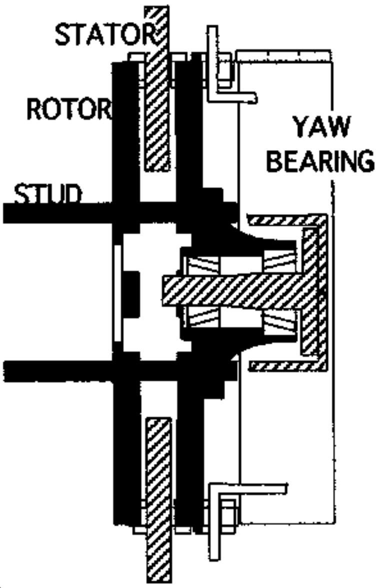
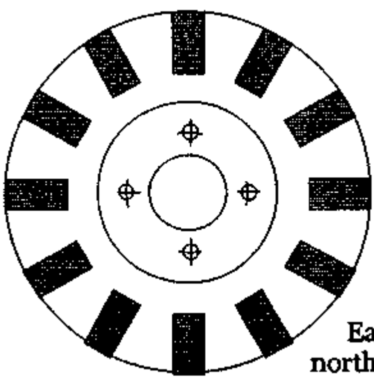
ALTERNATOR THEORY

The alternator consists of a stator disk sandwiched between two magnet rotors. Strong magnetic flux passed between the two rotors and through the coils in the stator. The movement of the rotors sweeps the flux across the coils, producing alternating voltages in them.

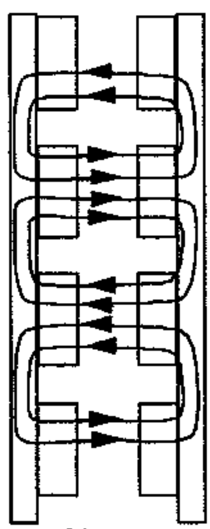
This sectional view shows the rotating parts in black. Four 1/2"[12 mm] allthread studs [threaded rod] support the two magnet rotors on the hub flange, and keep them at the correct spacing apart from each other. The same studs are also used for mounting the blades on the front of the alternator.





There are 12 magnet blocks on each rotor. We embed the blocks in a polyester resin casting to support them, and to protect them from corrosion.

Each magnet block has a north pole and a south pole. The poles are arranged alternately, so north faces the stator on one block and south on the next. The poles on the other magnet rotor are arranged in the opposite polarity, so that north poles face south poles across the stator. In this way, a strong magnetic flux is created through the stator between the magnet rotors.

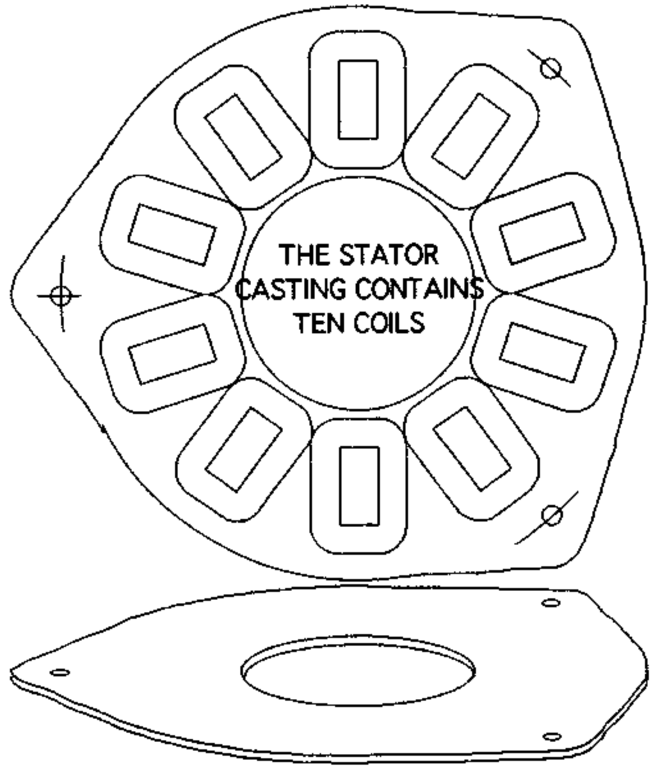


Magnetic flux travels best through steel. The rotor disks are made from thick steel plate to carry the flux. But the magnets have to work hard to push flux across the gaps, because there is no steel. A wider gap allows more room for a fatter stator, but weakens the flux.

The stator

The stator is mounted at three points around its periphery, using three more 1/2" [12 mm] studs. The coils embedded within it are dimensioned such as to encircle the flux from one magnet pole at a time. As the magnet blocks pass a coil, the flux through the coil alternates in direction. This induces an alternating voltage in each turn of the coil. The voltage is proportional to the rate of change of flux. Voltage therefore depends on:

- the speed of rotation
- the density of the flux
- the number of turns in the coil.

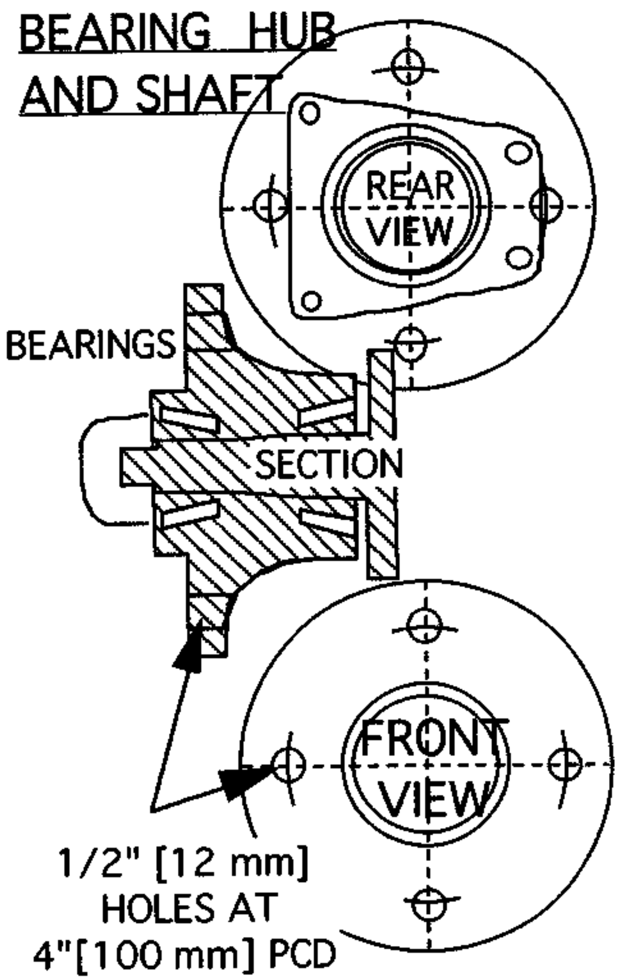


The number of turns of wire in each coil is used to control the speed of the wind turbine. If the number of turns is large, then the output will reach battery voltage and start to charge the battery at a low rotational speed (rpm). If we use fewer turns of thicker wire in the coils, then it will need to run faster. The number is chosen to suit the rotor blades and also the battery voltage.

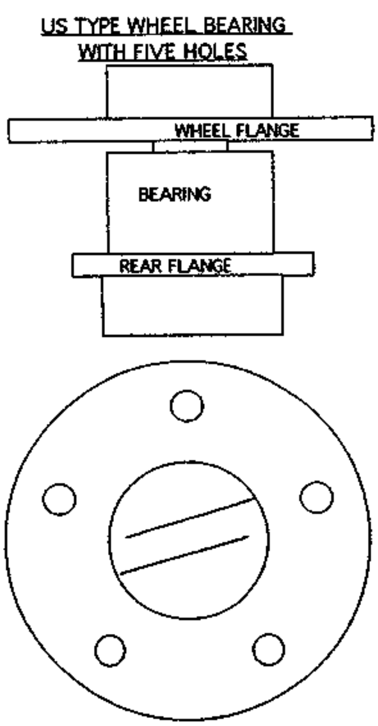
There are ten coils in the stator. The twelve magnet poles pass the coils at different times. This phase lag between coils means that the torque is much smoother than it would be if there were 12 coils. If all the coils were synchronised with each other (single phase) then the machine would vibrate quite intensely when producing power.

Preparing the bearing hub

A wheel-bearing hub from a car makes a good bearing for the alternator. In the UK, Vauxhall Cavalier rear bearing hubs from around 'B' or 'C' registered vehicles are ideal for example. Remove the stub shaft from the vehicle by removing four screws in the rear flange. Keep the screws if possible.



The level of corrosion is usually pretty high but this need not be a worry. Undo or drill out the small retaining screw on the brakedrum. Remove the brake drum using a hammer and a lever. Prise off the dust cover from the bearings. Remove the split pin and undo the retaining nut. Dismantle the bearings and inspect them. If they look worn or corroded, replace them. This entails knocking out the outer shells from the hub casting and replacing them too. Bearing sets are available from motor parts factors. You can discard the seal at the back of the hub. It will create too much friction and is not necessary.



Clean all parts with a rag or paint brush and some gasoline [petrol] or parafin. Take special care to clean the bearing races meticulously if you plan to re-use them. When the time comes for re-assembly of the hub to the shaft, grease the old bearings lightly to prevent excessive friction. Tighten the retaining nut with a spanner, rotate the hub and slacken the nut again. Tighten with fingers and check that there is no slack but the hub revolves freely. Lock the nut with a split pin and replace the dust cover.

In the USA it may be easier to find a different type of wheel hub with five holes in the wheel. The American hubs made by General Motors for the Citation, Cavalier and other medium sized cars has a wheel flange with five studs.

The USA/GM hub is like the UK hub reversed. The GM hub's wheel flange is mounted on a shaft that runs inside a bearing, rather than being mounted on a bearing that runs on a shaft. Consequently the bearing is at the back end in this type of hub. The inboard end of this hub unit also has a flange.

Drilling out the 1/2' [12 mm] holes in the flange

The wheel flange on the hub already has four holes in it. The holes may also have wheel studs in them. Knock any wheel studs out with a hammer. We need to enlarge the holes to 1/2" [12 mm] diameter. Support the hub on a drill press so that the flange is level, and drill the four holes out with a 1/2" [12 mm] drill.

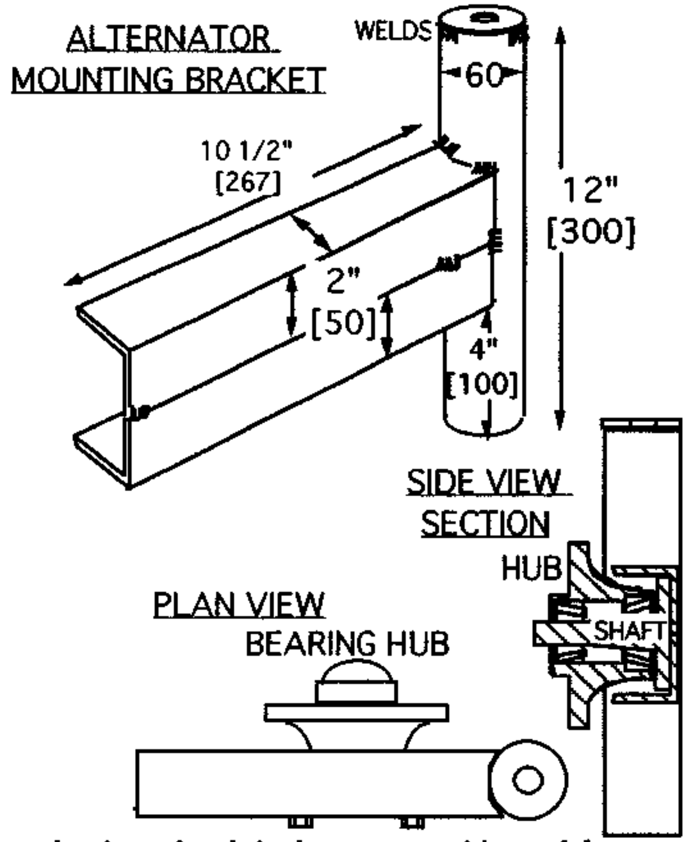
The holes in the shaft rear flange may have been tapped out with an unusual thread. If you still have the original screws in usable condition, this is not a problem. If not then enlarge these holes to 3/8" [10 mm]. Then you can use 3/8" [M10] bolts and nuts.

The rear flange may have a bulge or projection in the centre. It may be possible to grind this off. If not then you will have to make a hole in the mounting bracket to accommodate this lump.

Look ahead two pages for a *mounting diagram* for the GM hub with bearing housing at the rear.

Fabricating the alternator mounts

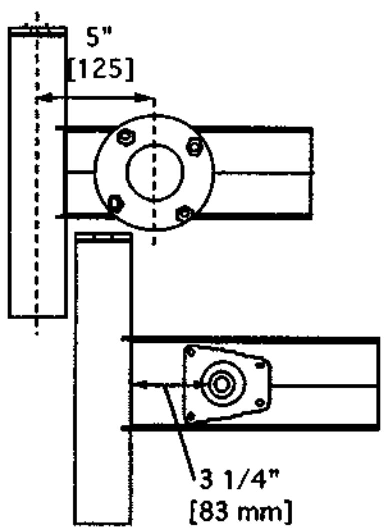
Materials				
Pieces	Material	Length	Diameter	Thick
1	Steel pipe 2" nominal	12" [300]	2 3/8" 60.3 OD	1/8" 3 mm
1	Steel plate	2 1/2"[65]	2 1/2"[65]	5/16"
2	Steel angle	10 1/2" [267 mm] or 11 1/2" for GM hub	2" [50 mm]	1/4" [6]
2	Steel angle	2" [50mm]	2" [50 mm]	1/4" [6]
1	Steel angle	4" [100 mm]	2" [50 mm]	1/4" [6]



The centrepiece of the wind turbine mounting is the yaw bearing. A 12" [300 mm] piece of 2"nominal bore pipe (60.3 mm overall diameter) will be used for the outer part of this bearing assembly. Weld a small disk onto the top of this pipe. An off-cut from the magnet-plate hole-saw operation is perfect. First enlarge the central hole to about 3/4" [20 mm] for wiring down the tower/mast. Take care to weld this top plate on square.

The 'yaw bearing' pipe will simply drop onto a piece of 1.5" nominal bore steel pipe and rotate on it with some grease (and maybe a washer) between them. It's such a simple concept that most people can't believe it but it works very well. In small wind turbine design, the simplest solutions are usually the most successful and reliable, as well as being cheap and easy.

The alternator mounting bracket consists of two pieces of 2" x 2" x 1/4" [50 x 50 x 6 mm] steel angle, each 10 1/2" [267 mm] long. They are welded to the centre of the yaw bearing outer tube, to form a channel into which the rear flange of the shaft fits, and is bolted on. See next page for an alternative style to suit the GM type of hub found in the USA.



The ends of the pieces of angle will need to be shaped with a grinder to the curve of the yaw-bearing pipe before welding. Note that the curve is symmetrical, and the bracket therefore sits centrally on the pipe in both directions. In the case of the GM hub the curve is asymmetrical but you can place the pipe over the piece of angle in the correct position and draw around it.

The bracket face should be near vertical (parallel to the yaw bearing). If there is any tilt, it should be slightly clockwise in the above side-view. This would increase the clearance of the blade tips from the tower.

Position the shaft flange centrally between the upper and lower faces of the channel, and 5"[125 mm] away from the centre of the yaw bearing. It is not easy to measure this offset as such but if you measure the shaft diameter as 15/16" [24 mm] (say) then you can compute that the space between the outside of the yaw pipe and the side of the shaft must be 3 1/4" [83 mm]. (125 mm - (60 + 24)/2) = 83 mm

Use a suitable drill size (5/16" [9 mm]?) to mark the positions of the four holes and then drill them out 3/8" [10 mm] to fit the mounting bolts.

Mounting diagrams

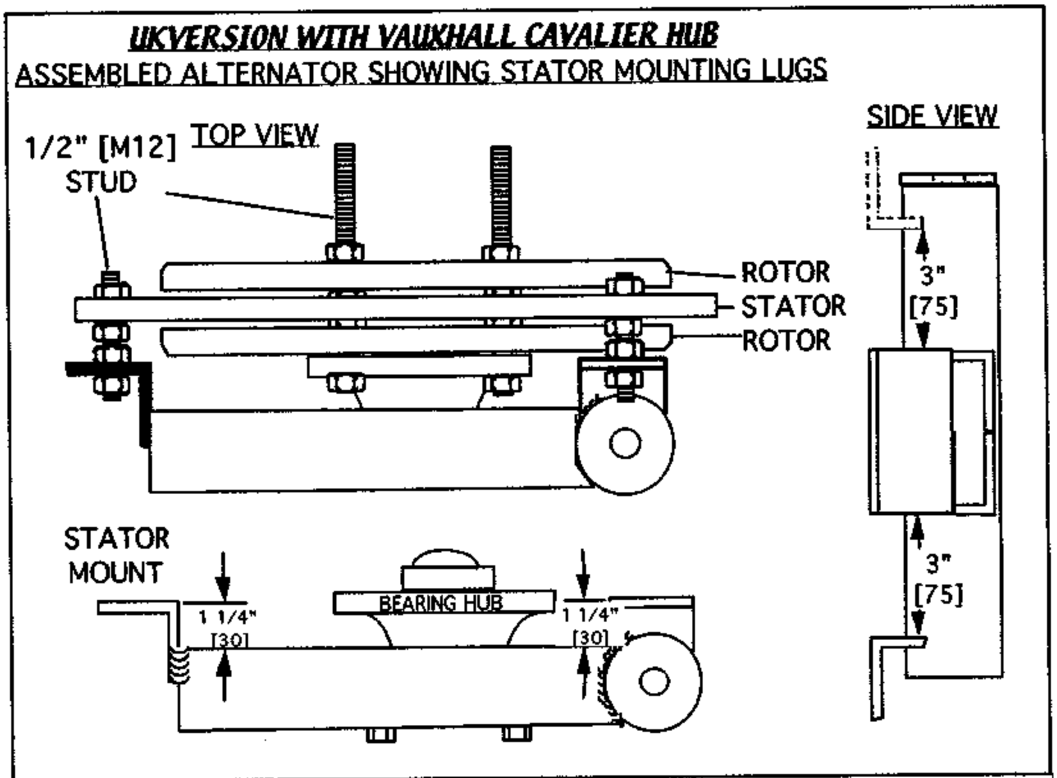
There are two diagrams on this page to show the two different types of hub. The top diagram is for the UK Cavalier hub. The lower one shows the USA General Motors hub.

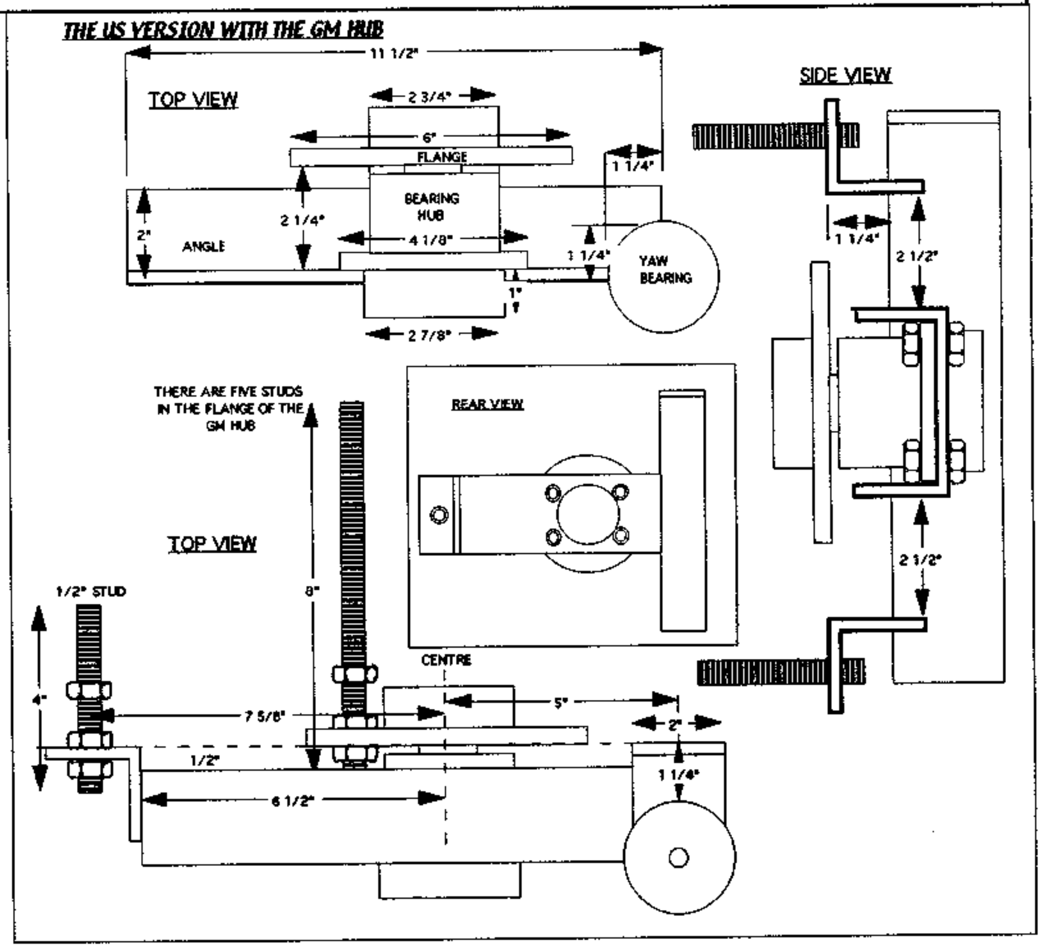
The bearing is at the back end in the USA type of hub. The inboard end of this hub unit has a flange that you can use to mount it within the channel, but the bearing housing projects beyond this rear flange. To mount this unit within the support bracket, you have to cut a hole about 3" in diameter through the bracket. Secure the rear flange to the bracket with four 1/2" bolts as shown in the lower diagram.

The stator will be mounted on three 1/2" studs. The studs in their turn will be supported by three lugs made from 2" [50 mm] steel angle. The lengths of angle required are 2"[50], 2"[50] and 4"[100 mm]. The 4" [100 mm] length needs to be welded across the end of the shaft support bracket (channel section) described above. The smaller brackets will be welded directly to the yaw bearing tube, top and bottom.

Stator lug positions

The USA magnet version has slightly different stator dimensions from the UK metric magnet version. The upper drawing applies to UK magnets, and the lower one is for 2" x 1" USA magnets.



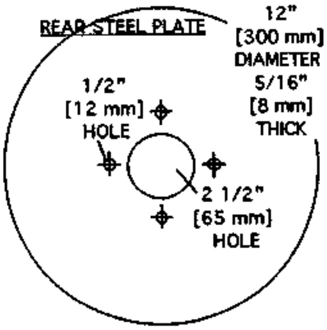


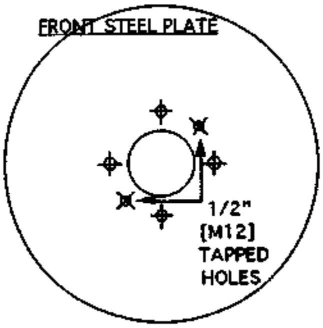
Drilling the magnet rotor plates

The magnet rotors consist of 12" [300 mm] diameter disks, cut out of 5/16" [8 mm] mild steel plate. 12 magnet blocks will be mounted on each magnet-plate, and encapsulated in a polyester resin casting.

The steel plates are then mounted on the bearing hub in such a way that the magnets face each other across a small gap. The stator will be mounted in this gap.

Once the hub flange has been drilled, it can be used as a guide for drilling the hole patterns in the magnet plates. This is more accurate than marking out all the centres of the magnet-plate holes by hand. It is important that the holes align accurately with the hub holes, or the mounting studs will be squint (in USA = askew).

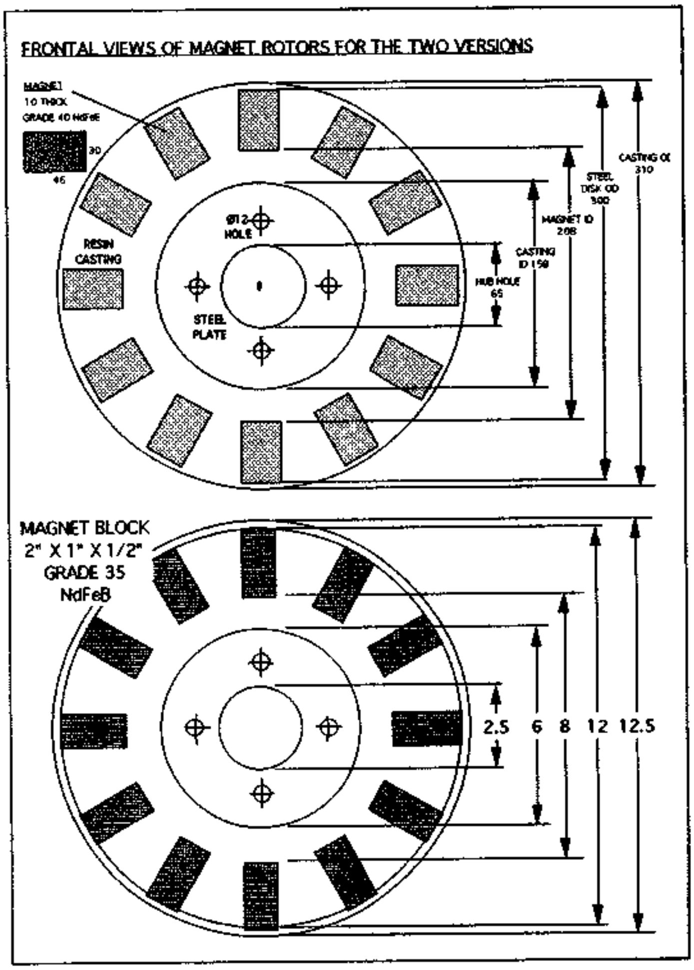




Use a holesaw to cut a clearance hole for the bearing stub on the hub. A 2 1/2" [65 mm] holesaw is a good size. This will allow the rear magnet-plate to sit flat on the hub flange. It is also useful to have a large hole in the second magnet-plate. Keep the off-cut disks from the holesaw for use in the yaw bearing and tail bearing.

Bolt the bearing hub onto each magnet-plate in turn and revolve the bearing to check for correct centring. Prop a ruler or piece of wire close to the edge and adjust the position until the plate runs true. Tighten the clamps and drill holes through the flange holes and into the plate. Fit a bolt into each hole as you go and re-check the centring. Make an index mark to record the position of the disk on the hub for future reference during assembly. Drilling an index hole through the hub flange and both disks is a good way to keep track of the positions. Mark the faces of the disk for correct reassembly.

Repeat this operation using the front plate. Finally drill two 3/8" [10 mm] holes in the front plate on the same circle as the 12-mm holes, but midway between them. Tap these holes out with 1/2" thread [M12]. These holes will be used to jack the font plate on and off the alternator using long 1/2" [M12] screws. This is necessary because the forces pulling the magnet rotors together will be very large when the magnet blocks have been added to them.



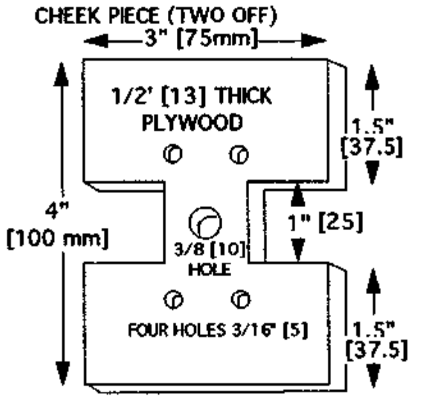
Remove any burr from the edges of all the holes. The magnet-plates are now almost ready for resin casting. (See 'Casting the rotors'). Sand them at the last minute.

Making the coil winder

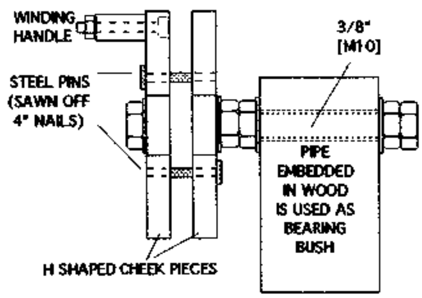
Materials				
Pieces	Material	Length	Width	Thick
3	Plywood	4" [100 mm]	Over 3" [75mm]	1/2" [13 mm]
4	Nails	4" [100 mm]	3/16" [5 mm]	
1	Stud or bolt	6" approx. [150 mm]	3/8" [10 mm]	
5	Nuts and washers		3/8" [10 mm]	

Make a coil-winding machine from pieces of 1/2" [13 mm] plywood mounted on a 3/8" [10 mm] bolt or allthread stud. Form the coil on four pins made from four-inch nails cut off short.

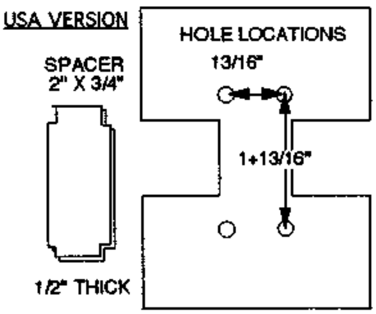
The sides of the coils are supported by two cheek-pieces, held 1/2" [13 mm] apart by a central spacer.



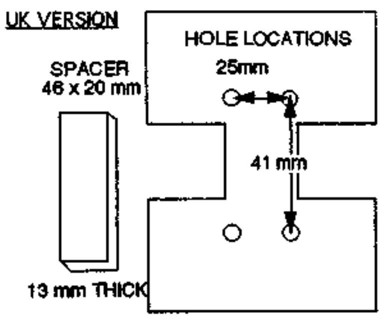
Each cheek piece has deep notches in opposite sides, to allow you to slip a piece of tape around the finished coil. The tape will hold the coil together when you remove it from the winding machine.



Fit a handle to one of the cheek pieces. You can use a small bolt carrying a piece of pipe for comfortable handling. The head of the bolt must be sunk into the wall of the cheek piece to prevent it from catching on the wires.



The positions of the holes for the nails will depend on the magnet shape. The top drawing is for the USA version with 2" x 1" magnet blocks. Note that the spacer has to be trimmed at the ends to clear the nails. Take care to drill the holes squarely into the cheeks.



It's a good idea to chamfer the corners of the cheek pieces slightly on the inside. This prevents the wire from catching on the corners as the winding machine revolves.

The 3/8 [M10] bolt is used as an axle. It rides in a hole through a piece of wood. It may turn more freely if the hole is lined with a bush of some sort - maybe a metal pipe. Tighten the nuts on the cheek pieces but <u>not</u> on the supporting bearing.

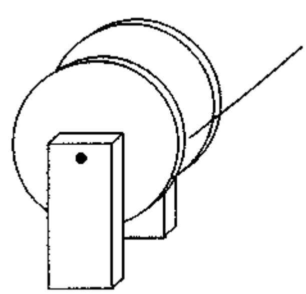
Winding the coils

Choose your wire to suit the magnet size and battery voltage. Metric sizes are suitable for metric magnet blocks.

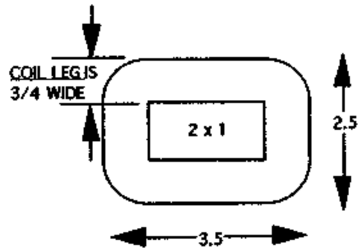
Materials			
Weight	Material	Turns per coil & size	Voltage
6 lbs. [3 kg] for ten coils	Enamel winding wire, called magnet wire	80 turns of #15 wire [90 turns of 1.4 mm]	12 V
		160 turns of #18 wire [180 turns of 1 mm]	24V
		320 turns of #21 wire [360 turns 0.7 mm]	48V

Build a stand for the reel of copper winding wire. Take care to keep the wire straight. Avoid bending it unnecessarily or scraping in the enamel. Align the coil winder to the reel stand, so that the wire can feed into it parallel to the cheek pieces.

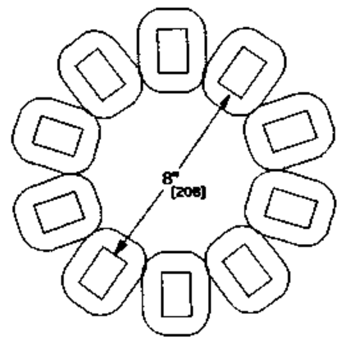
WIRE REEL HOLDER



Make a tight 90-degree bend about 4" [100 mm] from the end of the wire and place it into the coil winder, in a notch in the outer cheek piece. Tuck the wire in close against the cheek piece. Wind the tail of wire around the 3/8"[M10] nut, such that it cannot slip off.



Now grasp the incoming wire with one hand. Wind the handle with the other hand, counting the turns as you go. Use the first hand to keep a gentle tension in the wire, and to control how it lies in the winder. Lay the turns of wire together snugly, and build the coil turns up in neat layers. Work from one side gradually across to the other and gradually back. Do not allow the wire to 'wander to and fro' from side to side or the coil will not be able to accommodate the necessary number of turns.



When you have the right number of turns of wire on the winder, it is time to tape the coil. Do not release the tension in the wire until it is securely taped. Slide the end of a piece of tape under the coil using the notch and wrap it securely. Do the same on both sides before you release the tension.

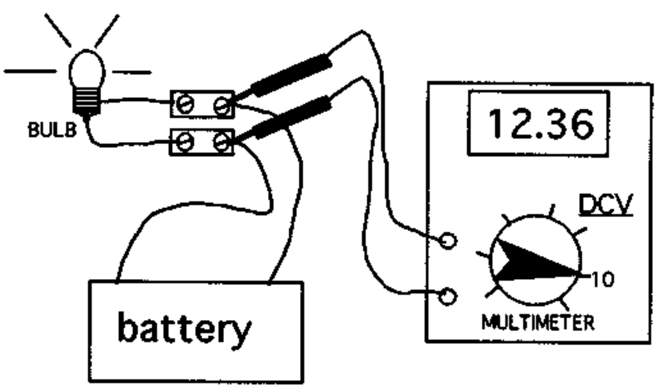
Check that the dimensions of the coil are as shown. Repeat this process until you have ten coils.

If in doubt about the number of turns, weigh each coil and compare them. Small errors are not significant but the weights should be the same within 5% or so at worst.

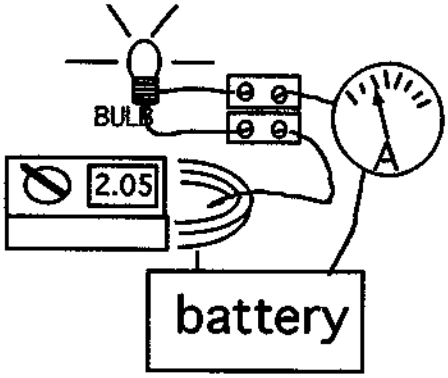
The ten coils will be laid out in a circle to match the magnet blocks. The spacing between the inner edges of the holes will be 8 inches, or 208 mm for the metric magnets, as shown.

ELECTRICAL THEORY

The electrical output of the wind turbine can be measured as a voltage and a current. Voltage is 'electrical pressure' and is usually constant for a particular supply (hence 12-volt or 240-volt supply). You can measure the voltage of a supply with a multi-meter. Touch the two probes of the meter to the two wires from the supply and read out the voltage.



Current in electric circuits can also be measured. Current in 'amps' normally varies slowly from zero to some high value and back, as time goes by and conditions change. When current flows in electrical circuits, then power is being transmitted from the supply to the 'load'.



This diagram shows two sorts of ammeter. One is analogue, and the other is a digital clamp-meter. In both cases the current passes through the meter in some way.

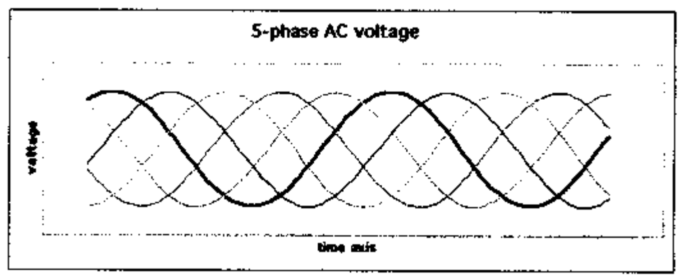
Here the supply is a battery and the load is a bulb. The supply can be a wind turbine and the load can be a battery. In either case the power transmitted is measured in 'watts'. Power output is calculated by multiplying the voltage by the current. For example a 20-amp current in a 12-volt circuit delivers 240 watts.

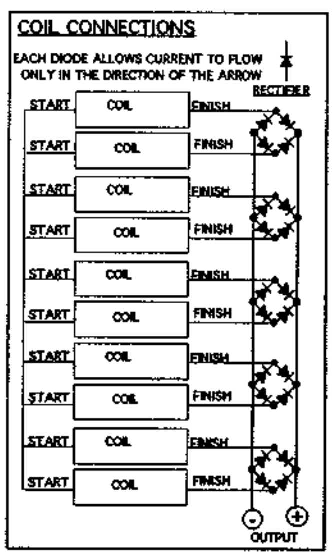
There are two types of supply, AC and DC. Batteries always provide Direct Current (DC). DC is constant in its polarity and magnitude over time. One wire is termed 'positive' and the other 'negative'.

The mains grid on the other hand supplies Alternating Current (AC). In the case of an AC supply, the polarity reverses constantly, many times each second, and the magnitude rises and falls in a 'waveform'. AC can be converted to DC using a rectifier, consisting of a number of one-way junctions called 'diodes'.

You can use a multimeter to measure AC voltage, but you need to change the selector switch to ACV. The voltage displayed will be a sort of 'average' value of the constantly varying level.

The alternator in our wind turbine produces 5-phase AC. This means that the voltages from the coils are rising and falling at different times from each other. Here is a graph, showing how the voltages vary over time.





We connect the coils in 'star' configuration, with all the starts together and the AC output taken from the finish tails. Connecting these tails to a rectifier converts the AC into DC by only allowing the current to flow in one direction through the DC output circuit.

The voltage produced by the coils will depend on both the speed of rotation (see 'Alternator Theory') and also on the current supplied by the alternator. Some voltage is lost internally when there is current through the coils.

Connecting the coils

Materials			
length	Material	Size	Voltage
30' [10 m]	Flexible wire with high temperature insulation	#14 [2 mm] or similar	12-V
		#18 [0.5 mm] or similar	24-V or 48-v
3' [1 m]	Resin cored solder wire		
3' [1 m]	Insulation sleeving	Large enough to fit over the joints	

Hints for soldering

Use a clean soldering iron and makes sure it is hot before you start. Touch some solder wire onto the tip of the iron and it should melt on instantly.

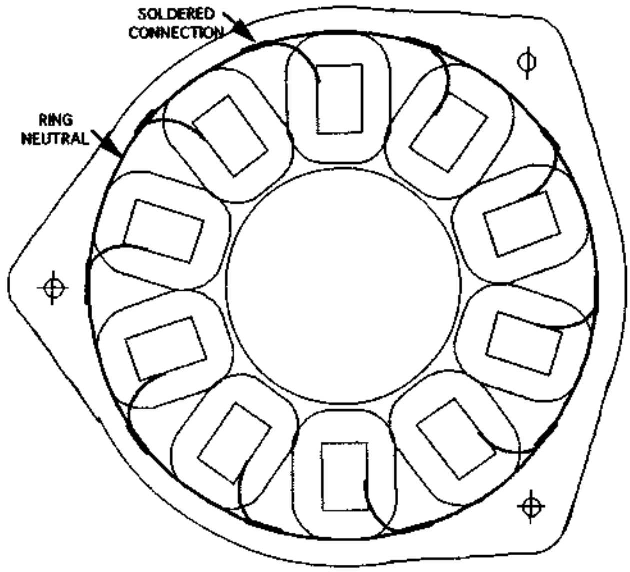
Twist the wires together in a joint and place the tip of the iron against this joint so as to achieve maximum contact area. Wait a second or two and then feed solder wire into the point of contact between iron and joint. The solder should melt into the joint and assist with carrying heat further into the joint. Give it time. Keep the iron there until the joint is full of solder and then remove. Take care not to disturb the joint until the solder sets (2 seconds). Never try to add solder to a joint from the iron. The solder must come from the reel of solder wire. The resin core in the wire helps the solder to flow into the joint.

Soldering the coil tails

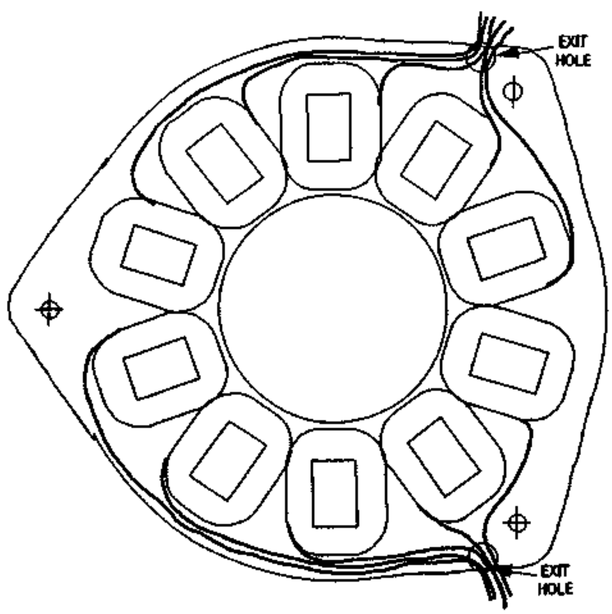
The copper winding-wire has enamel coating which insulates it from its neighbours in the coil. Before soldering the ends onto flexible tails, you must clean this enamel off a short length. Scrape 3/4" [20mm] of the coating off the end of the wire with a sharp knife or sandpaper. Use the soldering iron and some solder to coat or 'tin' the end of the wire with solder. Twist the flex around the tinned wire or place them side-by-side, bind them with a thin strand of copper. Then solder them together. Slip some insulation sleeving over the joint.

Lay the coils in the stator mould as shown below. They all have to be exactly the same in orientation, with the starting tail on top. It does not matter if your coils are a mirror image of the ones shown so long as they are all the same.

The ring neutral



Take a piece of flexible stranded insulated wire (flex), and make a loop that fits snugly around the outside of the coils in a ring. The loop will rest against the outer edges of the coils in such a way as to hold them in, against each other in the desired position.
(See "winding the coils" for correct spacing of 8" [208 mm]). There should be about 3/16" [5 mm] between the inside of the coils and the central disk.



Before soldering the insulated flex finally into a loop, cut ten lengths of sleeving 1 1/2" [30 mm] long, and thread them all onto the loop. Strip about 1/2" [15 mm] of insulation off the flex at equal intervals, to allow soldered connections at each coil as shown. Then solder the ends of the flex together so the loop fits around the ten coils with no slack. This loop of flexible wire is the 'ring neutral' connecting all the starts together. It will have no direct connection to anything else.

The output wiring

The finishes of the coils provide the output to the rectifier. Each finish wire needs a tail of flex soldered to it. The tails are then brought out through the two holes in the mould. The second diagram shows the output tails without showing the ring neutral. It also shows the positions where the mounting holes will be drilled.

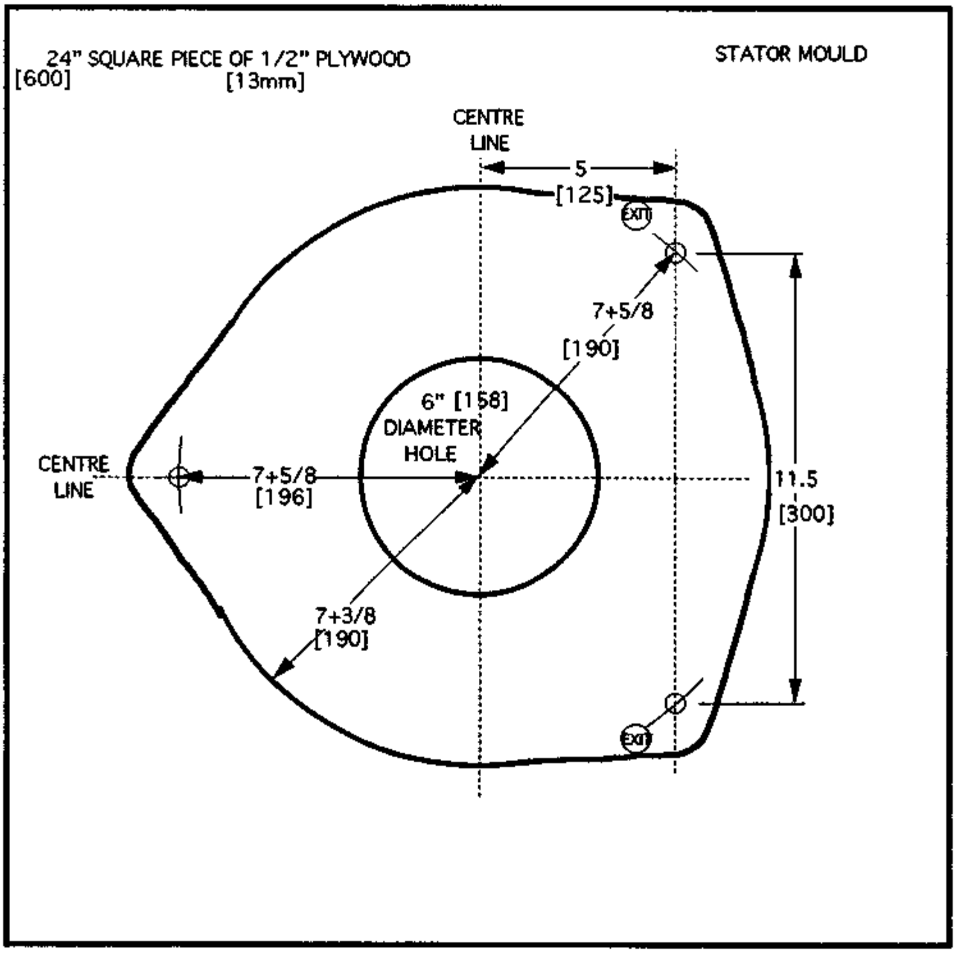
Take care to make the tails long enough to reach the rectifier. Use cable ties to secure the flex wiring together neatly. Ensure that they are secured away from the positions of the mounting holes or they could be damaged during the drilling of these holes.

When the wiring is complete, carefully slide the coil assembly from the stator mould and place it on a flat sheet of board. You can slide it into place in the casting when the time comes.

Making the stator mould

Materials				
Pieces	Material	Length	Width	Thick
1	Plywood	24" [600]	24" [600]	1/2" [13]
2	Smooth faced board	24" [600]	24" [600]	3/4" [19] suggested size
	Silicone sealant			
	Wax polish			
3	1/4" [6mm] x 1 1/2" [35mm] Bolts			
10	Screws			

The ten coils should fit neatly into a flat mould, where they will be encapsulated in polyester resin to form the stator. The stator will have a hole in the middle through which the four rotor-supporting studs will pass. At the periphery it will have three lugs where it is to be supported by 1/2"[M12] stainless allthread studs.



Mark out the shape of the stator.

Use the metric figures for the metric magnets

- Start with **a piece of 1/2"[13 mm] plywood approximately 24"[600] square.**

- Draw **vertical and horizontal** centre-lines, at exactly 90 degrees, and an **offset vertical line 5" [125 mm] to the right** of the vertical line.

- Draw two circles on the intersection of the centre lines. **The radius for the inner circle is 3"[79 mm] and the outer circle is 7+3/8"[190].**

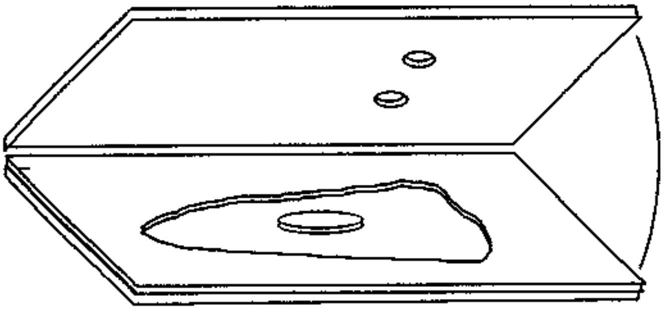
If you have no compasses big enough, then a strip of plywood will often work best. Drill a hole for a pencil at one point, and screw a wood-screw through at another point spaced at the correct radius.

- Mark the **mounting-hole centres 7+5/8" [196] away from the centre.** Mark two centres on the offset line. The separation should be 11+1/2"[300 mm]. Mark the third hole's centre on the horizontal centre-line, opposite the offset line. Do not drill any holes yet!

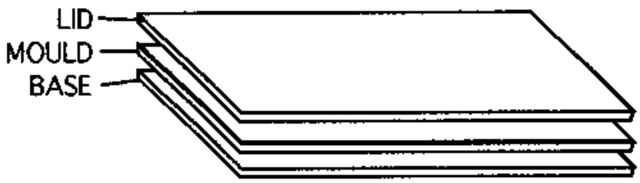
- Draw **arcs on these three hole-centres at 1+1/4" [30 mm] radius.** These describe the outsides of the mounting lugs. Finally use a ruler to connect the big circle to these new arcs with tangential lines so that the outside edge of the stator is a smooth shape. **Do not cut the mould out yet.**

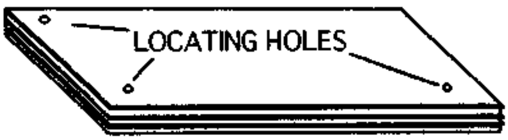
Sandwiching the stator mould.

While being cast, the stator will be sandwiched between two smooth-faced boards: a base and a lid. Discarded kitchen cabinets or worktops are good for this purpose, or you can use thick composite board for strength, and add smooth hardboard for the finish.



- **Stack** the three boards on top of each other. The smooth faces of the lid and the base need to be in contact with the mould plywood.

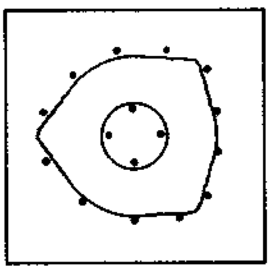




- **Drill** three locating holes through the stack so that you will be able to reassemble the sandwich accurately. This will help you get things in the right places. Fit each hole with a suitable bolt (say 1/4" [6mm]).

- **Mark** the boards for correct reassembly - lid, mould, base - tops and bottoms labelled clearly.

- Fit the mould to the underside of the lid, and **drill through** the surround into the lid with plentiful 3/16" [5 mm] holes for later use by clamping screws. Space these holes about 1" [25 mm] away from the lines.



You will later be able to screw the lid down hard to the base and squeeze the casting thickness to a minimum.

Cut out the stator shape in plywood.

- Use a jigsaw to **cut out the stator mould** by following the inner circle and then the outer shape including the lugs. It may be necessary to drill entry holes to get the saw blade through the plywood. Drill any such holes outside the inner circle and inside the outer shape.

The central island and outer surround will both be used later for moulding the polyester resin casting. Their edges should be as smooth as possible. If they have cavities then fill them and sand the surface smooth.

The stator-shaped piece left over (with the mounting hole marks) will be the exact shape of the finished stator. It will come in useful as a dummy when drilling the mounting holes into the supporting lugs and in the stator casting itself.

Wiring exit holes

- Replace the surround onto the lid, and **drill two 3/4" holes** in the lid to allow for the wiring to emerge from the mould. These exit holes will flood with resin. If you can form them into a smooth conical shape (perhaps using a tapered reamer), then this will facilitate removal of the lid without damage to the wiring. The wiring will emerge right at the stator edge, well clear of the magnet rotor edge. I recommend positioning these holes' centres about 1+1/2"[30 mm] away from, and to the left of the right hand mounting holes.

Screw the mould to its base

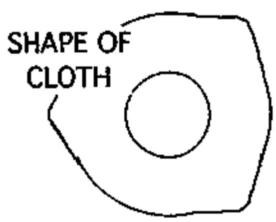
- Place the mould surround onto the base correctly and **screw it down,** using different holes (not the ones you drilled through the lid). Use the lid holes to position the central island on the base and then screw that down too. Cover the screw heads with polish and/or tape to prevent flooding with resin.

- **Apply a fillet of silicone sealant** to the inner corners, and polish all exposed surfaces of the mould: surround, island, lid and base generously so that the polyester resin will release. Apply plenty of polish to the wiring-exit holes. Run a thin bead of silicone around the rims of the surround and island to counteract resin leakage.

Casting the stator

Materials	
Quantity	**Material**
3lbs [1.4 kg]	Polyester resin (premixed with accelerator) casting resin or fibreglass resin in liquid form. Peroxide catalyst to suit.
2.5 lbs. [1.2 kg]	Talcum powder
3' x 18" [1 x .5 m]	Fibreglass cloth or chopped strand mat (1 ounce per sq. foot) or [300g per sq. metre]
20	Wood screws 1 1/4" [30 mm]

Before you start, read through the instructions and be sure you have everything to hand including resin, talcum powder, paint brush, fibreglass cloth, coils pre-wired, and screws to clamp the mould together.



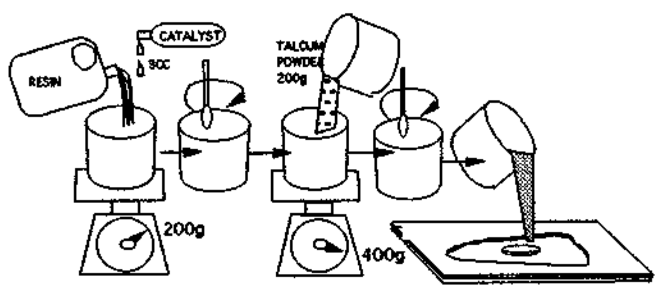
Cut two sheets of fibreglass cloth (or 'chopped strand mat' will do) to fit inside the mould. You can use the off-cut piece of 1/2' [13 mm] plywood as a template for the cloth. Mark the shape with a felt pen and then cut slightly inside the line so that your cloth will lie in the mould comfortably. Make provision for the wires where they exit the mould. Some small extra pieces of cloth can also be useful for strengthening the lugs (see later).

Dry run

Go through the process of assembling the stator as a dry run **without resin** just to check that everything fits and there will be no hold-ups when the resin is going into the mould.

Putting it together

When all is prepared, you can get out the polyester resin and start the job. Wear latex gloves to protect your skin. Take great care not to splash resin in your eyes. This job should be done in a well-ventilated area to disperse the solvent fumes. Cover the workbench with newspaper to protect against spilt or overflowing resin.



- **Mix** 1/2lb [200 grams] of resin with 1/2 teaspoon [3 cc] of catalyst. Use no talcum powder at first. You can use pigment if desired. Mix very thoroughly but try to avoid stirring in too much air. Use the mixed resin immediately. If you delay a few minutes it may heat up in the pot, and become useless.

- **Paint** some of this resin mixture onto the lower surface of the mould. Do not paint so vigorously that you remove the polish. Lay one sheet of fibreglass cloth onto the painted surface, and saturate it with more resin. Use a 'poking' motion of the brush to remove air bubbles.

- **Slide** the pre-wired coils into place, making sure the wires are positioned correctly for the exit holes in the lid.

- **Pour** the remains of the liquid resin mix over the copper coils so that it soaks in between the wires.

- Prepare **another resin batch** in the same container, using 1 lb. [400 grams] of resin and 1.5 tsp. [6 cc] of catalyst. Mix the catalyst in carefully, and then add about 11 lb. [400 grams] of **talcum powder**. Mix again.

- **Pour this mix** in between the coils and around the edge.

- **Bang the mould** to encourage air bubbles to rise. Add pieces of fibreglass to the lugs for reinforcement, and poke them to dislodge bubbles.

- **Add further resin/talcum powder mixes** until the mould is full to the brim.

- Apply the **second sheet** of fibreglass cloth. Paint resin onto the top surface of the cloth. Poke it to remove bubbles. Clean the paintbrush before the resin sets.

- **Place the lid** onto the mould, carefully threading the wiring through the two holes as you do so. Screw the lid down firmly. Wipe up any resin overflowing from the casting. Take care that the screw heads do not fill with resin, making it hard to remove them later. You can fill them with polish, grease or silicone as a protection.

- **Mop up** resin seeping out from the mould at the edges and through the wiring exits. **Tighten** the screws again.

Keep the mould in a warm place for a few hours. If the resin shows no signs of setting, then heat the mould in front of a radiant fire for a few minutes to kick-start the reaction. It is normal for the resin casting to heat up slightly once the resin begins to cure.

Removing the casting from the mould

When the resin is fully hardened, you can dismantle the mould. Remove all the screws. Prise the layers of board apart in several places. Use hammer blows to break the bond between the boards and the casting. Take special care in the area of the wiring exit holes to avoid damaging the insulation of the flexible tails.

The magnet-positioning jig

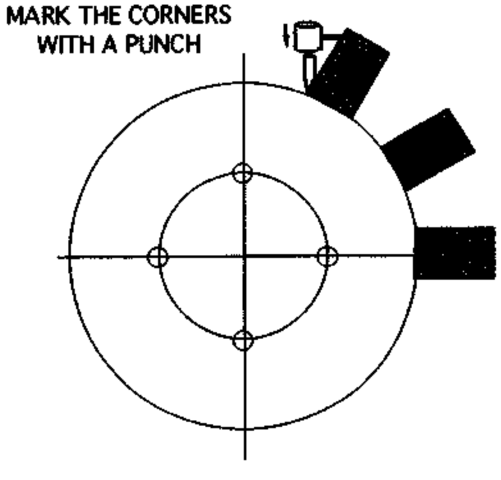
Materials				
Pieces	Material	Length	Width	Thick
1	Hardboard or plywood	12" [300]	12" [300]	1/4" 6]

The magnet layouts are different for the two versions 'English' and 'Metric'.

The drawing on the next page shows the magnet positions drawn to scale. There is only room for 1/4 of the magnet rotor on the page, but you can still use this drawing to make the magnet-positioning jig. Use this page or a photocopy of it to mark out the magnet positions on a piece of board as described below. Check that the dimensions are accurate and not scaled up or down by mistake.

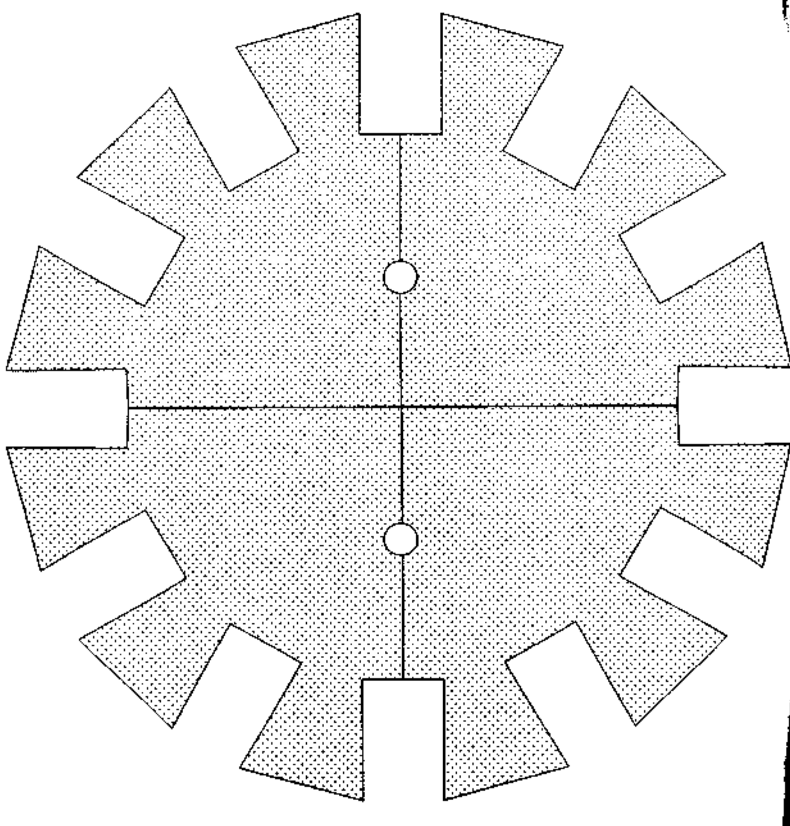
- Mark the centre of the board.
- Draw two circles with radius 2"[50 mm] and 4"[104 mm] respectively.
- Draw two lines through the centre of the circles at right angles to each other.

- Align the drawing exactly on each quarter of the jig and mark the corners of each magnet with a centre punch or sharp nail.
- Draw lines connecting the punch-marks, and cut along the lines to create the jig. Use a jig-saw (US = sabresaw) or a bandsaw.
- Check with a magnet for a free sliding fit.

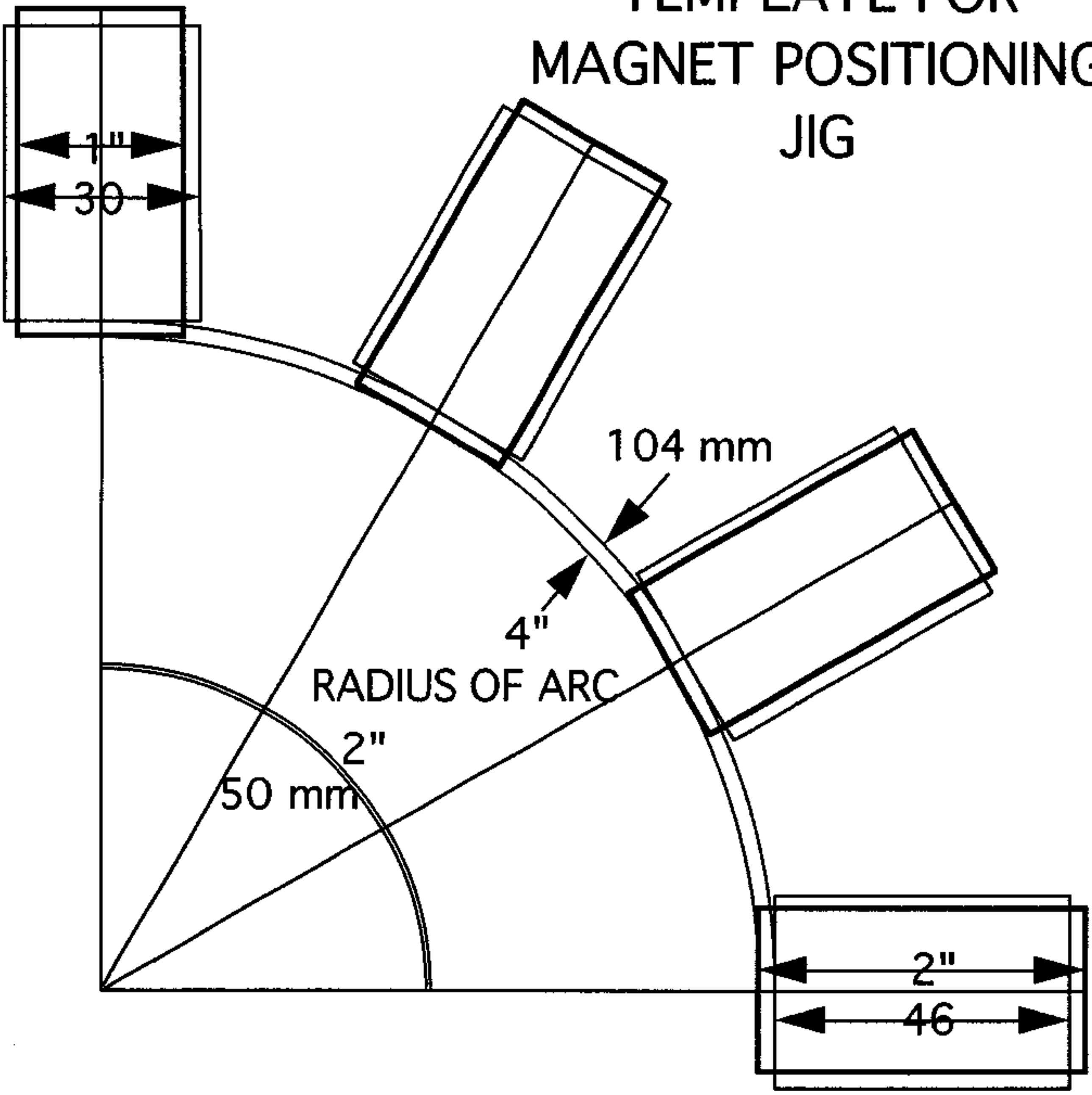


You will also need 1/2" [12 mm] holes on the 2"[50 mm] radius centres to locate the jig during use. I recommend you just use two bolts to do this, so two holes are sufficient. I recommend using a small pilot drill first to establish a reliable centre, followed by a 1/2" [12 mm] drill to fit the 1/2"[M12] bolt. Also drill the index hole to help keep track of the magnet pole positions.

The finished jig looks like this



TEMPLATE FOR MAGNET POSITIONING JIG



Making the two rotor moulds

Materials				
Pieces	Material	Length	Width	Thick
4	Floor board	16" [400]	16" [400]	3/4" [19]
2	Plywood	6" [158]	6" [158]	1/2" [10]
2	Hardboard	16" [400]	16" [400]	1/8" [3]
4	Bolts,nuts+ washers	3" [70 mm]	1/2" [12 mm]	
4	Screws			
	Silicone sealant			
	Wax polish			

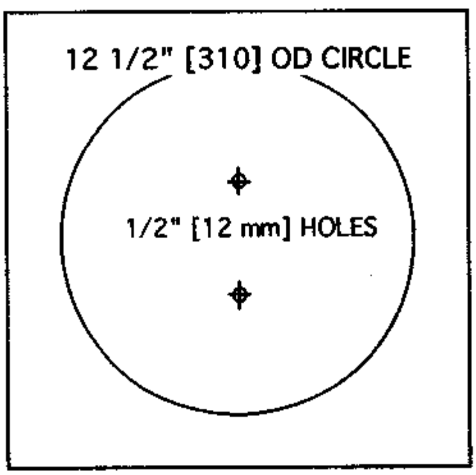
The magnets are mounted on 5/16" [8 mm] steel plates that have been drilled for mounting on the wheel-hub. We embed the magnets in resin to support them from flying off and to protect them from moisture that would cause corrosion. There is one mould for each rotor.

Index hole

It is a good idea to also drill the index hole for each magnet plate in each mould and in the jig, taking care to ensure that everything is assembled the right way up. This will keep all the magnets correctly aligned.

Parts of the moulds

Make the base of each mould from thick board with a smooth finish, (the same as the stator mould base). Cut a square 16" x 16" [400 x 400 mm], mark the centre, and draw a circle 6 1/4" [155 mm] radius to help you position the surround on it.



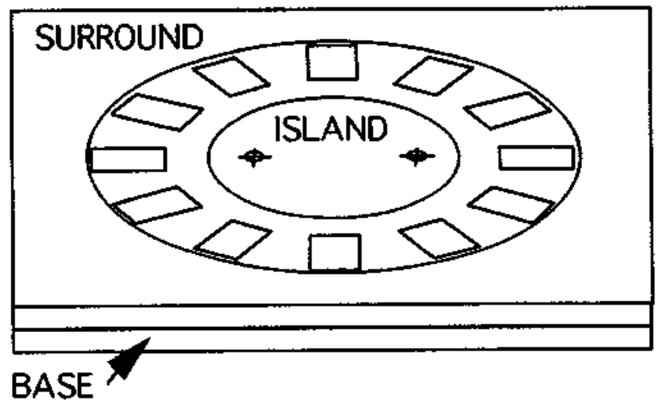
Place the steel disk at the exact centre of the base, and **drill** one or two 1/2" [12 mm] holes, and the index hole through holes in the plate. Counterbore the holes from the underneath to accommodate the heads of the bolts.

These bolts will later be used for positioning the steel plate, jig and island. Use the steel plate to guide the drill.

The **surrounds** are also 16" x 16" x 3/4" [400 x 400 x 19 mm] boards with a 12 1/2" [310 mm] diameter hole cut in it, to form the edge of the rotor casting.

The **islands** are made from 1/2" [10 mm] plywood. They keep the resin off the central portion of the steel disks where the mounts will be. The island diameter is 6" [158 mm](same as the stator-mould island). Again, each island needs to have holes at the correct positions to centre it on top of the steel disk.

Finally you will need **lids** for the moulds. Cut these out



these from 16" x 16" x 1/8" [400 x 400 x 3 mm] hardboard or anything thin and slippery. **Drill** oversized holes to fit over the nuts on the two bolts that secure the island.

Fill and sandpaper any cavities in the edges of the boards where the resin might penetrate and stick.

Screw the surround to the base, and run some silicone around the join. Coat the surfaces with wax polish, including the island (all over) and the lid. Be liberal with polish on the inside of the surround, and the outside of the island. Cover any screwheads with polish to facilitate disassembly later.

Casting the rotors

Preparation

Materials			
Pieces	Material	Diameter	Thick
2	Steel plate disks	12 " O.D. [300 mm]	5/16" 8 mm
Quantity	Material		
2.5lbs [1 kg]	Polyester resin (premixed with accelerator) casting resin or fibreglass resin in liquid form. Peroxide catalyst to suit.		
2.5 lbs. [1 kg]	Talcum powder		
3' x 18" [1 x .5 m]	Fibreglass cloth or chopped strand mat (1 ounce per sq. foot) or [300g per sq. metre]		
24	Magnet blocks 2 x 1 x 1/2" grade 35 NdFeB [46 x 30 x 10 mm grade 40 NdFeB]		
	Pieces of steel, spanners etc to load the lids.		

Cut out two disks of fibreglass cloth. Overall diameter is 12" [300 mm] and cut a central hole about 6 1/2" [170 mm] diameter.

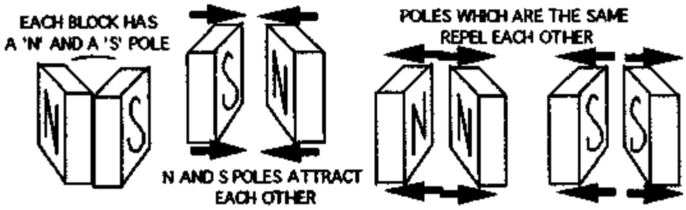
Check that the rotor disks have all the necessary holes drilled, and the front disk has tapped holes ready for the jacking screws.

Just before casting the rotors, **sand** any mill-scale off the area where the magnets will sit, and **clean** them to remove any grease.

Place the disks onto the two positioning bolts. The sanded side should be uppermost and the index holes should be aligned.

Handling the magnets

The Neodymium Iron Boron blocks are magnetised through their thickness so as to produce a north pole on one face and a south pole on the other. North and south poles attract each other. North repels north and south repels south.



The magnet blocks are <u>very</u> strongly attracted to each other, and to steel. Hold onto them very tightly with both hands while handling them, or they will fly out of your grasp unexpectedly, and may break or cause injuries. Most people are taken by surprise and many have pinched fingers as a result.

Magnets also pose a real threat to magnetic media such as credit cards, sim cards, floppy disks etc. They can damage watches and cameras. Keep the magnets and the media apart. Remove vulnerable items from pockets. Store magnets on a shelf until you need them.

Dry run

Before starting to mix resin for the rotor castings, try a 'dry run' of assembly. Place the magnet-positioning jig onto the two M12 bolts. Take magnet blocks from the stock one by one, and place them onto the steel plate. Hold each block with both hands and slide it into place as far as possible before releasing it.

Checking for magnet polarity

The magnets poles alternate north-south-north around the circle. Therefore each block has to be the right way up.

Each time a magnet block is placed, **hold it above its neighbour** just previously placed. It should be repelled. If it is attracted, then turn it over and try again. If it is repelled then place it into its slot without turning it over again. This will ensure that it has different polarity from the previous block. Check all the magnets in position periodically with a magnet in your fist. Your fist should be alternately attracted and repelled as you progress around the circle. Hold on tight!

When it comes to fitting magnets to the second disk you must ensure that the magnets opposite the index mark will be of opposite polarity. This will ensure that the magnet rotors will attract each other.

When you are satisfied that everything is to hand and that the magnets can be safely positioned, it is possible to start mixing the resin.

Putting it together

Mix 1/2 lb. [200 g] of resin with 1/2 teaspoonful [3 cc] of catalyst.

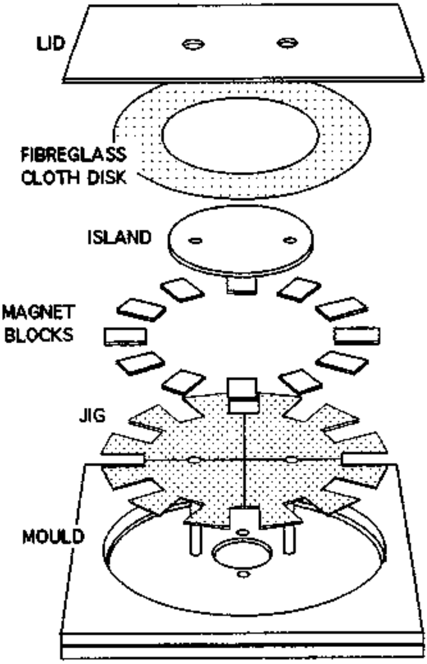
Paint this mixture over the area of steel where the magnet blocks will lie, and allow some to run over the edge of the steel disk (already in the mould).

Fit the magnet-positioning jig, and **insert the magnets** to each rotor casting in turn, removing the jig once they are all in position.

Place the **islands** onto the bolts. Clamp them down onto the disk with 1/2" [M12] nuts and washers to prevent resin from leaking under them.

If the liquid mix is still usable, **add talcum powder** to it and pour the mix into the spaces between the magnets.

Mix another 1 lb. [400g] resin with 1 1/2 tsp. [6 cc] of catalyst and then 300 g of talcum powder and pour this mix in next. **Continue to mix** and pour resin until the level rises to the top of the magnets. Paint resin over the magnet faces.



Take care to **avoid trapping air** in the space around the edge of the steel disks. Use vibration to dislodge bubbles and settle the resin mix.

When the resin fills both the moulds and has settled out most bubbles, **lay the fibreglass cloth disks** on top, taking care to centralise them. Paint the cloth with resin.

Finally lay on the hardboard **lids.** Clamp the lids down by placing steel objects such as spanner, nails etc onto the surface of the lid. The magnets will pull them down and squeeze the resin layer to a minimum.

Monitor the curing process, and adjust the temperature as required, just as with the stator casting.

To extract the rotors, first prise off the lids, remove the M12 nuts and bolts, and knock the rotors out of the moulds. Finally knock the island out from the centre, through the 2 1/2" [65mm] hole in the steel plate.

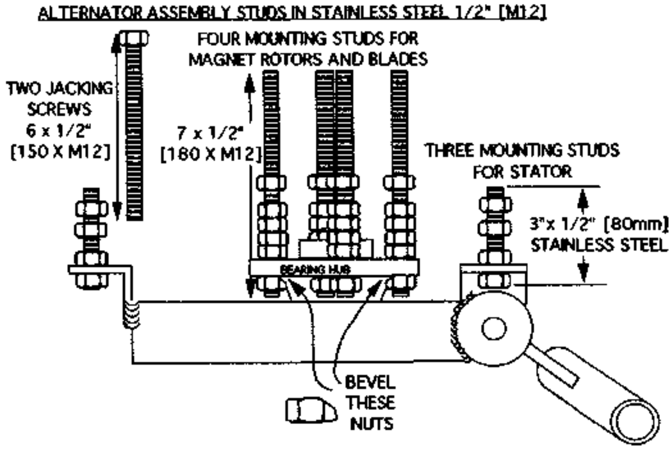
Do not use violent blows to release the casting in case you break the resin or a magnet. Use persistent tapping all around the edges and be patient.

Assembling the alternator

Materials			
Pieces	Material	Length	Width
3	Stainless steel all-thread rod	4 " [80 mm]	1/2" [M12]
4	Stainless steel all-thread rod	8" [180mm]	1/2" [M12]
2	All-thread rod with nut welded on	6 " [150mm]	1/2" [M12]
40	Stainless steel nuts		1/2" [M12]

Preparation

Check that the threads at the ends of the studs are clear of burrs, so that the nuts can be added at either end.



In the case of the UK Cavalier hub, the four nuts at the back of the wheel hub flange may need to be ground to fit the curve of the casting on the inside. A bevel on one corner is usually sufficient. These nuts must seat onto the back of the flange without putting eccentric loads on the studs which would push them squint and make the magnet disks hard to fit.

Clean up the mating surfaces of the magnet disks so they sit true on the hub flange and mounting nuts.

Hub and shaft

Bolt the shaft flange to its bracket with four screws, ensuring that it sits securely. Lock the screws with threadlock compound.

Stator mounting holes

Drill three 5/16" [5 mm] holes in the stator dummy (the off-cut piece of plywood from making the stator mould). Mark the side of the dummy that represents the back of the stator (wiring exit). Place this side of the dummy onto the front of the stator so that it is **centred**, and drill pilot holes for the mounting studs, working through the holes in the dummy into the stator casting. Enlarge the holes to 1/2" [12 mm].

Place the back of the dummy (again) on the stator mounts so that it is **centred** on the shaft and the right way up so the stator wiring will emerge at the back of the stator. Drill pilot holes for the mounting studs, working through the holes in the dummy into the stator mounting lugs. Enlarge the holes to 1/2" [12 mm].

Mount the bearing hub and adjust the bearings. Fit the dust cover to the bearing.

Set the alternator bracket level on the bench so that the hub flange is level on top.

Back magnet rotor

Spin four nuts onto each of the four long studs and tighten them evenly against each other so that there is about 3/4" [20mm[of free thread projecting.

Pass the short end through the back rotor and the hub flange. Thread the (bevelled) nuts at the back of the flange (using thread-lock), and tighten down so that the back plate is locked in place. Take care not to rotate the bevelled nuts at the back or they will not sit true.

Rotate the plate on the bearing and see that it runs true. A piece of copper winding wire attached to a stator stud is a good indicator of how true the disk is. Set the wire up so that it just brushes against the magnet surfaces. If the disk does not run true then you may have to clean it better where it meets the flange.

The stator

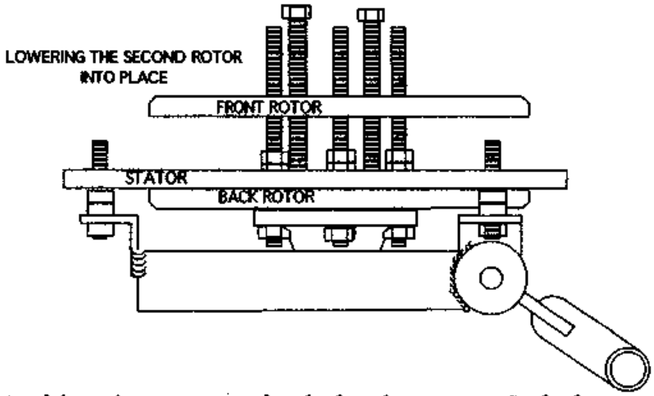
Spin two 1/2" [M12] nuts onto each stator-mounting stud, and pass the stud ends through the stator lugs. Add nuts to the back (with thread-lock). Squirt threadlock between the lug and the first nut above and tighten the nut down.

Check that the stator fits easily onto the three studs before the stud-lock sets (10 minutes). If not then try to adjust the positions of the studs, or enlarge the holes in the stator. Verify that the stator is central relative to the four rotor-mounting studs.

Fit the stator between nuts and big washers. Spin the nuts downward on the stator studs so that the stator sits on the first magnet rotor.

Front magnet rotor

Now fit the second magnet rotor. The jacking screws should be in place and screwed down about half way to prevent the rotor from crashing into place. When the screws make contact with the first rotor, start to unscrew them, and allow the rotor to descend into place gently until it rests on the four nuts.



At this point you can check the clearance. Jack the stator upwards gently, using nuts on each of its three mounts, until it stops rubbing against the back rotor. There should still be about 1/8" [3 mm] of clearance between the stator and the front rotor. Raise the stator until the clearance is equal on both sides.

If in doubt about the clearance, remove the front rotor using the jacking screws. Allow the stator to sit back down on the back rotor during this operation, so that you can lever against it if necessary without undue stress on the stator itself. Place washer(s) on each stud to pack it further out. Reassemble and try again.

Magnetic flux is better if the magnets are closer together, but it is important to keep them far enough apart to allow for mishaps and for wear in the bearing. Reliability is more important than performance.

When the clearance is correctly adjusted, tighten all the nuts using thread-lock, and test the alternator.

Testing the alternator

Short circuit tests

Make sure that none of the wires from the stator have bare ends touching each other. The stator should spin freely.

Strip two wires from the same half of the stator, and touch them together. The alternator will become stiff to turn. The torque as you try to turn it will pulsate. The magnets pass certain positions where they produce large currents in the short circuit.

Connect all five wires together and the torque will be smooth and very stiff. There will be current flowing all the time.

AC voltage tests

Disconnect any short circuits and rotate the magnets steadily. Use a multimeter on AC-voltage range to check the voltage between any pair of wires from the same half of the stator. Note that the voltage varies in proportion to the speed of cranking. You will read one of two possible AC voltages, depending on the phase difference between the wires in a pair. Find a pair with the higher voltage between them.

The AC voltage indicates the output voltage at any given speed, but the DC output will be higher by a factor of about 40% than the AC voltage, less a fixed amount around 1.5 volts DC, due to the fixed voltage drop in the rectifier. The reason for the 40% difference is that the AC reading is an average (root mean square actually) value, whereas the rectified DC will be the peak voltage available.

Turn the magnet rotors at 60 rpm (once per second) and measure the AC voltage. For a 12 volt alternator it should be about 3.5 volts. To charge a 12-volt battery you will need about 165 rpm, at which point the AC voltage would be 9.6 volts and the DC would therefore be:

$$(1.4 \times 9.6) - 1.5 = 12 \text{ volts DC.}$$

DC voltage tests

Connect the rectifier (see next page) and check the DC output while cranking the alternator. It will be difficult to monitor the rpm by counting, but you can use a multimeter with frequency testing abilities. Connect the frequency meter to any pair of AC wires and the Hz reading will be 1/10 of the rpm. As a rule:
Frequency in Hz = rpm x number of poles / 120

If you can crank it fast enough it should be possible to obtain 12 volts DC at about 165 rpm (16.5 Hz).

Note that when the DC wires are shorted together the alternator is still easy to turn at low speeds but becomes very hard to turn faster than about 5 times per second. This is because the diodes in the rectifier do not conduct until there is a voltage around 1.5 volts across them in total. Then they will conduct, and the torque will rise rapidly.

Connecting the rectifier

The actual wiring between coils and rectifier is simple. Each of the ten wires is terminated on an AC terminal of the rectifier. AC terminals are in diagonally opposite corners.

The DC terminals are recognisable because the positive terminal is at right angles to the others.

There are two ways to connect to the bridge rectifiers. The easiest way is to use crimped 'faston' or 'receptacle' push-fit connectors, which slip onto the blade terminals on the rectifier units. Take care that the blade enters the right slot, and does not force itself between the receptacle and its insulating sleeve.

A more secure method of connection is to solder wires to the blade terminals. This is only an improvement over the crimp connectors if the soldering technique is very good.

In both cases, the connections will need to be protected against damp or they will corrode and fail. A plastic bottle makes a good rain shield.

Connecting the battery

Fuses or circuit breakers

Always use protection on every circuit from a battery. This is an important safety issue. Use separate fuses or breakers for the wind turbine and for the loads. Use smaller fuse for circuits with thin wire such as the voltmeter supply.

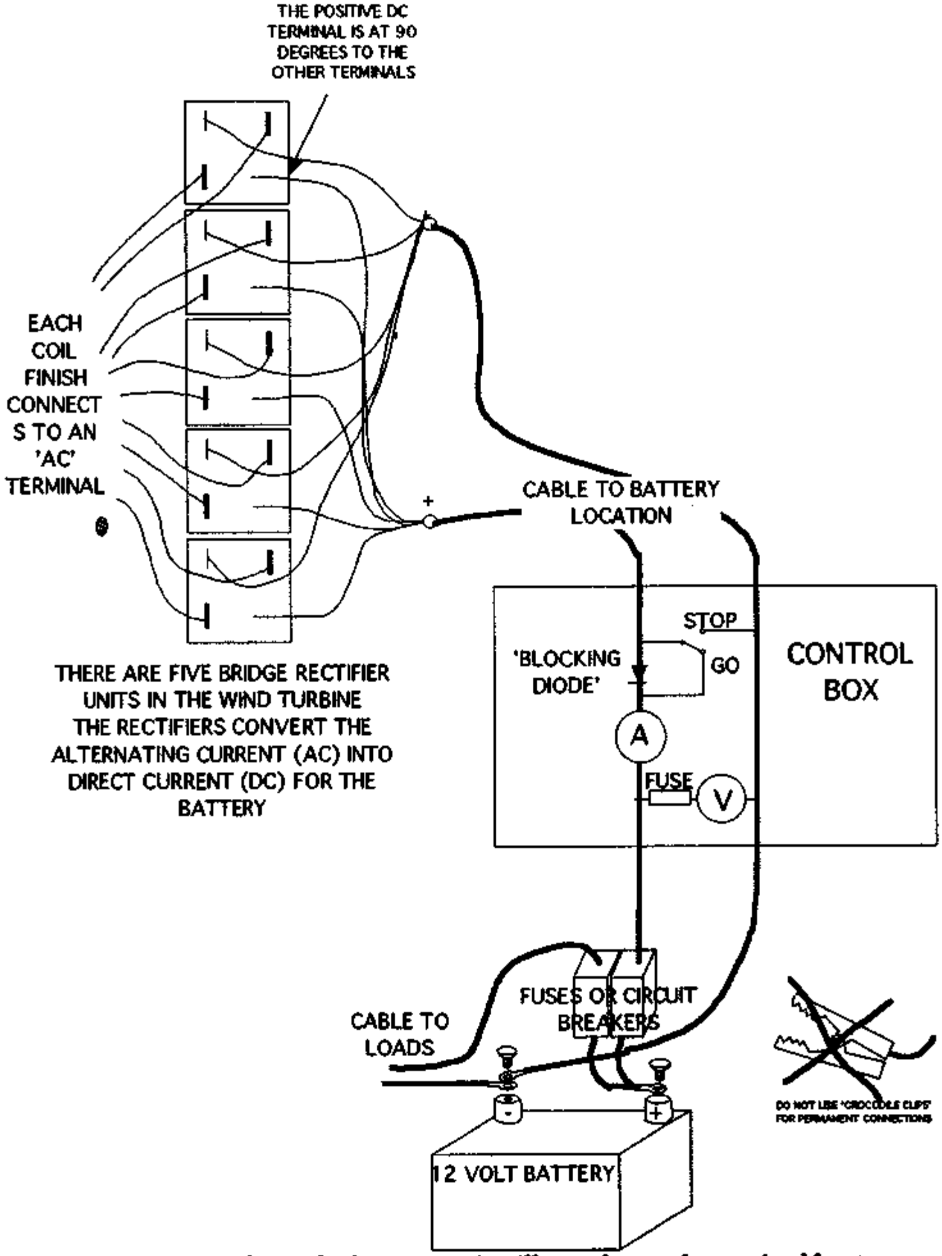
Connections

Never use crocodile clips for a permanent connection to a battery. Crimped lugs are the best terminals.

Brake switch

The brake switch is a useful feature for stopping the wind turbine if necessary. When you short-circuit the alternator it can only turn very slowly. Do not short-circuit the battery or you will blow the fuse.

If you disconnect the wind turbine from the battery, the voltage will be out of control and may become dangerously high. Do not touch any bare wiring under these conditions. Do not disconnect the wind turbine



from the battery or it will run fast and wear itself out.

An arrangement using a blocking diode and changeover switch solves these issues. The switch bypasses the diode in normal use, to prevent loss of power in the diode. See diagram.

Choosing suitable wire sizes

Power is lost in wiring due to its resistance to current flow. The current flow is larger for lower battery voltages. Loss varies in proportion to the square of the current, so 12-volt battery systems will end much thicker wire than 48 volt battery systems.

The wires from the wind turbine to the battery have to be large enough to carry the current without over-heating.

Battery	Minimum wire size for 500 watts
12-volts	#10 [6 mm]
24-volts	#12 [2.5 mm]
48-volts	#14 [1.5 mm]

If the wire run is long then you also need to check whether the power lost is acceptable. Use thicker wires for longer runs. The wire run is the distance from the wind turbine to the battery one way. The calculations assume a low wire temperature around normal ambient.

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The table assumes that 500 watts is reaching the battery and that it is at nominal voltage. The % figure is the loss as a % of the total power generated. If the percentage loss is high then the wind turbine will have to produce a lot of extra power. This can only happen when there is enough wind. So you will get less power at the battery in any given windspeed. The machine may turn away from the wind (furl) before you get 500 watts to the battery under these conditions. It may be necessary to add weight to the tail to get full output. Do not worry about overloading the alternator. So long as the current is not increased then it will not overheat.

Some of the loss figures look awful but they are not as bad as they seem. Bear in mind that most of the time the wind machine will be generating less than its full output. The most important conditions to have good efficiency are low windspeed conditions. At half power the loss percentage is only one half of the % shown.

Another mitigating factor is the improvement of blade efficiency when they run faster. This alternator holds the blades speed down very low at high power, which is nice from the point of view of minimising nose, but can cause the blades to stall. If the wire loss is high then the alternator has to run faster to produce the higher voltage. This will probably mean that the blades work better.

Wire type

Use flexible tough, single conductor wires in the tower drop where the cables will be subject to movement and twisting.

Use heavier cable for fixed wire runs and protect it with conduit or use armoured cable.

Percentage power lost in wiring from wind turbine to battery for 500 watt output to battery

Battery Voltage	Wire Size	Wire run		
		100' [30m]	200' [60 m]	300' [90 m]
12 V	#10	41%	59%	68%
12 V	#8	31%	47%	57%
12 V	#6	22%	36%	46%
12 V	#4	15%	26%	35%
12 V	#2	10%	18%	25%
24 V	#12	22%	36%	46%
24 V	#10	15%	26%	35%
24 V	#8	10%	18%	25%
24 V	#6	7%	12%	17%
24 V	#4	4%	8%	12%
24 V	#2	3%	5%	8%
48 V	#12	7%	12%	17%
48 V	#10	4%	8%	12%
48 V	#8	3%	5%	8%
48 V	#6	2%	3%	5%
48 V	#4	1%	2%	3%
48 V	#2	1%	1%	2%

Battery Voltage	Wire area Sq.mm	Wire run		
		100' [30m]	200' [60 m]	300' [90 m]
12 V	2.5mm	60%	75%	82%
12 V	6.0mm	38%	55%	65%
12 V	10.0mm	27%	43%	53%
12 V	16.0mm	19%	32%	41%
12 V	25.0mm	13%	23%	31%
12 V	35.0mm	10%	18%	24%
24 V	2.5mm	27%	43%	53%
24 V	6.0mm	13%	24%	32%
24 V	10.0mm	9%	16%	22%
24 V	16.0mm	5%	10%	15%
24 V	25.0mm	4%	7%	10%
24 V	35.0mm	3%	5%	7%
48 V	2.5mm	9%	16%	22%
48 V	6.0mm	4%	7%	10%
48 V	10.0mm	2%	4%	7%
48 V	16.0mm	1%	3%	4%
48 V	25.0mm	1%	2%	3%
48 V	35.0mm	1%	1%	2%