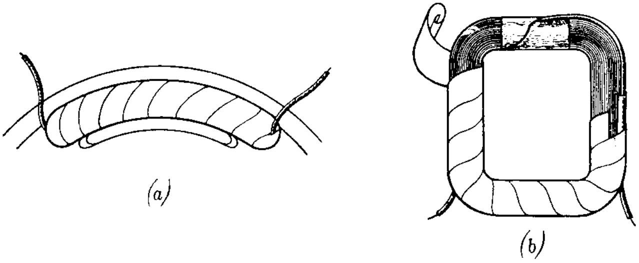


36. The growler test for armatures.
The armature is shown with a few coils omitted for the sake of clarity.

Current is fed into the commutator by two contacts at approximately 90°, an angle which, for various reasons, will be suitable for testing both lap and wave connections. The current is d.c. and can be conveniently taken from a 12 V accumulator with, if necessary, a variable resistance in series to limit the current passing through the winding. Diametrically opposite the contacts is a pair of test prods so arranged that they will make contact on two adjacent commutator bars.

These points are connected to a variable-range d.c. voltmeter.

After the set-up has been adjusted to obtain a suitable reading of approximately half full scale, the armature is slowly rotated and each pair of commutator bars is tested in turn. All the readings obtained on the voltmeter should be exactly, or very nearly, the same. A very high reading indicates an open circuit, due either to a bad connection at the soldered joint or to a break in a wire. A very low, or zero, reading shows that a short is present; this may be between the turns of a particular coil or between the commutator bars, or may result from an incorrect connection. Reversed polarity on the meter shows that the armature was incorrectly connected.



37. Salient-field winding.

In small universal motors the normal field winding is a taped coil threaded over the horns of the field stampings. When the coil is wound, flexible leads are attached and the inner lead insulated where it crosses the coil as shown in (*b*). The leads are anchored by taking them some distance round the coil under the tap.

This test is very sensitive and will locate almost any fault, except those due to vibration as a result of movement when the armature is rotating.

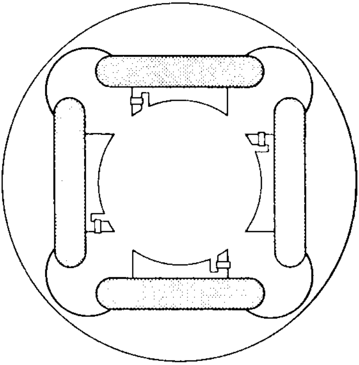
The Growler Test

The growler test is most useful and very quick, but it cannot be considered to be a substitute for the voltage-drop method described above. It should rather be used as a preliminary test because it will immediately indicate a bad fault and save the time required for the longer method.

The growler used can be precisely the same instrument as that used for testing the stator. Usually, however, the construction is slightly different so that the armature can lie in the jaws as shown in Fig. 36.

With the armature in the position shown, each slot is

38. Shaded-pole motor. This uses the type of field coil shown above in Fig. 37.



tested in turn as the armature is rotated, a light feeler of thin steel strip being held over each slot as it is tested. If the winding is good it will have no effect on the feeler, but a shorted turn or turns will attract the feeler quite strongly.

This test only indicates shorts in the wires. Open circuits can certainly be detected with a growler by adding a pair of test prods in series with an a.c. ammeter or voltmeter, and testing each pair of commutator bars connected to the coil or coils which give a distinct pull on the feeler. It is better, however, to use the volt-drop test for checking open circuits.

Field Coils

In a small universal motor such as those fitted to electric drills, grinders, vacuum cleaners, etc., the normal field winding is a taped coil which is threaded over the horns of the field stampings (see Fig. 37). These are called salient fields.

Precisely similar fields are fitted to d.c. motors, where the poles may be bolted to a circular steel yoke, and to shaded-pole squirrel-cage motors.

In most cases these field coils are extremely simple and the only complicated examples are found in field coils for variable-speed machines and for compound d.c. motors, or generators.

The fields are wound on formers similar to those used for stator winding. The conductor is invariably enamel- or synthetic-covered wire, except for very high-temperature coils where a glass covering is used instead. Once the coils are wound, the flexible leads are attached and the inner lead insulated where it crosses the coil to reach the outside (see

Fig. 37(*b*)). It is usual to anchor the flex leads by taking them half-way round the coil under the tape before they emerge.

For a simple electric drill the coils are now inserted in the stampings, usually with a layer of paper insulation under the lips. They are finally secured by lashing or by metal clips and subsequently varnished.

In spite of their simplicity, many of the universal motors on the market have economised still further by omitting the taping entirely. Instead, the fields are secured by a turn of adhesive paper tape on each side and the coils are fitted in the usual way.

Some small field systems, where space is rather restricted, use the skein wind. The process is precisely the same as that illustrated in Fig. 13, except that there are only two slots, as it were, for the coil. A skein of 50 turns of fine wire could be used for a particular field coil; four throws of the skein would therefore give 200 turns. Cash-register motors often use the skein wind for their field system.

Shaded-pole Motors

Miniature squirrel-cage motors using salient-pole coils with a shaded-pole winding to effect starting are becoming very common and are used for all manner of mechanisms where very low power is required, e.g. timer mechanisms, fans, blowers, roasting-spit revolving mechanisms, etc.

Fig. 38 shows a simple shaded-pole motor which uses the same type of field coil as that shown in Fig. 37. The shaded pole is merely a rectangular ring of heavy-section copper laid in the slots provided in the field stampings. Current is induced in this ring by the main field flux and this current gives rise to another pole, a starting pole out of phase with the main running winding.

Larger shaded-pole motors use either the concentric or the distributed wind instead of the salient coils of the example.

5

D.C. Motors

With the widespread distribution of a.c., both one- and three-phase, it might be thought that the d.c. motor is virtually obsolete. While this is perfectly true as far as the normal power requirements of industry are concerned, it is not the case in a wide variety of specialised equipment where d.c. still reigns supreme. Indeed, some equipment is virtually impossible to replace with a conventional a.c. machine.

D.C. Motor Applications

One example of a pure d.c. machine is the traction motor now being used on electric milk floats and invalid chairs. Also, the machines found in amusement arcades still use d.c. motors. Many of these have been running for a large number of years and, although assisted by some kind of maintenance, they are regularly abused. It is probably quite safe to say that, in this particular application, a low-voltage d.c. motor is the only power unit which can stand up to the really violent duty cycle.

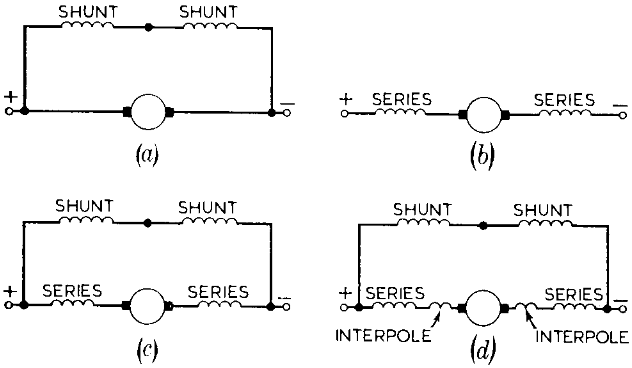
Small portable generator sets offer another example where a d.c. supply furnishes current for such apparatus as hedge and grass cutters and log saws. In addition, aircraft still use d.c. motors, ships use d.c. pumps and, of course, private and commercial vehicles rely on a d.c. supply even though the alternator is gradually finding a place—the alternator output is rectified to d.c. for consumption by the electrical equipment.

It will be seen, therefore, that an electrical fitter may have to service a d.c. machine at any time and maybe encounter trouble in diagnosing faults preparatory to repair. There was a time, in the early part of this century, when many public supplies were d.c. and fitters, by necessity, became *au fait* with the trials and troubles of the d.c. system. The converse is now the case, and the almost universal distribution of a.c.

precludes an electrician from obtaining training and practice in the use of d.c. so far as electric motors and, for that matter, generators are concerned.

Types of D.C. Machine

There are three main internal connections of a d.c. motor or dynamo. Both motors and dynamos are very similar, the difference being that one drives and the other is driven. The four basic types are shown in Fig. 39.



39. Internal (schematic) connections of the four main types of d.c. motor, *Se*, series coil; *Sh*, shunt coil; *Ip*, interpole.

It is essential that the field layout and connection should be permanently impressed upon the fitter's mind, so that the type of winding can be immediately recognised and identified.

The Shunt Connection

Fig. 39(*a*) shows the shunt connection where both the armature and the field, or fields, are in parallel. Hence the shunt fields are connected directly across the mains.

It will, therefore, be apparent that the resistance of the fields must be sufficiently high to permit a reasonably small flow of current, governed of course by the size of the machine in question. This current, multiplied by the number of turns in a field, gives the necessary *AT* (ampere-turns) to energize each pole and, since the current is low, the turns must be high to satisfy the expression. Assume, for example, that the design of a particular motor required 1000 *AT* per pole and that a current of 0.1 A was flowing. This field will therefore be wound with 10,000 T of 0.2 mm wire.

The Series Connection

In this example the fields are in series with the armature and consequently the fields must pass the total current taken by the motor (see Fig. 39(*b*)). From this it can be deduced that the wire used for the series fields must be large in sectional area and of low ohmic resistance with fewer turns than that used in a shunt connection.

For example, let us again assume a field in a motor requires 1000 *AT* (it is, of course, the *AT* turns which determines the magnetic flux developed by the winding). We could, therefore, have 1000 turns carrying 1 A, with a wire of 0.63 mm diameter for a shunt winding, but a series coil to give the same *AT* would have 100 turns at 10 A, with a wire of 2 mm diameter, or two wires in parallel of 1.6 mm. This latter example is a common field winding on 110-V fairground 'dodgem' motors rated at 570 W.

The Compound Connection

The compound connection is merely the incorporation in one machine of the two circuits shown in Fig. 39(*c*). The shunt is still in parallel across the mains, but the armature is in series with the two series windings.

The Compound Interpole Machine

In Fig. 39(*d*), the previous compound connection, has an addition of an interpole winding which is intended to control the commutation of the machine. These poles are placed at 90° electrical from the main pole. The interpole winding is also a series winding because the main current must flow through it, and consequently the interpole coils are wound with a very heavy wire to keep the resistance as low as possible.

Winding D.C. Shunt Fields

Methods of Counting the Number of Coil Turns

Generally speaking, the rewinding of a d.c. shunt field is a simple, if tedious, operation. In fact, the biggest job can quite easily be the assessment of the number of turns on the original coil, which may run into many thousands. There are various ways of doing this:

1. By actually counting the cut coil by hand.
2. By machine counting.

3. By electrically counting a sound field coil by comparison with a coil of known turns.
4. By ignoring the actual turns and winding a precisely similar coil to the exact size and weight, and to give the same ohms as a similar sound field, should one be obtainable.

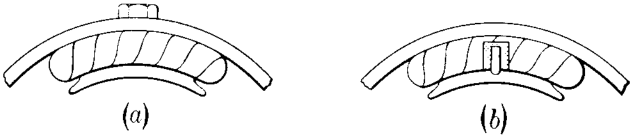
Of these various methods No. 1 is probably the best, but it can be a slow job at times. It is, nevertheless, frequently the only method that can be used to copy a field coil that has been very badly damaged, or has been partly burnt out.

The second method is excellent, provided that the coil is capable of being unwound and a suitable machine is available on which to do the unwinding. Since most field coils are taped and varnished, it will, of course, be necessary as a first step to remove the outside covering. In many cases this cannot be done without roasting the entire field coil over a gas flame until it is sufficiently charred for the wires to become separated. The unwinding machine is quite a simple device, and mainly consists of a mandrel attached to a counter, and the wire is either unwound by pulling with the hand or by winding off automatically.

The third method is out of the question for a small shop because of the somewhat specialised equipment required. Therefore, it is not proposed to consider this in the scope of this book. The last method is also an excellent way of overcoming what could be a very trying job, assuming that the original wire diameter and the thickness and profile of the coil can be ascertained with some accuracy. However, in this case the peripheral length of the former on which the coil is to be wound is critical and, although the ohms obtained from the original coil by measuring the diameter of wire and taking its weight may be apparently correct, it is nevertheless questionable whether the actual *AT* of the coil will be precisely that of the original. Not only is this due to a possible variation on the original internal profile of the coil, but it is also due to the tolerance permitted in the manufacture of the wire diameter and the temperature at which the coil is made and tested and, of course, to the accuracy of the test meter.

It will be seen, therefore, that a good approximation of a shunt can be made, but a precise one is never easy to achieve, and in any case it is seldom necessary.

These last remarks also apply to small d.c. solenoid coils, more especially to those of small dimensions using wire down to 0.1 mm. Here, with a nominal value of, say, 10,000 ohms, a number of apparently precisely similar coils may vary ± 400 ohms, due solely to the diameter tolerance of the wire and the many thousands of turns of fine wire.



40. Two types of d.c. field with (*a*) bolted pole shoe and (*b*) integral pole shoe.

Making the Former and Rewinding the Coil

Having determined, by one of the above methods, the turns required and the diameter of the wire to be used, it is then necessary to make a wood or Bakelite former to the inside dimensions of the original coil. To do this, the coil is first removed with as little damage as possible. This is quite simple when the pole is bolted to the yoke, but quite difficult when the coil is thrust under the lips of an integral pole in the stamping and subsequently varnished hard (see Fig. 40).

The extracted coil is then slowly roasted over a gas flame as previously mentioned and then pressed under a block of steel. This quickly quenches it and restores it to its original outline in one plane. From this the length and breadth of the original former can be found, but the thickness is ascertained by gently squeezing a corner of the field coil in a vice and measuring the gap between the jaws, remembering that a field coil is always thicker than the former on which it was originally wound, and smaller on the inside than the external periphery of the original former.

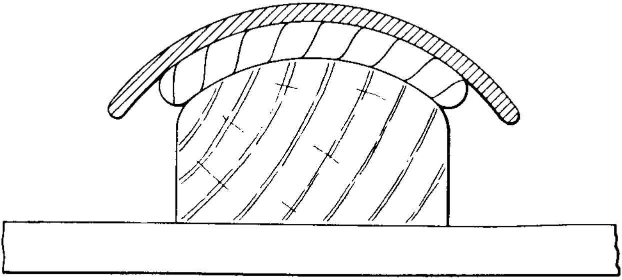
The wooden former is made in a similar manner to that illustrated in Chapter 4, but it is worth remembering that a fairly large coil with thousands of turns of fine wire exercises a considerable pressure on the cheeks of the former. Therefore, the cheeks must be high enough to retain the coil and exert enough pressure to prevent a fine wire slipping down between the actual former and the cheeks.

The finishing treatment is very similar to that already described on page 49 with the exception that the insulation, depending of course on the voltage of the machine, is better, and frequently consists of a layer of oil fabric of silk underneath the normal cotton covering. It is usual to varnish shunt coils, but this again depends upon the duty of the machine. In damp conditions it is absolutely essential to impregnate a field coil wound with a fine wire which otherwise could easily and rapidly corrode in moist conditions and develop minute 'green spots' and lead to fracture of the fine wire.

When a field is fitted with a bolted pole, as in Fig. 40(*a*), the field coil can be varnished and baked before assembly, but where the coil is to be threaded under the lips of an integral pole, as in Fig. 40(*b*), it is usual to insert them in the 'white' and varnish them as a last process.

Winding Series Fields

In many ways these are simpler than the shunt coils. For one thing it does not take long to count 100 or so turns of wire. On the other hand, the large size of the series conductor may give rise to a very stiff coil, particularly when it is wound with a synthetic-covered wire.



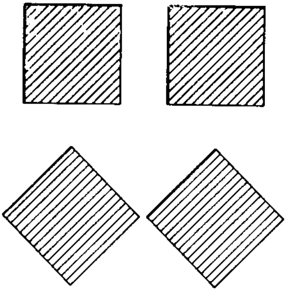
41. A simple jig for shaping field coils.

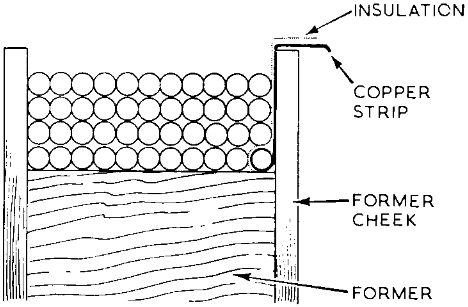
Having wound and taped the coil, we are now presented with a problem of shaping the coil to fit into the curved space behind the pole and, with the very heavy conductors used on some of these fields, considerable pressure will be required to shape the coil. Some means of compressing the coil between two curved surfaces must be found. The jig need not be elaborate for the occasional job. All that is necessary is a half cylinder of wood to the correct dimension and a curved made mould by sawing an old d.c. yoke in half (see Fig. 41).

If a fly press is available the coil can be compressed quite easily; alternatively a G-cramp could be used. Forming by hitting with a mallet is not particularly desirable.

Winding with Heavy Conductors

So much for the general methods of winding series field coils, but there is one difficulty always present to a greater or lesser degree, where heavy conductors are used. This is





42. (*left*) **Showing shape of conductor section when winding.**

43. (*right*) **Method of bringing out the beginning (inner end) of heavy conductor by use of copper strip.**

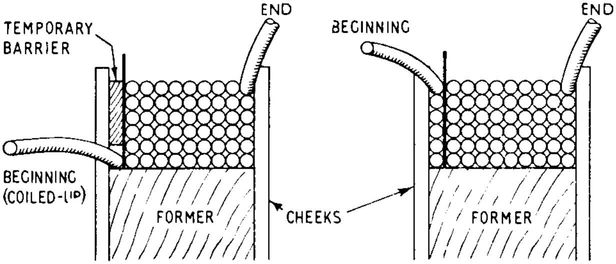
the problem of taking the inner end of the coil to the outside of the coil, that is to say, the cross-over. If the conductors are not too big they can be taken out as a simple cross-over, as in the case of the coils illustrated on page 48. Each cross-over must be adequately insulated from the rest of the coil, because considerable pressure is exercised in forming the coil, and there is, therefore, a danger of wires shorting together.

Where space, as far as the thickness of the coil is concerned, is very restricted, as is frequently the case in many modern machines of compact dimensions, another expedient can be used to get the inner turn to the outside. Fig. 43 shows how this can be done by soldering the beginning of the winding to a copper strip of adequate sectional area which will take far less space on the width of the coil than would the original solid conductor.

Where the field coils have very heavy conductors, particularly in the case of low-voltage machines, round wires are replaced either by strip conductors or by twisted strands D.C.C. covered. If the former is to be used, always avoid, if possible, a square-section conductor, because it is very tricky to handle: it will try to wind its edge in a diamond-shaped pattern instead of a rectangular pattern (see Fig. 42). This may seem rather surprising to the beginner, but it is one of those things worth remembering. A rectangular strip with a ratio of width to height of about 1 to 2, is much easier to handle and will wind a neat coil.

As an alternative, the stranded conductor is very easy to handle, being extremely soft and flexible, but it has the disadvantage of having a bad space factor. This is merely another way of saying that less copper can be wound in a given space than would be the case if a solid conductor of an equivalent section area was used, particularly a rectangular conductor.

There is yet another method of winding a coil in a compact area, using heavy conductors, by a special technique illustrated in Fig. 43. Here a long length of wire is left spare, as it were, and coiled neatly out of the way until the field coil is nearly complete (see Fig. 44(*a*)). The shaded space in the drawing is then completely wound and the end will emerge from the top of the coil (see Fig. 44(*b*)).



1st STEP
(a)

FINAL STEP
(b)

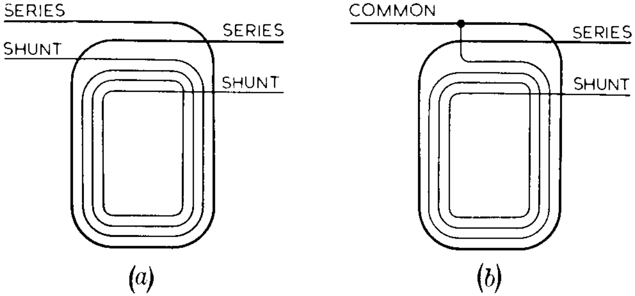
44. Method of winding heavy coils where both beginning and end of coil emerge from the outside of the winding.

The final stage is to wind the original spare end spirally in the space left for it and the end of this will also emerge from the top of the coil. Hence, both the beginning and end of the coil emerges from the outside layer and there are no cross-overs whatever.

There is still one other method of winding a very heavy series field. This is by using bare copper strips with paper inter-leaving between each turn, and is used in winding series fields in automobile starters. However, this method is seldom used in the machines which are dealt with in this book.

Interpoles

Most large d.c. machines are fitted with interpoles, but in the f.h.p. range they tend to be omitted. Nevertheless, it is quite possible to find a small 200 W motor fitted with this additional winding.



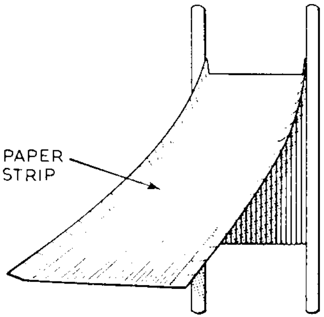
45. Compound field with (*a*) all leads out, (*b*) three leads out.

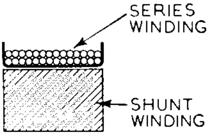
These interpoles, so far as f.h.p. motors are concerned, present few problems to the winder, and the technique adopted is merely a repetition of that explained for the series coils.

Compound Fields

It was explained in the first part of this section that the compound motor is virtually an addition of Fig. 39(*a*) and 39(*b*), and in most cases the two field windings are actually incorporated in one field coil. This is shown diagrammatically in Fig. 45(*a*), where a compound field is illustrated with all the leads brought out. A similar field where the ends of the series and the end of the shunt winding are joined to a single emerging lead is shown at Fig. 45(*b*).

Normal practices require the shunt winding to be wound directly on the former as the first stage, and for the series winding to be added on top of this. However the coils are





46. Crimped paper insertion between shunt and series winding.

wound, either with series on top or inversely, there must be adequate insulation between the two sections, and this can be conveniently done by inserting a strip of insulation paper with a 'pie crust' edge. The notched edges of the paper enable it to lie evenly between the edges of the former, and to go a little way up the side of the coil, so adequately insulating the two circuits (see Fig. 46).

Alternatively, a few turns of oiled fabric can be wound on the first coil or, to adopt American practice, ordinary black insulation tape of suitable width is equally suitable.

Winding Techniques

Further details of winding field-coils, particularly on the use of winding machines, techniques and coils are given in Chapter 7.

Armature Winding

Details of armature winding are given in Chapter 8, since wound armatures are used on machines other than d.c.

6

Former Making

Having determined the dimensions of a former by carefully assessing the original size of the coil to be copied (as described in the previous chapter) we can now proceed to make the former.

Former for a Simple Field Coil

In the case of the simple field coil (as found, for example, on an electric drill) or a straightforward d.c. compound or shunt field, little skill is required, but there are one or two points to be watched. In the first place the former must be flat and with the sides parallel, otherwise a gap may be left between the former itself and the cheeks. This is of particular importance when fine wire is being used. Indeed, as the wire gets finer so the accuracy of the former must improve.

For example, some very small universal series motors and small d.c. shunt machines have coils wound with a conductor as 0.14 mm or even down to 0.112 mm, and hence any gap left between the former and the cheek will allow a turn or two of wire to drop down into the cavity. This, apart from making a coil with loose inner turns, will make it extremely difficult to extract the former from the completed coil.

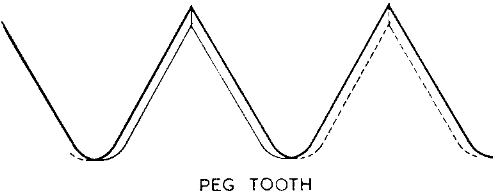
Materials Required

Plywood is an excellent material for making the former. As most field coils tend to fall into certain common thicknesses, stock material of 6 mm, 8 mm and 10 mm thickness will cover nearly every requirement. The larger sizes can be made up by pinning two or more pieces together. For the thinner formers below 6 mm, it is better to use Bakelite sheet. This is not very expensive, having regard to the fact that only small quantities are required.

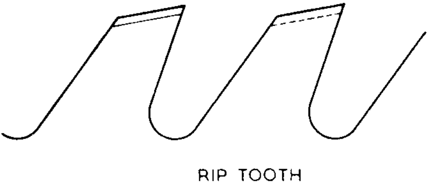
Cutting Out the Former

The corners of all formers must be carefully rounded, the radius required depending on the original sample. The corners and the sides must be tapered a few degrees to permit the coil to be slid off the former. Having marked out the size of the former required on the plywood, it is then cut as accurately as possible on the sides and cut approximately on the corners, *adding* the taper required, i.e. the unmarked side of the ply will be approximately 2.5 mm wider, in each dimension than that inscribed on the face.

A small circular saw is the obvious choice for cutting wood (or Bakelite) and the type of tooth which will give the best results for general use is shown in Fig. 47.



47. (*top*) **Peg tooth shape.**

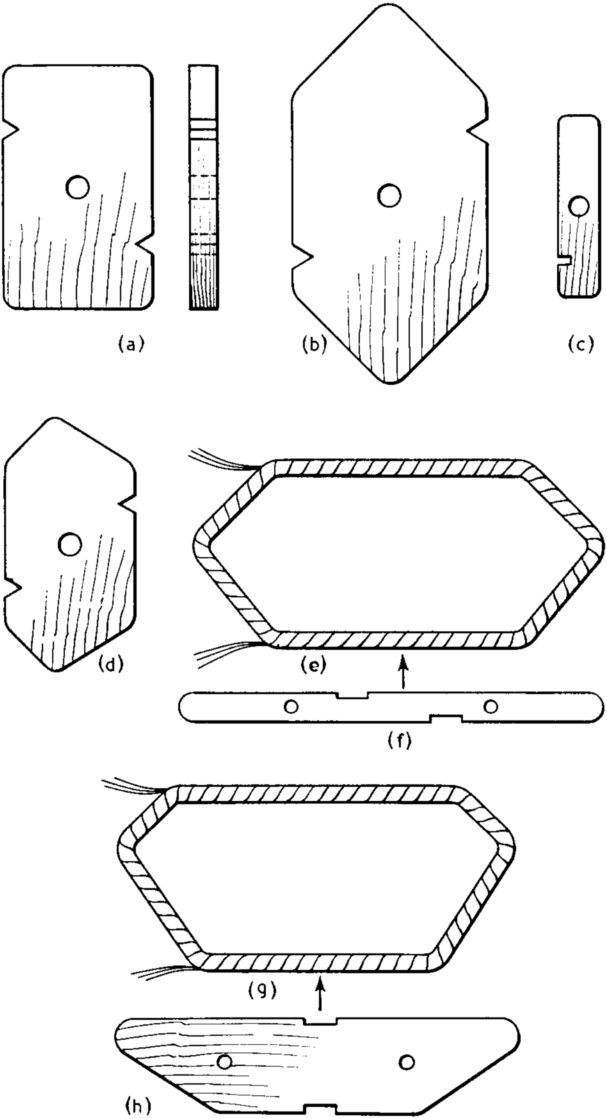


48. (*bottom*) **Rip tooth shape.**

All saws must be set to give clearance to the saw in its cut, but the finer the set the better the finish obtained on the former edges. The deep gullied rip-saw blades fitted to portable electric saws are not suitable for former making; they are far too coarse and have only two points to the inch instead of eight illustrated in Fig. 47. It is perhaps fatuous to add that the saw must be sharp and will require regular resharpening.

Preparing the Corners

Having cut the former roughly to size, the corners must now be carefully smoothed. These are most important and determine the size and shape of the finished coil. The sides of the former affect the coil to a much lesser degree. The rough cut corner must be carefully rounded to the correct radius and the angle of taper preserved. This finishing



49. Formers of various types (see text).

operation may be carried out using a disc or belt sander, but, in fact, the emery wheel on a bench grinder will perform the task much better. This is because not only will the emery remove the surplus left by the saw, but it also seals the pores of the ply by the slight burning the surface. It will, therefore, leave a very smooth radius which is of great value if fine wires are to be used. It should be remembered that an emery wheel can only be used for occasional work because the wood from the former will quickly clog the pores of the stone and reduce its cutting effect.

Completing the Former

When the profile of the former is finished, do not attempt to sand the former sides unless absolutely necessary. Any fine rags left from the sawing and edge sanding, unless very gross, will help to make the former fit closely to the cheeks. It is also an excellent idea to rub the edges of a former with a candle as this will help the coil to slip off quite easily. Remember to cut one or two tie slots as, although these may not be required for some coils, they may be most essential for others. Hence, they should always be cut as a routine operation. The cheeks hardly need describing as they are so obvious, but a point to remember is that they must be thick enough to withstand the pressure from a mass of wire. In some coils this pressure is very considerable, but these are mostly beyond the range considered in this book.

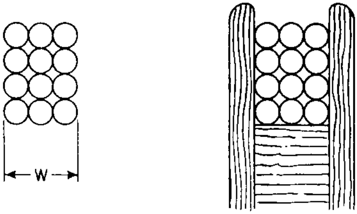
Formers for Complex Coils

The previous paragraphs relate to the simple straightforward former and most coil-winding jobs fall into this category. However, when a more complicated former is required then, naturally, greater care is required in the construction.

For example, the formers (*a*, *b*, *d*, *h*), shown in Fig. 49, while varying in size and shape, present no problems, but the narrow on (*c* and *e*) may need greater precision in cutting and the use of Bakelite to get adequate strength for a former of this nature. Moreover, some of these narrow coils are frequently limited in thickness. This may result in a rather odd measurement and, in this case, the difference can be made up by adding a piece of insulation paper or fibre to the sides of a standard piece of bakelite and cutting the paper to the correct profile with a sharp penknife.

Hair-pin Coils

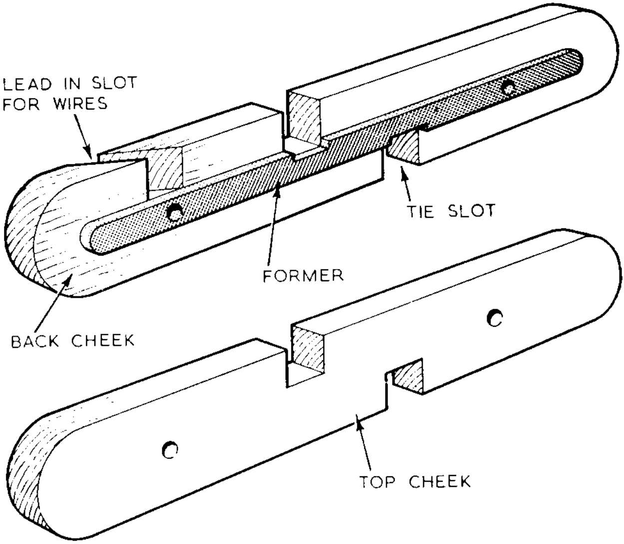
Fig. 49(*f*) illustrates an entirely different problem. This particular former is the first step in making a hair-pin coil



50. Showing arrangement of conductors.

which will subsequently be pulled in the shape illustrated in Fig. 49(*e*). Considerable difficulty may be experienced in deciding the correct size required because the sample coil (in this case an armature coil) will have been so distorted by the pulling and bending operation as to make it almost impossible to reform it to its original initial outline and to measure the distance between the rounded corners.

Formers of this kind are used for both heavy round or strip conductors and the thickness must be accurately adjusted to the aggregate thickness of the conductors (see Fig. 50). Here again paper side strips can be used as a micrometer adjustment to the former thickness, remembering



51. Special cheeks for shuttle coils.

that these heavy conductors must fit tightly between the former cheeks. Bakelite or steel is essential for these formers and, in view of their length, two fixing holes are required. They are not rotated on a mandrel, as in the case of the smaller formers, but are fixed to a rotating faceplate.

Making the Side Cheeks

Side cheeks for formers of these types (Fig. 51) are made in an entirely different manner. They are very much thicker, unless made of steel, and they must be slotted in a special manner to allow the heavy conductors to run into the former without an acute, or rather obtuse, entry. Further, the entry slot must be in such a position so as not to interfere with the subsequent pulling operation. The last former (Fig. 49(*h*)) is only a variation of that shown in Fig. 49(*f*) to obtain an asymmetrical coil shown in Fig. 49(*g*).

Two further points of interest may be mentioned. Self-adhesive tape, such as Speedfix or Sellotape, is excellent for securing the wound coil using the cheeks drawn in Fig. 51, where the 'tie' slots are made wide enough for that purpose. The slot must also be deep enough to allow the adhesive tape to pass through easily. The static charge developed by unrolling this tape makes it very prone to adhere to the coil sides, especially when D.C.C. conductors are used which is a common type of covering for these special coils.

Nail Former

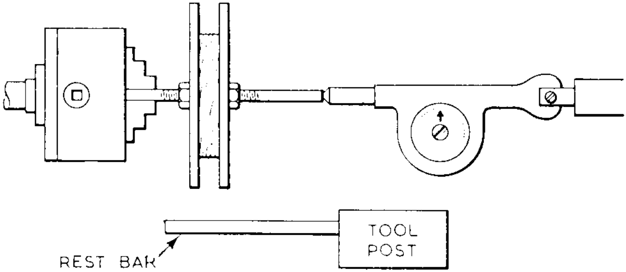
The simplest former of all is the simple 'nail former', This comprises a few wire nails driven into the bench around which the coil is wound by hand. This is very primitive, but is perfectly satisfactory for a coil of small wire and few turns.

7

Coil Winding

For coil winding is it essential to use some form of machine, however simple this may be. It can be said with some truth that many machines and jigs in a well-equipped shop are basically simple and only tend to become elaborate when the machines have to cater for a wide variety of work and produce various items in large numbers. Indeed, a simple piece of apparatus, in the hands of an intelligent craftsman, can often produce excellent work.

Mass production, however, is an entirely different matter, and introduces a range of special equipment designed, usually, with one end in view: to perform a certain and possibly a single operation as rapidly and cheaply as possible. For example, one manufacturer of portable electric drills uses a fully-automatic four-station winder, with two operatives, to produce field coils. A machine such as this might cost thousands of pounds, but a single coil could be made comparatively easily on an ordinary hand brace. This chapter covers only those machines which can be cheaply and simply made. Whatever type of machine is employed, final result



52. Simple coil-winding rig-up using lathe and rev-counter.

will depend more on the craftsmanship of the winder than the design of the machine. Craftsmanship is a *sine qua non* as far as good winding is concerned.

A Simple Winding Machine

First, let us consider a simple device to wind small field coils. If it is not intended to make up a special gadget, a small lathe will suit admirably. The former and the cheeks are mounted on a bolt which is chucked at one end while the other end engages an ordinary revolution counter supported by the back centre (see Fig. 52).

A smooth steel bar is mounted on the saddle to act as a guide and rest for the winder. There is nothing wrong with such a simple set-up except perhaps its comparatively slow speed, from a professional winder's point of view. However, as the revolution counter must be watched and each complete revolution of the pointer recorded, the lack of speed may be an advantage.

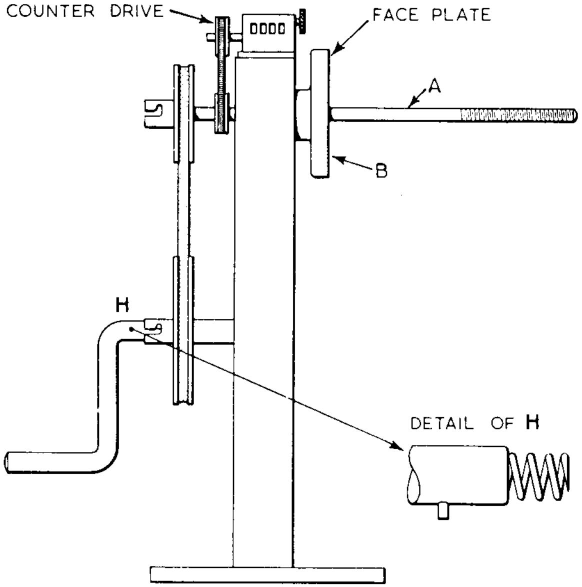
Precisely the same set-up can be used for heavy series or interpole coils with the lathe back-gear thrown in to reduce the speed to the very lowest. This is dealt with later on in the chapter.

If the fitter wishes to make something more elaborate, a variety of methods can be adopted to make up a simple winding head.

Hand Winder

Fig. 53 illustrates a hand-winder, based on a similar workshop example which has done excellent work for many years. The mandrel *A*, screwed for some 150 mm ($\frac{3}{8}$ Whit) is provided with a face-plate and a V-pulley at *C*. The mandrel is driven by a second vee-pulley at *B*, the ratio between the two pulleys being 2, 3 or 4 to 1, depending on the type of work dealt with. The driving handle is removable and can be fixed either directly to the mandrel for a 1 to 1 ratio or to the lower pulley for a 2, 3 or 4 to 1 ratio for fine wires. The method of attachment is shown in detail in Fig. 53.

A counter must be added and, in the machine illustrated, it is driven by two small vee-pulleys, of 1 to 1 ratio, via a spring belt. The purchase price will not be a large sum for a simple four-figure counter, but will be quite an item for a special high-speed, six-figure immediate-reset and reversible unit which is a normal fitment on a production machine. The value of a counter that 'uncounts' when wire is taken



53. **Simple hand winder with two speeds.**

off a coil is very great. It is easy to over-run a number and when winding a precision coil it is frequently necessary to unwind a little in order to correct a faulty layer. Unfortunately most simple counters only add and will not subtract.

A guide bar must be fitted to the machine and provision made to vary its distance from the former. The winder's hand will rest on this bar to guide the wire and therefore it must be adjustable.

Motorising the Winder

The same machine drive by a motor instead of the lower vee-pulley is the next obvious improvement. An ideal drive for such a head would be a clutch-operated motor of some 200 W as fitted to industrial sewing machines. The clutch is, of course, operated by foot control.

The provision of a motor to this winding head will also require the addition of a hand-wheel behind the face-plate (or incorporated with it) for manual control and inching.

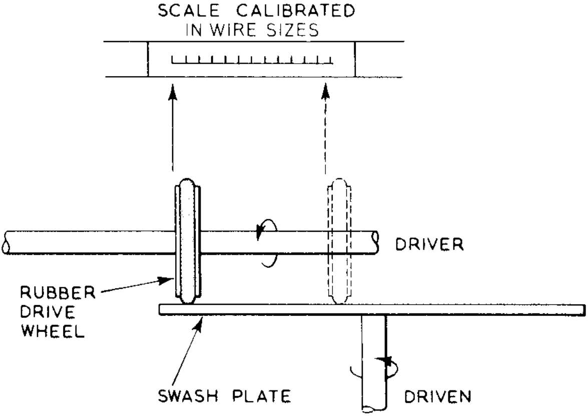
Automatic Traverse

All the preceding set-ups and machines require the wire to be hand-fed and hand-layered on the coil. Taking matters in their logical sequence the next, and major, improvement would be the addition of an automatic traverse, infinitely variable between certain limits, to accommodate a range of conductors and possibly the provision of an automatic reversing device. Such requirements immediately take the device far beyond the simple machines already described into the realm of expensive and complicated equipment, neither of which are within the scope of this book. Nevertheless, for those who wish to tackle such problems and are willing to have an attempt at making their own machines, a few methods will be described. The result will depend, of course, on the skill of the fitter and the availability of a reasonably well-equipped machine shop. With skill and patience the expense can be kept within bounds, but the machines will certainly take a long time to make.

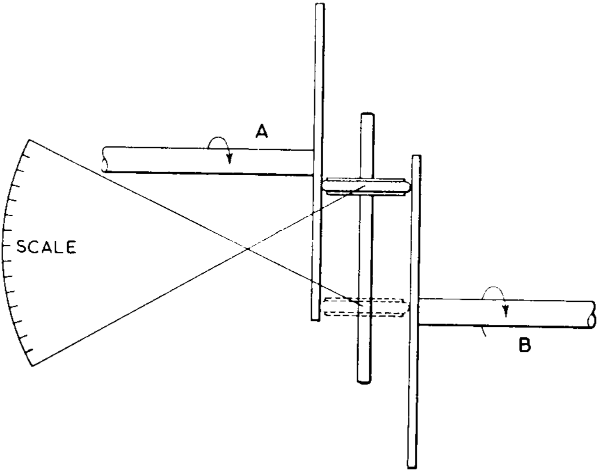
A winding machine is, in essence, a light lathe with a headstock, back poppet and a saddle which slides along the bed of the machine; but the tool-post normally fixed to the saddle is replaced by an arrangement to guide the wire onto the coil being wound. As in a lathe, the saddle is moved along the bed by a lead screw, and since the winding of a layer of wire on a coil is, in principle, precisely the same operation as cutting a thread, some means must be provided to vary the speed of traverse of the saddle relative to the motion of the main mandrel. On a lathe this is done by a train of gears and, indeed, some winding machines also adopt this mode of conveying motion to the saddle. It is, however, only suitable for a run of coil winding using the same diameter of conductor and, although the gear train can certainly be altered to suit another size of wire, it is a slow business. The machine should have an infinitely variable gear which can be instantly adjusted, not only to accommodate different conductors, but to vary the wire spacing which the work demands.

Methods of Speed Control

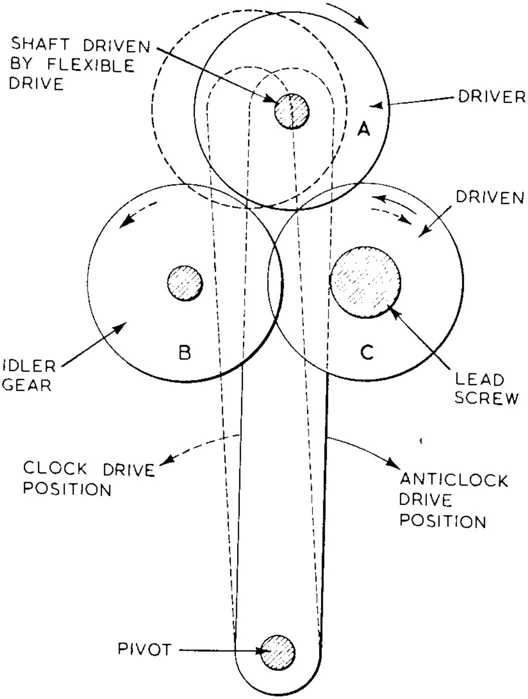
There are two methods which may be used; they are both based on a swash-plate drive. In Fig. 54 the drive is via a small wheel which carries a rubber ring on its periphery. This rubber drive acts on the spring-loaded swash-plate whence the motion is conveyed to the lead screw. The swash-plate drive is a very old idea; it is extremely simple and is quite capable of conveying the power needed to move the saddle along the bed of the machine. It is important to



54. **Simple form of swash-plate drive to obtain infinitely-variable ratio between limits.**



55. **Compound swash-plate drive by either A or B.**



56. Simple reversing gear for lead-screw. Pinion C and B permanently engaged. Driver pinion engages either C directly or engages B.

note that the swash-plate must be as smooth as possible for a rough surface will reduce the friction between the rubber drive and the plate, giving rise to slipping and variable wire spacing.

A better but more complicated scheme is shown in Fig. 55, which is the equivalent of a compound gear train. Here the jockey pulley is sandwiched between two swash-plates, giving greater cohesion and a wider range of speed between the driver and the driven shaft which, of course, permits the use of a wider range of conductors.

In both examples the jockey pulley can be immediately adjusted while the machine is *running;* but with the machine stationary the spring tension must be released on the swash-plate to free the jockey pulley.

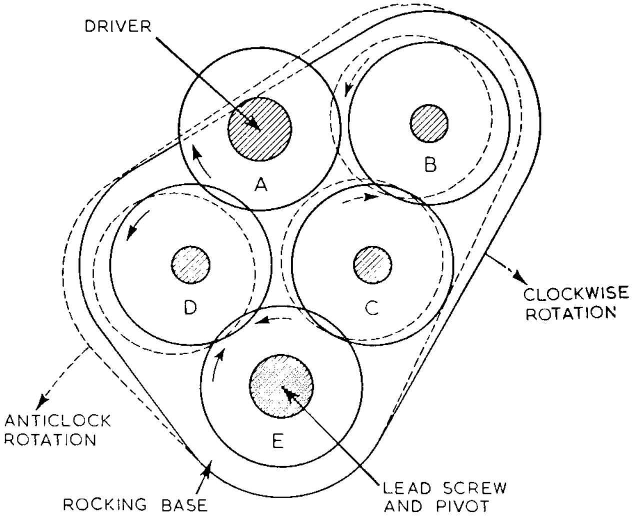
On both mechanisms the position of the jockey pulley is marked by a pointer on a scale, directly in Fig. 54 and indirectly via a pivoted lever in Fig. 55.

Reversing the Lead Screw

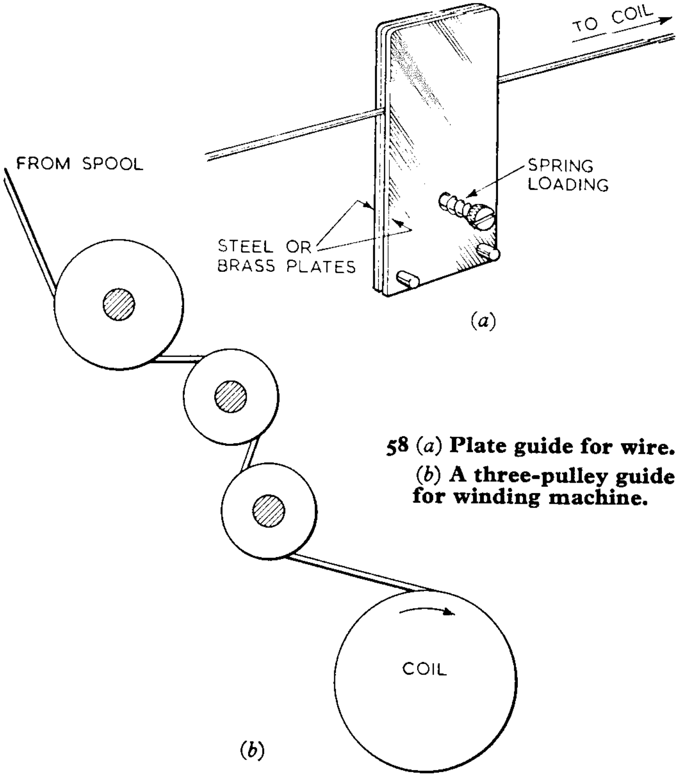
As the saddle runs along the bed of the winder it must be returned at the end of the winding. Therefore, means must be provided to reverse the rotation of the lead screw at the precise moment.

Possibly the simplest manual reversing gear is shown in Fig. 56, which requires three gears only. The operation is self-explanatory, but the pinions should have pointed teeth. These are not particularly easy to obtain, but they are used for large clock mechanisms. The driving pinion, since it rocks from side to side, is driven, in this example, by a flexible shaft.

The next arrangement obviates the need for a flexible shaft by using a rocking-gear plate with two pinions on one side and three on the other, the extra pinion being necessary to obtain the reverse rotation (Fig. 57).



57. **Reversing gear for lead screw. Pinions A and E in fixed location. Pinions B, C and D swing about pivot on lead-screw.**



58 (*a*) **Plate guide for wire.**
(*b*) **A three-pulley guide for winding machine.**

There are many ways of reversing the rotation of the lead screw, but the two described above are by far the simplest solution to the problem and can be built without any great difficulty.

The Wire Guide

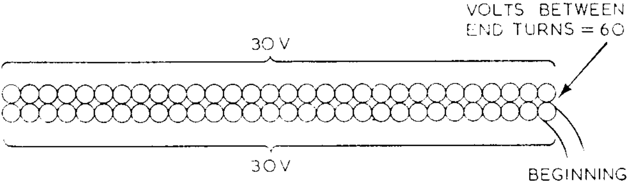
A passing reference has been made to a device, mounted on the saddle, which actually guides the wire on to the coil. Two ways of doing this are shown in Fig. 58.

In Fig. 58(*a*) the wire, after passing under a guide pulley, passes between two spring-loaded plates. Both the guide wheel and the guide plates are made adjustable to accommodate various sizes of formers.

In Fig. 58(*b*) the wire is guided by two or three deep-grooved vee-pulleys with ball-bearing pivots. Again, these pulleys must also be adjustable as a group to suit different coil diameters.

Winding the Field Coil

Having explained the various kinds of winding machines, there remains the problem of winding the various types of coils likely to be encountered. While a fully-automatic winding machine can be a useful acquisition, it is not essential and, as stated at the beginning of this chapter, work can equally be done on very simple apparatus. It must not be thought, however, that a coil can be wound anyhow. Far from it; each particular example should be layered as carefully as possible with adequate tension on the wire.



59. Field coil where volts-per-turn are approximately 1.

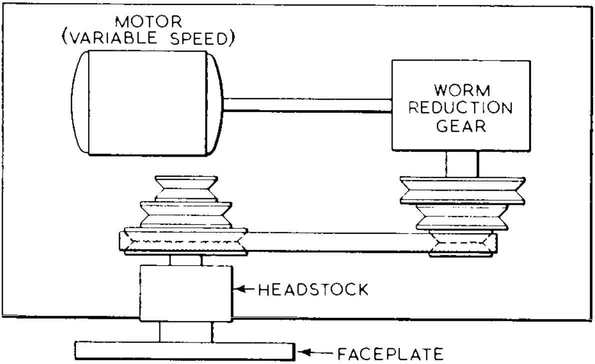
The technique of winding is governed to a very great extent by the voltage of the coil. Take, for example, a small coil for a 6 V machine and assume that each coil (of two) has approximately 3 V superimposed on it. With a synthetic-covered wire the insulation provided is, to say the very least, adequate. On the other hand, consider a d.c. shunt coil on 100 V. Here the potential difference between the beginning of the coil and the outside of the coil is 100 V and the need to insulate the inner end as it is brought out to the outside of the winding is very apparent.

In most cases the volts between adjacent turns are very low, but the voltage between different layers may be considerable. Fig. 59 shows a coil where the volts-per-turn are approximately 1, a very low voltage for any type of wire insulation. At the end of a layer of 30T, the voltage between the beginning and the end is 30, but when the second layer is complete the voltage difference is 60.

Coil Shape

The shape of the coil is of prime importance. A circular coil is by far the easiest shape to handle and winding can be done at high speed (i.e. 2000–4000 r.p.m.) even with a fine wire, without any danger of breaking the conductor. Unfortunately circular coils are very rare, the nearest approach being the square coil common to motors and generators. These square coils wind very well but, as the shape changes and a coil becomes more rectangular, so the difficulty of winding increases and the speed used must decrease.

Long narrow coils are particularly difficult. Very low speeds must be used to avoid a very considerable snatch given to the wire (twice in each revolution) and, while the narrow end of the former may layer quite neatly, the wire will not lay so neatly down the long side and tends to be wavy.

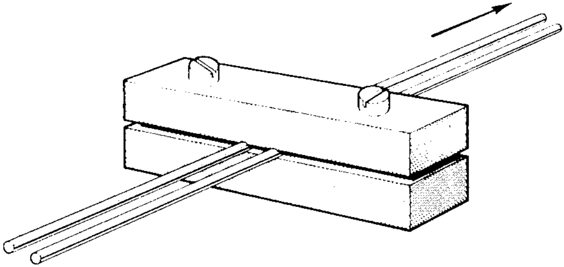


60. Layout for heavy winding head.

Typical Winding Machines

The winding of series coils using very large conductors presents additional problems. Heavy tension is necessary to obtain a close lay of the wire on the former, a tension which could easily amount to 45 kg and quite beyond manual application. Some kind of machine is therefore necessary to turn the former slowly and to apply tension to the wire. A lathe would, of course, suit for the occasional job, but it is hardly a convenient machine to use when coil winding becomes repetitive.

A machine capable of winding coils of almost every description is shown in Fig. 60. It is not particularly elaborate and can be made up by any fitter. This machine requires a high-ratio worm gear to reduce the speed of the motor, but



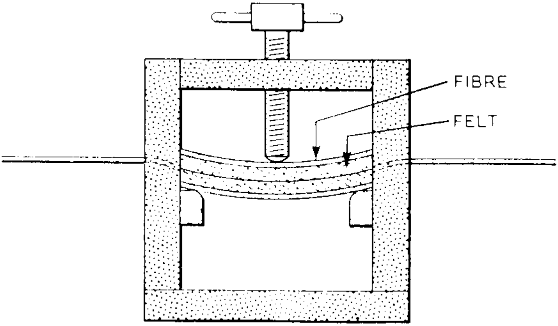
61. Hand-tension device for heavy conductors. Made from red fibre.

it may be pointed out here that a worm gear can be replaced with a compound train of vee-belts. This method does, however, take up rather a lot of space.

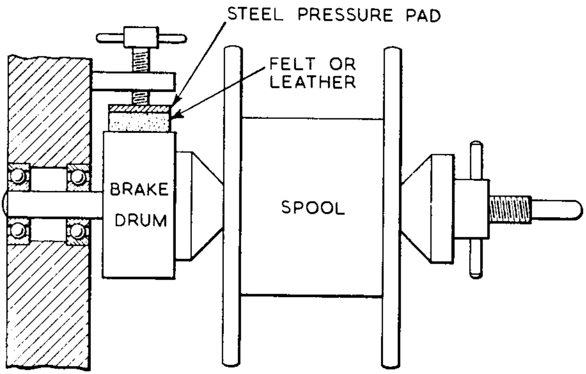
It will be noticed that the machine in Fig. 60 does include one vee-belt on the final drive via two three-step pulleys. This is necessary to effect the final speed adjustment down to a mere crawl, some 20 r.p.m. The faceplate itself should be tapped to receive a mandrel which, if very long, can be supported by an outboard back centre. A four-jaw clutch to fit on the faceplate is a valuable accessory. To make the set-up ideal the motor should be of a variable-speed type, about 250 W.

Wire Tension

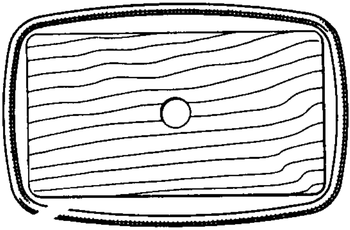
The importance of maintaining considerable tension on the conductor when heavy coils are being wound has already



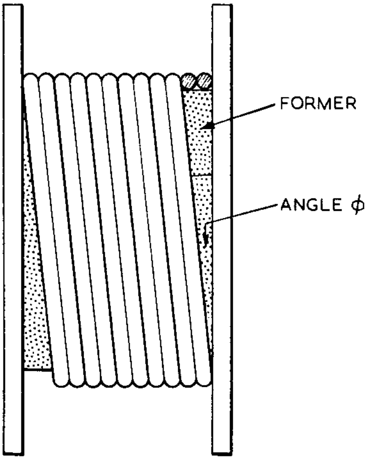
62. Simple tension box.



63 (*top*) **Tension device for spools**



64. (*centre*) **Effect of winding heavy circular of rectangular conductor on small former.**

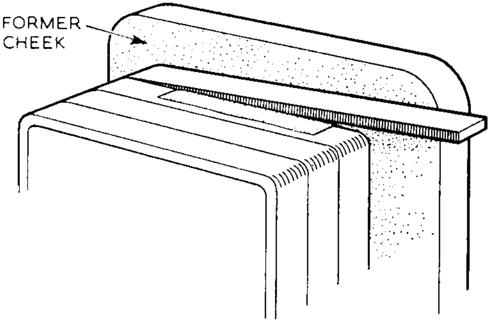


65. (*bottom*) **Showing wide angle phase when winding coils with two heavy conductors in parallel.**

been mentioned. There are two or three ways of doing this and one of the simplest is illustrated in Fig. 61, which is made to suit the size, and number, of wires being used.

The two blocks of fibre are bolted together and the device is anchored to a fixed point, thus applying tension to the wire and enabling the wire to traverse the coil face. Another method is shown in Fig. 62, which is a similar gadget and is usually attached to the winding machine by a traverse rod, along which the box slides. The wire passes through holes in the sides of the box and then between felt pads sandwiched between fibre plates which are curved by applying pressure via the bolts. Alternatively, the mechanism drawn in Fig. 63 can be constructed where the tension is applied to the spool itself by means of a brake drum.

66. Showing insertion of insulation on shear point in strip winding.



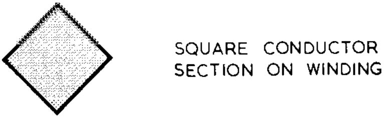
Irrespective of the method used to apply tension when winding a heavy coil, each turn must be laid as accurately as possible and each complete layer is usually drifted flat with a mallet and fibre or wood drift. This is to dress the coil to shape and, as the winders say, 'take the wind out of it'.

The 'wind' is an important point in heavy coil winding because no matter how much tension is used, a large conductor always tends to wind a coil with bowed sides as shown in Fig. 64. When the space available for the coil is very restricted, it is quite usual to press the complete coil to shape, either before or after taping, in a press or by a large G-cramp with flat wood jaws.

Winding with Parallel Conductors

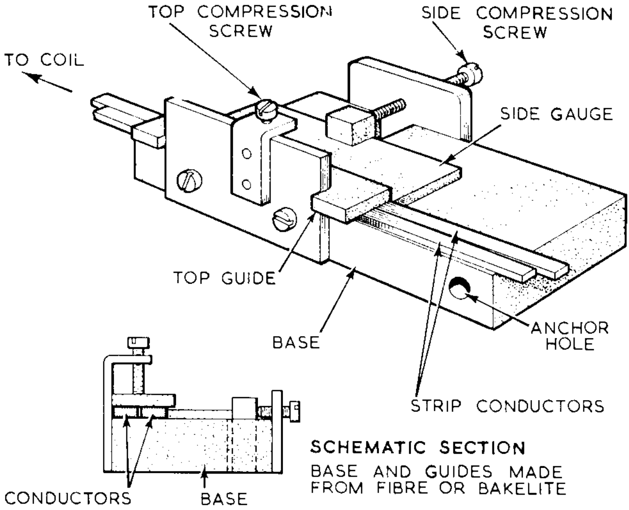
It will be noticed that Fig. 65 shows two conductors being used in parallel. This is quite common where heavy currents have to be considered, for two reasons. First, the use of two or more conductors may enable the designer to obtain a

67. A rectangular conductor when wound on the flat, is easy to handle.

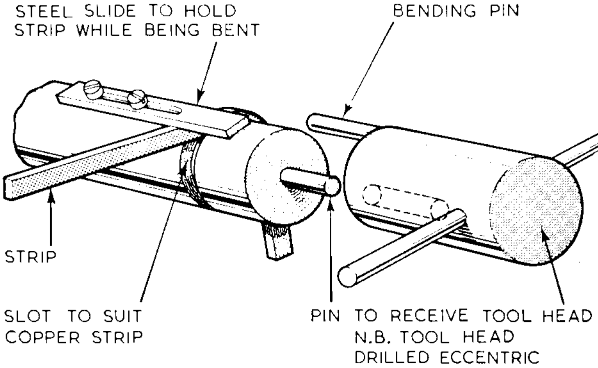


68. A square conductor always tends to wind on edge.

precise sectional area of copper utilizing standard gauges of wire; and secondly, two conductors in parallel are much more flexible in use than equivalent single conductors. On the other hand, the use of two wires adds to the difficulty of layering a coil, particularly a very narrow one (see Fig. 65). It will be noticed that the angle ϕ becomes appreciable when two large round, or rectangular, wires are laid side by side, and that they will leave a cavity at the end of each layer into which either one or both conductors of the first turn on the next layer will fall, thus giving very uneven layering. This



69. Muff jig to guide rectangular strips or rounds in parallel and to give tension.



70. Hand tool for strip bending.

fault can be mitigated by inserting interleaving paper, of suitable thickness, between each layer which in some coils is not permissible because of the increase in the overall size of the completed coil.

Conversely, the cavity left does sometimes enable a slight saving in total winding space used, albeit with a rather irregular layering.

Winding with Strip and Rectangular Conductors

The use of strip conductors gives a much neater coil, but to produce a good result will require an additional point of technique; the addition of extra insulation where the end of one layer rises to start the next (Fig. 66). Where thick interleaving paper is used, the separately-inserted pieces can be dispensed with.

Rectangular conductors, especially with a section as shown in Fig. 67, wound on the *flat*, are very easy to handle, but as the conductor approaches the square section so the winding difficulty increases. Curiously enough, a square conductor (seldom used) always tends to wind on edge (Fig. 68). To obviate this the conductor is passed through a straightening muff which also applies tension to the wire at the same time.

This jig is made almost entirely from fibre or Bakelite sheet and, if carefully designed, will serve for a variety of jobs, not only for the type of coil winding being dealt with here, but also for winding special coils for armatures, a much more difficult problem (see Fig. 69).

A hand tool for bending strip conductors on edge is shown in Fig. 70.

8

Armature Winding

Before dealing with the methods of winding armatures there are several general points which are worthy of note.

First, it does not matter how an armature is wound as long as it satisfies certain basic requirements. That is to say, the correct number of turns must be used and the correct gauge of wire provided. Secondly, the wind should be neat, regular as far as the disposition of the coils are concerned, and comply with the restrictions due to available space. Thirdly, the winding must withstand the centrifugal force due to the rotation of the armature and the insulation used must be suitable for the voltage and heat rise of the machine. Finally, the leads must emerge from the armature coils as near as possible to the commutator bars to which they must be connected. In addition, there is the very obvious proviso that the method of winding chosen should be as simple and as economical as possible.

The reason for mentioning the above points will be much more apparent when it is realized that it is quite possible to wind a single armature in at least twelve entirely different ways. Of these, only one or two will be described here; the others belong to rare and very special items of equipment.

Also the reader may be surprised to find that this section should include such a diversity of armatures, not only of type, but of apparently entirely different electrical characteristics. There are two excellent reasons for this. Firstly, as far as an armature *by itself* is concerned, it would be impossible to say in many instances whether it came from a d.c. or a.c. machine. Secondly, the several types of armature are grouped together because they are all subject to similar winding techniques, irrespective of their ultimate applications.

Winding Series, Repulsion, Repulsion-induction and Repulsion-start Induction-run Armatures

Armature winding is a vast subject and the complexities likely to be encountered in the range of machines included in the above categories are equally formidable. It is, therefore, somewhat difficult to choose representative types for inclusion in a book of this nature, especially when a particular method of winding, once considered to be unusual, suddenly becomes commonplace with the advent of a new piece of apparatus on the market. A general approach to the subject is therefore essential and the examples chosen will be those most likely to be met.

Lap and Wave Winds

First, the difference between a lap and a wave wind must be thoroughly understood. This point was explained in Chapter 4, where very small armatures were being dealt with.

In most cases, as far as the larger armatures are concerned, a wave wind can be recognized by a winder at a glance, but, to confuse the issue, there are some types of wave winds which can only be determined as such by very careful examination and by tracing the actual commutator connections. External examination of an armature can be misleading because it is quite possible to have two apparently identical armatures, with similar coils, one connected as a wave wind and the other as a lap wind.

This is in contradiction to many textbooks, with a strong bias to theory, where two types of coils are shown labelled respectively 'lap' and 'wave'. While this is perfectly true for coils of certain construction it is by no means true for all coils, and it must be repeated here that, in many machines, there may be no difference whatever between a lap and a wave coil, as far as the actual coil of wire is concerned. Indeed, it would be more accurate to call an armature lap- or wave-connected. These remarks apply most especially to the method of winding described in Chapter 7.

To assist the reader in determining whether an armature is lap- or wave-connected the following list is a summary of normal machines:

1. Most large armatures are wave wound.
2. Welding generator armatures are usually lap wound.
3. Almost all small armatures, e.g. drills, grinders, vacuum cleaners, etc., are lap wound.
4. Single-turn strip-wound armatures are almost always wave wound.
5. Small d.c. generator armatures can be lap or wave wound.
6. Armatures (or rotors) from the repulsion and repulsion-induction group of motors are also lap or wave wound.
7. A machine with two brushes at 90° has a wave-wound armature.

8. A machine with two brushes at 180° is lap wound.
9. A machine with four brushes at 90° can be either lap or wave connected.
10. A lap-wound armature *usually* has a commutator with an even number of bars.
11. A wave-wound armature *usually* has an odd number of bars.

In theory a lap wind must have an even number of bars and the wave wind an odd number; but many examples can be found where commutators are fitted with an incorrect number of bars. Various expedients are used to get rid of the extra bar in each case.

The Former Wind

The winding of very small armatures, such as those fitted to drills and vacuum cleaners, has already been described and, while the general principle remains the same, the methods adopted in winding the larger types of armatures are entirely different. It has been shown that, in the small armatures, the wire or wires were wound directly into the slots, turn by turn, whereas in the larger machines the wire is not directly applied, but is first wound on a former to produce coils of the correct shape which are subsequently laid in position in the armature.

The 'former wind' is a generic term and merely indicates that the armature conductors are preformed and prefabricated in one of several ways to suit a particular armature.

We shall therefore subdivide the general heading into:

1. The mush- or random-wound coil, of comparatively fine wire, usually taped all over.
2. The precision-wound and layered coil, usually with larger conductors, and normally wound firstly as a shuttle coil which is then pulled to the required shape.
3. The former wound coil using large strip or rectangular conductors, either bare or taped.

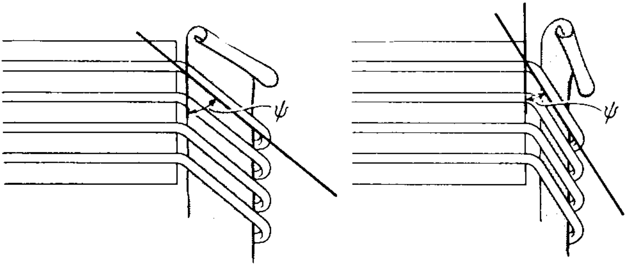
Each method listed above demands its own technique and the order also indicates increasing difficulty of manufacture. The last type, in particular, requires quite complicated jigs.

The Random-wound Former Coil

This is undoubtedly the easiest of all former winds and, apart from the considerable amount of work involved, seldom presents any difficulties beyond two conditions which will be dealt with later.

We will assume, therefore, that all the necessary connecting and winding data for a particular armature has been carefully recorded and that at least two of the original coils have been saved. Like field coils, these armature coils will probably be impregnated with varnish and somewhat distorted after removal. The first step is to roast the coil; this will automatically remove, by carbonization, all varnish and tape and leave a mass of extremely soft copper wire. Carefully restore the coil to its original shape and, by following the procedure laid down for the treatment of field coils in Chapter 7, ascertain the original shape. The wood former can now be made.

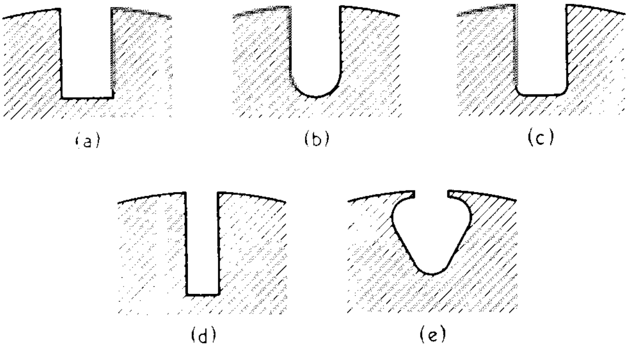
A sample coil is now wound using, whenever possible, two or more different coloured conductors so that each circuit can be recognized when the coil is connected to the commutator. It should be remembered that, although the former wound coil illustrated in Chapter 3 is called a 'coil', in fact it may consist of two or more separate coils of wire, but because it is a self-contained unit it is still referred to as a 'coil'.



71. Showing the effect of a short coil leading to coil crowding.

If this sample coil is deemed to be a reasonably accurate copy of the original, the whole set can be wound with, possibly, one extra coil in case of accident and for filing purposes as a sample for a future job.

If, however, the first coil was not suitable, the former will have to be altered. If this is found to be too big it can easily be cut down, but it will be a drawback if the size must be increased. For this reason, it is prudent to make the first trial coil slightly larger than required, not only to obviate the difficulty just mentioned but because the larger the coil the easier it is to insert in the armature. Fig. 71 illustrates this point and shows how the length of the coil alters the angle ψ and governs the space available for the coil end. Generally speaking, the operation of former making for a four-pole armature is quite simple, but where an armature has to be wound for a two-pole machine, this will be more difficult.



72. Showing the various shapes of armature slots.

In particular, difficulty will arise where the end space is very restricted because of first, the proximity of the commutator to the stampings, and secondly, the obstruction due to a fan or flange at the opposite end of the armature. An armature for a four-pole machine has a short pitch coil, i.e. the coil will only span, roughly, one quarter of the periphery. The sample coil can be laid in its correct slots and the space left for the underlying coils easily assessed, but this is not the case for a two-pole machine. Here the coil must reach almost half-way round the armature and the insertion of a single sample coil will not provide the necessary information for very restricted conditions. Two, or perhaps three, sample coils may be required before the winder can be certain that the size and shape are correct.

Coil Taping

The next step is to tape the coils, usually with 15 or 20 mm superfine cotton tape. High temperature armatures using glass-covered conductors will obviously require a glass tape, a very common treatment today, particularly for traction motors.

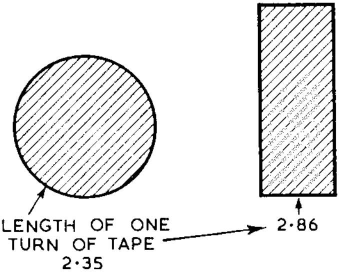
Coil taping is not easy and considerable experience is necessary to obtain a neat coil rapidly and easily. A small coil will be taped with length of tape little over 1 metre, otherwise trouble is met in drawing the end through the coil after each turn. A large coil is much more easily taped, and indeed very much quicker, by taping 'off the reel', thus avoiding the long length of hanging tape and the necessity for joints in the taping.

As the taping proceeds two points must be remembered. First, the coil leads must emerge at the correct place and in order; secondly, the tension used in taping must be determined by the type of slot in the armature being wound. Most armature slots are similar to that illustrated in Fig. 72 and a coil for such a slot can be taped reasonably tightly. With a deep narrow slot, such as (*d*), the taping on the coil slides must be loose enough to permit the coil to be flattened. If the coil were tightly taped it would form a circular section and be impossible to flatten. It may not be realised that the length of tape around a rectangular coil is considerably longer than that around a circular coil of equivalent sectional area. This is demonstrated in Fig. 73.

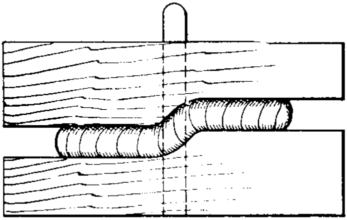
Inserting the Coils in the Armature

The coils can now be inserted in the armature, which must have been previously cleaned and insulated. Very soft and flexible coils, wound with fine conductors, can be laid in without any other preparation, but stiffer coils will rest much better if the knuckles are set in a simple jig (see Fig. 74). Insertion of the coils follows exactly the method described in Chapter 3 for basket winding of stators, with the obvious exception that, in the stator wind, the coils are placed inside the stampings.

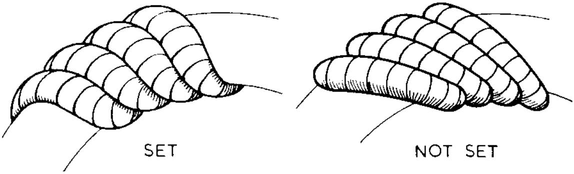
Assuming an armature with 21 slots and a coil throw of 6, the first coil is laid in slots 1 and 6, the next coil in 2 and 7, and so on until the coil is reached. Before this coil is inserted, the first 6 coil (the 'throw coils') must be lifted out of slots 1, 2, 3, 4 and 5 to permit the last coils to be laid in position. The final step is to relay the coil sides in slots 1 to 5. Fig. 103



73. The length of tape wound round a coil of rectangular section is considerably larger than that around a circular coil of equivalent section area as shown here.



74. A simple jig which can be used for inserting the coils in the armature.



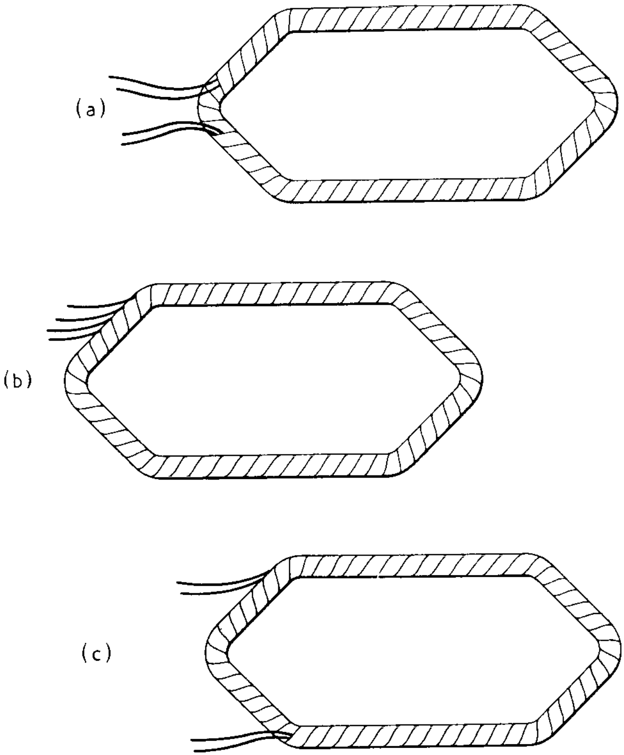
will help to explain the procedure. It probably sounds complicated and a first attempt may seem confusing to the operator, but it is really quite simple.

If the armature being wound has the normal type of open slot and if the coils are not a tight fit they may persist in popping out as further coils are inserted; by this it can be inferred that the slot insulation should be thick enough to hold the coils in position. In any case, they can all be drifted down again when the winding is complete.

Commutator Connections

For this example it is assumed that comparatively fine wire was used in the former coils. The size of the conductor governs the method used to take the tails down to the commutator bars and the smaller the wire, within limits, the easier the job.

A lap wind, as has already been pointed out, uses a coil similar to that shown in Fig. 75 and, once the coils have been inserted, the leads should be more or less opposite the commutator bars to which they must be connected. The first operation is to dress the coil ends flat, using a mallet and drift and the cavity between the end of the coil knuckles and the back of the commutator filled either with a few turns of tape or, if the cavity is large, with strips of thick Presspahn

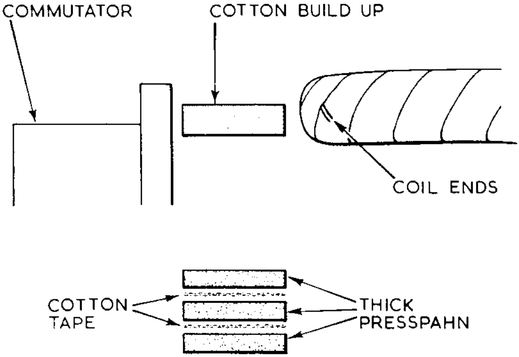


75. Three methods of commutator connections.

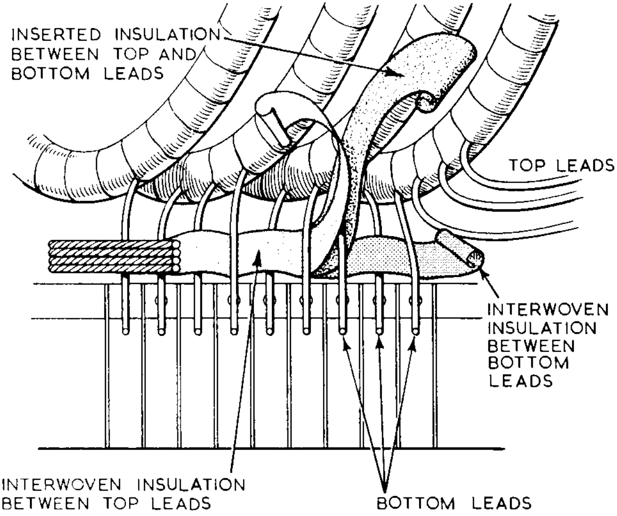
inserted under the tape as it is wound on (see Fig. 76). A few turns of tape are laid over the coil ends as a temporary lashing to keep them in order until the steel binding is added.

The actual connection is quite straightforward. The bottom leads are laid down first with a strip of cotton tape threaded over and under each successive wire. Cover these bottom leads with a few turns of tape and complete the top leads. It is usual to add string binding on the leads, just behind the commutator (see Fig. 77).

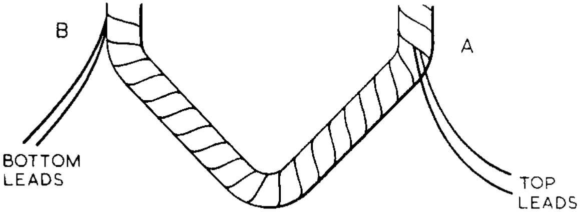
A wave-wound armature requires a different technique. Consider the coil illustrated in Fig. 78. The top leads *A* will give no trouble because they can be taken down, as a final



76. **Building up behind the commutator.**

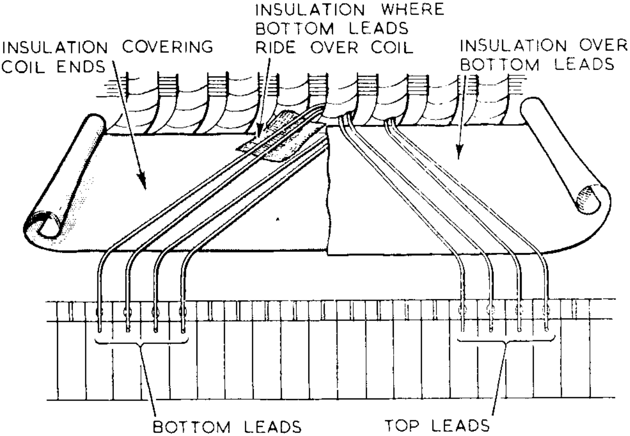


77. **Two layer connection of lap-wound armature with three coils per slot.**

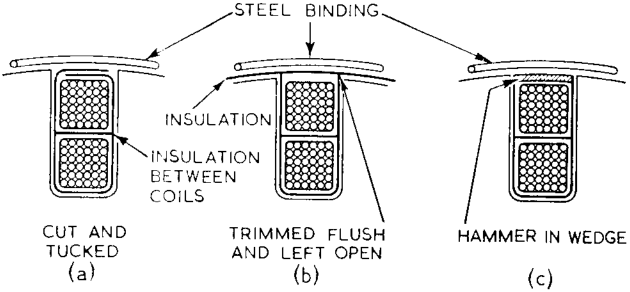


78. **Showing lead outlets from wave-connected coil.**

step, on top of all the coil ends, but the bottom ends at *B* emerge from a coil side which will be below the side of another superimposed coil in contradistinction to the position at A where, in this example, the coil side is in the top of the slot and not covered by any other coil. When the coils are wound with small wire it is usual to pull these bottom leads up the cavity between two adjacent coils and then take them down to the commutator for the first layer of connections (see Fig. 79).



79. **Two-layer connection for wave wind.**



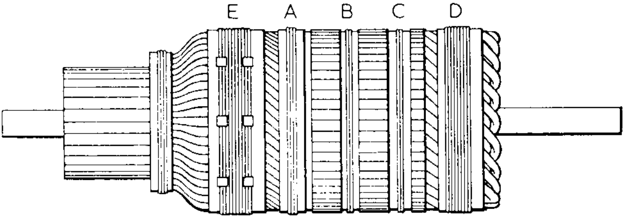
80. Three methods of closing slots.

(*a*) slot linings cut and tucked over the coils.
(*b*) slot left open and subsequently covered with a strip of insulator.
(*c*) slot closed with a hammered-in wedge and the papers cut flush.

There are other methods of connecting adopted by various makers. The subject can be quite complicated and experience can only be gained by observing and recording the different methods as they are met.

Securing the Windings

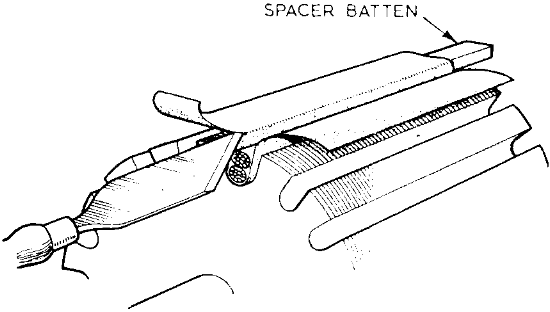
It has been explained that the normal slot for the armature under discussion is an open one and some means must be used to keep the coils in position and prevent them slinging out by centrifugal force which, in high-speed armatures, may be very great. The usual practice is to bind the armature in several places with tinned-steel wire which is afterwards soldered all over to form what is virtually a continuous steel band.



81. Binding the commutator. A, B, C, and D are bound but E is left until the connection has been made.

This time-honoured method is beginning to give way to an entirely new technique using glass-fibre tape, specially impregnated, which shrinks and 'solidifies' after the armature is baked. Nevertheless, steel wire is still used extensively and will be the method adopted here.

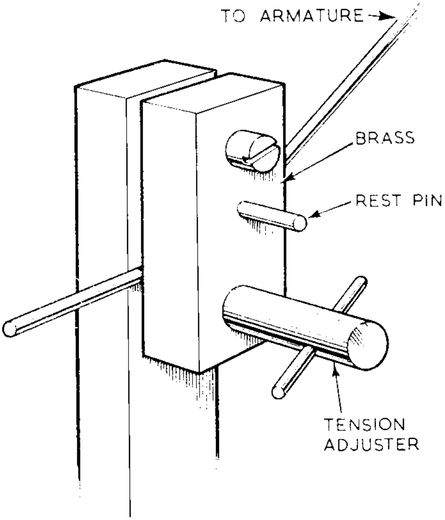
So far we have an armature with all the coils inserted, but the slot linings still await preparation prior to binding. There are three common treatments, shown in Fig. 80: (*a*) with the slot linings cut and tucked over the coils; (*b*) the slot left open, but subsequently covered with a strip of insulation as the binding is applied; and (*c*) the slot closed with a hammered-in wedge and the papers cut flush. In the last method the wedges can either be the full length of the slot or separate pieces of wood, fibre, Bakelite or glass-fabric sheet, inserted under each banding position.



82. Trimming the paper to the correct height.

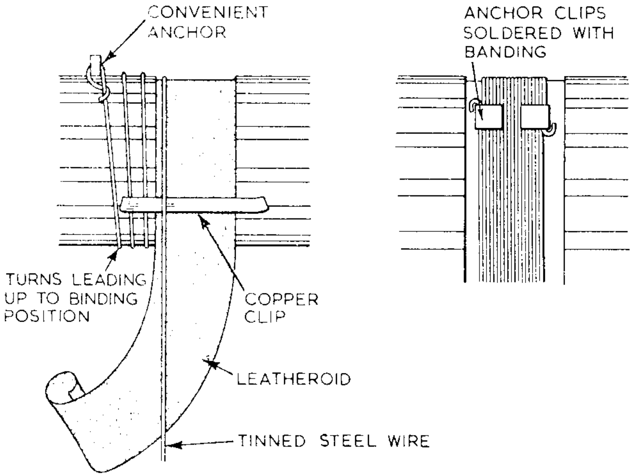
These banding positions on the stamping are shown at *A*, *B* and *C* in Fig. 81 and a slight recess is usually provided on the armature stack for this purpose. Occasionally these recesses are omitted and the steel binding is added to the outside of the armature. Although this last method certainly increases the overall diameter, there is usually plenty of room in the air space below the pole faces to allow for the binding, remembering, of course, that we are considering d.c. machines here and not a.c. machines where the air gap is often very small.

Cutting the papers flush for methods (*b*) and (*c*) (Fig. 80) is easily done using a special knife. This is somewhat like a bread knife with an acutely-ground cutting edge and is illustrated in Fig. 82. When the slot is 'cut and tucked', the insulation must be sheared off at a predetermined height



83. *(left)* **Simple tension device for steel binding wire**

84. *(below)* **Steel binding. The tags are turned over the binding and each one soldered.**



leaving sufficient paper to fold over the coils. Fig. 82 shows how this can be done, using the skew knife and a wood, or steel, batten as a cutting jig to obtain the correct height of paper.

If the 'cut and tuck' method is used, each fold of paper will have to be drifted down with a wood or Bakelite drift and mallet. Where method (*c*) is adopted the papers are cut flush after the wedge has been driven in.

The armature can now be bound at A, B, C and D, but the commutator end at E must be left, obviously, until the connection has been made.

Steel Banding

This is a comparatively simple process for small armatures (up to, say, 15 kW), but a few simple tools are essential. Naturally, a certain amount of practice is necessary before a neat binding can be applied.

In the first place, the armature must be slowly rotated with sufficient power to withstand a very heavy pull from the steel wire which may amount to well over 50 kg. The tension used will depend on the diameter of the armature, the gauge of steel used and the type of winding being bound. The steel wire is tinned to facilitate soldering, and is slightly softer than piano wire, but still troublesome to handle if a spool snarls up. The gauges used will vary from 0.45 mm to 1.25 mm; the latter being quite suitable for comparatively large armatures.

Having determined the gauge required, which by inference will be that originally used on the armature, the spool of wire is set up and the wire passed through a simple tension device illustrated in Fig. 83. The armature itself can be rotated in a lathe or driven by the winding head described in Fig. 68. Anchor the end of the wire to any convenient point, a wood wedge passed between two coils will serve excellently and with a little tension applied lay on a quick spiral gradually leading up to the binding place required. When the wire is running parallel and adjacent to the first position, lay on one or two more turns and then add the insulation necessary to insulate the coils from the binding. This insulation can be a continuous strip of leatheroid, mica-folium, glass fabric or a combination of any of these. It is usually preferable to add the insulation in overlapping short strips; this will overcome any lack of parallelity in the winding and give a neat strip of insulation. When the armature has slowly rotated one turn, all the insulation will have been inserted. Tension must now be increased to the maximum and very gradually slackened a trifle as subsequent turns are made. After one or two turns have been added, the copper solder tags are laid under the steel wire, at least four of them spaced at 90°. Banding continues until the correct width has been applied and, *without releasing the tension*, the tags are turned over the binding and each one soldered. Then, and only then, can the wire be bent back and cut (see Fig. 84). In practice, however, the wire is not usually cut at the end of each band but is carried on to the next place on the armature.

Assume that bands A, B and C have been wound, the wire is changed for a heavier gauge and the banding at D begun. This position may give trouble for two reasons: first, the winding may be spongy and a preliminary compressing banding necessary to consolidate the winding; secondly, the coils at the drive wind of an armature are frequently hollow and the cavity at the surface must be levelled before binding commences. Levelling is effected by layers of cotton tape and/or strips of thick paper mica or similar material, leaving the building up slightly proud to allow for compression.

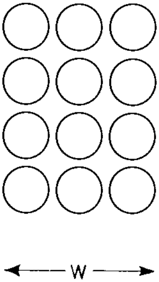
Banding proceeds in the same way as before. If, however, the hollow has not been built up sufficiently or the winding has not been sufficiently compressed, a loose, uneven layer will result and the banding will have to be done again.

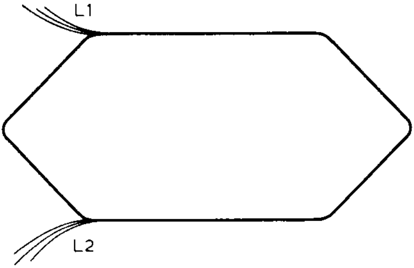
The commutator end banding can now be tackled, assuming that the leads have all been connected to the bars. A considerable amount of drifting with a mallet will probably be necessary and any hollows or inequalities built up with insulation, using tape or thick strip pressboard as required. The prepared surface should be flat and parallel to the axis of the armature. Sloping binding should be avoided at all costs because the banding is liable to step off, even after varnishing and baking. A considerable degree of shrinkage occurs in all winding as a result of baking, and this is particularly the case with a deep wind of fine conductors. Indeed, the shrinkage may be so great as to require a fresh banding when the armature has been finally baked.

Strip windings do not suffer from such an excessive shrinkage.

The Layered Former-wound Coil

The previous section dealt with armature coils where the wire was wound on the former at random. 'Random-wound' does not imply that the coil was wound anyhow, but it does suggest that the wire was not precision layered. Indeed, it would be extremely difficult, if not impossible, to wind a





85. *(left)* **The former-wound coil. The illustration shows a section of a coil in an armature slot. The width** ***W*** **must be accurately measured in order to make the former correctly.**

86. *(right)* **The completed coil.**

coil, accurately layered, using fine conductors, i.e. wire up to approximately 1 mm. Conductors larger than this are wound very precisely, in layers, so that each conductor will occupy the same relative position in each coil. Moreover, the coil is not wound directly on to a lozenge-shape former, but is first wound as a 'shuttle' coil, which is subsequently pulled to the required shape.

Making the Former

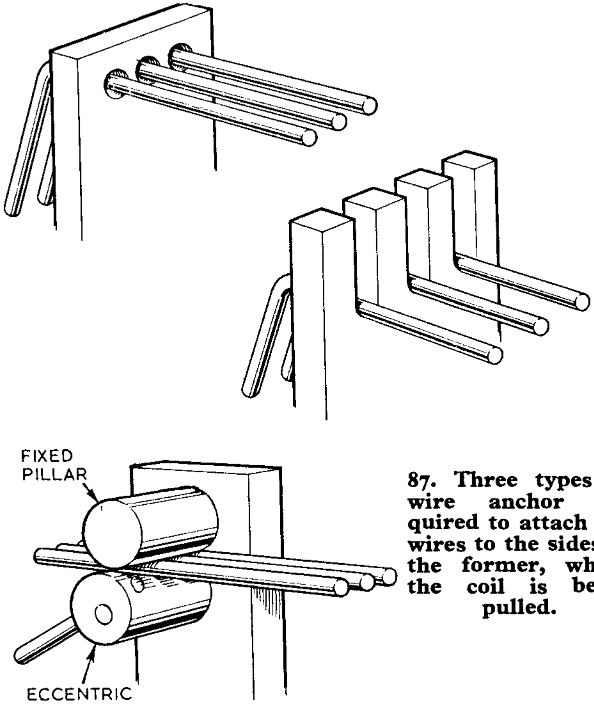
The steps necessary to obtain the correct former size have already been explained in Chapter 7, 'Field-coil Winding', and it is not proposed to repeat them here. It must be emphasized, however, that the assessment of an armature is much more difficult than measuring a rectangular field coil because, not only must the lozenge shape be recorded, but it must be carefully 'unpulled', as it were, to discover the dimensions of the shuttle former on which the coil will be initially wound.

Assuming, for the sake of example, we have a coil with 12 turns of 2 mm D.C.C. wire (this is a case where D.C.C. wire still holds sway) with three circuits, i.e. each circuit will have four turns, and assume also a very common arrangement illustrated in Fig. 85 representing the section of a coil in an armature slot. The width *W* must be measured quite accurately using three (new) conductors side by side in the jaws of a micrometer or slide gauge. They should be a good fit in the jaws to simulate the close fit necessary in the intended former.

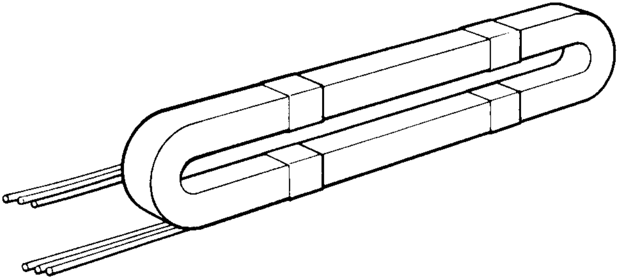
The measurement obtained determines the thickness of the former which can now be made, preferably from Bakelite sheet. If this is not stocked in the required thickness it can easily be reduced by passing the former by the circular saw. The complete former with its cheeks will be similar to that illustrated in Fig. 49 (f). Care must be observed in fixing, or rather cutting, the lead in slot *L*1, remembering that the shuttle coil will have to be pulled to shape and that the lead outlet must not foul the jaws of the pulling machine.

In this particular example we are describing a wave-connected armature, by far the commonest wind for this kind of former wind. Because it is a wave wind the conductors must emerge from the coil at *L*1, *L*2 (Fig. 86).

With the completed former bolted to the faceplate of a



87. Three types of wire anchor required to attach the wires to the sides of the former, whilst the coil is being pulled.



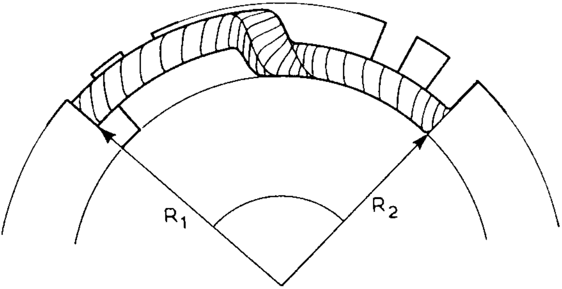
88. **General appearance of shuttle coil ready for pulling.**

winding machine similar to that shown in Fig. 103 winding can commence, but as we shall be winding with three wires 'in hand', i.e. one for each circuit, a very heavy pull will result and some means must be used to anchor the end of the wires to the former sides. All kinds of devices can be made up to do this and three are shown in Fig. 87. Of these the eccentric is by far the best; it is quick to clamp and equally quick to release. A chuck of this sort is usually built as a separate item and attached to a former as required.

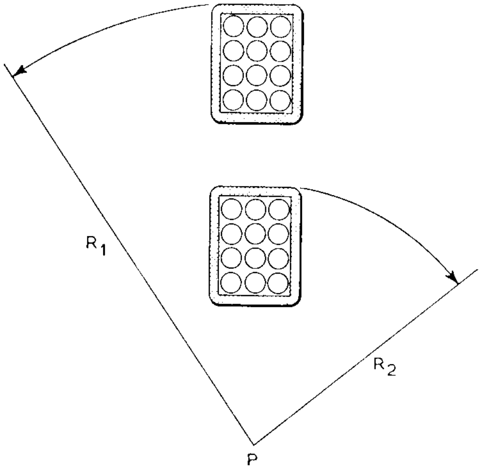
Tension is applied by passing the three conductors through the muff shown in Fig. 69.

Winding the Coil

As each turn (of three conductors) is laid on it will require dressing with a drift and mallet to make sure that the wires lay flat on the former. We have here a repetition of the



89. **Tension applied by passing the three conductors through the muff as shown.**



90. Section of the coil in puller jaws.

problem encountered in field-coil winding where, notwithstanding the tension applied, a gap is invariably left between the first turn and the long side of the former.

When all the turns are laid on and the mass of wires secured by pressure-sensitive tapes in the slots provided, the coil can be removed and it should appear as shown in Fig. 89.

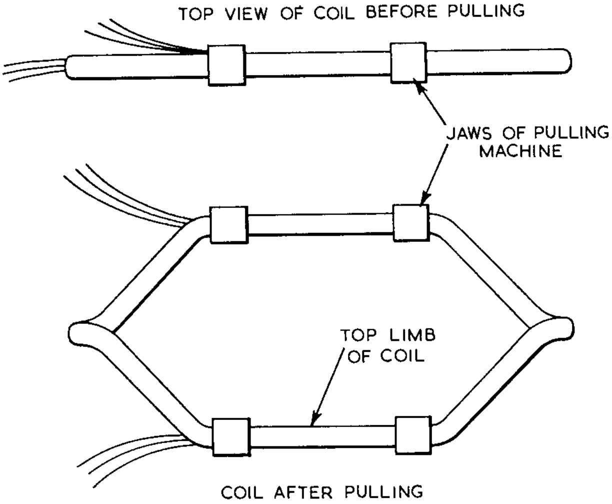
Pulling to Shape

Having made the shuttle coil, it must now be pulled open until it assumes the lozenge shape shown in Fig. 49(*e*). This cannot be done by hand and some kind of machine is essential. The design of such a machine depends entirely on the range of work undertaken. If, for example, large numbers of precisely similar armatures are to be wound, it would be an economical proposition to make a machine for one particular size of coil. If, however, a wide range of armatures is expected the machine must be sufficiently adjustable to accommodate the varying sizes of coils and the machine will be much more complicated.

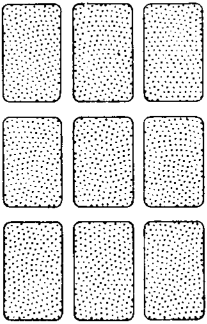
To explain the duty of the pulling machine in greater detail it is necessary to understand the position and shape of a coil when it is in position on the armature. Fig. 89 shows the end view of a single coil and it will be seen that the coil sides must conform to the angle and that the radius of the bottom limb will be R1 and that of the top limb R2. In small armatures this angle is very important and becomes more so as the size of the conductor increases and the coil becomes more intractable. Its importance decreases a little as the armature diameter increases. Apart from the angle between the coil sides, the coil as a whole will have to conform to the curve of the armature surface.

Bearing these two points in mind, we can now envisage the necessary pulling operation. Fig. 90 illustrates a section of a shuttle coil with the top and bottom limbs held in clamps which are moved in the direction indicated to form a lozenge-shaped coil.

It will be appreciated that these clamps must be pivoted about the point *P*, or approximately so, to obtain *R*1 and *R*2 (Fig. 90). A plan view of the coil in Fig. 91 again shows the clamps. This drawing will emphasize the necessity of taking the conductors into the coil so that they will not foul the clamps; a point previously mentioned. Two pairs of clamps are used because they can easily be adjusted to fit coils of different lengths. One other point must still be dealt with: the curve of the coil to conform to the diameter of the armature. In most cases this is partly obtained by lifting the knuckle ends of the coil while it is still fixed in the puller



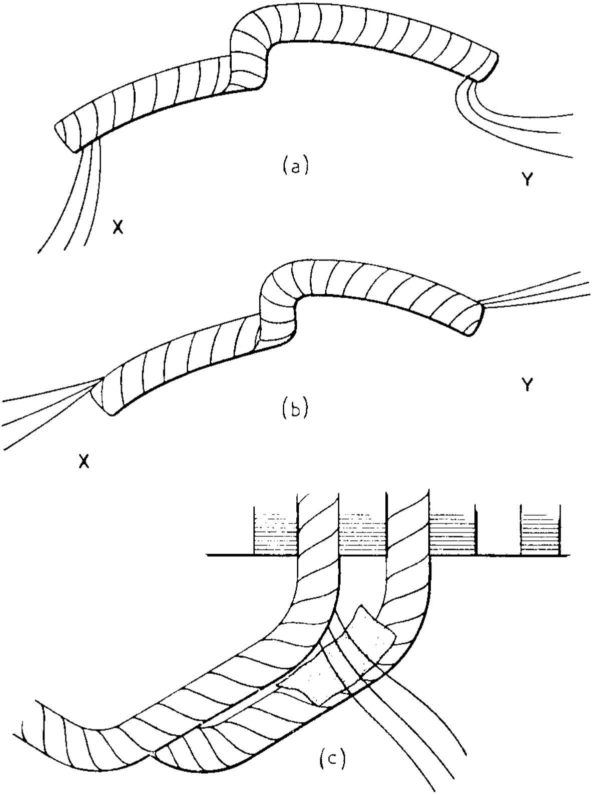
91. The coil after pulling, showing the clamps in position.



92. (*left*) **Position of conductors. Strip bent on edge.**

93. (*below*) **Winding using rectangular conductors.**

(*a*) and (*b*) show two methods of winding a normal coil with round wire. (*c*) illustrates the method using wire of rectangular section.



jaws and partly by dressing the coil as it is inserted in the armature slots. Extremely stiff coils are shaped in another jig, as will be explained in the later section.

An elaborate pulling machine which can be adjusted to fit almost any coil up to 600 mm long can be seen in the picture sequence at the end of the Chapter on page 115. In this machine the clamps are virtually small vices, each fully adjustable for different height and width of coils.

Taping the Coils

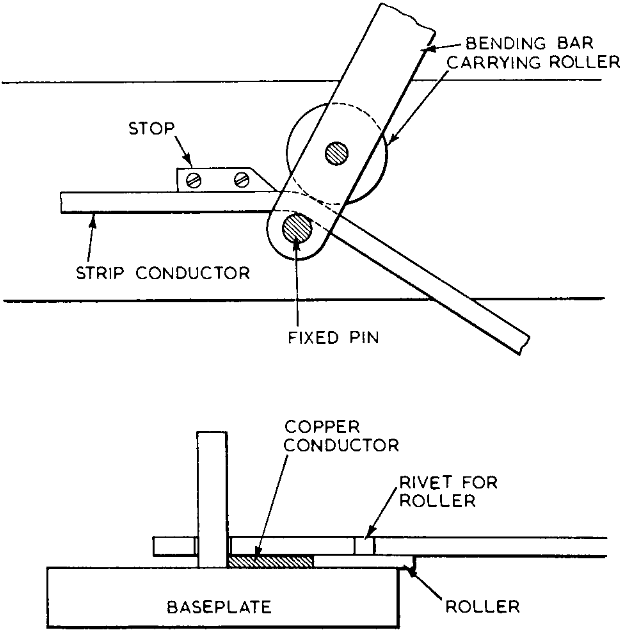
The coil, now pulled to shape, is offered on the armature and, if correct, is ready for taping. The tape, usually of superfine cotton, should not be too wide; a tape 20 mm wide wound with a half lap gives excellent results for most coils. Layer-wound coils of this type are taped fairly tightly; generally the larger the conductor the tighter the taping. Occasionally a coil is taped twice over, once with oiled linen or silk and finally with cotton.

The Layer-wound Pulled Coil using Rectangular Conductors

Coils wound with rectangular conductors follow precisely the same technique as described in the previous section. The shuttle coil is first made and pulled to shape in the normal manner, but there are two important points requiring special attention, which, if neglected, could easily lead to an armature failure.

The first point concerns the section of the conductor. If it is definitely rectangular it will be quite straightforward to wind but, if the section is nearly square, extra care will be needed in layering the shuttle coil and preventing the conductor from riding edge-up. This difficulty was discussed in Chapter 7 on coil winding and it is equally applicable here. Rectangular conductors are often wound on edge, this arrangement not only suiting the slot width, but also permitting a large wire to be connected to a narrow commutator bar. Fig. 92 shows a section of a coil wound in this manner.

The second and much more important point is the treatment necessary when rectangular conductors from the bottom coil side ride over the superimposed top coil *en route* to the commutator. This point is better explained visually by referring to Fig. 93. A normal coil, wound with round wire, will either be like (*a*) or (*b*). Method (*a*) is the one usually adopted, mainly because the bottom leads, *X*, can be taken straight down to the commutator, in a wave wind, as each coil is inserted. In this case the top lead will emerge from

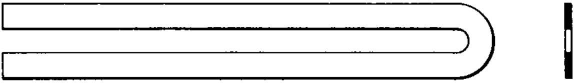


94. Strip bending jig.

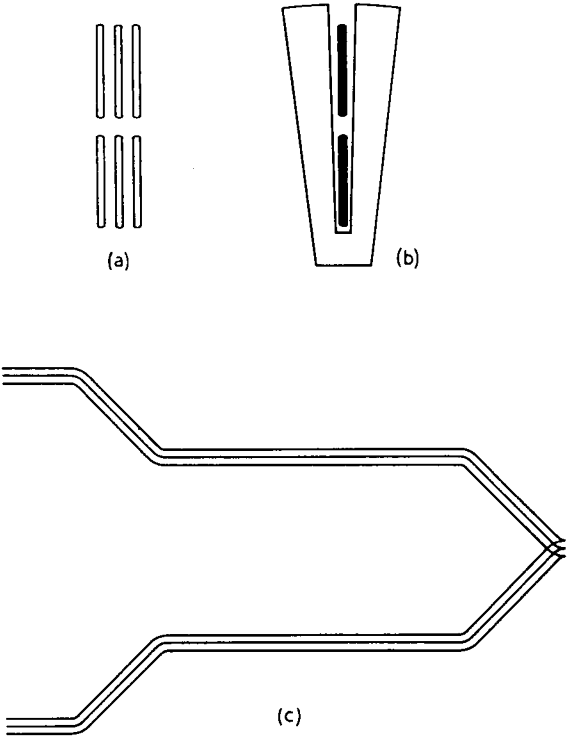
the bottom of the top limb *Y*. They are, nevertheless, still called top leads because they will ride over the coil ends and knuckles on the way to the commutator. Hence, these top leads must be diverted from the coil and brought up in the gap left between two adjacent coils where they emerge from the armature slots.

Such treatment is perfectly satisfactory with round wire and no other insulation is usually necessary beyond a small piece of added insulation at the crossover pressure point (see Fig. 79).

When rectangular conductors are brought out in this manner they *must* have cotton (or glass) tubes threaded on each lead to prevent the angular corners piercing its own D.C.C. covering and shorting to its neighbour. Rectangular leads running parallel and nesting evenly will stand any amount of pounding and pressure, but immediately they are diverted away from the coil they tend to twist and ride on edge.



95. The finished hairpin-shaped coil after bending.



96. (*a*) Common arrangement of strip conductors.
(*b*) Conductors in commutator bar.
(*c*) Plan of coil after pulling.

Bare Strip-wound Coils

Strip-wound coils employ a conductor very much wider than it is thick, such as a conductor of 1 mm × 7.5 mm. An armature wound with this material will have only one turn per coil and be wave connected. Typical examples can be found in traction motors on 76 V D.C., used in large numbers on electric milk vans and floats.

These pulled coils can be extremely difficult and possibly beyond the capabilities of a casual winder unless he is well versed in the technique and has adequate resources by way of a machine shop and tool-making experience. Because of this the short description which follows is mainly of a general nature and not a detailed process.

Bare copper strip is used and each single coil is taped after the completion of the forming process.

The first step is to make a hairpin-shaped coil with the strip bent on edge. This is done by rolling the strip in a jig (see Fig. 94) around a pin of suitable diameter. The pin itself also acts as a pivot on which the winding device rotates. Fig. 95 illustrates the finished hairpin. Three of these are stacked together and held in two places with adhesive tape prior to pulling to shape in the pulling machine already described.

We have now obtained a shaped coil of three conductors which will be similar in plan only to the illustration in Fig. 96. It still remains to form the coil in the other plane, i.e. to curve the coil to conform to the radius of the armature and also to set the coil ends so that they proximate the commutator bar to which they will have to be connected. This curving and setting operation requires a fairly elaborate hemispherical jig provided with slots to simulate the actual slots on the armature. One such jig is shown in Fig. 97.

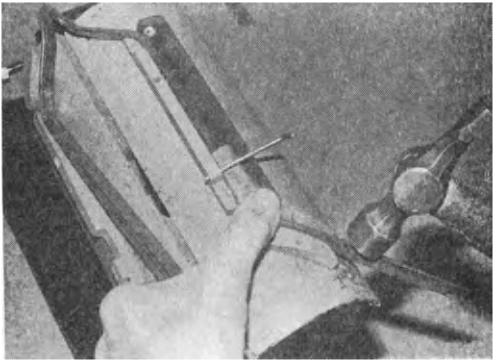
Now the coils are correctly formed, the stack of three conductors is dismantled and each coil separately taped. Regrouping in their original order completes the job.

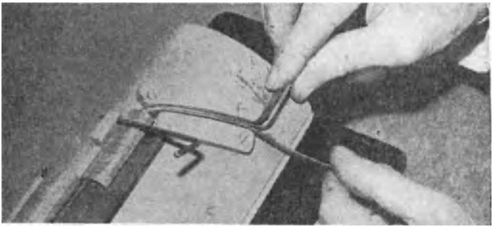
The Machine Wind

This is a method of winding which can be used on a wide variety of armatures, from a mere 75 mm to as much as 600 mm long. It is equally suitable for both lap and wave winds. To a certain extent it follows the procedure adopted in the two-in-hand wind, already described in Chapter 7, but there is one distinct difference. In a small drill armature, for example, the conductors used are, comparatively, quite fine and flexible. When these armatures are wound by hand, a twist develops in the two (or more) wires as each turn is laid on.

97. Using the barrel jig for the curving and setting operation.

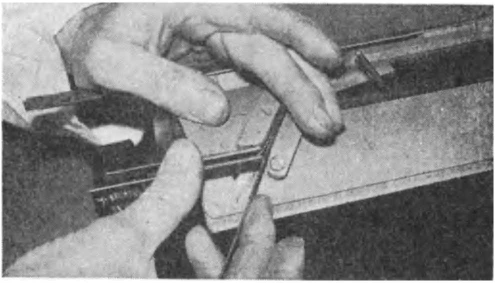
(i) **Forming the coil on the jig**

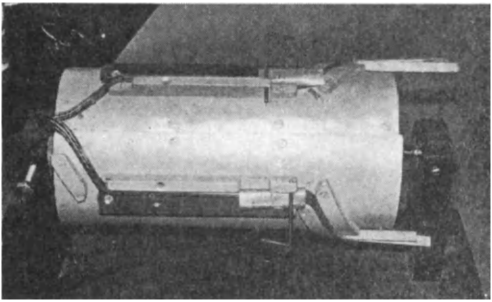




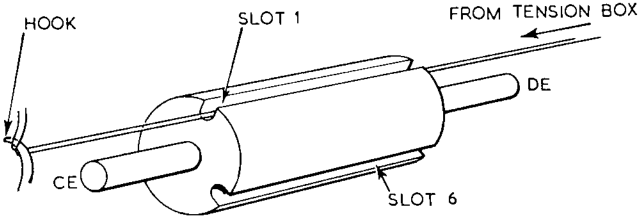
(ii) **Separating the coil ends**

(iii) **Bending the ends**

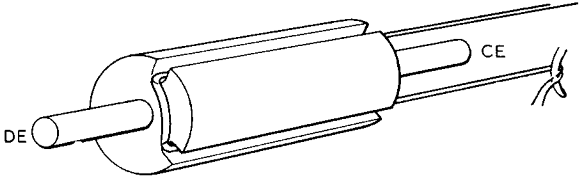




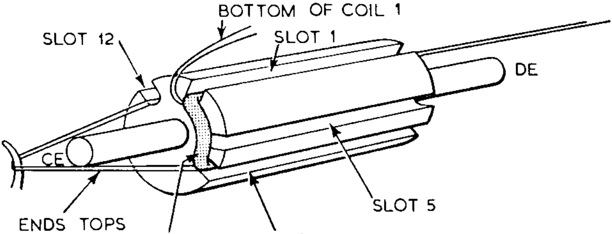
(iv) **The finished coil.**



98. The machine wind (1).
Beginning of the wind.



99. The machine wind (2).
One turn on.



100. The machine wind (3).
Completion of the first coil and the start of the next coil. Note that the insulation has been omitted from the drawings.

This twist is of no importance in these fine wires, but when the conductors become much larger the twist becomes a nuisance, so much so as to make it impossible to wind certain types of armatures, particularly where the space behind the commutator is very restricted. A twist in two or more conductors gives trouble for two reasons. In the first place, a twist occupies far more room than that occupied by the same conductors running parallel and, by reason of the disturbed parallelity, it becomes impossible to wind a neat compact coil.

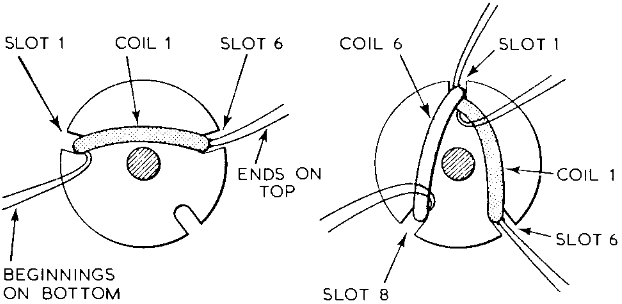
It is perhaps fatuous to add that while three wires of 0.355 mm (for a drill) can be handled with ease, three conductors of 1.6 mm are almost impossible to wind by hand. It should, therefore, be quite apparent that if the armature is rotated and the wires fed to it, all crossovers will be eliminated and further, if the armature is rotated by power, heavy conductors can be handled with ease. A suitable form of machine is therefore essential and a typical device has already been shown in Fig. 60. All this machine requires is the addition of a simple clamp to the faceplate so that the armature can be rotated axially. Attached to the faceplate is a hook, the purpose of which will become apparent later. The wire is fed to the armature either via a tension box or by a hand tension block.

Method of Winding

As an example we will assume an armature to be wound which has 12 slots, 24 C.B., 6Th and 6T of 1 mm.

Winding commences by attaching the end of the two conductors to the hook on the faceplate. The two wires are laid in slot 1 and passed back via slot 6 as the armature slowly rotates. Fig. 98 shows the initial stage and Fig. 99 the armature with one turn wound on.

The armature is again rotated and the second turn laid in the same slot. Winding proceeds until the six turns have been added. At this point the armature will again be horizontal and, although the drive end of the armature will have six turns of two-in-hand conductors, i.e. 12 wires in all, these will be only five turns at the commutator end. Slots 1 and 2 have now been wound, but before the next pair of slots is tackled the wires emerging from slot 6 are taken over the hook. At this point we are back to the initial stage illustrated in Fig. 100 and the wires are ready to be laid in the next pair of slots 12 and 5. Fig. 100 illustrates the position, and it will be seen that the wires originally anchored to the



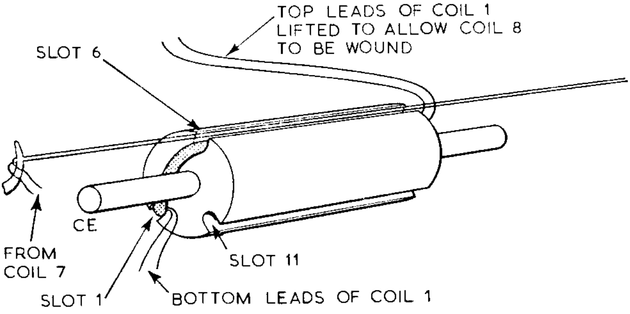
101. The machine wind (4). Showing position of bottom and top lead in coils.

hook have been removed and are now lying back over the stack.

The hook serves as an anchorage for the first turn against a heavy tension and, also, it is placed at such a distance as to allow sufficient length for the wire, when cut adrift close to the hook, to reach the commutator, not yet fitted. Further, the hook enables the wind to be carried out continuously without releasing the tension. The wires are not cut adrift until after the next successive coil has been wound.

Having completed the first coil, it is worthwhile to examine the coil end and note the positions occupied by the beginnings and ends of the coil. This is shown in Fig. 101.

The second coil is wound in slots 12 and 5 and winding proceeds thus until the sixth coil is reached, in slots 8 and 1. Fig. 102 shows this position, viewed from the commutator



102. Commencement of coil 8 showing throw leads.

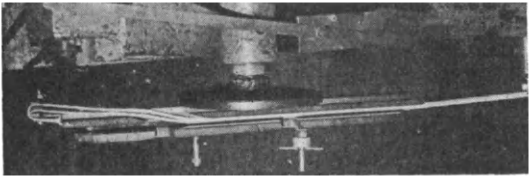
end. To make matters clearer only the coil No. 1 and No. 6 are drawn. It will be seen that coil No. 6 overlies coil No. 1 in slot 1 and before coil No. 6 is wound the bottom, i.e. beginning ends of coil 1 are thrown to the right for a lap wind and to the left for a wave wind. The two methods of throwing the leads are merely for future convenience, bringing the leads out at the most convenient place for the subsequent commutator connection (see Fig. 77).

The necessity for adhering to a strict order in the leads now becomes apparent. Slot 1 in Fig. 101 has four wires coming from it. By following the system described above we know that the pair on top of the slot belong to coil No. 6 and those from the bottom to coil No. 1.

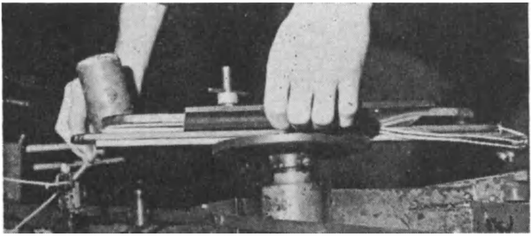
Winding proceeds until coil No. 8 is to be laid in slots 6 and 11. This is the first 'double-closing' coil, i.e. it will complete two slots which can ultimately be wedged. Before it is wound the top leads from coil No. 1 in slot No. 6 must be lifted out of the slot and laid out of the way while the eighth coil is being wound. The top leads are then relaid in the top of the slot, i.e. on top of the left side of coil No. 8. These lifted leads are called throw leads and the operation is illustrated in Fig. 101. If they were not thrown out of the way they would be buried beneath coil No. 8 in slot No. 6 and it would be difficult to discriminate between four wires coming out of this slot. By lifting and relaying them they retain their relative order.

The two picture sequences on the following pages show step-by-step procedures for winding two types of rotor. The first sequence, on page 112, depicts the winding of a rotor of a 25-kVA 3-phase alternator and the second sequence, commencing on page 124, shows winding a rotor of a repulsion-start single-phase motor. These useful sequences are included in this chapter as, although the previous text has related to winding armatures, the winding technique involved whether for armatures or rotors is similar.

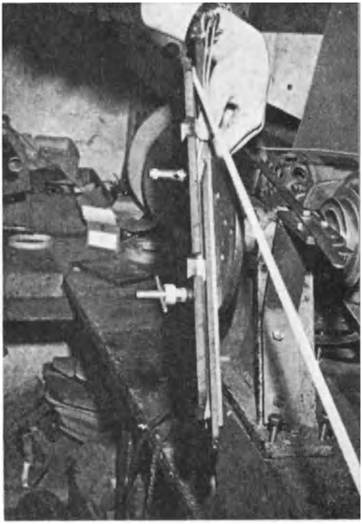
103. Winding the rotor of a 25 kVA 3-phase alternator. The technique of coil making in the following sequence of pictures is much more elaborate than usual and is merely one out of a large number of variations. The process includes all the basic steps of pulling and taping.



Coil winding (view from above). Beginning the coil. Former is assembled and bolted to face-plate. Each coil wound with two D.C.C. strips, 8 turns. In this example the two conductors do not form two separate circuits, the ends of the coil are connected in parallel. The two conductors are laid in the bottom of the former, diverted through the slot in the former cheek and anchored.

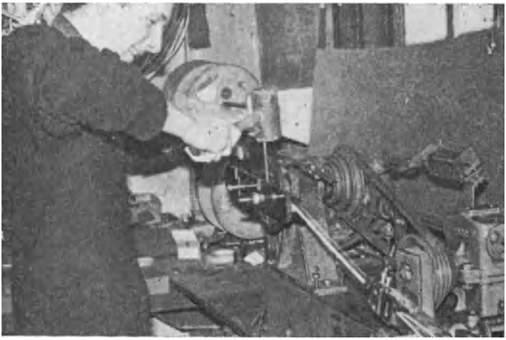


Face-plate now rotating slowly. Bottom leads being pressed into position with Bakelite drift.

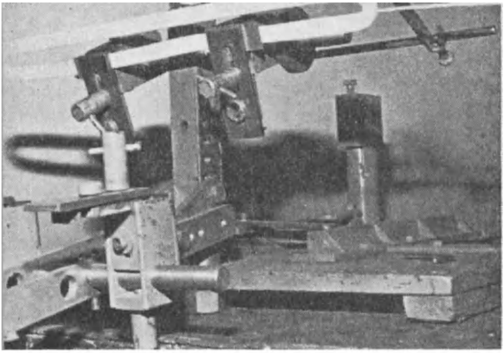


(left) **Another view of the coil winding. The winder is holding down the bottom ends (underneath the former) with a Bakelite drift. Face-plate has rotated approximately 180°.**

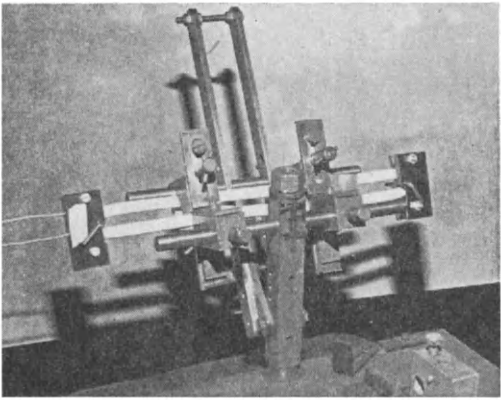
(right) **Face-plate rotated 360°. One turn on. Notice that the operator keeps outlet tails from bottom in position.**



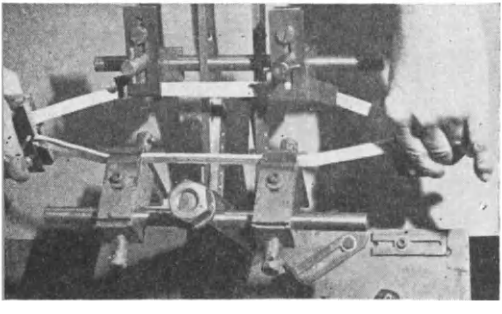
Drifting coil side flat.



Pulling the coils. The former-wound coils, wound in pairs, are separated and each coil is pulled separately. This shows the first step. The coil is clamped on one side. Note the end stop to ensure each coil is accurately positioned.

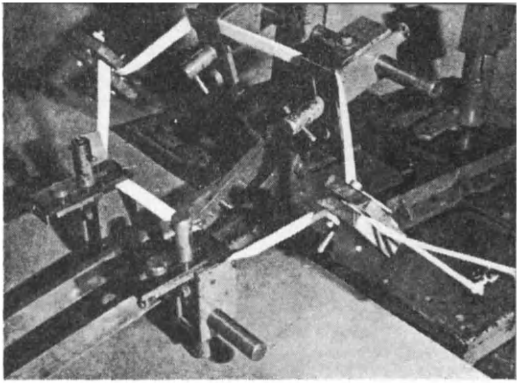


The other side of coil now gripped in jaws and position indicator removed. Knuckle holders, of Bakelite sheet, added to each coil end and retained in position by a cranked pin. Coil ready for pulling.

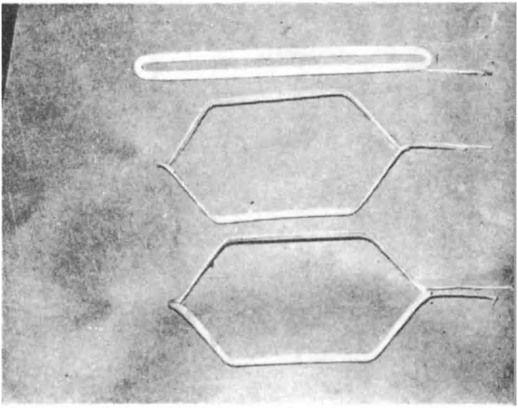


Coil being pulled. Knuckle clamps being held. (Note: if this was a production operation the knuckle clamps would be held automatically.) Note the pieces of paper in jaws to prevent damage to the conductors.

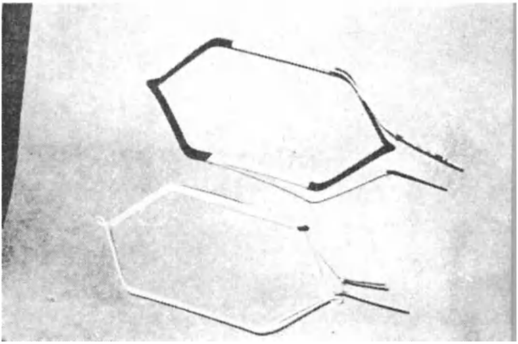
Coil fully pulled. This shows clearly the general construction of this particular pulling machine which can be adjusted to pull coils up to 600 mm long with a coil section from 1.5 mm rectangular section to 32 × 19 mm.

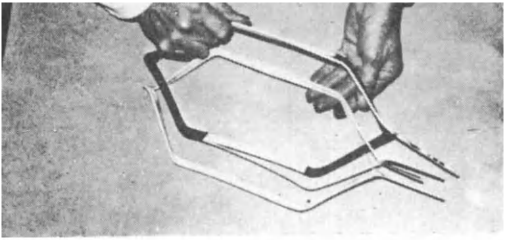


The original coil and the coils after pulling.

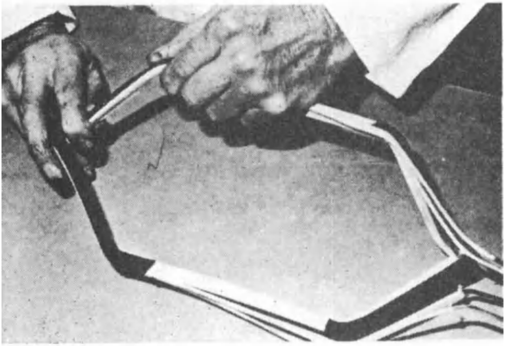


Having pulled the coils they are then paired but one coil has the knuckle ends taped. To make the photograph clear, black tape has been used. These coils are then laid side by side.

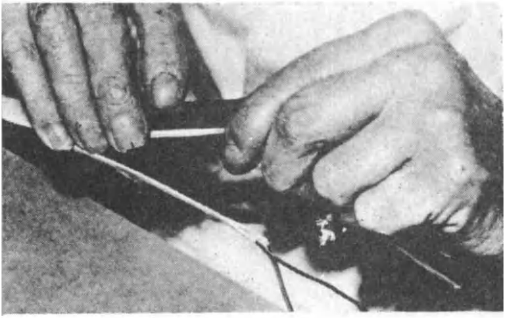




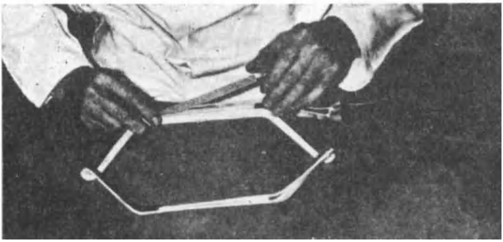
Threading the two coils together to make one coil.



Nesting the coils together before securing them with speedifix.

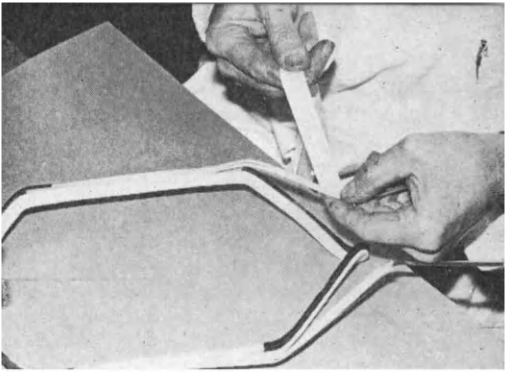


Securing the twin coil with adhesive tape.

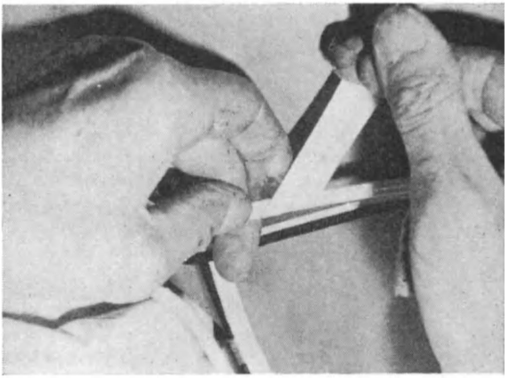


The coils have been nested and the winder is inserting a strip of 0.25 mm presspahn between the two coils.

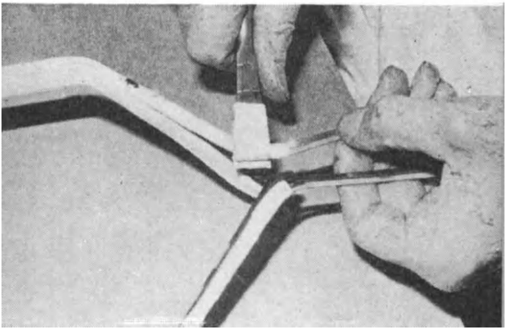
The two ends (one from each coil) are then taped together to form one conductor.

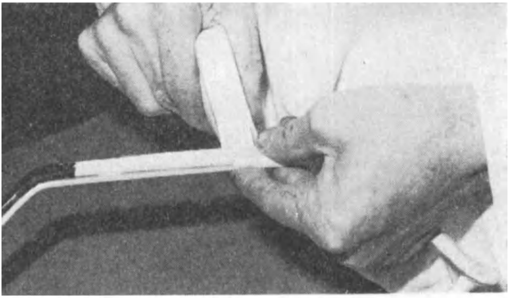


Another view showing the two outlet leads being taped together.

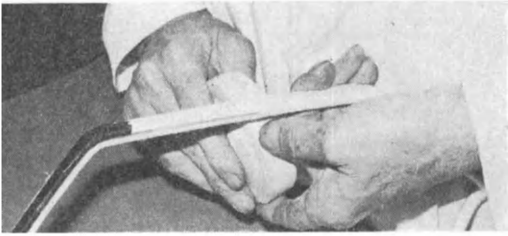


This shows the taped lead end being dressed with a pair of flat-nosed pliers. Note the jaws of the pliers are covered with a turn of adhesive cotton tape to avoid damaging the coil.

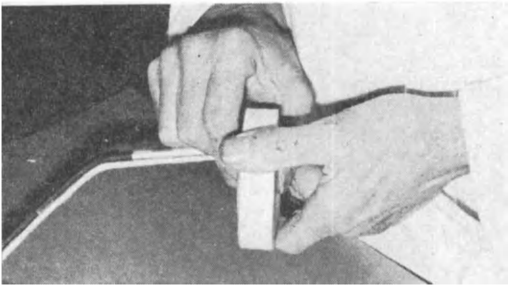




Taping the two coils together. This is "taping off the reel" and the next two illustrations show the technique adopted.



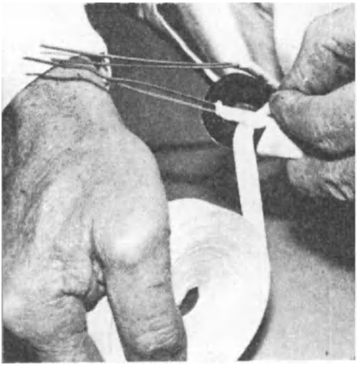
Coil taping.

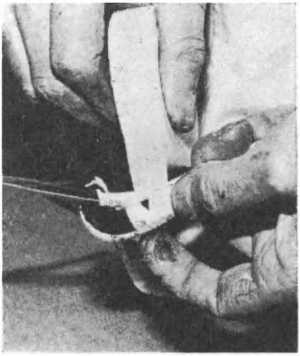


Showing how the reel of tape is passed over the coil.

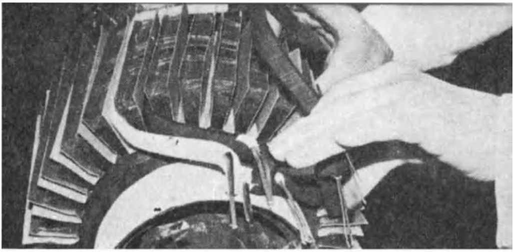
(*bottom left*) **Treatment of taping outlet leads. (1st step).**

(*bottom right*) **Treatment of lead outlets (2nd step).**

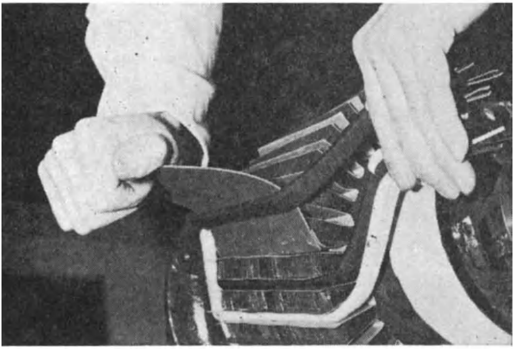




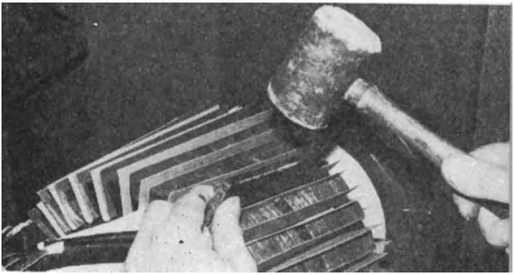
Winding the rotor of a 3-phase alternator. An early stage in winding. The first coil to be inserted has been specially taped with white cotton to identify it during the subsequent photographs. Inserting the bottom limb of the coil.

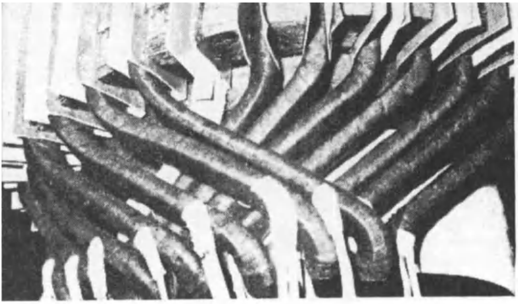


When the bottom limb has been inserted the top limb must be stretched slightly to reach the necessary slot. A 'shoe-horn' of red fibre is used for this process.

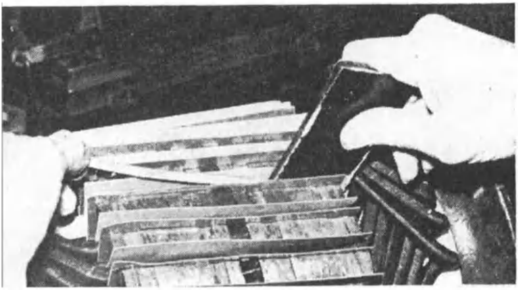


Bottom side of coil driven down to the bottom of the slot with a strip of Bakelite and a mallet. The top limb of the coil *is not* driven down because it has to be lifted out at a later stage.

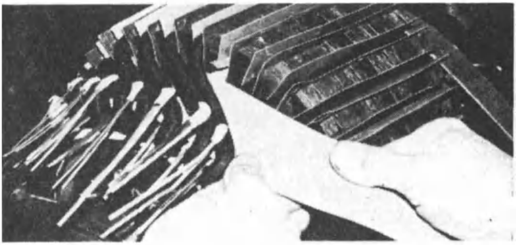




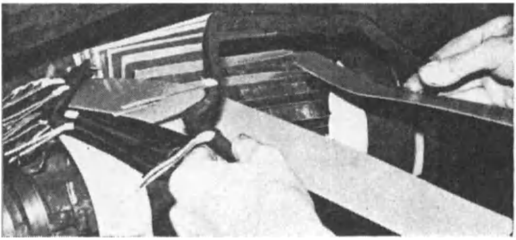
When seven coils (in this particular example) have been inserted the eighth coil will lie in a slot already occupied by the bottom limb of the 1st coil inserted, taped white. Insulation must be inserted between the two coil sides occupying the same slot. This insulation or 'willie' is a strip of 1.5 mm presspahn cut wide enough to wedge tightly between the slot sides.



Showing how the 'willie' is inserted, using a Bakelite drift.



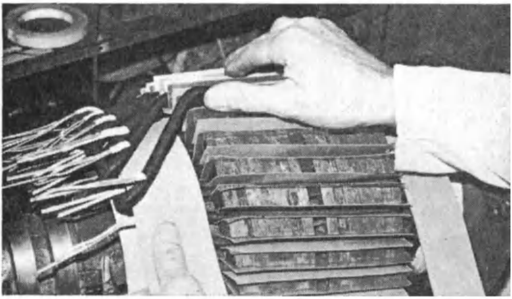
After a few coils have been laid in, insulation is added at each end of the winding. This insulation is of 1.5 mm presspahn and is thrust between the top and bottom knuckles of the coils.



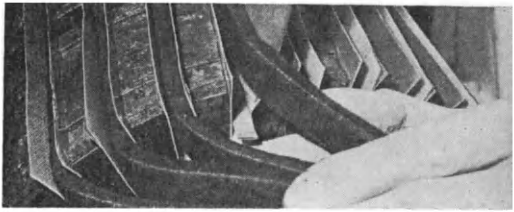
Each successive coil must now be threaded over this insulation before the bottom side is laid in the slot.

This shows the bottom limb being pushed down with the thumbs prior to drifting down with mallet and Bakelite drift.

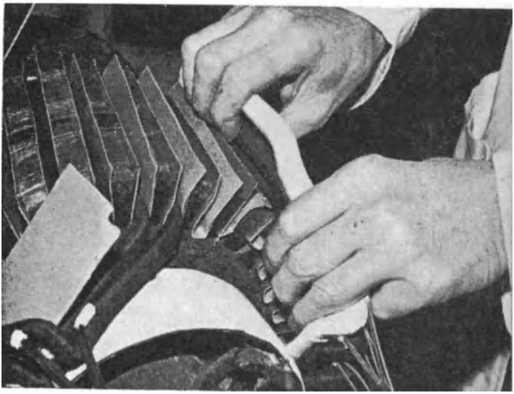
The bottom limb has now been laid down and the top limb is being thrust over into position while the insulation is pulled down. The coil will be finally laid in position by a 'shoehorn'.

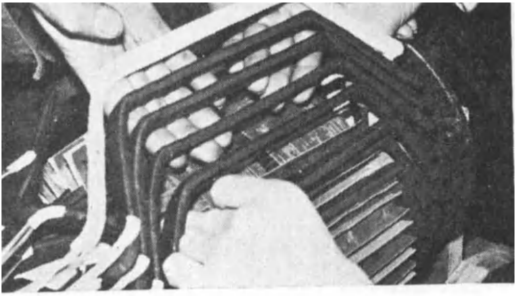


Here the top limb is being stretched with a 'shoe horn' into position. The 'willie' can be clearly seen.

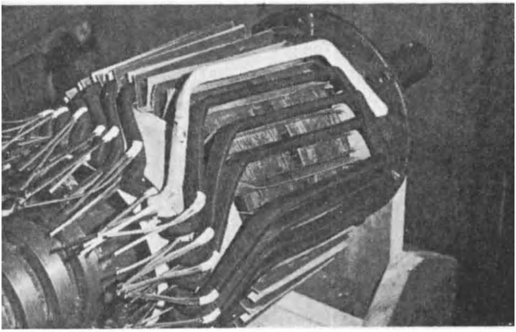


Except for the last seven, all the coils have been inserted. The rotor has been rotated until the 1st coil is reached. This coil must now be lifted from its slot and raised to permit the next coil to be inserted.

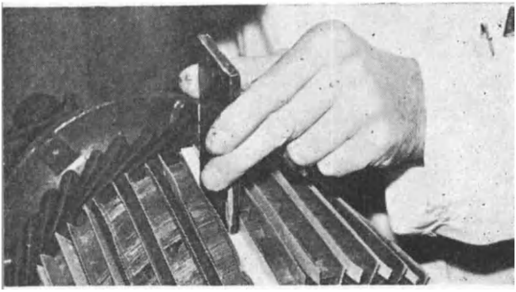




Showing the 1st few coils being lifted. Another assistant makes the work a lot easier. The winder is placing the last coil in position.

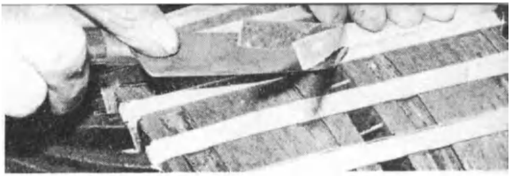


All the coils have now been inserted. This leaves the first eight coils to be reinserted. These are called 'throw' coils. They were originally laid in the top of the slots and had to be lifted to permit the final 8 coils to be laid beneath them.

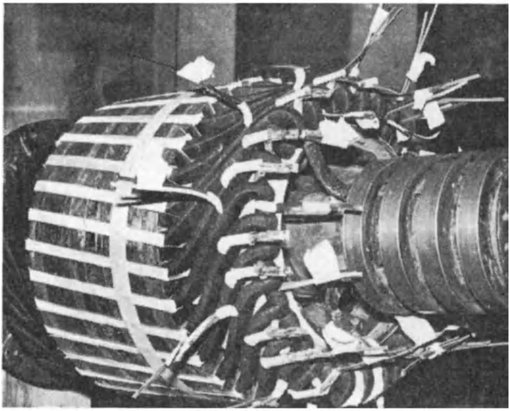


The winding is now complete and each coil is secured with a wooden wedge drifted, in this case, between the slot insulation.

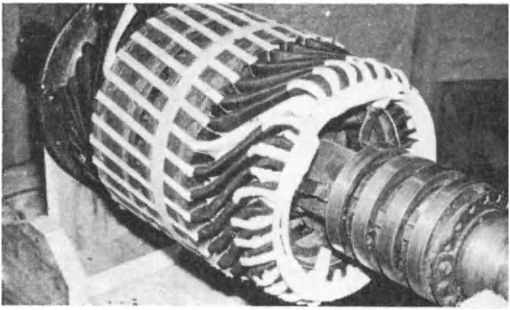
With all the wedges in position the slot insulation is sheared off flush with the stampings.

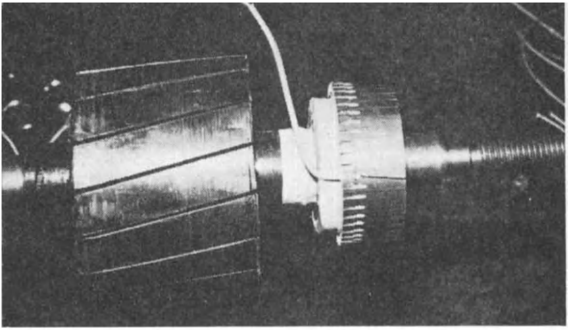


The winding is now complete and the coil ends are marked for connecting.



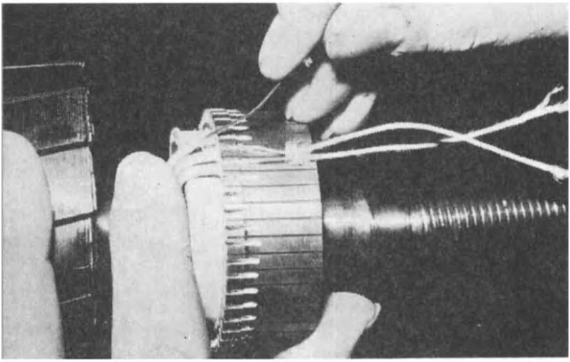
The connections are made and the rotor is complete except for varnishing and balancing. The connection is star with the star point taken down to the inside slip ring.



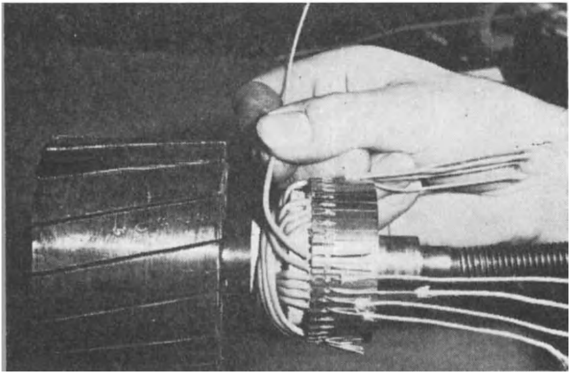


104. Winding the rotor of a repulsion-start induction - run single - phase motor.

Commencement of 'back shorting' the commutator. Here each commutator bar is shorted to one 180° mechanically opposite.

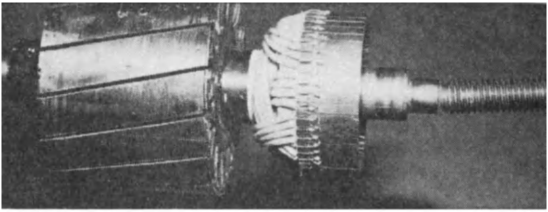


Back shorting. 3 leads in.

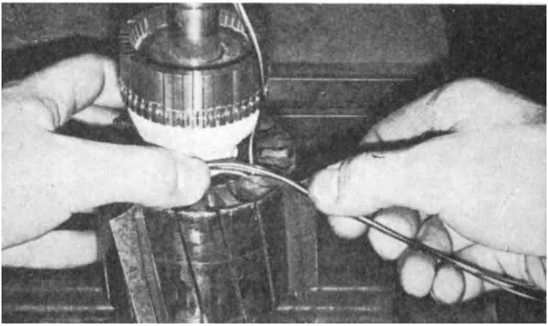


Back shorting. Operation nearly complete.

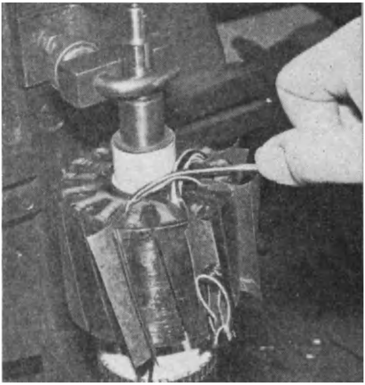
Back shorting complete. Note that back shorting uses D.C.C. wire for ease of stripping. Empire tubes are used for the insulation where the leads cross over.

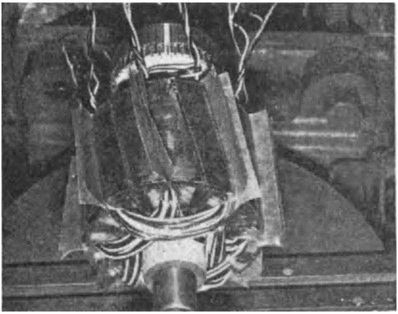


Back shorting covered with white masking tape. Armature mounted on winding machine. First coil being wound.

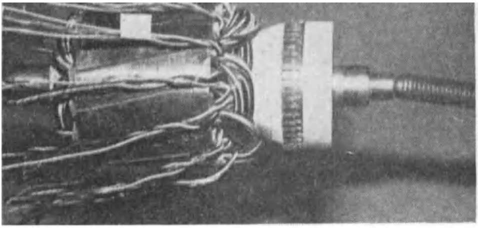


1st Coil complete. Second coil being wound. Note that in this example each alternate slot is wound. By this means the complete armature wind will consist of two layers and a better mechanical balance is obtained.

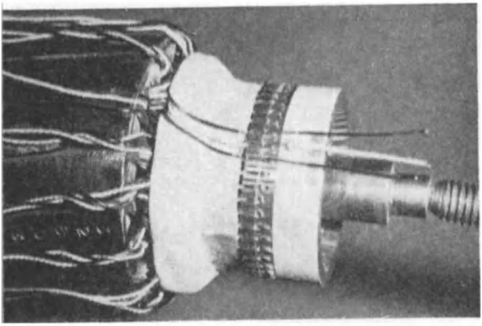




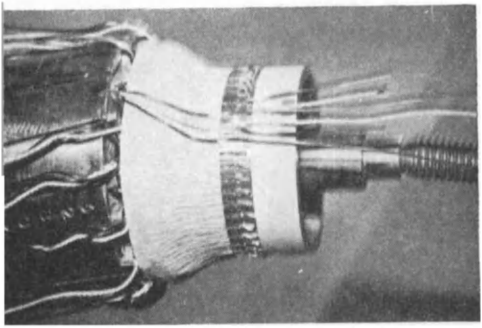
(left) **First layer of winding complete.**



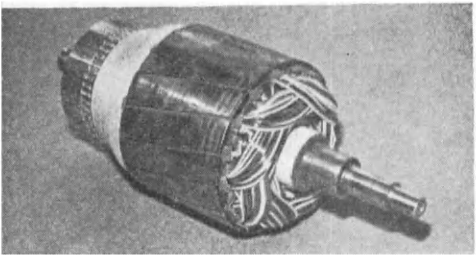
Second layer complete and therefore armature completely wound. Armature now removed from winding machine and insulation added behind commutator.



Commencement of commutator connecting. End of winding is insulated by crepe kraft paper. First three bottom leads laid down. Note the paper tape around commutator bearing 4 marks to indicate the bars to be connected.



Completion of bottom layer, covered by another layer of kraft paper, and commencement of top layer of connection. Note how the leads co-incide with the markings on the paper strip. All other leads other than these have been sheared off for clarity.



Commutator connection complete. String binding added. The winding is now ready for soldering and varnishing.

Appendix

Wire Gauge Comparison Table

S.W.G. = British standard wire gauge
B & S = Brown & Sharpe wire gauge

B.S. sizes		Nearest s.w.g. sizes			Nearest B & S sizes		
m	in	in	mm	s.w.g.	in	mm	B &S
5.00	0.19685	0.192	4.877	6	—	—	—
4.75	0.18701	—	—	—	0.1819	4.620	5
4.50	0.17717	0.176	4.470	7	—	—	—
4.25	0.16732	—	—	—	—	—	—
—	—	—	—	—	0.1620	4.115	6
4.00	0.15748	0.160	4.064	8	—	—	—
3.75	0.14764	—	—	—	—	—	—
—	—	0.144	3.658	9	0.1443	3.665	7
3.55	0.13976	—	—	—	—	—	—
3.35	0.13189	—	—	—	—	—	—
—	—	—	—	—	0.1285	3.264	8
—	—	0.128	3.251	10	—	—	—
3.15	0.12402	—	—	—	—	—	—
3.00	0.11811	—	—	—	—	—	—
—	—	0.116	2.946	11	—	—	—
—	—	—	—	—	0.1144	2.906	9
2.8	0.11024	—	—	—	—	—	—
2.65	0.10433	0.104	2.642	12	—	—	—
—	—	—	—	—	0.1019	2.588	10
2.5	0.09843	—	—	—	—	—	—
2.36	0.09291	0.092	2.337	13	—	—	—
—	—	—	—	—	0.0907	2.304	11
2.24	0.08819	—	—	—	—	—	—
2.12	0.08346	—	—	—	—	—	—
2.00	0.07874	0.080	2.032	14	0.0808	2.052	12
1.90	0.07480	—	—	—	—	—	—
1.80	0.07087	0.072	1.829	15	0.0720	1.829	13
1.70	0.06693	—	—	—	—	—	—
1.60	0.06299	0.064	1.626	16	0.0641	1.628	14
1.50	0.05906	—	—	—	—	—	—
—	—	—	—	—	0.0571	1.450	15
1.40	0.05512	0.056	1.422	17	—	—	—
1.32	0.05197	—	—	—	—	—	—
—	—	—	—	—	0.0508	1.290	16
1.25	0.04921	—	—	—	—	—	—
—	—	0.048	1.219	18	—	—	—
1.18	0.04646	—	—	—	—	—	—
—	—	—	—	—	0.0453	1.151	17
1.12	0.0441	—	—	—	—	—	—
1.06	0.04173	—	—	—	—	—	—
—	—	—	—	—	0.0403	1.024	18
1.00	0.03937	0.040	1.016	19	—	—	—
0.950	0.0374	—	—	—	—	—	—
0.900	0.03543	0.036	0.9144	20	0.0359	0.9119	19
0.850	0.03346	—	—	—	—	—	—
0.800	0.0315	0.032	0.8128	21	0.0320	0.8128	20
0.750	0.02953	—	—	—	—	—	—
—	—	—	—	—	0.0285	0.7239	21

B.S. sizes		Nearest s.w.g. sizes			Nearest B & S sizes		
m	in	in	mm	s.w.g.	in	mm	B &S
0.710	0.02795	0.028	0.7112	22	—	—	—
—	—	—	—	—	0.0253	0.6426	22
0.630	0.0248	—	—	—	—	—	—
0.600	0.02362	0.024	0.6096	23	—	—	—
—	—	—	—	—	0.0226	0.5740	23
0.560	0.02205	0.022	0.5588	24	—	—	—
—	—	—	—	—	0.0201	0.5105	24
0.500	0.01968	0.020	0.5080	25	—	—	—
0.450	0.01772	0.0180	0.4572	26	0.0179	0.4547	25
0.425	0.01673	0.0164	0.4166	27	—	—	—
0.400	0.01575	—	—	—	0.0159	0.4039	26
0.375	0.01476	0.0148	0.3759	28	—	—	—
0.355	0.01398	—	—	—	0.0142	0.3607	27
—	—	0.0136	0.3454	29	—	—	—
—	—	—	—	—	0.0126	0.3200	28
0.315	0.0124	0.0124	0.3150	30	—	—	—
—	—	0.0116	0.2946	31	—	—	—
—	—	—	—	—	0.0113	0.2870	29
0.280	0.01102	—	—	—	—	—	—
—	—	0.0108	0.2743	32	—	—	—
0.250	0.00984	0.0100	0.2540	33	0.0100	0.2540	30
0.236	0.00929	0.0092	0.2337	34	—	—	—
0.224	0.00882	—	—	—	0.0089	0.2261	31
0.212	0.00835	0.0084	0.2134	35	—	—	—
0.200	0.00787	—	—	—	0.0080	0.2032	32
0.190	0.00748	0.0076	0.1930	36	—	—	—
0.180	0.00710	—	—	—	0.0071	0.1803	33
0.170	0.0067	0.0068	0.1727	37	—	—	—
0.160	0.0063	—	—	—	0.0063	0.1600	34
0.150	0.00591	0.0060	0.1524	38	—	—	—
0.140	0.00551	—	—	—	0.0056	0.1422	35
0.132	0.0052	0.0052	0.1321	39	—	—	—
0.125	0.00492	—	—	—	0.0050	0.1270	36
—	—	0.0048	0.1219	40	—	—	—
0.112	0.00441	0.0044	0.1118	41	0.00445	0.1130	37
0.100	0.00394	0.0040	0.1016	42	0.00397	0.1008	38
0.090	0.00354	0.0036	0.0914	43	0.00353	0.0897	39
0.080	0.00315	0.0032	0.0813	44	0.00314	0.0798	40
0.071	0.0028	0.0026	0.0711	45	0.00280	0.0711	41
0.063	0.00348	—	—	—	0.00249	0.0632	42
—	—	0.0024	0.0610	46	—	—	—
0.056	0.00220	—	—	—	0.00222	0.0564	43
0.050	0.00917	0.0020	0.0508	47	0.00198	0.0503	44
0.045	0.00177	—	—	—	0.00176	0.0447	45
0.040	0.00157	0.0016	0.0406	48	0.00157	0.0399	46
0.036	0.00142	—	—	—	0.00140	0.0356	47
0.032	0.00126	0.0012	0.0305	49	0.00124	0.0315	48
0.028	0.00110	—	—	—	0.00111	0.0282	49
0.025	0.00099	0.0010	0.0254	50	0.00099	0.0251	50