THE 2MM SCALE ASSOCIATION

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Making Small Motors.

Denys Brownlee, Nigel Cliffe, Stewart Hine, Brian Tilbury.

Introduction

The making of small motors is considered by many to be a black art practised by the high priests of model making. Often one hears comments that it can't be done by the ordinary model maker, it requires special equipment or vast theoretical underpinnings. Even if one can overcome the perceived problems, why bother - there are plenty of commercially available motors.

We hope to refute all of the points above. Motors can be made quite simply, with a minimum of equipment and rudimentary theory. The resulting item can be superior to the many commercially available items, and made to fit the space available in a small model.

The 2mm Handbook (4th edition) describes various modifications which can be made to commercially available motors. We do not propose to repeat that information here.

The material in this technical note is from the following sources: Basic Motor Design was written for this technical note, Conventional Motors and Coreless Motors are taken from the notes made available at an Association seminar held in January 1994, Commutators and Brush Gear is taken from the 3rd edition of the 2mm Handbook.

Technical Notes are intended to be regularly updated. If there are comments, suggestions or improvements, please send them to the Editor of the Association.

Commercially Available Motors.

There are a wide variety of commercial motors used in 2mm model making. They can be used as supplied, or modified to fit the available space.

A handful of motors are really superb, and to make a better example at home would be difficult. If they can be fitted into the available space, and finances permitting, they are highly recommended. Examples favoured by the authors include: Mashima, Portescap and Faulhaber. Care must be taken with coreless designs to avoid exceeding the manufacturer's recommended current (eg. when stalling) and to use a correctly designed controller. Pulsed controllers, both with and without feedback, don't mix with coreless designs.

The most common motors used in 2mm models are iron cored. Examples include: Sagami, Tenshodo, Minitrix and Fleischmann. These all suffer from various compromises. They work, and can be used very successfully in models. Some can be improved by re-shaping the pole pieces and altering the magnetic field strength. Better motors than these designs can be made at home, and furthermore, the motor can be made to fit the space, rather than the motor dictating the space which must be made available.

Basic Motor Design.

There is no intention of giving a thorough treatment of the theory of electric motors. However, it would be useful to present a little background and describe the basic structure of iron cored motors commonly found in models.

A motor consists of three main components; the pole pieces which position a magnetic field, the armature which rotates within the field and the commutator which transfers electric current to the coils of the armature.

The simplest motor consists of a single coil connected to a two piece commutator placed in a magnetic field (fig 1). The current flowing through the parallel wires perpendicular to the magnetic field results in thrust perpendicular to the wires and the field. The direction of movement is described by Flemming's Left Hand Rule. The two thrust components form a couple which acts about the axis of the armature, rotating the armature. The commutator reverses the direction of current flow as the armature rotates through 180 degrees.

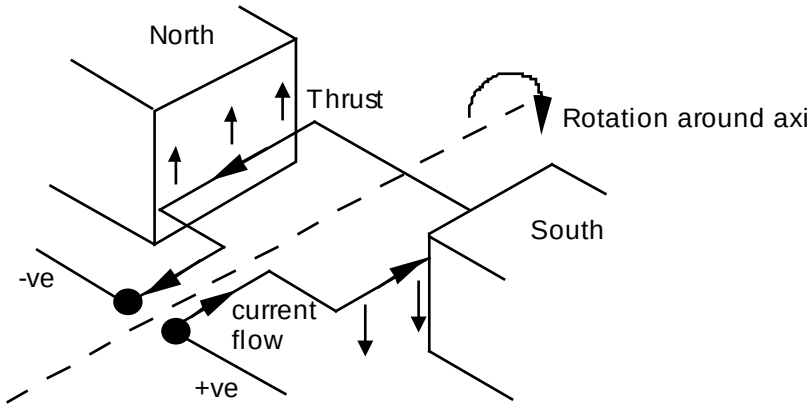

Figure 1. Simple electric motor.

A single coil motor (fig 1) will work, though will not be particularly smooth or controllable. It can also stop in a stalled position. More commonly, multiple coils are used, attached to a segmented commutator. Theoretically, the coils are wound across the axis of the armature (as in fig 1). However, this creates a number of problems for small motors, due to the length of wire which lies across rather than along the armature axis. This wire adds to the resistance, yet generates no rotation. If there are a lot of coils it adds to the length of the armature in a situation where we require a small motor.

If an odd number of coils are used in a motor, winding across the axis is not possible, instead a chord is wound. Theoretically, this should be across the longest available chord. But, it can be advantageous to "short chord" a motor (see page 4).

Conventional Motors

Stewart Hine

Anyone who has the equipment and skill to build a 2mm locomotive can build a better iron-cored motor than is obtainable commercially.

This sweeping statement is justified by the facts that the modeller does not have to build down to a price; that he can design a 'one off' motor to make the utmost use of the space available in a given locomotive; and that many commercial motors, either through commercial pressures or sheer lack of knowledge, are simply not as well designed as they ought to be.

The would-be builder is often deterred by the thought that if he gets the number of turns wrong the motor will be useless. This is not so; the number of turns can vary between half and twice the optimum and still produce a viable motor. If too few, the motor will run fast and perhaps take a lot of current; if too many, it will consume little current and run slowly. Once one has made one's first motor and seen it run, an assessment can be made of whether the number of turns is too far from the optimum and a rewind with a different gauge of wire undertaken. In fact, I find that over a very wide range of motor types in a given scale one wire gauge seems to do for all; thus for most 4mm motors wire of 40-42SWG is suitable, while nearly every 2mm motor I have made has been wound with 46SWG. A typical number of turns is around 700 for the whole armature, i.e. 100 turns for each of 7 coils or 140 for each of 5.

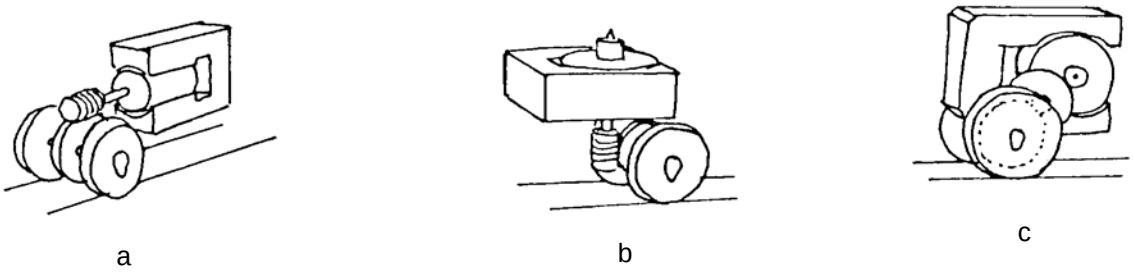

Fig 2. Common motor arrangements

There are three main ways of fitting a motor into a steam-outline model locomotive (Fig. 2). The long-motor-plus-worm-gear layout (a) is common in commercial 4mm practice, as a single design of motor can be used in a wide range of prototypes, but it is uneconomical of space in most of them and usually requires a high gear ratio to compensate for the small diameter of the armature (typically 8mmø). The large-diameter short motor with vertical shaft (typically 11mmø x 5mm) and worm drive (b) is suitable for side-tank engines, especially those with medium to small driving wheels; it was used by H.B.Whall, refined by H.H.Groves and used by Stewart Hine in the 'Small Prairie' design. A similarly-proportioned motor, with its shaft parallel to the driven axle and coupled thereto by spur gears (c), fits well into a wide range of tender engines and enjoys the advantages of high efficiency and reversible drive associated with such gearing.

Most commercial small motors are made with 3 or 5 armature teeth, for ease of machine winding. The amateur builder need not conform to this convention; indeed, a larger number of teeth means fewer turns per coil and less wasted time if the wire breaks during hand winding! 'Cogging', the bane of the miniature loco-builder, is minimised by using a large, odd number of teeth; nine is an attractive number since it permits the winding of a fully symmetrical armature with inherently good balance, but is difficult to arrange in rotors with diameters less than about 10 mm.

Cogging can be further reduced by correct choice of pole arc, and this is where many commercial motors fall short; indeed, some notorious coggers have been tamed by quite minor modifications to their magnetic systems. Briefly, the arcs subtended by the active polefaces should be a multiple of 360° divided by the number of rotor teeth, erring slightly on the low side to allow for 'fringing flux' (fig 4). Use the biggest magnet that can be fitted in and try to ensure that the cross-section of the polepiece yoke is about the same as the total of the armature teeth opposite either poleface at one time. Saturation of the armature iron is possible but unlikely.

Pole pieces are simply filed or machined to shape from mild steel bar or rod. Start by boring the armature tunnel in the lathe, then cut away the 'bridges' between the poles bit by bit, soldering (preferably silver-soldering) in a brass bracket to preserve the alignment before finally separating the parts. The magnet should be a fairly tight sliding fit between the parts designed to accept it, but not so tight as to bend the bracket. In most motors the magnet will stay in place by its own attraction. The motor is mechanically completed with brackets to carry brushgear and bearings (pin-point or ball race for preference). It is a good idea to test-assemble the motor before winding the armature, to make sure everything fits.

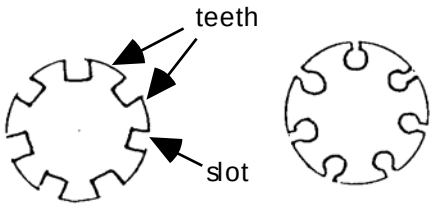

Fig. 3
Armature teeth

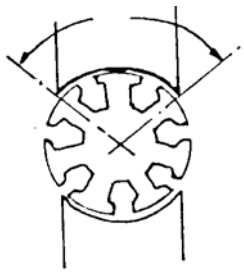

Fig 4
Pole Arcs

Commutators can be of disc or drum type to suit the space available. In either case the copper is Araldited to a Tufnol core before slitting into segments with a very fine (4/0) saw blade. Alternatively disc commutators can be made from glass fibre-based printed circuit board, but provision should then be made for easy replacement; the thin copper does wear out in time!

The armature core can be made from annealed mild steel or transformer iron, in a stack of laminations around .015" thick. Rough-cut the required number of discs and drill centre holes to take an 8 BA screw, then coat each lamination with Araldite, clamp up and cure in a warm place. When set, it is usually possible to knock the bolt out - if not, drill it out. Make a mandrel to hold the assembly in the lathe and finish-turn it to the required diameter. Transformer iron is crystalline and rough on the tools; a carbide tip is a good idea if you have one.

There is no need to reproduce the skinny, T-headed teeth found in commercial motors. The slots can either be plain rectangular grooves cut with a Woodruff keyway cutter - or even hacksaw and files! - or a series of holes drilled just inside the periphery of the discs and broken out with hacksaw or piercing saw. I have tried both and there seems to be no real difference in performance, but it is worth while making the slots no bigger than is necessary to contain the wire. Before winding the slots should be deburred, lined with tissue or cigarette paper and shellacked.

Ideally, each active coil of an armature should lie across the core at right angles to the stator field. With an odd number of slots this is obviously not possible and each coil must lie off-centre; this is known as short-chording'. In a short armature with many teeth there will be a good deal of `dead' wire in the overhang at the ends of the winding; this contributes nothing to the motor's operation but adds to the resistance. Further short-chording reduces this amount of dead wire; thus a 7-slot armature might have 2 teeth per coil rather than 3 or a 9-slot 3 instead of 4, the theoretical loss of efficiency being compensated for by the reduction in dead wire. Short-chording also usefully reduces the overall length of a short armature without altering the effective length, i.e. the thickness of the iron stack.

Once the number of teeth per coil is decided, the commutator should be set on the shaft in the correct orientation to the armature teeth. In most cases the best line for the brushes is in line with the magnetic axis; each commutator slot is then aligned with the slot or tooth which will be in the centre of the coil connected across that slot. If the design demands a different axis for the brushes, the commutator and its connections must be turned round to suit; the rule is that a coil which is shorted out by a brush should be at that moment at right angles to the stator field. The end of one coil is connected to the start of the next and so on all the way round the armature.

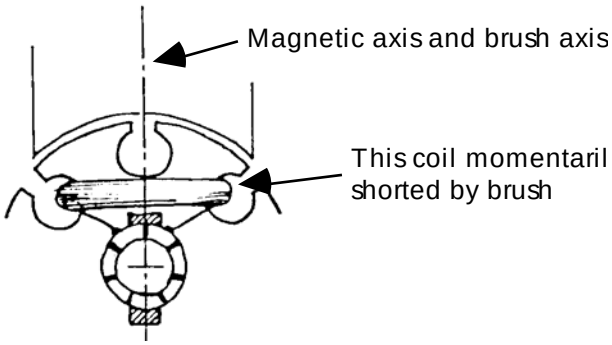

Fig 5. Commutator Orientation

It will be realised that in most cases it will not be possible to wind directly on to the core without introducing asymmetry into the windings, the first coil being completely buried while later coils are buried at one end only, the last one lying on top in both slots. In long armatures this can be overcome by pre-winding the coils and fitting them in sequence, but with short armatures this results in a lot of overhang which is difficult to tuck away tidily. Even in such small armatures, balance is quite important. The 9-slot armature, as already mentioned, allows the coils to be wound as three equilateral triangles making the balance intrinsically good. At the other end of the scale, a 3-slot armature can give quite good results provided care is taken to avoid skinny teeth and to get the pole arcs right.

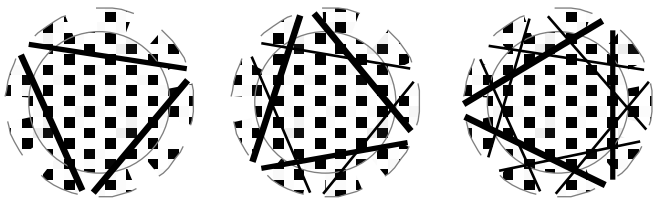

Fig 6. Winding a 9 slot armature as three equilateral triangles for good bal

It is usually possible to solder the wires to a drum commutator without overheating it, but disc commutators require some sort of heat sink at this stage. A clamp similar to that shown in Fig. 7 (left) is helpful both in winding and terminating the coils; the type shown in Fig. 7 (right) is suitable for longer armatures with drum commutators. A coil-winding machine is the ideal but the lathe, fitted with a handle at the left-hand end and perhaps a turns counter, will serve as will that old modeller's standby - the handbrace held in the vice. Counting turns is an exasperating business requiring intense concentration, and if a turns counter cannot be rigged up, it is better simply to wind a measured length of wire on to each coil. Test each coil for continuity and for insulation from the core before starting on the next; the enamel of modern wires is very tough and there is no real need to test for shorts to the other coils. Once the

armature is completed (which sounds a little like 'With one bound, our hero was free!') it should be carefully checked for turns lying proud of the slots; these should be prodded back into place with a cocktail stick. The winding is then brushed with shellac or coil varnish and stood on end, commutator upwards, to dry.

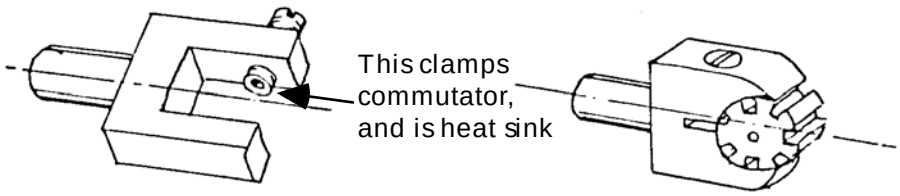

Figure 7 Winding tools

Large-diameter armatures with 5,7 or 11(!) slots will probably benefit from balancing. Dynamic balancing is ideal but hardly practical, but static balancing is possible. Clamp two razor blades in the vice with a spacer such that the rotor bearings can rest on the edges, which of course should be dead level. The rotor will probably tend to come to rest in one position each time it is released. Glue a small slip of lead foil (from the bottle of your favourite tipple) in the uppermost slot; repeat until the rotor shows no preferred position of rest.

Now comes the moment of truth. Reassemble the motor and connect to a power source, preferably via an ammeter. A healthy 2mm motor should start on about 3 volts and draw no more than 100 mA unloaded at 12 volts. The optimum brush pressure can be found by running the motor at about 6 volts and gently pressing the brushes on to or away from the commutator. The ideal setting is just a shade tighter than that which gives maximum speed.

Coreless Motors

Denys Brownlee

These notes on coreless motors are by no means definitive but rather a guide for anyone wishing to experiment further in this field.

Ideally the armature of a coreless motor consists solely of the wire coils and commutator fixed to a central shaft which can rotate within the pole-pieces with the minimum of air gaps. In the Portescap motor the windings are wave or basket wound, held together with a special impregnating lacquer and supported by an end disc fixed to the commutator. Thus they come near to the theoretical ideal of the gap between the pole pieces being completely filled with copper.

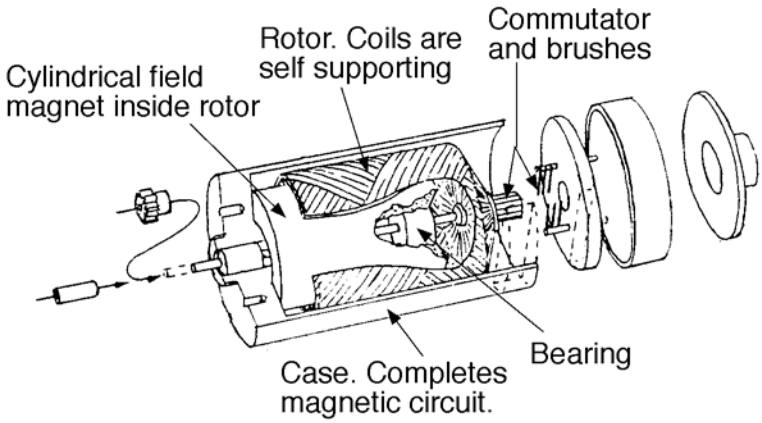

Figure 8. Exploded view of commercial coreless motor

Wave winding machines have a wire guide driven by a cam which causes it to zigzag back and forth across the width of the coil, normally by almost one cycle per revolution of the former. A system of change wheels causes the zigzag to vary its phase with the former so that each turn of wire lies alongside its predecessor. Such machines were once extensively used in making radio coils but are rare nowadays; it is just possible that one might pick up one secondhand. However, to construct coreless motors with the equipment usually available to the model-maker it is necessary to modify the design. The difficulty of wave-winding can be overcome by the use of discrete coils (3,5 or 7) wound as individual units on a simple former and then potted with resin in a suitable mould. In my experiments I have used 3 and 5 coils consisting of approximately 150 turns of 46 SWG self fluxing wire.

In order to lay down the basic dimensions - in particular the diameter - it is necessary to obtain a cylindrical magnet with the poles across the diameter. I used 'Bremag', a rare-earth type obtainable from Magnetic Applications of Berkhamstead, Herts; this material has the unusual property of being machinable and at the same time having a very high field strength, equal to or better than ceramic ferrites of similar size. The magnets used in my experiments started as 5 x 5 x 10 mm and were turned down to .1875" (3/16") diameter with a small axial hole for a bearing.

Starting with the .1875" diameter, the inside diameter of the coils can be established; in this case .1875" plus 2 x .010" air gaps giving 0.2075". Following from this, the width of the coils can be obtained from the formula:

$$\frac{0.2075\pi}{(no.\ of\ coils)}$$

The length of the coils is not critical but a reasonable proportion is a minimum of twice the width. The thickness of the coil is best found by experiment; I found that .050" was a good average and it may be adjusted by varying the number of turns. The exact number of turns is not critical but must, of course, be the same for each coil. Having established the thickness it follows that the O.D. will be .3075”, i.e. .2075" plus 2 x .050".

The next item to be considered is the commutator, described in the next section.

After constructing the commutator, it is necessary to make a mould in which to assemble and 'pot' the coils and commutator. This I turned from PTFE rod; if this is not available Tufnol or aluminium could be used but will need to be well coated with wax to prevent the potting resin from sticking. Essentially, this mould is in two parts. firstly a length of .2075" diameter for the centre core, drilled to accept the shaft (I used 1mm silver steel) and secondly an outer sleeve drilled through the diameter of the commutator and then opened up to .3075" except for the last 5 mm of length. To

start the final assembly, fit the commutator to the shaft and then slide on the centre core so that the end is about 1mm from the commutator solder tags. Next cement the coils in position around the core (I found that polystyrene cement was strong enough for this temporary fixing) and solder the tails of the coils to their respective tags on the commutator segments. At this stage it is advisable to make simple electrical checks to ensure continuity of the coils and absence of short-circuits. If all is well, carefully slide this sub-assembly into the outer shell. It may be necessary to squash the coils a little to ensure a sliding fit; a wooden spatula is an ideal tool.

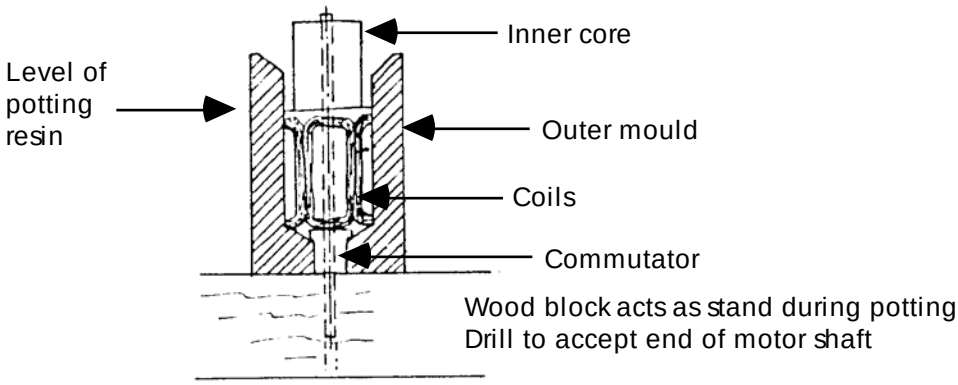

Figure 9. Potting a coreless motor

Next comes the messy bit. Mix the potting resin according to instructions and, standing the mould vertically (commutator downwards) carefully and slowly pour into the gap. It is essential to completely fill the cavities between the coils and commutator tags, avoiding air bubbles; the ideal would be to vacuum- fill. Although the setting time of the resin is relatively short, it is best to leave it overnight in a warm place (the airing cupboard) after which the assembled armature may be pushed out of the outer sleeve by carefully tapping the commutator end of the shaft, and the inner core finally pulled out. A suitable potting resin is obtainable from Alec Tiranti Ltd.

There only remains the stator, consisting of the magnet and outer sheath. The sheath is a piece of mild steel tubing with an inside diameter approximately .010" - .015" larger than the armature and a wall thickness of about .020"; In some cases this can form part of the locomotive boiler. The magnet is then supported within the sleeve by means of a brass or plastic bush.

The brush gear for this design of motor is quite conventional and can take the form of those described in the next section, taking care that it is in line with the magnetic axis. This is, unlike iron core units, not visibly apparent, so it is probably a good idea to test and mark the magnet with a scratch or spot of paint prior to assembling the outer sheath. My favourite space-saver is to make the brush holders part of the loco mainframes.

Commutators and Brush Gear

Brian Tilbury

There are two sorts of brush gear (see Fig. 10), brushes sliding in tubes and brushes on swinging arms. The motor outline can be changed by substituting one sort for the other or by rotating the brushgear about the armature axis. There are also two sorts of commutator: drum and disc (see fig 10 again). They use different brushgear arrangements and changing from one sort to the other changes a motor's outline.

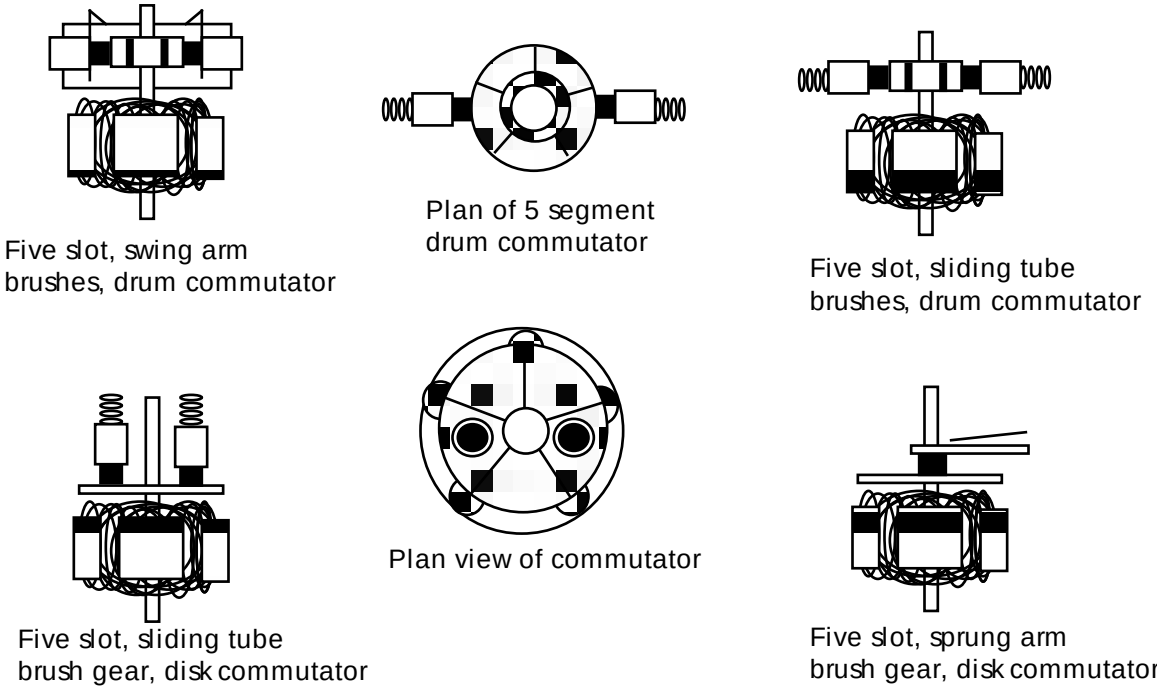

Figure 10, Types of brush gear and commutators.

Brush Gear

Tubes for sliding tube brushes can be rectangular or circular and made of copper, brass or nickel silver and should be mounted to clear the commutator by 0.2 to 1.0mm. The brushes should be a close but free sliding fit in the tubes. They can be cut from car dynamo, vacuum cleaner or pistol drill brushes - even worn out ones. car starter motor brushes often contain so much copper that they can be soldered. Do not use pencil leads; they work but will soon groove the commutator.

The swinging arm type of brush is best cut from the ones sold as spares for Hornby, MW, Airfix or similar motors. Unsolder the brush from the arm, cut it to size leaving part of the original soldered area on each new brush and solder it to a new arm. At least two 2mm brushes should be obtained from each 00 spare. The arms can be made from 0.01" brass, nickel silver or tinplate. They must pivot easily but be firmly located; a reduced version of the knife-edge pivots on the Hornby or Airfix motors is the simplest way. Alternatively, Minitrix, Fleischmann or Märklin Miniclub spares may be the right size. In all cases each brush should span an arc of the commutator roughly equal to the arc between the pole-pieces (see diagrams) and be 1mm to 2mm wide. One brush must be insulated from the motor frame.

Metal brushes are quick to make but wear rapidly. They are often used on low voltage motors in toys but should be replaced with carbon brushes if possible. They will destroy a commutator or themselves in a few hundred hours. Coreless motors also use metal brushes, but of precious metal, as are the commutators which have many segments, all of which, with coreless armatures, lessen the rate of wear.

Springs are required to push the brushes onto the commutator. Leaf or hairpin shaped springs are the easiest to make and adjust. A single balanced spring arrangement is easier to adjust than two separate springs. The thickness of material (hard brass, phosphor bronze or spring steel) can be decided by experiment: start with 0.005 to 0.010in. Coil springs often require spring wire of 38 SWG or finer. Some model engineers' suppliers stock such wire in brass or phosphor bronze. To set the springs run the motor at full speed and adjust the spring force to maximise

that speed - too strong and the brushes act as brakes, too weak and electrical contact is bad. If using coil springs with tube brushes, make sure that the tube and not the spring is carrying the current. Otherwise there is a risk that the current will heat the spring and change its characteristics.

Much of the foregoing effort can be avoided if a complete brushgear can be transferred from another motor.

Rotation of the brushgear around the axis of the armature requires the commutator to be twisted on the armature shaft through the same angle in the same direction.

If you lose track of where you started from remember that if the brushes are aligned with the centres of the field poles, a division between two commutator segments must be in line with the centre of an armature coil, that coil being connected between the two segments.

Commutators.

The two sorts of commutator use different brushgear arrangements and changing from one sort to the other changes a motor's outline. The number of commutator segments must equal the number of armature coils, the spans of the segments not differing by more than 5 degrees. In what follows "solvent" means acetone, cellulose paint thinners or nail varnish remover (non-oily).

A disc commutator can be cut from copper-faced Paxolin or glass fibre circuit board. The thickness does not matter. Make the diameter equal to that of the armature and drill a central hole to fit the armature shaft. Countersink the hole on the copper side just enough to prevent the copper touching the shaft and use twin knife cuts to remove narrow (less than 0.25mm) radial strips of copper to form the segments. File a nick across the circumference at the centre of each segment, then polish away any burrs with fine abrasive paper. A bush is needed temporarily to hold the commutator perpendicular to the shaft while it is glued on. This can be made in a lathe, with a handbrace[1] or mini-drill. Face both sides, and chamfer one edge to less than commutator diameter. Then drill the centre of the bush to an exact sliding fit on the armature shaft. Finally, countersink the end almost to the chamfer, remove any burrs and cut off the bush 5mm long. Decide how the segments are to be aligned - see preceding paragraphs on brushgear rotation - then clean the armature shaft and the commutator bore with solvent, put a smear of epoxy resin round the shaft only where the commutator is to be and slide the latter on, copper face outwards. Slide the bush onto the shaft with the countersink against the commutator and clamp it there while the resin sets, then remove the bush.

A drum commutator can be made from copper rod 1.5 to 2mm larger in diameter than the armature shaft. Copper is difficult to cut dry so use a lubricant: water with detergent will do. Begin by making a bush as for the disc commutator already described, but make the central hole 0.5mm larger than the armature shaft and 8mm deep; replace the countersink with a counterbore 5mm deep and a close fit on the outside diameter of the rod. Cut off the bush 7mm long. Put a piece of copper

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[1]A handbrace held horizontally in the vice can be used as a "handtool lathe". Put a short piece of metal rod in the chuck. Face the rod by filing the end at right angles while turning the handbrace file until it is almost flat (it will remain obstinately domed). The spiral file marks on the end of the bar will indicate the centre. Drill any holes required in the centre of the bar while still turning the handbrace.

Alternatively, a Minidrill can be used as a small lathe, either clamped in the vice, or (preferably) mounted on a frame to form a "Fonly" lathe.

rood in the drill chuck and file the end at right angles, then slip the bush over the rod and drill into the rod 0.5mm larger than the armature shaft to a depth of 8mm, using the hole in the bush as a guide. Remove the bush and drill the hole to 0.5mm smaller than the rod diameter for 1mm depth. Use a piercing or razor saw to slit the tube lengthways for 5mm to form the segments, then file the slits wider to leave a projection 0.5mm wide and 1mm long on each segment so that the end of the rod has a castellated appearance. Cut the commutator 7mm long overall (the segments will remain united at one end) and bend the castellations radially outward to form solder lugs for the coil connections. Remove all burrs inside and out, ensuring that the brush contact area is smooth, and swab the bore clean with solvent ready for glueing.

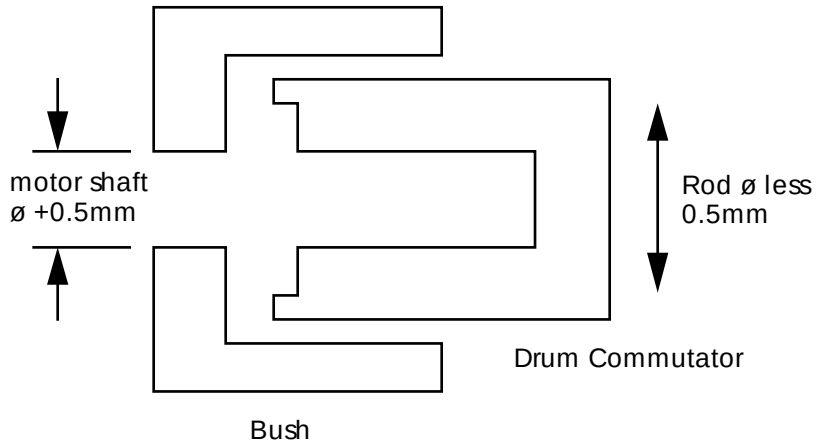

Figure 11. Making a commutator

The insulator for the commutator can be turned from Paxolin or similar material (plastic knitting needles, or Keramot have been used). File the diameter of a piece of Paxolin rod down to fit the commutator bore exactly, make a drill centering bush like the one used on the commutator and drill the rod centrally to fit the armature shaft to a depth of 6mm. Cut the insulator 5mm long, clean the shaft and glue the insulator on. Alternatively, form the insulator by winding 1mm wide strips of airmail paper, well smeared with slow epoxy resin, directly onto the cleaned shaft in helical layers 5mm long. The strips will stick more easily if their ends are first tapered to points over a 5mm length by single diagonal cuts. Do not overlap adjacent turns in a layer and keep the strips taut. Clean surplus resin off everything with solvent before the resin sets. It may be necessary to halt at intermediate stages and mix fresh resin.

Spread epoxy resin thinly and evenly in the commutator bore and slide only the slit length onto the insulator, castellations toward the armature coils. Orientate the segments correctly (see the description of brushgear rotation), clean off surplus resin and leave it to set. Lastly, saw off the unslit end of the commutator and remove any burrs.

On either commutator use a test meter or a battery and lamp to check that all segments are insulated from each other and the shaft, find and remove the offending metal whiskers if they are not. Then connect the armature coils to the nicks in the disc or lugs on the drum.

Recommended Reading

The 2mm Handbook 4th edition.

"Small Prairie" Booklet. 2mm Association Library, and 2mm Magazine 79/57, 79/73, 80/3.

"River Fal" Bulldog 4-4-0 2mm Magazine, Jan - Oct 1968

"The Big One" Castle 4-6-0 2mm Magazine 81/41

An intrinsically balanced Armature 2mm Magazine 80/73

Constructing a Coreless Motor 2mm Magazine 86/29

Modifying Motors 2mm Magazine 82/17

Fonly lathe and drilling machine 2mm Magazine, Jun-Dec 1994

2881 In Miniature, Model Railways Sept/Oct 1971

The Low-down on Motors, YMR Oct 1984

The Basic Attraction. Magnetic theory. YMR Jan 1985

Improve the Whining Power. Improving commercial motors. YMR Sept 1985

Rolling Your Own. Home made motors. YMR Oct 1985

Sources of Material

Winding Wire

Scientific Wire Company.

Phosphor bronze wire - Clarkenwell Screw Company.

Surplus relay coils.

Stewart Hine can supply limited quantities of 46SWG

Iron for armature core

Try local radio repairer for scrapped small transformers, or Stewart Hine.

Magnets

Magnetic Applications, North Bridge Road, Berkhamstead, Herts, HP4 1EH. Tel 0442 875081

Magnet Developments, Unit 17, Highworth Industrial Park, Highworth, Swindon, SN6 7NA. Tel 0793 766001,

Scrapped loudspeaker magnets, cracked and ground to size.

Potting Resin

Alec Tiranti, (adverts in model railway press from time to time).

Transformer Resin

RS Components insulating varnish (555-550),

Brown French Polish from DIY shop.

Note that RS Components do not sell direct to the public, but do operate a sister organisation, Electromail. An alternative is Maplin Electronics.