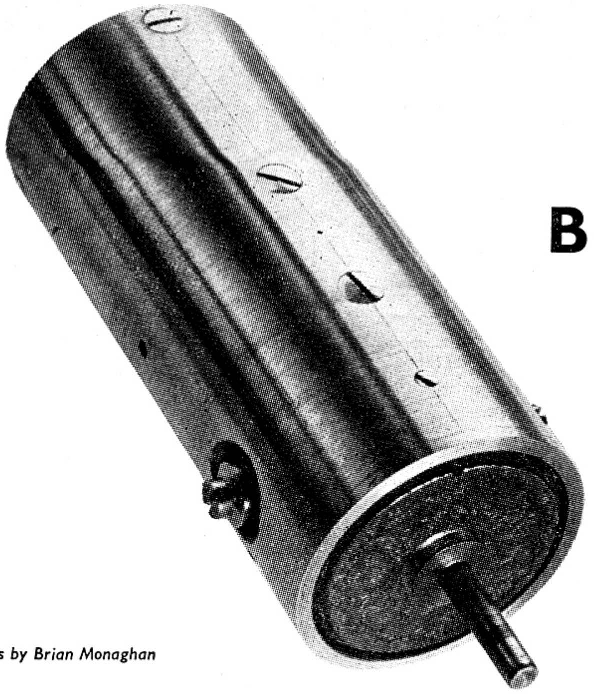


BUILDING YOUR OWN MOTOR

John Langan, A.M.I. Prod.E., Chairman of the Manchester Model Railway Society, still finds the time for practical modelling. This is the first of two instalments.

Pictures by Brian Monaghan

EXHIBITING a layout brings many questions from the onlookers, both fellow modellers and the general public, about the various aspects of our hobby. On my EM layout I am very fortunate in that I receive the assistance of a number of excellent modellers who in addition to contributing locomotives and rolling stock also enjoy running the trains at realistic speeds with good control. We have been very pleased and encouraged with the reception that such running has received, and from the number of enquiries we have had in this connection I believe that the amount of interest in the motors which we use in driving our locomotives, is greater than reflected by the number of articles which have appeared in the model journals in recent years. In the main, these contributions have been in the correspondence columns and have often related to the poor performance of, or improvements to, commercial products. This does not mean that all bought motors have poor performance, though to make a motor for the prices now charged one will no doubt occasionally get a motor which requires some adjustment. The present notes are an attempt to redress this balance, and to describe in particular the construction and manufacture of some motors I have recently completed. I hope by this means to encourage some of those who are interested, to undertake the building of a motor. I am convinced that having once achieved this, and experienced the immence satisfaction of seeing your own motor run then you will continue to build motors as part of your modelling programme.

However, for those who, whilst using commercial motors, would like to have some understanding of them, I also describe briefly the action which makes a motor run. As a mechanical engineer I find a certain fascination in switching on a controller, and seeing a motor start to run, especially one with a flywheel attached, causing speed changes to be made very gradually in response to the controller. Although I believe my description of motor rotation to be technically accurate it may not be as complete as our electrical friends may have described it. If I have missed some point essential to our better understanding of our motors then I should be very pleased to hear of it.

Since there are on the market at the present time some reasonably priced motors of varying design why bother to

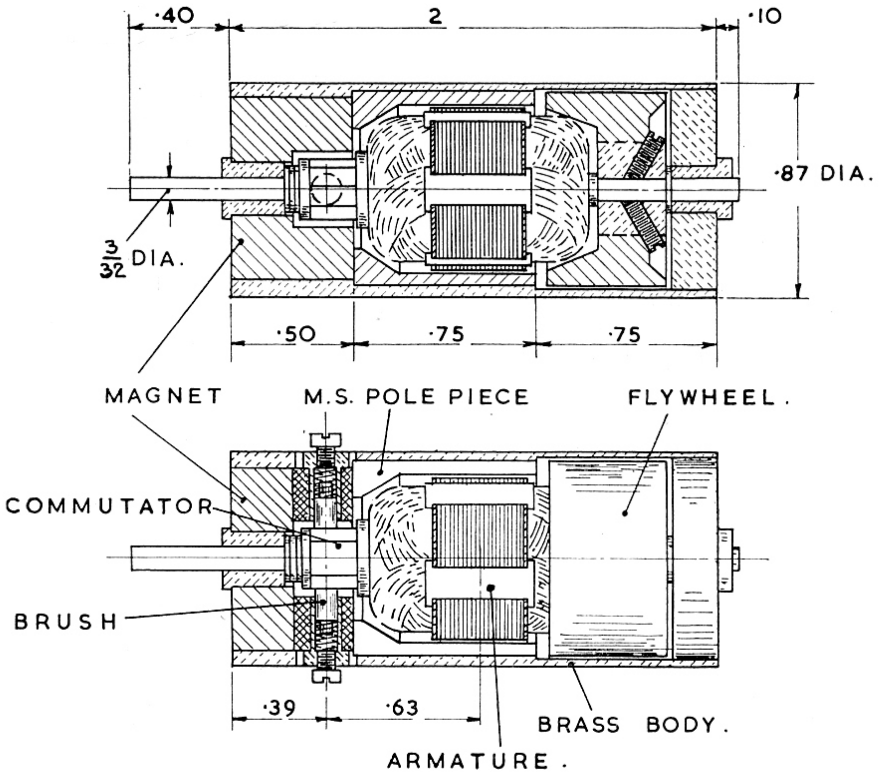


FIG. 1. GENERAL ARRANGEMENT.
DIMENSIONS IN INCHES.

MANCHESTER MODEL

spend time in making them ? This is a legitimate question which I accept, and my own answer to it is twofold. First, some years ago when I returned to modelling, the motor supply was not as good in price and reliability. Secondly, and more important, members of the M.M.R.S. began using 24 volts as their standard, rather than the popular 6 volts and later 12 volts. This higher voltage, with its smaller amperage for a given power, enabled quite powerful and controllable motors to be made even when using a plain variable resistance as a controller. It did mean, however, that armatures had to be rewound and from this we came to accept motor building as an interesting sideline to locomotive building. We can with some justification claim that such motors with our scratch built locomotives have achieved a high standard of realistic running. A further advantage of using 24 volts has been the availability of ex-government equipment and P.O. relays in this voltage which have been used extensively on our layouts. Designing the motor to fit into the tender, and driving to the locomotive through a universal shaft enables the largest possible motor to be used. Accommodation for a motor within the locomotive varies considerably whereas space within a tender is more constant enabling one design of motor to fit a number of different engines. In these circumstances it is more economical to build a small batch of motors than just the odd one. I have in fact made enough components for six motors and completed two for the locomotives I am building.

The work involved in making your own motor, requires care and patience, and as most modellers bring these qualities to their work, not accepting shoddy workmanship, then they should be able to make a good job of a motor. They may not possess the equipment to produce the design described in these notes, but simpler examples for a first try could be reproduced, and it is hoped that some of the information presented here will be of assistance.

Fig. 1 shows two views of the general arrangement of the motor I have made, and for the moment let us look at the basic items which are common to all small motors of this type. At the left hand end we have the magnet which is sending a magnetic field across the two pole pieces. In this field, revolving in bearings at each end of the casing, is the armature, which is receiving current through the brushes contacting the commutator. These are the basic components, and how they combine to make rotation possible is a most interesting electro-mechanical device. Firstly, let us investigate how and what makes a motor "tick," as an understanding of this process very often helps us when we have some trouble with a motor.

When we wish to move an object we generally have to make contact with it, but a magnet has the property of moving pieces of iron and steel without having direct contact with them. The space around a magnet in which this influence may be detected is the magnetic field. The action of this field may be seen by placing a magnet beneath a piece of paper and sprinkling some iron filings on the latter—a most impressive demonstration for non-technical friends. Fig. 2 is the conventional way of showing such a field for the type of magnetic poles with which we are concerned.

In the case of a wire carrying an electric current we also find the presence of a magnetic field. Shown conventionally with the current travelling away from us at Fig. 3, it is also to be noted

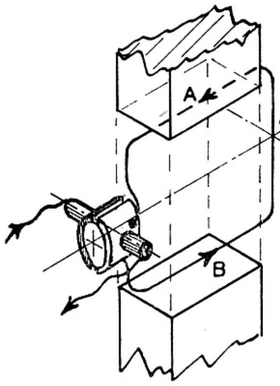


FIG. 12

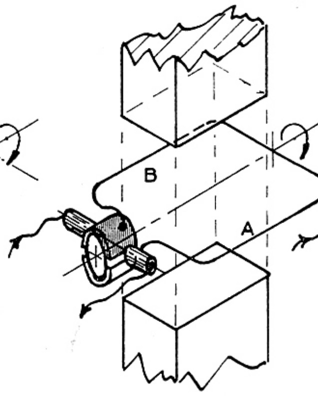


FIG. 13

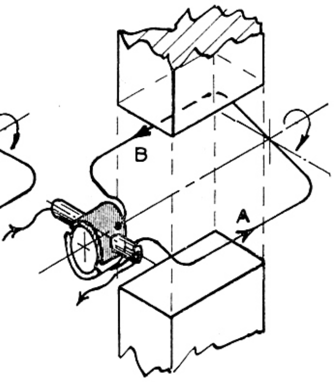


FIG. 14

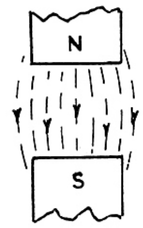


FIG. 2

FIG. 3

FIG. 4


FIG. 5

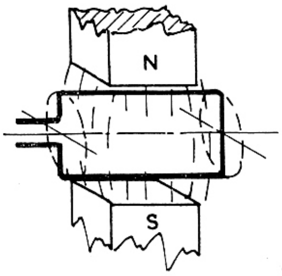


FIG. 6

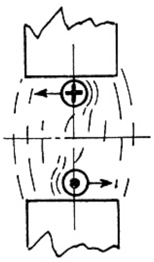


FIG. 7

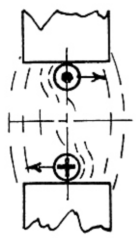


FIG. 8

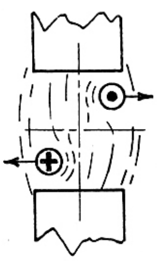


FIG. 9

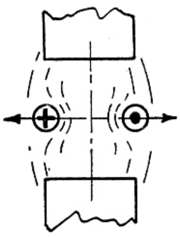


FIG. 10

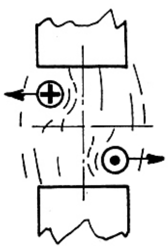


FIG. 11

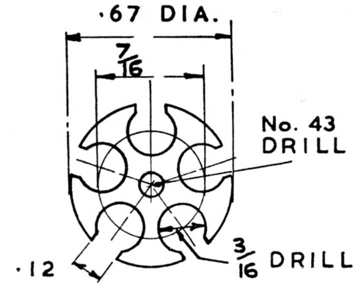


FIG. 15

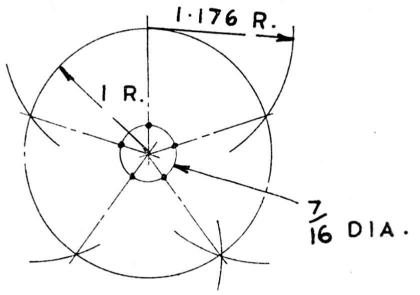


FIG. 17

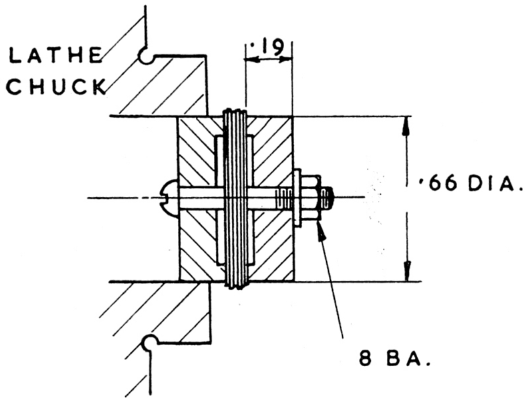


FIG. 16.

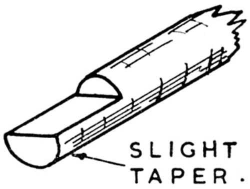


FIG. 18.

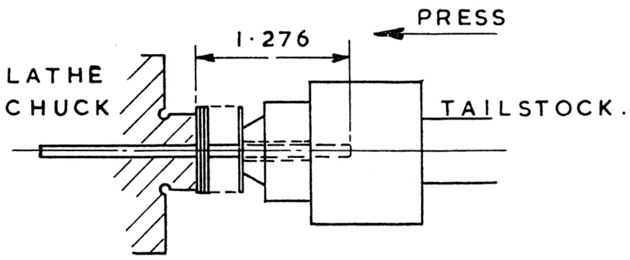


FIG. 19.

that the field is strongest near the wire. Reversing the direction of the current flow will also reverse the magnetic field, as shown at Fig. 4. Of particular interest to us is what happens when we place such a wire in the magnetic field between the poles of the magnet. This is illustrated at Fig. 5, and we see at once that the direction of the field from the wire strengthens the field from the magnet on one side and opposes and weakens the opposite side. The wire will then tend to be moved into the weaker area by the unbalanced forces of the distorted field. If we suppose that our armature is formed by a single loop of wire as at Fig. 6 we can study the effect of these forces in causing the wire loop to revolve. Fig. 7 shows a current passing around the loop and since each wire will tend to move into the weakened field zone, a twist action will be made upon the loop. Note that at Fig. 8 a reversal of the current in the loop will produce a torque or twist in the opposite direction since the field of the magnet remains unchanged, being a "permanent" magnet. So we get movement of the loop, say to Fig. 9, and we find the twisting forces still in action until the loop eventually reaches a horizontal position, Fig. 10, in the magnetic field, and the forces becomes directly opposed to each other. This is a most important position, and a critical one for us, since further movement of the loop produces a situation as at Fig. 11. Due to their relative position to the centre, the forces in the loop now produce a twist which is opposite to our requirements for continuous rotation, and the loop would move back to, and dither about, the horizontal plane. To overcome this balanced situation we require some mechanism to switch off the current in the loop when it reaches the horizontal position in the magnetic field, and then to reverse the current in the loop as further rotation takes place. Such a mechanism would cause the forces on the loop to act in the required direction for full rotation. This action is called commutation and the simple mechanism which achieves this is our good friend the commutator.

At Fig. 12 we see that the ends of the single loop are now attached to a cylinder, the surface of which is in two pieces, each receiving current through "brushes" rubbing against the surface. Current therefore flows to the coil until the horizontal position is reached and it will be seen (Fig. 13) that the brushes now cover the gaps in the commutator which short circuit the current in the coil preventing the stalling forces from acting. When further motion takes place (Fig. 14) we see that the segments of the commutator and also the coil are

DIAGRAM
OF
COIL WINDING
MACHINE

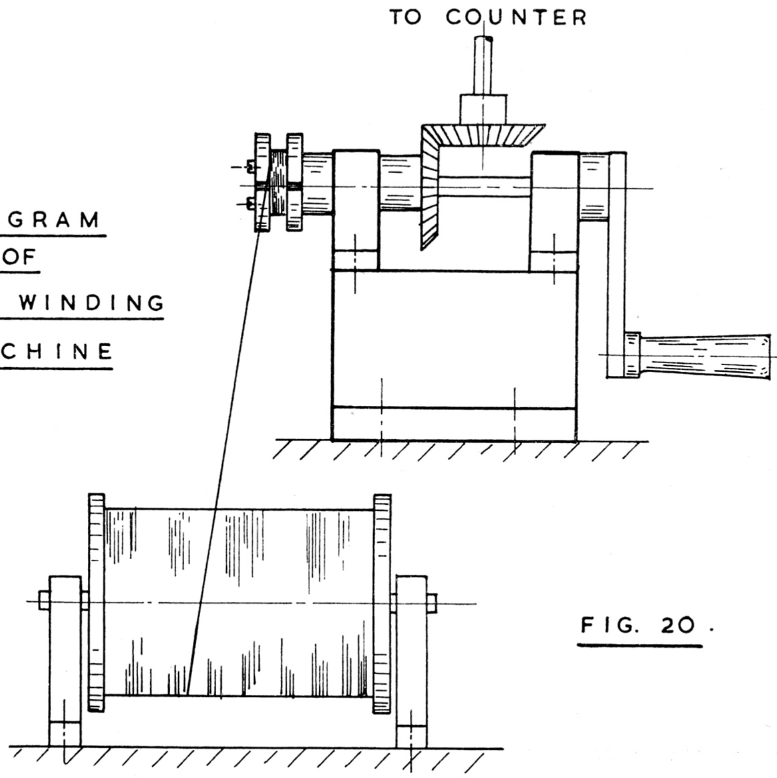


FIG. 20.

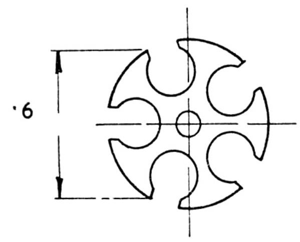


FIG. 21

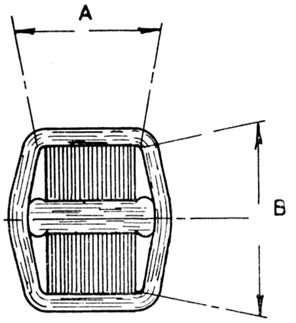


FIG. 22

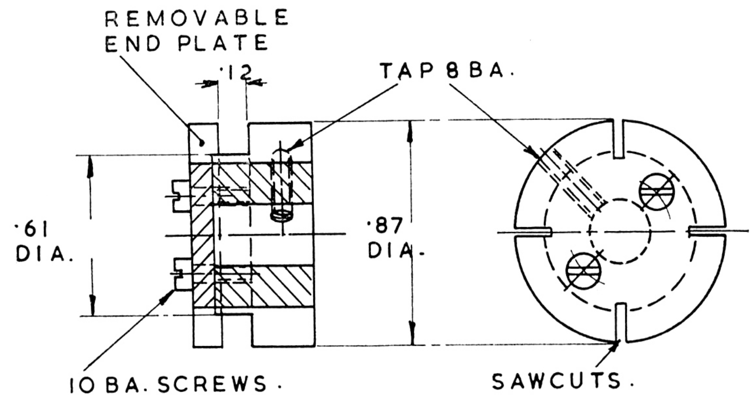
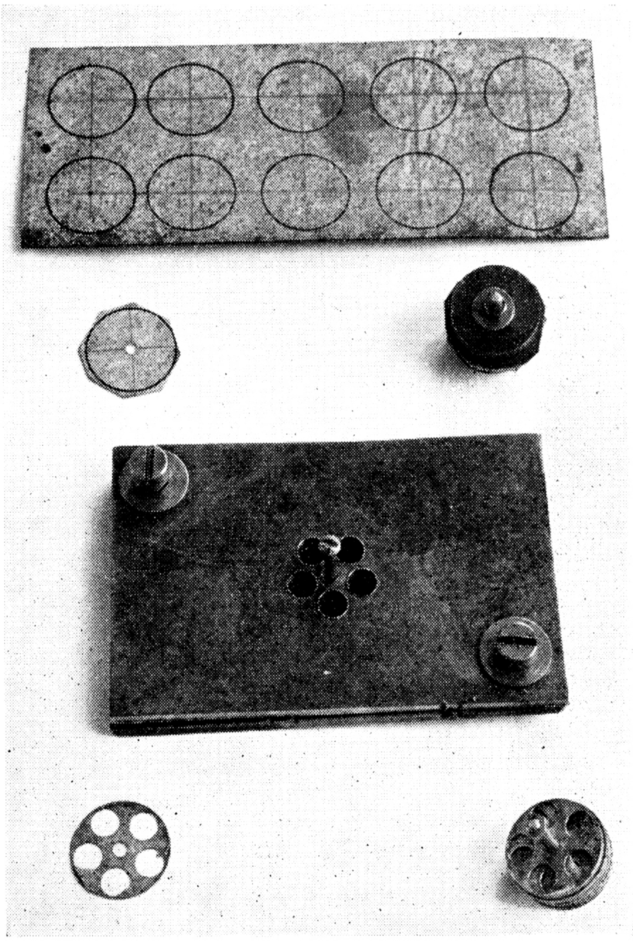


FIG. 23



Armature plates in various stages and the drilling jig.

receiving current of opposite polarity so that the forces induced in the coil are now in the correct direction to ensure continuous rotation. This then is the simple yet extremely ingenious way in which our small motors are caused to operate, and it will be seen that the more coils we have on the armature the more power we shall have. The coils are arranged in a number of sets around the armature and connected to an equal number of commutator segments. Also an increase in the number of coils, and commutator segments, means a less jerky drive. For this reason we generally make our motors with 5 pole armatures (or 5 sets of coils), this being a workable number for the size we have to contend with. [It must be admitted that there are some very good 3 pole motors working merrily away without any trouble. Equally so, some motor builders have adopted 7 or more poles with splendid results, but, for myself, 5 poles meet my motor requirements.]

Reference has already been made to the increased voltage (24 v.) which we use for our motors, and the details of the size of wire and armature data have been developed from the experimental work which was undertaken some years ago by the late Alex F. Jackson. Another worker in this field is Sidney Stubbs, who recently completed a batch of six excellent motors which it is hoped he will describe in due course. One feature which we all have endeavoured to include as part of the motor design is a lead flywheel. Although such a feature does not make a poor motor into a good one, the desired effect when used with a good motor is to cause changes in speed to occur gradually. It will also be appreciated that the flywheel assists the smooth running of the motor by over riding the critical position of the commutator as described earlier. A loco with a flywheel motor will start slowly and gradually build up speed, and in a similar way when switching off, the speed will gradually reduce. Very often a motor with flywheel will cause the overload relay to trip when switched on too quickly on the controller, rather than cause the loco to chase away like an animated mouse! Again, when switching off, one has to allow for the over-run of the loco due to the inertia of the flywheel. A loco containing a flywheel has to be driven with more care, and then the results are more realistic and satisfying. In making the motors totally enclosed as shown in Fig. 1, the flywheel cannot be as large, and therefore as effective, as possible with an open type of motor frame. This is a disadvantage to be put against the advantage that with an enclosed motor, assembly into the tender may be made without fear of the flywheel fouling the tender structure.

My first motors are still running satisfactorily and so I have retained some of the basic sizes in this present design. The shape of the magnet determines the construction of the framework of the motor and, as my idea was to make as much as possible in the lathe, I was pleased to find that "Eclipse" produce a range of button magnets which are available in most tool shops. Such a range of magnets also allows various sizes of motors of similar design to be made if required.

Let us then consider the manufacture of the armature, and a fundamental requirement of this item is that it shall run truly concentric. The shaft is therefore a piece of $\frac{3}{32}$ in. diameter by $2\frac{1}{2}$ in. long silver steel, selected to be quite straight. The ends are smoothed in the lathe with a smooth file or fine carburundum cloth to ensure that there are no burrs on the edges. Fig. 15 shows the sizes of a finished armature plate. These are made from 0.010 or 0.015 in. thick soft iron sheet, one side of which has a coating of thin paper. Old stator plates or transformers are a good source for this, and a friend in the electrical industry is your best contact to obtain a supply of this material.

On the thin paper side of the plate, draw circles 0.68 or 0.69 in. diameter with your ink spring bows. Drill the centre of each disc with a No 43 (0.089 in.) drill. Take this operation slowly, otherwise some beautiful triangular holes will result. Alternatively use a smaller drill first and then finish with the No 43 drill. The plates may now be cut out of the sheet with the tin snips, keeping away from the marked circle. The operations so far are shown in the photograph, which also shows the steel plates which are used for holding a number of discs when rough turning in the lathe.

Details of the holding plates are given in Fig. 16, and with the discs held in this manner they are turned to 0.68 to 0.69 in. diameter. To start with a file is useful to remove the high spots left by the tin snips. At each end of the armature plates is a 0.015 in. thick fibre disc of the same dimensions as the iron plates, so it is necessary to include some of these when turning the discs. After turning carefully remove any burrs formed on the side of the plates. The number of plates required (about 20) per motor depends, of course, on the thickness of the plate used, but enough should be prepared to make up $\frac{3}{8}$ in. wide.

Also shown in Fig. 15 is the type of slot used to hold the coils of wire. To drill the holes in the plates accurately requires a drill jig similar to that shown in the photograph, or, of course, for the more ambitious, a press tool could be devised. To make such a drill jig you require two pieces of $\frac{1}{8}$ in. thick mild steel plate about $2\frac{1}{4}$ in. square. Apply a coating of engineers' blue to one plate and mark out as shown in Fig. 17, by dividing the larger circle into five equal parts using the chordal distance as shown. Joining these points to the centre will enable the correct position for the $\frac{3}{16}$ in. holes to be obtained very accurately. The centre hole is drilled with the No 43 drill and the $\frac{3}{16}$ in. holes are obtained by gradually increasing the size of drill to $\frac{3}{16}$ in. in order to obtain a good smooth finish. This is now the master plate. Make two holes as shown for the holding screws. These holes should be to suit the actual diameter of the screws, saving the use of dowel pins. Remove the blue from the master plate (with methylated spirits) and harden by holding the plate in a gas flame until cherry red and then plunging it into cold water. Clamp the two plates together, and mark off the holding screw position, and then make tapped holes in the soft plate to suit. The two plates may now be held together by screws to enable the remaining holes to be drilled through to complete the jig.

Place four or five plates in the drill jig and hold central with an 8 BA bolt. Drill one $\frac{3}{16}$ in. hole into the plates and then insert a $\frac{3}{16}$ in. diameter brass plug. This will prevent the plates moving when the remaining holes in the plates are drilled. A flat filed half way across the brass plug, as at Fig. 18, will be found helpful when inserting into the plates. After drilling, the plates can be finished, turned to 0.67/0.675 in. diameter and a final check made to remove all burrs.

The plates are now ready to assemble on to the $\frac{3}{32}$ in. shaft. Hold the shaft firmly in the lathe chuck and allow to project as shown in Fig. 19. First press on a fibre disc and then the iron plates, ending with the second fibre disc. When pressing on to the shaft make sure that the $\frac{3}{16}$ in. holes are in line, using the brass plug. As you press on the discs put a spot of Durofix on to the shaft to help to fix things. I found that a drill chuck held in the tail stock, as in Fig. 19, very useful for pressing the discs on square. A brass disc packing piece may also be required to obtain sufficient movement.

Take two spare iron plates and carefully cut the $\frac{1}{8}$ in. slots as shown in Fig. 15. These are then used as guides for marking out the slots on the actual armature. Place one at each end, with the $\frac{3}{16}$ in. holes all lined up, and mark across the plates using an 80T/inch piercing saw. Replace the marking off end plates by thin brass discs and clamp in the vice for cutting the slots. The brass plates clamping the discs will prevent the end plates from snagging when you are sawing across them. File the slots smooth after sawing.

In our early motors, the coils were wound individually, in sequence, directly on to the armature. This was a slow and rather nerve racking business and a broken wire meant starting that particular coil all over again. Some time ago Sidney Stubbs developed a method of winding the coils separately, in the lathe, on to a former. Applied to the armature in correct sequence meant that it was both electrically and mechanically balanced, and, of course, followed prototype practice. I find trying to wind the coils in the lathe rather fast and prefer to wind with a simple home made gadget as shown in Fig. 20.

Determining the size of the winding former requires a bit of calculation, plus some approximation. With the armature plates as shown in Fig. 15 and winding for 24 volts, my motors have 5 coils each of 300 turns, using 42 gauge "Lewmex" wire. This has proved very satisfactory in practice. Determining the size of wire, number of turns of wire per coil, to suit a given armature size and applied voltage is a complex problem, and one where our electrical friends might help. One indeterminate factor is the strength of the magnetic field. It may well be that such electrical calculations are beyond the scope of this journal and a recommended set of sizes would be equally useful.

However, having the number of turns and gauge of wire as given above, we require to check that the space available is adequate. 42 gauge wire (0.004 in. diameter) is about 0.005 in. diameter when enamelled. To have some idea of the size of a bundle of 300 wires I use the following approximation:

$$W = 3n^2 + 3n + 1 \quad \ldots\ldots (1)$$

$$R = (2n + 1)r \quad \ldots\ldots (2)$$

where W = number of wires
n = number of wire layers from centre
R = radius of bundle
r = radius of wire

For 300 wires of 0.005 in. diameter wire, R is approximately 0.05 in. and the cross sectional area of such a bundle would be $\pi \times 0.05^2$, which is 0.0078 sq in. Now, when we wind a coil on to a former we make a coil which is rectangular in shape, although when removed and free it does tend to assume a circular shape. If we assume therefore, that because the circular bundle is 0.100 in. diameter, we make the former slot $\frac{1}{8}$ in. wide, then from the cross sectional area above, the depth of the wires in the slot will be 0.0078 divided by 0.125, which equals 0.062 in. That is the coil will be $\frac{1}{8}$ by $\frac{1}{16}$ in. in cross section, which checked very well with the coils produced. With this cross section, the slots in the armature could be $\frac{3}{32}$ to $\frac{1}{8}$ in. wide, as already stated in Fig. 15.

Adapting the same formulae, we may also check the wire capacity of the $\frac{3}{16}$ in. holes in the armature plates. Allowing for insulation the hole would reduce to, say, 0.180 in. diameter, therefore, from equation 2

$$0.09 = (2n + 1)0.0025$$

from which

$$n = 17 \text{ (nearest whole number)}$$

and then from equation 1

$$W = 3(17)^2 + (3 \times 17) + 1 = 919.$$

This is approximately the number of wires we could get into each $\frac{3}{16}$ in. space. We have 600 wires (two coils) to fit into this space, but as they are fairly loose and not geometrically arranged, the proportion to the maximum possible is reasonable and in practice, it does require some persuasion to get these wires tucked into the slots.

Having established a reasonable cross section for our bundle of 300 wires we can now proceed to make an enlarged drawing of the plates as shown in Fig. 21 and Fig. 22, since the coil must allow for fitting over the armature plate and also allow for clearing the adjacent coils. From these layouts the inner distance around the coil 2(A + B) may be approximated. This distance divided by π will give us the diameter to make the former. In the present example the distance around the coil is 1.88 in. and this gives a corresponding diameter for the former as 0.61 in. From the foregoing estimates the former shown in Fig. 22 was developed and proved successful.

Continued on page 569

BUILDING YOUR OWN MOTORS

Continued from page 567

An essential feature of the coil former is that it should be possible to tie the coil with cotton and then remove the coil from the former. To this end four slots are cut with a hacksaw as shown, Fig. 23, to below the 0.61 in. diameter, making sure all the burrs are removed. It will be noted from Fig. 23 that the end plate is removable. Having wound sufficient turns on to the former, cotton is passed under the coil and tied in four places. After removing the end plate, the coil may be gently prized off the former. I find a plastic rod sharpened like a chisel useful for this operation.

To be continued