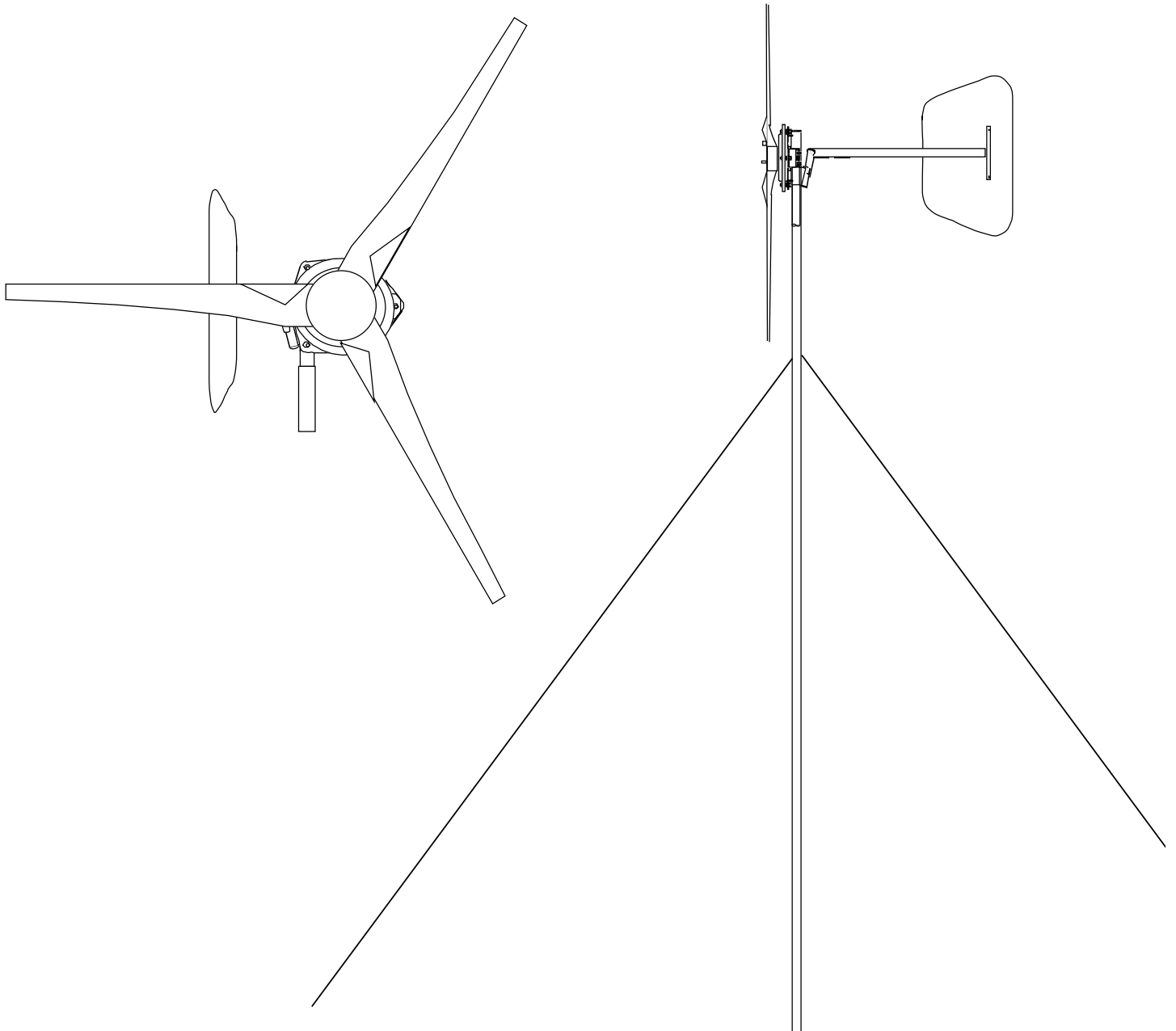


How to build a WIND TURBINE

Axial flux alternator windmill plans
8 foot and 4 foot diameter machines

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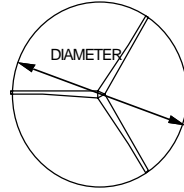
Introduction

Blades

These plans describe how to build two sizes of machine. The diameter of the larger wind-rotor is 8 feet [2.4 m]. The smaller machine has 4' diameter [1.2 m].

The diameter is the width of the circular area swept by the blades.

The energy produced by wind turbines depends on the swept area more than it does on the alternator maximum output.



Alternator

The plans describe how to build a permanent magnet alternator.

The alternator can be wired for 12, 24 or 48-volt battery charging. Essentially this choice only affects the size of wire and the number of turns per coil. But the tower wiring for the 12-volt version will be much heavier than the others. And the stator for the small machine is different in thickness.

The alternator design is integrated into a simple tower-top mounting arrangement (called a 'yaw bearing'). A tail vane faces the turbine into the wind. A built in rectifier converts the electrical output to DC, ready to connect to a battery.

Small wind turbines need low speed alternators. Low speed usually also means low power. The large machine alternator is exceptionally powerful because it contains 24 large neodymium magnets. The power/speed curve for a very similar design is shown below. Maximum output is about 500 watts under normal circumstances, but it is capable of more than 1000 watts for short periods.

The starting torque (force required to get it moving) is very low because there are no gears, nor are there any laminations in the alternator to produce magnetic drag. This means that the wind turbine can start in very low winds and produce useful power. Power losses are low in low winds so the best possible battery charge is available.

In higher winds the alternator holds down the speed of the blades, so the machine is quiet in operation, and the blades do not wear out. You can easily stop the wind turbine by short-circuiting the output with a 'brake switch'. These features make the wind turbine pleasant to live with.

Blades

The blades are carved from wood with hand tools. You can also use power tools if you prefer. Carved blades are good for homebuilders because the process is pleasant and

the results are quick for a one-off product. Moulded fibreglass blades are usually better for batch production. Wooden blades will last for many years.

Furling system

The plans include a description of how to construct a furling tail for the larger machine. This tail prevents overload in high winds. This type of furling system has been in use on Scoraig for decades and has passed the test of time.

Units

This document caters for both American readers and European/UK readers, so the dimensions are in both inches and millimetres. The mm figures are in brackets [like this]. In some of the theory sections I use metric alone, because it makes the mathematics so much easier.

In some cases, the metric dimensions will be direct conversions of the English dimensions, but **not always**. The reasons are that different size magnets are used for the metric design, metric wire sizes are different from AWG, and some important physical dimensions are rounded off to make more sense in mm.

The US version typically uses a standard GM hub (Citation, Cavalier, etc) with five studs and a bearing at the back. The bearing housing needs a large circular hole in the mounting at the back.

I suggest you use only one system of measurement, either metric or 'English' and stick to that system. Your best choice of measurement system will depend on the magnet size you choose.

Tolerances

Most of the dimensions given are nominal - the accuracy is not critical, so you need not follow the drawings slavishly.

The shapes of the blades are important near the tip but much less so near to the root (the larger, inner end of the blade).

The alternator parts must be constructed and assembled with enough accuracy that the magnets pass the coils centrally as the machine rotates.

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Glossary

AC - Alternating current as produced by the alternator.

Allthread - USA word for 'threaded' or 'spun' rod or studding

Brake switch - A switch used to short-circuit the wires from the alternator so that it stops.

Catalyst - A chemical used to make the polyester resin set solid. Catalyst reacts with 'accelerator' already present in the resin mix. The heat of reaction sets the polyester.

Cavalier - A make of car. The cavalier in the UK is not the same as the Cavalier in the USA but both have useful wheel hubs.

DC - direct current with a positive and a negative side, as in battery circuits.

Diameter - The distance from one side of a circle to another. The width of a disk right across the middle.

Drag - A force exerted by the wind on an object. Drag is parallel to the wind direction at the object. (see Lift)

Drop - Used here to describe a certain measurement of the shape of a windmill blade. The 'drop' affects the angle of the blade to the wind.

Flux - The 'stuff' of magnetism. Similar to 'current' in electricity. It can be visualised as 'lines' coming out of one pole and returning to the other.

Furling - A protective action that reduces exposure to violent winds by facing the blades away from them.

Jig - A device used to hold the magnets in place before setting them in resin.

Leading edge - The edge of a blade that would strike an object placed in its path as the rotor spins.

Lift - A force exerted by the wind on an object. Lift is at right angles to the wind direction at the object. (see Drag)

Mould - A shaped container in which resin castings are formed. The mould can be discarded after the casting has set.

Multimeter - A versatile electrical test instrument, used to measure voltage, current and other parameters.

Neodymium - The name given to a type of permanent magnet containing neodymium, iron and boron. These magnets are very strong and getting cheaper all the time.

Offset - An eccentric position, off centre.

Phase - The timing of the cyclical alternation of voltage in a circuit. Different phases will peak at different times.

Polyester - A type of resin used in fibreglass work. Also suitable for making castings.

Power - the rate of delivery of energy

Rectifier - A semiconductor device that turns AC into DC for charging the battery.

Root - The widest part of the blade near to the hub at the centre of the rotor.

Rotor - A rotating part. Magnet rotors are the steel disks carrying the magnets past the stator. Rotor blades are the 'propeller' driven by the wind and driving the magnet rotors.

Soldering - A method for making electrical connections between wires using a hot 'iron' and coating everything with molten solder.

Stator - An assembly of coils embedded in a slab of resin to form part of the alternator. The magnets induce a voltage in the coils and we can use this to charge a battery.

Styrene monomer - A nasty smelling solvent in the polyester resin mix.

Talcum powder - A cheap filler powder used to thicken the resin and slow its reaction (prevent it overheating).

Tail - A projecting vane mounted on a boom at the back of the windmill used to steer it into or out of the wind automatically.

Tap - a tool for making thread inside holes so you can fit a screw into the hole.

Thrust - The force of the wind pushing the machine backwards.

Tower - The mast supporting the windmill.

Trailing edge - The blade edge furthest from the leading edge. The trailing edge is sharpened, so as to release the passing air without turbulence.

Wedges - Tapered pieces of wood used to build up the blade thickness and increase its angle to the wind near the root.

Workpiece - The piece of wood or metal being shaped in the workshop.

Yaw bearing - the swivel at the top of the tower on which the windmill is mounted. The yaw bearing allows the windmill to face the wind.

Workshop tools

MECHANICAL

TOOLS

- electric welder
- 'saws-all'
- oxy-acetylene torch
- welding mask
- chipping hammer
- vice
- G clamps
- pillar drill
- cordless drill
- handheld electric drill
- 1/2" [13mm] chuck
- drill bits
- holesaws
- 1/2" [M12] tap
- angle grinder
- belt sander
- cut-off machine
- hacksaw
- cold chisel
- hammer
- centre punch
- files
- tin snips
- tape measure
- steel ruler
- set square
- protractor
- scriber
- chalk
- compasses
- angle/bevel gauge
- spirit level
- vernier calipers
- ear protectors
- safety glasses/goggles

- face masks
- screwdrivers
- pliers
- vice grips
- 10" adjustable wrench
- combination wrenches 3/8"-3/4" [10-19mm]
- socket wrenches and ratchets 10-19mm

WOODWORKING

TOOLS

- vice
- G clamps
- hammer
- wooden mallet
- draw knife
- spoke shave
- planes large and small
- wood chisel
- oilstone
- jig saw
- screwdrivers
- handsaw
- circular saw
- pencil
- tape measure
- steel ruler
- set square
- spirit level
- calipers

PLASTICS ETC

TOOLS

- multimeter
- surform/rasp
- weighing scales
- spoons, knives for mixing
- safety glasses
- face masks
- screwdrivers
- knife
- scissors
- felt pen
- soldering iron
- pencils
- tape measure
- steel ruler
- spirit level
-

Miscellaneous consumables

Welding rods, grinding disks, hacksaw blades. Epoxy glue and bondo for misc. repairs. Lead flashing for balancing blades (1/8" x 12" x 12" approx. piece)
Heatsink compound for rectifier mounting

Some extra tools for the smaller machine
1" diameter wood boring bit for moulds.

Materials for the large machine

BLADE WOOD				
Pieces	Material	Length	Width	Thick
3 blades	Light, straight grained wood	4 feet [1200mm]	6 " [150 mm]	1 1/2" [37 mm]
1 wedges	Off-cut of wood, with some straight-grained portions	Enough to find some nice portions	Over 3" [75mm]	1 1/2" [37 mm]

PLYWOOD ETC.				
Pieces	Material	Length	Width	Thick
2 lids	Hardboard	16" [400]	16" [400]	1/8" [3]
1 jig	Hardboard or plywood	12" [300]	12" [300]	1/4" [6]
2 island	Plywood for magnet	6" [158]	6" [158]	1/2" larger [9] smaller
1 tail vane	Exterior plywood for tail vane	36" [900 mm]	24" [600]	3/8" [9 mm]
2 hub disks	Exterior quality plywood	10" [250mm]	10 " [250mm]	1/2" [13 mm]
1 stator	Plywood	24" [600]	24" [600]	
3 coil winder	Plywood	4" [100 mm]	3" [75mm]	
2 lid and base	Smooth faced board	24" [600]	24" [600]	3/4" [19] suggested size
4 rotors	Floor board	16" [400]	16" [400]	3/4" [19]

STEEL AND ALUMINIUM				
Pieces	Steel pipe	Length	Overall Diam.	Wall Thick
1Yaw bearg.	2" nominal	12" [300 mm]	2 3/8" 60.3 OD	1/8" [3mm]
1Yaw brg.	1 1/2 " nominal bore	16" [400 mm]	1 7/8" [48 mm]	1/8" [3mm]

1 Tail boom	1 1/4" nominal bore	4' 6" [1350 mm]	1 5/8" [42.2]	1/8" [3mn]
1 tail hinge	1 " nominal bore	8" [200 mm]	1 5/16" [33.4]	1/8" [3mn]
Pieces	Steel disk	Diam.	Thick	Hole
2	Magnet rotor disks	12 " O.D. [300 mm]	5/16" 8 mm	2 1/2 [65]
1 tail bearing cap	Steel plate disk or square	1 5/8" [42.2] minimum	5/16" [8mm]	
1 yaw bearing cap	Steel plate disk or square	2 1/2" [65]	5/16" [8mm]	
Pieces	Material	Length	Width	Thic
1 tail hinge	Steel plate	4" [100]	2 1/4" [56 mm]	3/8" [10]
1 tail	Steel bar	12" [300] approx.	1 1/2"[30]	5/16' [8]
2	Steel angle	10 1/2" [267 mm]	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]
1	Aluminium angle or channel	9" [220 mm]	2" [50]	3/16' [5 mm]

MAGNETS	
24	Magnet blocks 2 x 1 x 1/2" grade 35 NdFeB Item 76 from www.wondermagnet.com [46 x 30 x 10 mm grade 40 NdFeB see below

UK SOURCES OF PARTS	
Fibreglass resin etc	Glasplies 2, Crowland St. Southport, Lancashire PR9 7RL (01704) 540 626
Magnets	CERMAG Ltd. 94 Holywell Rd, Sheffield SA4 8AS (0114) 244 6136 or sales@magna-tokyo.com
Winding wire	EC WIRE LTD (01924) 266 377 Percy Hawkins (01536) 523 22
Rectifiers and other components	FARNELL www.farnell.com
	JPR Electronics www.jprelec.co.uk
	www.Maplin.co.uk

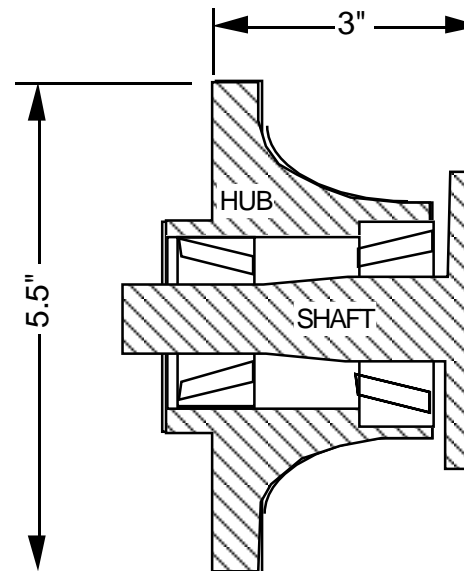
STEEL FASTENERS			
Pieces	Material	Length	Width
1	Stainless steel all-thread rod	5' [1.5 m]	1/2" [M12]
40	Stainless steel nuts		1/2" [M12]
10	Stainless steel washers		1/2" [M12]
4	Bolts, nuts + washers	3" [70 mm]	1/2" [12 mm]
4	Nails or pins	4" ? [100 mm ?]	3/16" [5 mm]
1	Stud or bolt (winder shaft)	6" approx. [150 mm]	3/8" [10 mm]
5	Nuts and washers		3/8" [10 mm]
3	Bolts, nuts washers	2 1/2" [60 mm]	3/8" [M10]
2	Bolts and nuts	1" [25]	1/4" [6]
6	Bolts and nuts	1" [25]	3/16" [5]
100	Wood screws	1 1/4" [32 mm]	

FIBERGLASS RESIN	
Quantity	Material
6lbs [2.5 kg]	Polyester casting resin or fiberglass resin in liquid form (premixed with accelerator). Peroxide catalyst to suit.
5 lbs. [2.2 kg]	Talcum powder
3' x 3' [1 x 1 m]	Fiberglass cloth (or use chopped strand mat) 1 ounce per sq. foot= [300g per sq. metre]
	Wax polish
	Silicone sealant

WIRE ETC			
Weight	Material	Turns per coil & size	Voltage
6 lbs. [3 kg] for ten coils	Enamel winding wire, called magnet wire www.otherpower.com	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
30' [10 m]	Flexible wire with high temperature insulation	#14 [2 mm] or similar	12-V,
		#18 [.75 MM] bundled in a protective sleeve	24V or 48V
3' [1 m]	Resin cored solder wire		
3' [1 m]	Insulation sleeving	Large enough to fit over the solder joints	
5	Bridge rectifiers	35A 6-800V single phase http://www.rfparts.com/bridge.htm	
1	Connector block		

BEARING HUB	
1	Automotive rear hub with flanged shaft for convenient mount to wind turbine.

UK VERSION HUB



Notes on workshop safety

GENERAL

Workshop safety depends on correct behaviour. There are intrinsic dangers. Be aware of the risks to yourself and others and plan your work to avoid hazards. Protective clothing will reduce the risks, but without awareness the workshop will not be safe.

Keep the workshop tidy. Avoid trailing leads, precarious buckets or other unnecessary hazards, which people could trip over or spill.

Watch out for others, to avoid putting them at risk and beware of what they might do which could put you at risk.

Wear protective clothing - eye protection, gloves, helmet, mask, etc as appropriate to prevent danger. Avoid loose clothing or hair, which could be trapped in rotating tools and pulled inwards.

Take care when handling tools which could cut or injure yourself or others. Consider the consequences of the tool slipping or the workpiece coming loose. Attend to your work, even when chatting to others.

SPECIFIC HAZARDS

METALWORK

Grinding, sanding, drilling etc can produce high velocity dust and debris. Always wear a mask when grinding. Take care that any sparks and grit are directed into a safe zone where they will not injure anyone, or cause fires. Consider how the tool might come into contact with fingers or other vulnerable body parts.

Welding, drilling etc makes metal hot, so take care when handling metalwork during fabrication.

Welding should take place in a screened space where the sparks will not blind others. Wear all protective clothing including mask. Do not inhale the fumes. Protect the eyes when chipping off slag. Do not touch live electrodes or bare cable.

Steel mechanisms can fall or fold in such a way as to break toes or fingers. Think ahead when handling steel fabrications to prevent injury. Clamp the workpiece securely.

Take great care when lifting steel assemblies, to avoid back injury. Keep well clear of towers and poles that could fall on your head. Wear a safety helmet when working under wind turbines.

WOODWORKING

Take care with sharp tools. Clamp the workpiece securely and consider what would happen if the tool slips. Watch out for others.

Wear a dust mask when sanding. Do not force others to breathe your dust. Take the job outside if possible.

Wood splinters can penetrate your skin. Take care when handling wood to avoid cutting yourself.

RESINS AND GLUES

The solvents in resins can be toxic. Wear a mask and make sure there is adequate ventilation.

Avoid skin contact with resins. Use disposable gloves. Plan your work to avoid spillage or handling of plastic resins and glues. Be especially careful of splashing resin in the eyes.

MAGNETS

Magnets will erase magnetic media such as credit cards, sim cards, camera memory cards, and damage watches. Remove suchlike from pockets before handling magnets.

Magnets fly together with remarkable force. Beware of trapping your fingers. This is the most likely cause of small injuries. Slide magnets together sideways with extreme caution.

ELECTRICAL

Check for dangerous voltages before handling any wiring.

Battery voltage systems are mostly free from dangerous voltages, but there is a shock hazard from wind turbines running disconnected from the battery. Under these conditions the output voltage can rise to dangerous levels.

Even at low voltages there is a danger of burns from electric arcs or short circuits. All circuits from batteries should have fuses or circuit breakers to prevent sustained short circuits causing fires.

Be especially careful with batteries. Metal objects contacting battery terminals can cause large sparks and burns. Gas inside the battery can be ignited, causing an explosion that spatters acid in the eyes. Acid will burn clothing and skin. Avoid contact, and flush any affected parts with ample water. Take care when lifting and moving batteries to prevent back injury or acid spills.

BLADE THEORY

Blade power

The rotor blade assembly is the engine powering the wind generator. The blades produce mechanical power to drive the alternator. The alternator will convert this into electrical power. Both types of power can be measured in watts.

It's a good idea to use metric units for aerodynamic calculations. The power (watts) in the wind blowing through the rotor is given by this formula:

$$\frac{1}{2} \times \text{air-density} \times \text{swept-area} \times \text{windspeed}^3$$

(where air density is about 1.2 kg/m³)

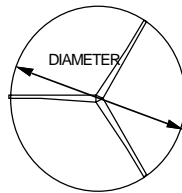
The blades can only convert at best half of the wind's total power into mechanical power. In practice only about 25 -35% is a more typical figure for homebuilt rotor blades. Here is a simpler rule of thumb:

$$\begin{aligned} \text{Blade power} &= 0.15 \times \text{Diameter}^2 \times \text{windspeed}^3 \\ &= 0.15 \times (2.4 \text{ metres})^2 \times (10 \text{ metres/second})^3 \\ &= 0.15 \times 6 \times 1000 = \mathbf{900 \text{ watts approx.}} \end{aligned}$$

(2.4m diameter rotor at 10 metres/sec or 22 mph)

Diameter is very important. If you double the diameter, you will get four times as much power. This is because the wind turbine is able to capture more wind.

Windspeed is even more important. If you can get double the windspeed, you will get eight times as much power.



Blade speed

The speed at which the blades rotate will depend on how they are loaded. If the alternator has high torque and is hard to turn, then this may hold the speed down too low. If the wiring is disconnected and electricity production is disabled, the rotor will accelerate and 'run away' at a much higher speed.

Rotor blades are designed with speed in mind, relative to the wind. This relationship is known as 'tip speed ratio' (tsr). Tip speed ratio is the speed the blade tips travel divided by the windspeed at that time.

In some cases the tips of the blades move faster than the wind by a ratio of as much as 10 times. But this takes them to over 200 mph, resulting in noisy operation and rapid erosion of the blades edges. I recommend a lower tip speed ratio, around 7.

We are building a rotor with diameter 8 feet [2.4 metres]. We want to know what rpm it will run at best in a 7 mph [3 m/s] wind when first starting to produce useful power.

$$\begin{aligned} \text{Rpm} &= \text{windspeed} \times \text{tsr} \times 60 / \text{circumference} \\ &= 3 \times 7 \times 60 / (2.4 \times 3.14) = \mathbf{167 \text{ rpm}} \end{aligned}$$

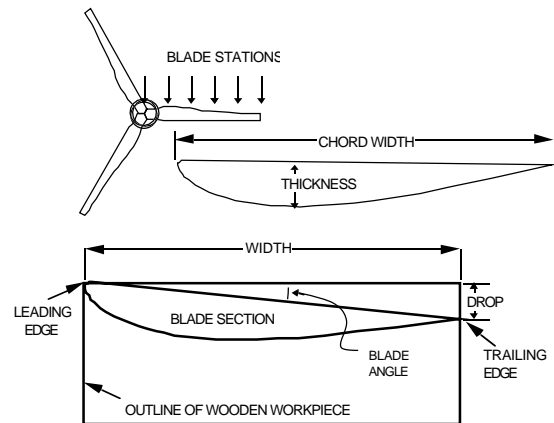
Blade number

People often ask "Why not add more blades and get more power?" It is true that more blades will produce more torque (turning force), but that does not equate to more power. Mechanical power is speed multiplied by torque. For electricity production you need speed more than you need torque. Extra blades help the machine to start to turn slowly, but as the speed increases the extra drag of all those blades will limit how much power it can produce. Multibladed rotors work best at low tip speed ratios.

Fast turning blades generate much more lift per square inch of blade surface than slow ones do. A few, slender blades spinning fast will do the same job as many wide ones spinning slowly.

Blade shape

Any rotor designed to run at tip speed ratio 7 would need to have a similar shape, regardless of size. The dimensions are simply scaled up or down to suit the chosen diameter.



We specify the shape at a series of stations along the length of the blade. At each station the blade has 'chord width', 'blade angle' and 'thickness'. When carving a blade from a piece of wood (a 'workpiece') we can instead specify the **width** of the workpiece and also what I call the '**drop**'. These measurements will then produce the correct chord width and blade angle. The drop is a measurement from the face of the workpiece to the trailing edge of the blade.

The shape of the blade **near the root** may vary from one wind turbine to another. A strongly twisted and tapered shape is ideal. But in some cases a much less pronounced twist is also successful. I prefer the strong twist and taper because

- it is strong
- it starts up better from rest,
- I think it looks better.

In fact it is not going to make a huge difference if the root is a different shape. The blade root shape will probably be determined more by practical issues such as available wood and the details of how to mount it to the alternator than by aerodynamic theory.

Carving the blades

Materials				
Pieces	Material	Length	Width	Thick
3	Light, straight grained wood	4 feet [1200mm]	6" [150 mm]	1 1/2" [37 mm]

The wood should be well seasoned and free of sap. It is sometimes possible to cut several 'blanks' out of a large beam, avoiding knots. You can glue a piece onto the side of the workpiece to make up the extra width at the root. Do not increase the length by gluing, as this will weaken the blade.

Check for any twist on the face of the workpiece, using a spirit level across the face at intervals along its length. If the wood is levelled at one point, it should then be level at all points. If the piece is twisted then it may be necessary to use different techniques to mark out accurately the trailing edge (see next page).

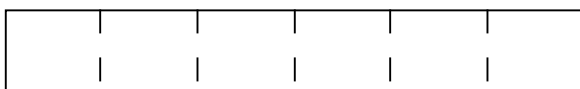
STEP ONE is to create the tapered shape.

The blade is narrow at the tip and fans out into a wider chord near the root. This table shows the width you should aim for at each station. You may wish to do the marking out once with a template of thin board. Then cut out and use the template to mark the actual blades.

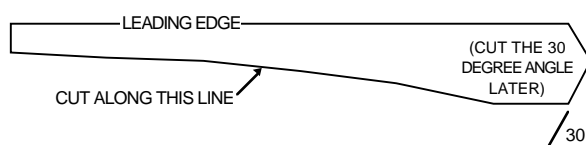
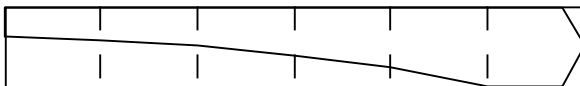
station	width	
1	6"	150 mm
2	4 3/4"	120 mm
3	3 15/16"	100 mm
4	3 1/8"	80 mm
5	2 3/4"	70 mm
6	2 3/8"	60 mm

- Mark out the stations by measurement from the root of the workpiece.
- Draw a line around the workpiece at each station, using a square (lines shown dotted).
- Mark the correct width at each station, measuring

PENCIL LINES AT STATIONS



MARK OUT THE SHAPE ON THE FACE OF THE WORKPIECE



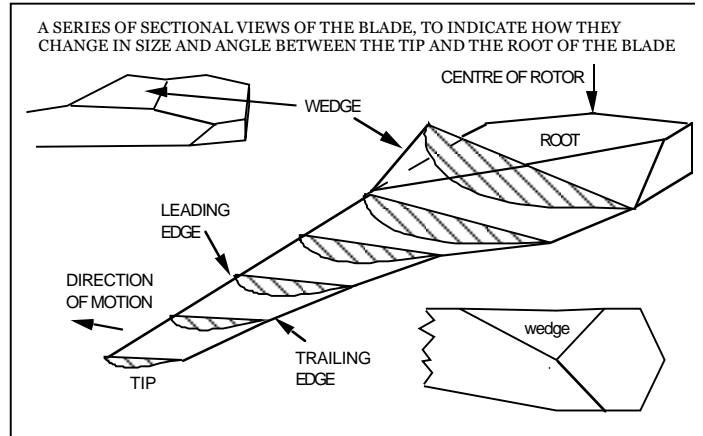
from the leading edge, and join the marks up with a series of pencil lines.

- Cut along these lines with a bandsaw.

Alternatively you can carve away the unwanted wood with a drawknife. Or crosscut it at intervals and chop it out with a chisel. In any case the final cut face should be made neat and square to the rest of the piece. Make each blade the same.

STEP TWO carving the twisted windward face

The windward face of the blade will be angled, but somewhat flat, like the underside of an aircraft wing. The angle will be steeper (removing more wood) at the root than it is at the tip. The reason why blade-angle should change is because the blade-speed becomes slower as we approach the centre. This affects the angle of the apparent air velocity striking the blade at each



station.

- Start by marking the stations (with a square) on the face you cut in Step One.
- Then mark the 'drop' on each of these new lines, measuring from the face of the wood as shown below and marking the position of the trailing edge at each station.

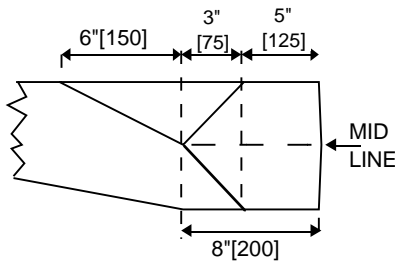
station	drop	
1	1 1/2"	37 mm
2	1	25 mm
3	7/16"	12 mm
4	1/4"	6 mm
5	1/8"	3 mm
6	1/16"	2 mm

- Join these marks to form the line of the trailing edge. The leading edge is the other corner of the workpiece.

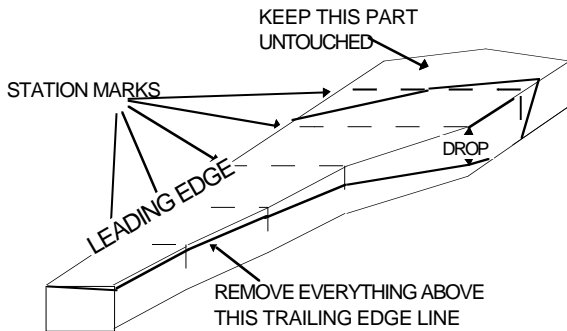
The 'drop' near the root is not large enough to give the best blade angle. In step six you will use a wooden 'wedge' to build up the leading edge, and double the effective drop. This wedge creates the desired blade-angle without needing such a thick workpiece. Leave a

portion of the face uncut where the wedge will fit. In this area around the first station, you will be cutting a face between the trailing edge and the outline of the wedge footprint.

- Remove all the wood above the trailing edge line, so that you can place a straight edge between the leading and trailing edges.



In this way you will be forming the twisted windward face of the blade. I use a drawknife and a spoke-shave to do the inner part, and a plane is useful on the straighter part. You can use a sander if you prefer. Take care to be precise in the outer part near the tip where the blade angle is critical. **Do not remove any of the leading edge**, but work right up to it, so that the angled face starts right from this corner of the wood.



Leave the blade root untouched, so that it can be fitted into the hub assembly. The hub will be constructed by clamping the blades between two plywood disks (see step five). The carving of the windward face ends with a ramp at the inboard end. This ramp is guided by lines, which meet at a point just outside the hub area. The line

on the larger face has two legs – one for the wedge and one for the ramp.

Checking the drop

If in doubt about the accuracy of the blade angle, use a spirit level to check the drop.

- First use the level to set the blade root vertical (or horizontal if you prefer, but be consistent).
- At each station, place the level against the leading edge and check the drop between the level and the trailing edge.

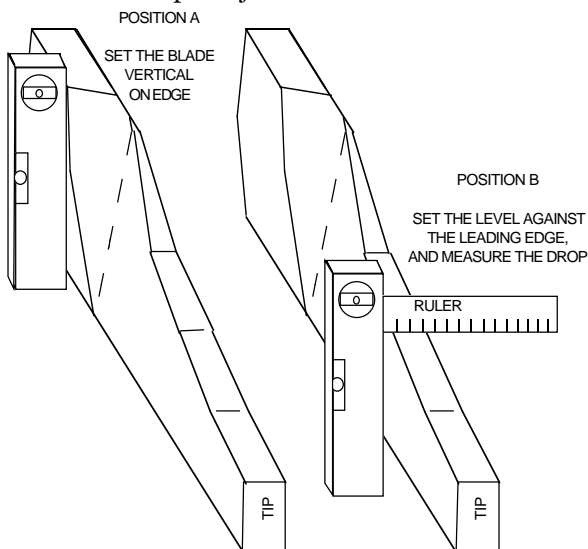
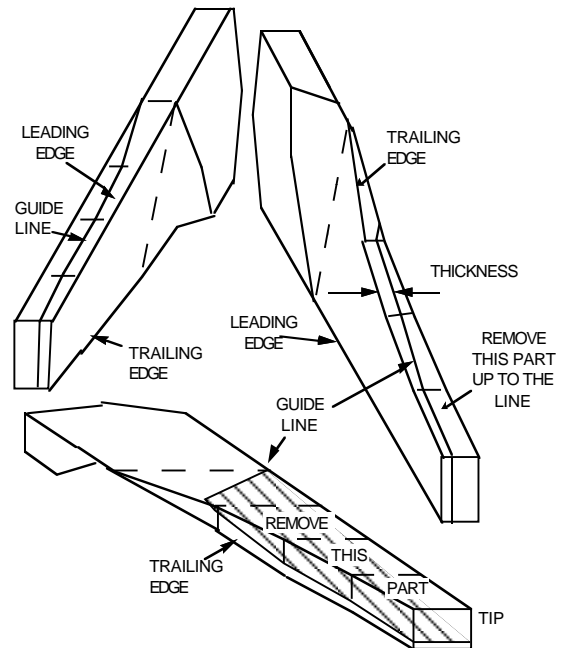
When measuring the drop, make sure that the level is vertical (or horizontal if appropriate). If the drop is too large or small, adjust it by shaving wood from the leading or trailing edge as required.

STEP THREE carving the thickness

This table shows the thickness of the blade section.

station	thickness	
1	1 3/8	36 mm
2	15/16	25 mm
3	1/2	13 mm
4	3/8	10 mm
5	5/16	8 mm
6	1/4	7 mm

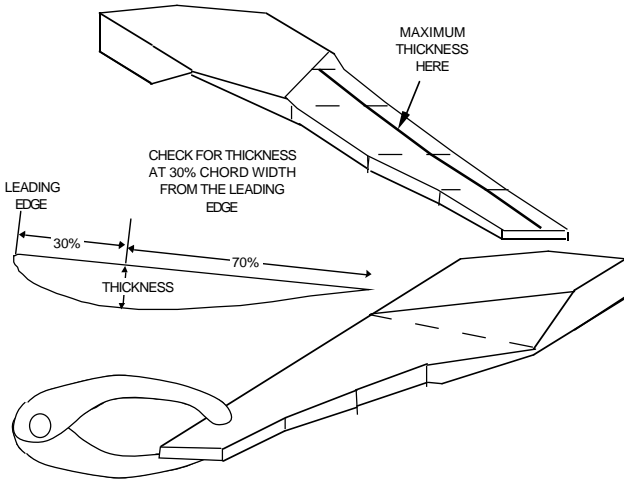
- At each station, measure the appropriate thickness from the windward face, and make a mark. Join the marks to form a line.
- Do this again at the trailing edge.
- Where the thickness runs out at the trailing edge, draw a diagonal line across the back of the workpiece to meet the line at the leading edge.



These lines will guide you as you carve the section, to achieve the correct thickness. Carve the back of the blade down to these lines.

- As you approach the lines themselves, you should begin to check the thickness with callipers at each station.

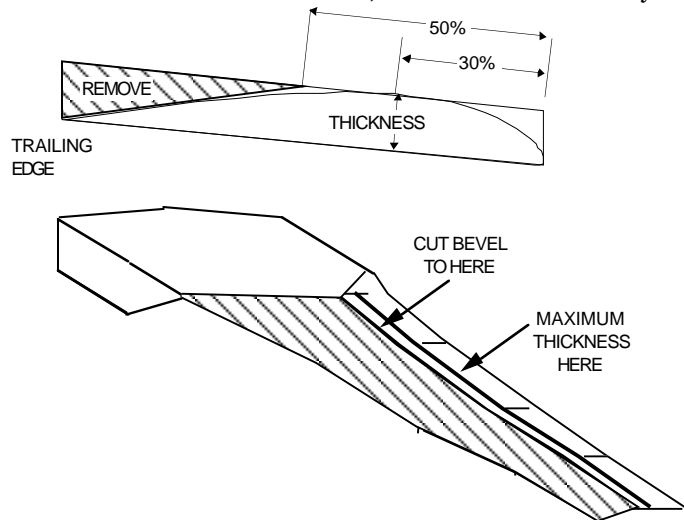
Both sides of the blade should now be flat and parallel to each other, except at the inner part where this is not possible, because the workpiece is not thick enough to



allow full thickness across the whole width. In this area you need not worry about the part nearer to the trailing edge, but try to make the faces parallel where you can. The final blade section will only be full thickness along a line that runs about 30% of the distance from leading to trailing edges.

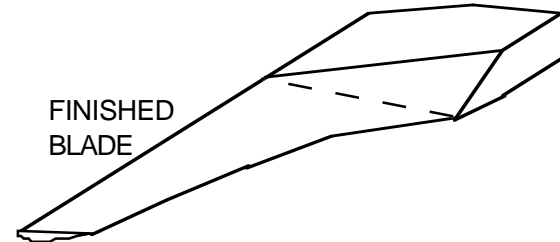
STEP FOUR Carve the curved shape on the back of the blade

The blade is nearly finished now. The important dimensions, width, angle and thickness are all set. It only remains to give create a suitable airfoil section at each station. If this is not done, the blade will have very



high drag. This would prevent it from working well at high tip-speed-ratio.

The first part of this step is to make a feathered trailing edge. Take great care to cut only into the back of the



blade. This is the face you just cut out in step three. Do not touch the front face. (You carved the front face in Step Two.)

- Draw two lines along the back of the blade, at both 30% and 50% width measured from the leading toward the trailing edge. The 50% line is to guide you in carving the feathered trailing edge.
- Now carve off the part shown hatched, between the trailing edge and the middle of the blade width. This will form the correct angle at the trailing edge. When you have finished, it should be possible to place a straight edge between this line and the trailing edge. The trailing edge should be less than 1 mm thick.
- When this is done, the blade has to be carved into a smoothly curving shape according to the section shown.

It is hard to prescribe exactly how to produce the curve. The best description is simply 'remove any corners'. As you remove corners, you will produce new corners, which in turn need to be removed. Run your fingers over the wood lightly to feel for corners. Remove less wood each time.

Take care not to remove too much wood. The 30% line represents maximum thickness part and should not be carved down further. Take care not to produce a corner at this thickest point.

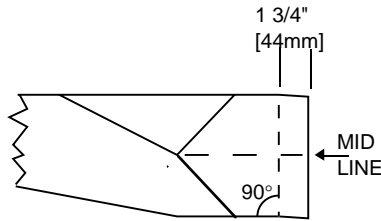
STEP FIVE Assembling the rotor hub.

Materials			
Pieces	Material	Diameter	Thick
2	Exterior quality plywood	10 inches [250mm]	1/2" [13 mm]
54	Woodscrews	1 1/4" [32 mm]	

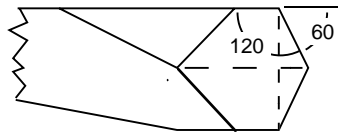
Cutting the roots to 120 degrees

If the roots of the blades have not already been cut to a 120 angle already, then this is the time to cut them.

- Draw a mid-line at 3" [75 mm] from each edge.



- Draw a line at right angles (90 degrees) to the edge, and 1 3/4 [44 mm] away from the blade root. The blade root may not be square. Be sure that this line is drawn square.

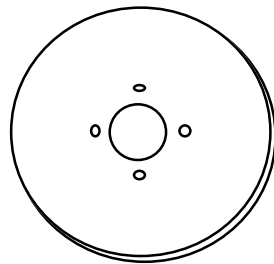


- Draw angled lines connecting the ends of this line to the point where the mid-line hits the end as shown. These two lines should turn out to be angled at 120 degrees to the edge of the wood.
- Saw off the triangular pieces from the corners by cutting along the angled lines, leaving a central 120-degree point on the blade root. Set the lines up vertically while you cut the workpiece.

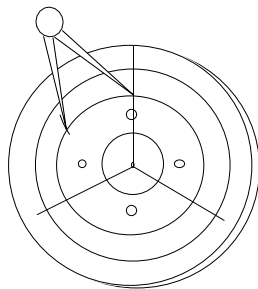
Marking and drilling the plywood disks

Choose one disk to be the **master**. Draw a circle at the same diameter as the mounting hole centres.

Lay the front (outer) magnet rotor onto the disk centrally and drill five 1/2" [four 12 mm] holes through the disk. Carefully mark the disk with any index marks so that you can place it against the magnet rotor in exactly the same position again.

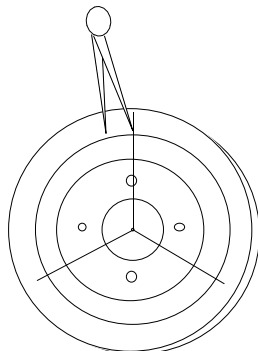


Draw two circles on the disk using diameters 6" [150] and 8" [200].



Use the compasses to walk around the outer circle marking six, equally spaced points.

Use every second point to draw a line radiating from the centre. Each line represents the middle of one blade for the purpose of marking out screw holes (nothing accurate more than that).

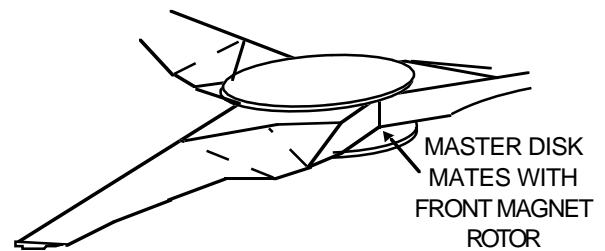
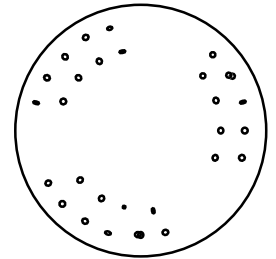


Now set the compasses for a 1" [25 mm] radius and walk them

around the outer circle for two steps from the line in each direction, marking five hole centres.

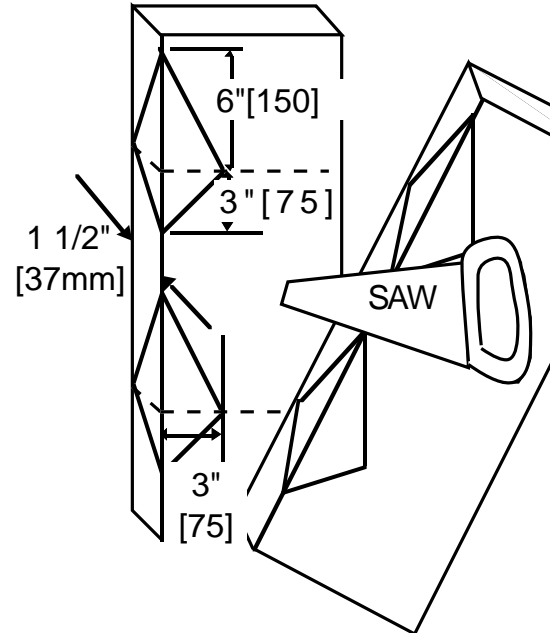
Mark another four hole centres with the compasses on the inner circle in a similar fashion but straddling the centre line.

Place the master disk on top of the other plywood one centrally and lay them on some waste wood for support. Drill 27 neatly spaced screw holes through both disks. Countersink the screw holes from the outsides. Consider which face will meet the magnet rotor.



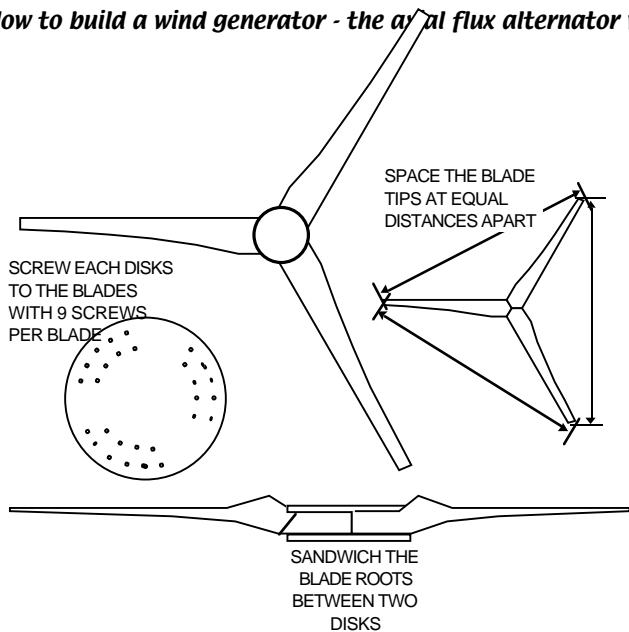
Clamping the blades together

Lay the blades out on the floor, windward face down (curved faces up). Fit the root together. Make equal



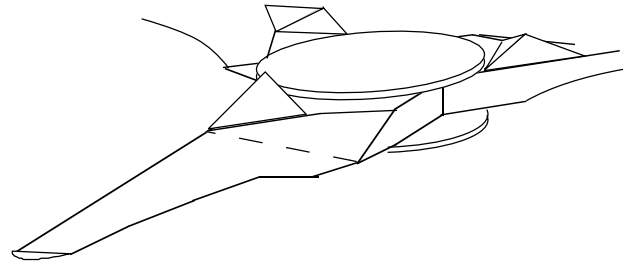
spacing between the tips.

Make a mark on each blade at 5" [125 mm] radius from the centre of the rotor.



lines up with both lines demarcating the cut. Then saw out the wedge.
The position to glue the wedge on is shown in Step Two.

Paint the blades and disks before final assembly.



Position the master disk centrally on the blade roots by aligning the disk's edges on these marks. Screw it onto the blades with 9 screws per blade.
Turn the assembly over and repeat, using the other disk.

Turn it back again. Mark the centres of the four 1/2" [12 mm] holes by drilling very slightly through the master disk into the blades. Remove the master disk. Lay the front of the hub on waste wood, and use a 5/8" [16mm] drill to follow through at the same positions. Take great care to drill square to the face.

These holes provide a clearance fit for the 1/2" [M12] studs that secure the blade assembly to the alternator. The assembly locates precisely on the master disk.

Now unscrew the front disk, ready for painting.

STEP SIX Cutting out and gluing on the wedges

Materials				
Pieces	Material	Length	Width	Thick
1	Offcuts of wood, with straight grained portions	Enough to find some nice portions	Over 3" [75mm]	1 1/2" [37 mm]

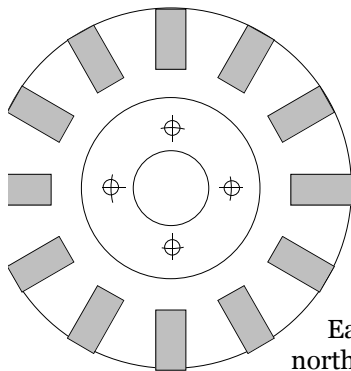
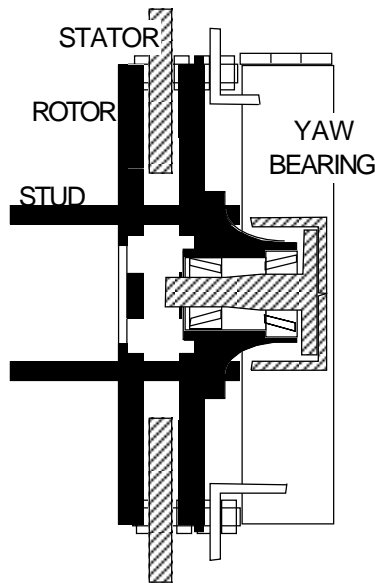
This diagram shows the dimensions of the wedges. The simplest way to produce them is to cut them from the corners of blocks of wood as shown.

Choose a clear part of the block and draw two lines at right angle to the corner, shown dashed in the diagram. Measure out the 3" and the 1 1/2", and draw the angled lines, marking the cuts you will make. To cut out the wedges, place the block of wood in a vice with one line vertical. Align the blade of the saw carefully so that it

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.



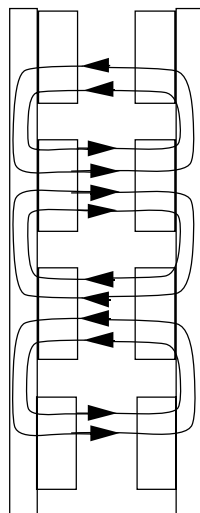
There are 12 magnet blocks on each rotor. We embed the blocks in a polyester resin casting to support them, and to protect them from corrosion.

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.

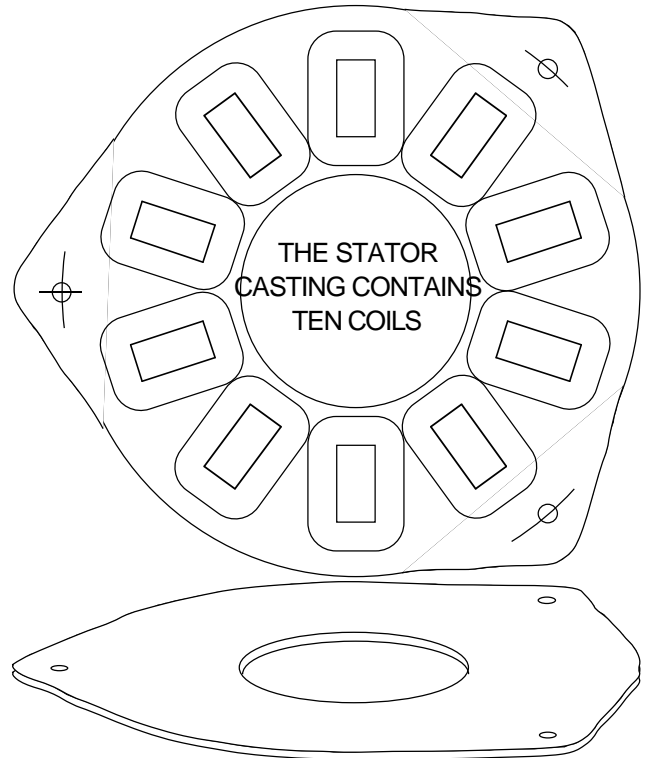
The stator

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.



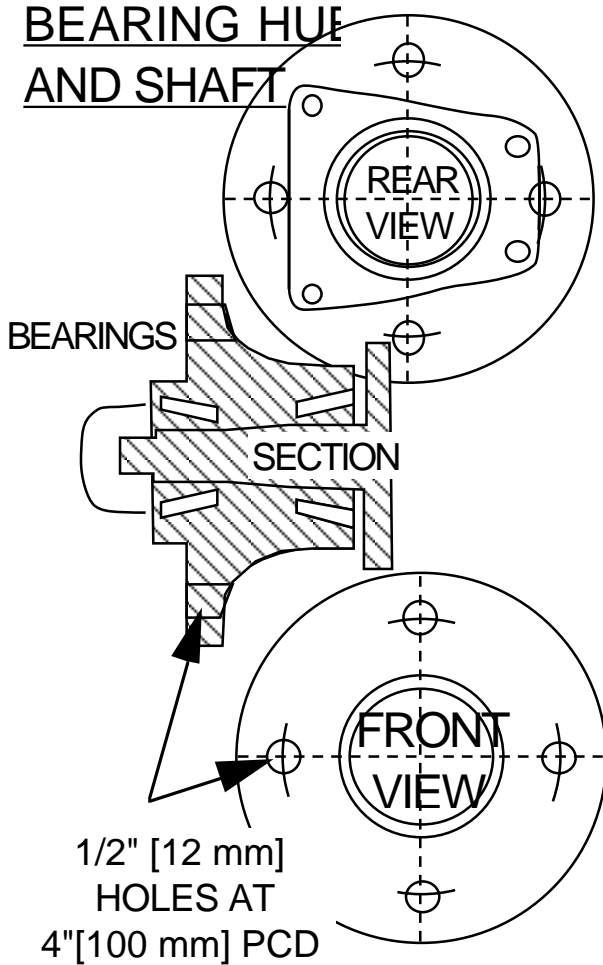
The number of turns of wire in each coil is used to control the speed of the wind turbine. If the number of turns is large, then the output will reach battery voltage and start to charge the battery at a low rotational speed (rpm). If we use fewer turns of thicker wire in the coils, then it will need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

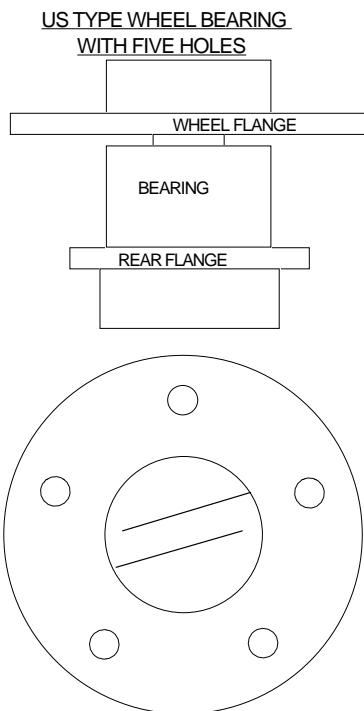
Preparing the bearing hub

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.

BEARING HUB AND SHAFT



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

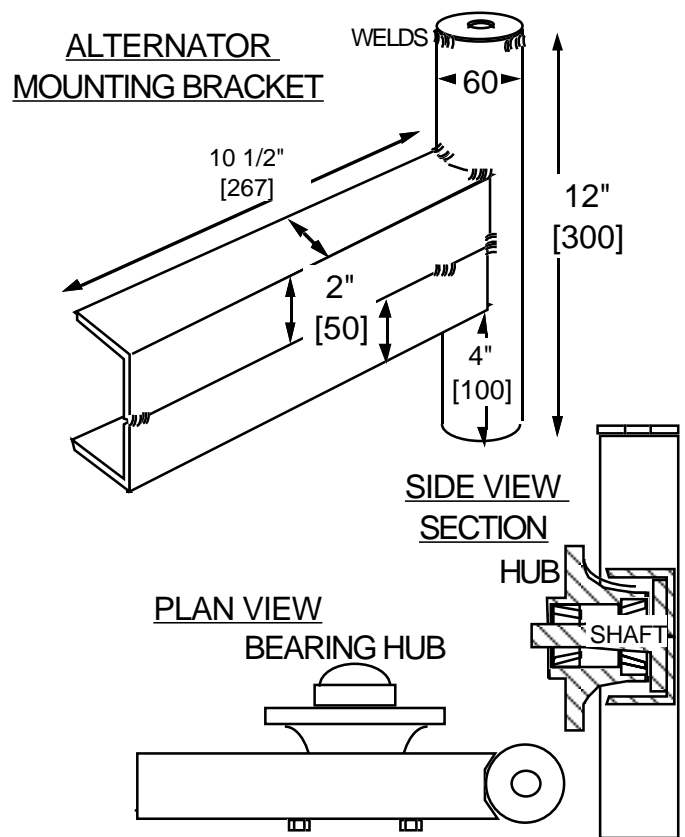
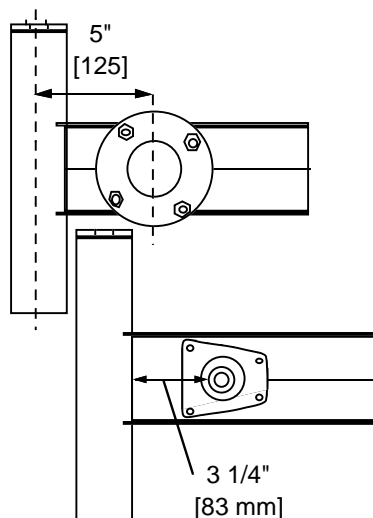
Materials				
Pieces	Material	Length	Diameter	Thick
1	Steel pipe 2" nominal	12" [300]	2 3/8" 60.3 OD	1/8" 3 mm
1	Steel plate	2 1/2" [65]	2 1/2" [65]	5/16"
2	Steel angle	10 1/2" [267 mm] or 11 1/2" for GM hub	2" [50 mm]	1/4" [6]
2	Steel angle	2" [50mm]	2" [50 mm]	1/4" [6]
1	Steel angle	4" [100 mm]	2"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

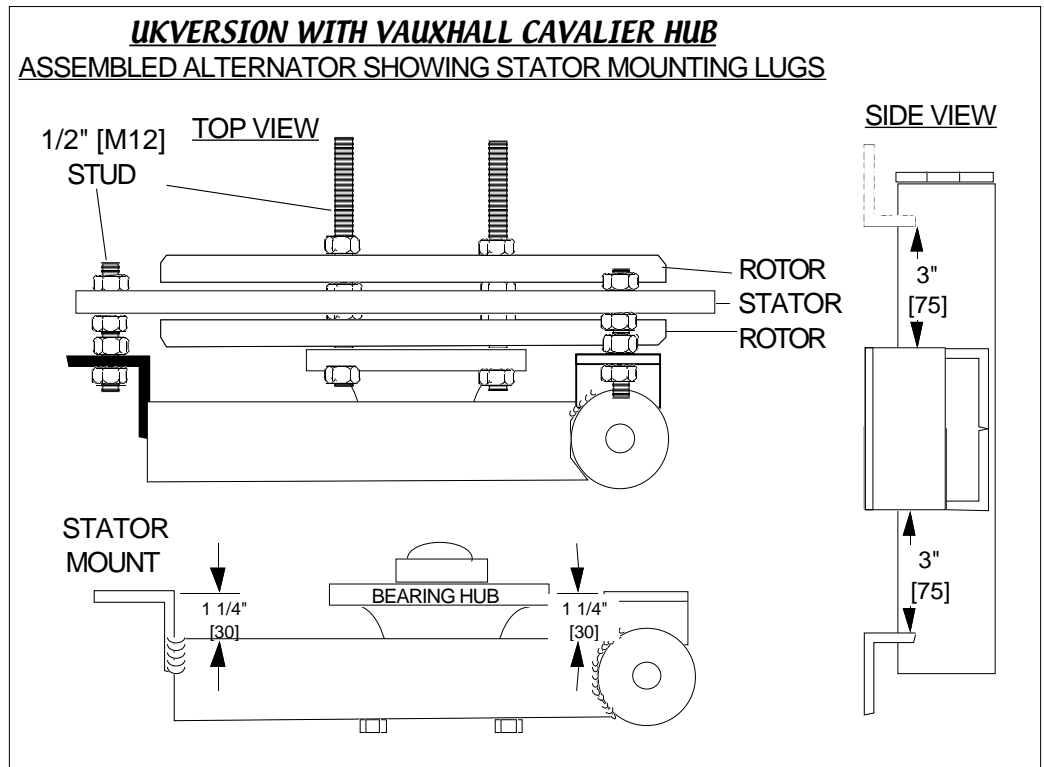
Position the shaft flange centrally between the upper and lower faces of the channel, and 5" [125 mm] away from the centre of the yaw bearing. It is not easy to measure this offset as such but if you measure the shaft diameter as 15/16" [24 mm] (say) then you can compute that the space between the outside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

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.

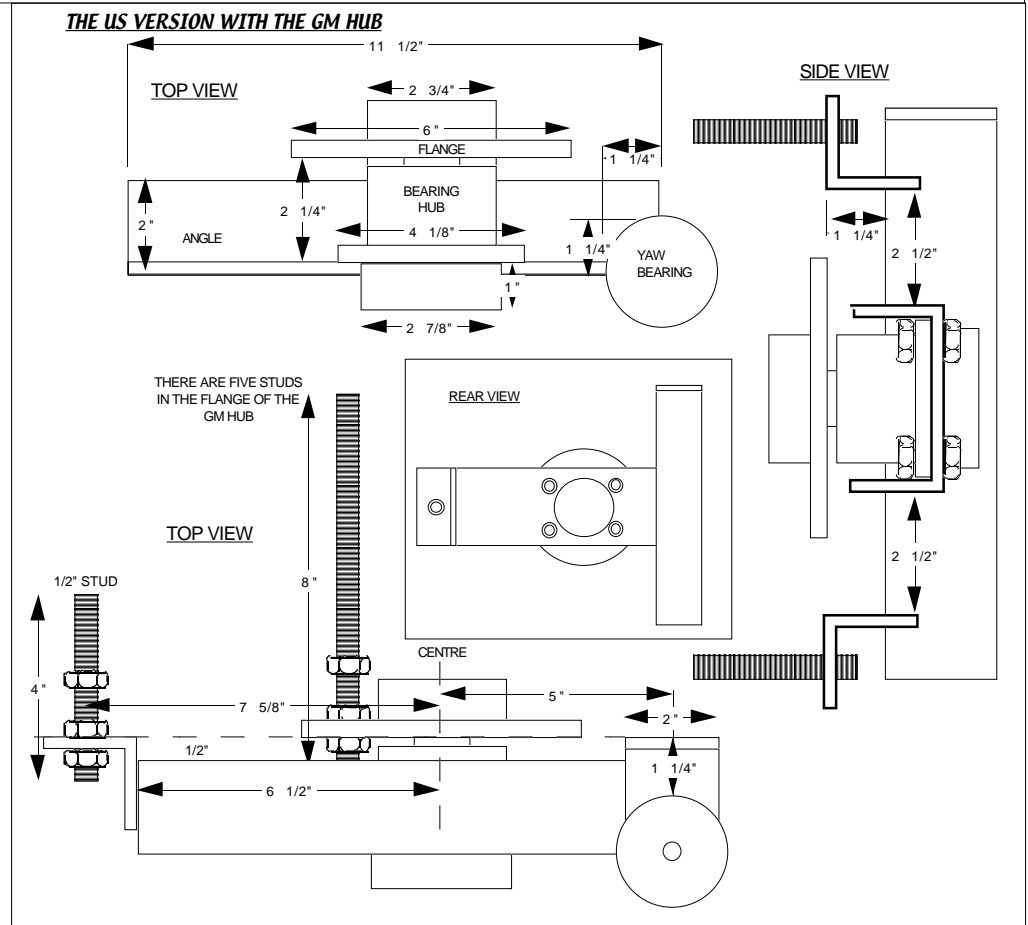
Mounting diagrams

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

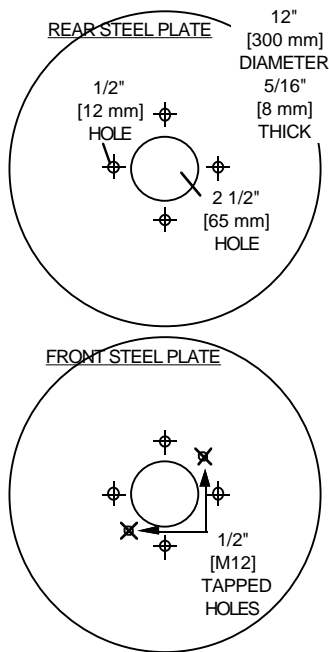
The USA magnet version has slightly different stator dimensions from the UK metric magnet version. The upper drawing applies to UK magnets, and the lower one is for 2" x 1" USA magnets.

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).

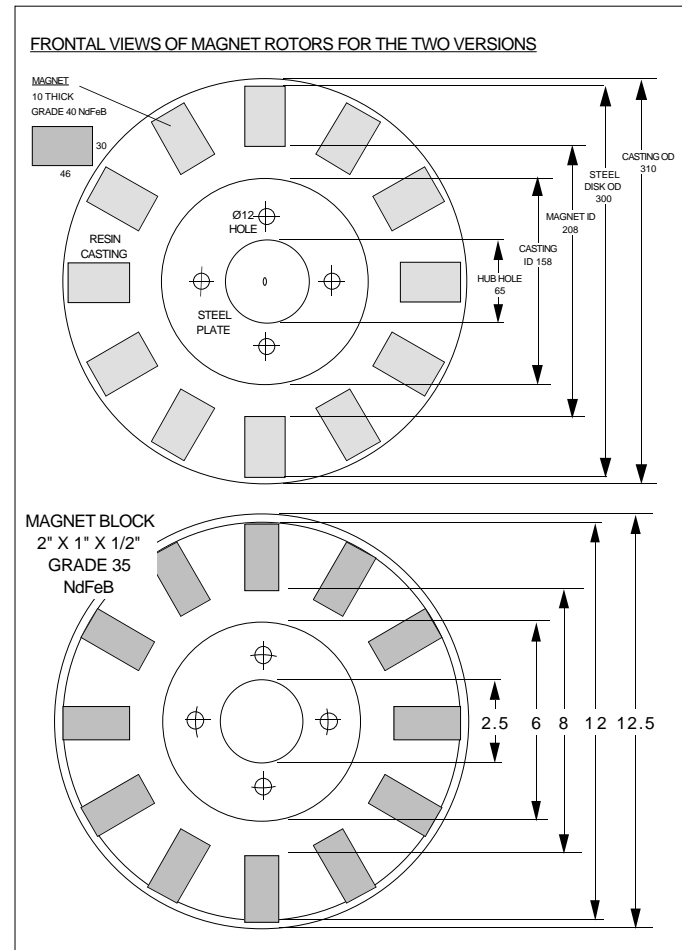


Use a holesaw to cut a clearance hole for the bearing stub on the hub. A 2 1/2" [65 mm] holesaw is a good size. This will allow the rear magnet-plate to sit flat on the hub flange. It is also useful to have a large hole in the second magnet-plate. Keep the off-cut disks from the holesaw for use in the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

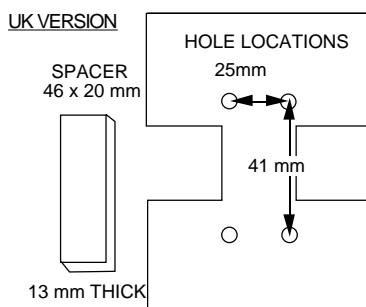
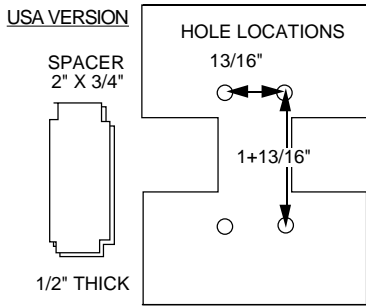
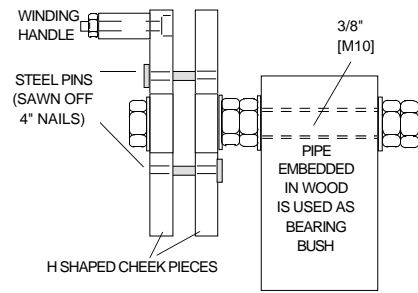
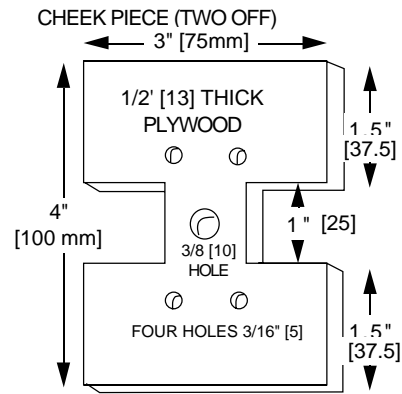
Each cheek piece has deep notches in opposite sides, to allow you to slip a piece of tape around the finished coil. The tape will hold the coil together when you remove it from the winding machine.

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 not on the supporting bearing.



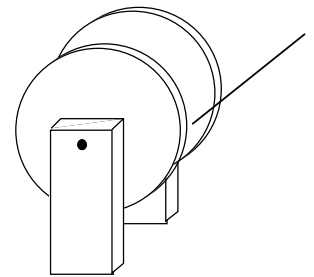
Winding the coils

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

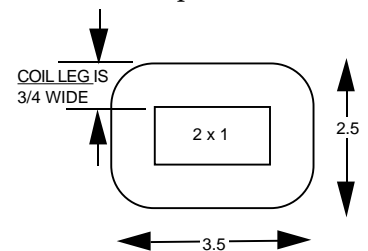
Build a stand for the reel of copper winding wire. Take care to keep the wire straight. Avoid bending it unnecessarily or scraping in the enamel. Align the coil winder to the reel stand, so that the wire can feed into it parallel to the cheek pieces.

WIRE REEL HOLDER

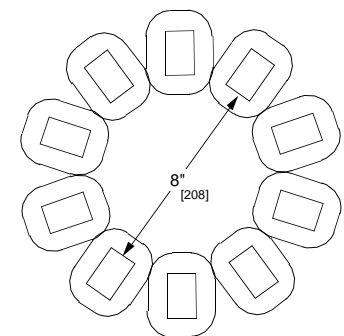


Make a tight 90-degree bend about 4" [100 mm] from the end of the wire and place it into the coil winder, in a notch in the outer cheek piece. Tuck the wire in close against the cheek piece. Wind the tail of wire around the 3/8" [M10] nut, such that it cannot slip off.

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.

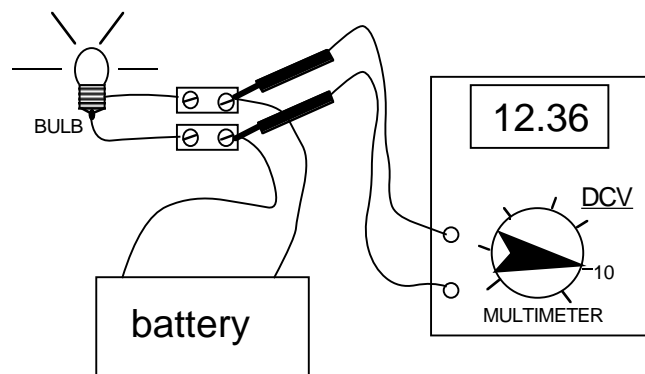
Check that the dimensions of the coil are as shown. Repeat this process until you have ten coils.

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.

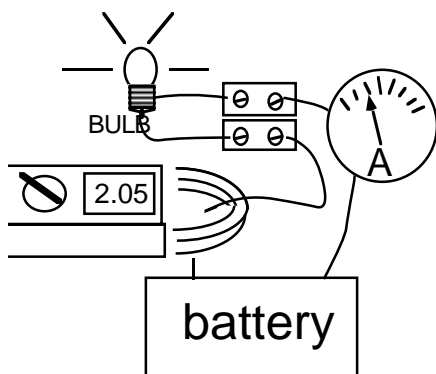
The ten coils will be laid out in a circle to match the magnet blocks. The spacing between the inner edges of the holes will be 8 inches, or 208 mm for the metric magnets, as shown.

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 multimeter. 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.

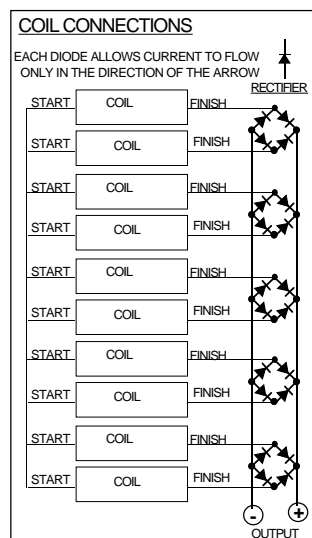
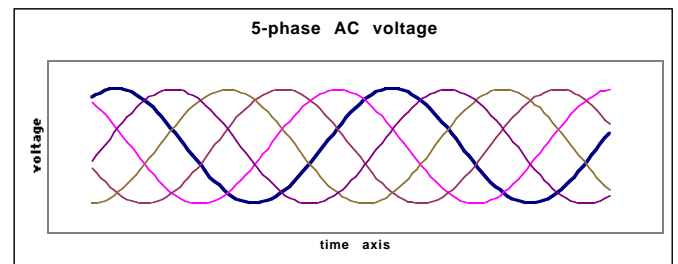
Here the supply is a battery and the load is a bulb. The supply can be a wind turbine and the load can be a battery. In either case the power transmitted is measured in 'watts'. Power output is calculated by multiplying the voltage by the current. For example a 20-amp current in a 12-volt circuit delivers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

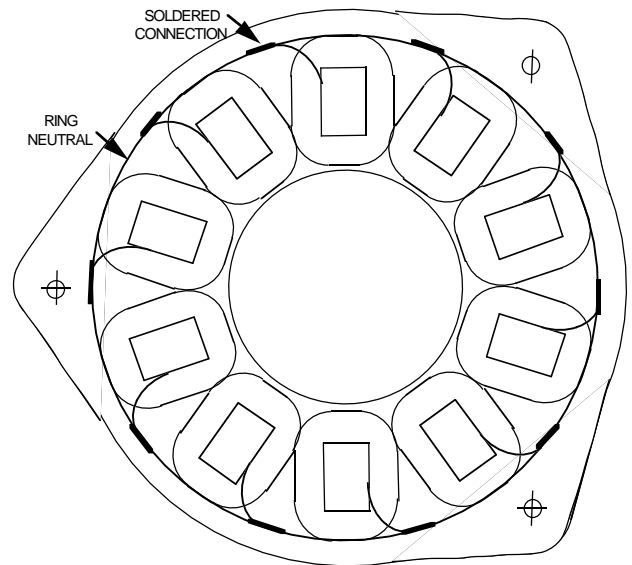
Soldering the coil tails

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.

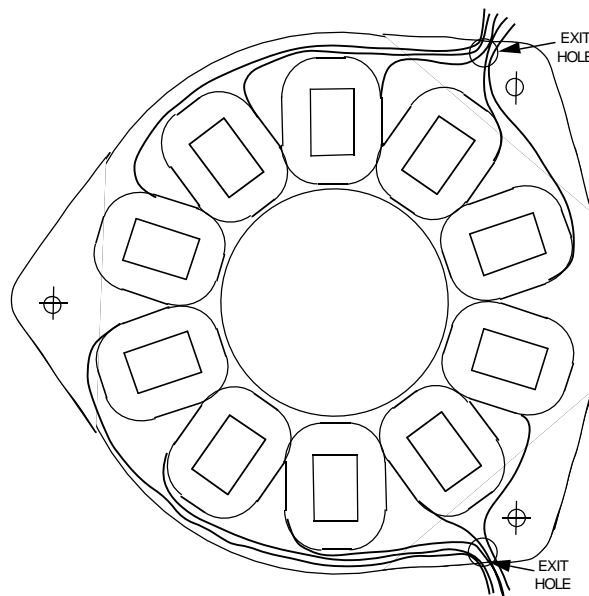
Lay the coils in the stator mould as shown below. They all have to be exactly the same in orientation, with the starting tail on top. It does not matter if your coils are a

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.

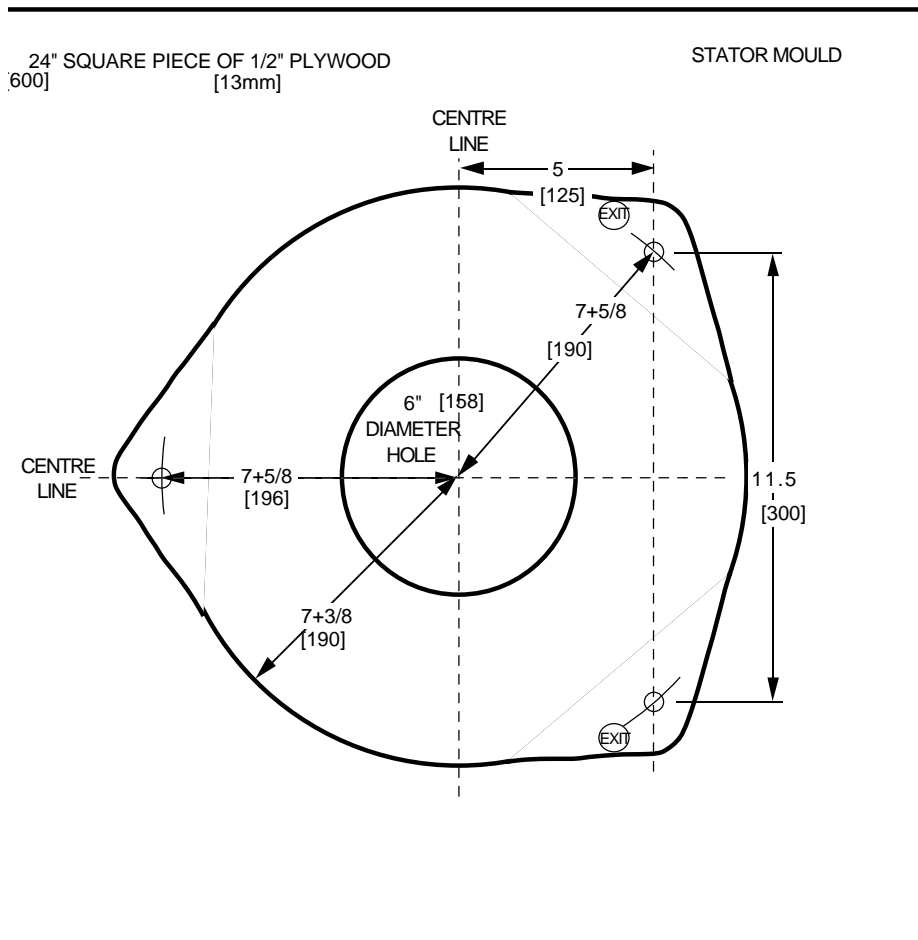
Take care to make the tails long enough to reach the rectifier. Use cable ties to secure the flex wiring together neatly. Ensure that they are secured away from the positions of the mounting holes or they could be damaged during the drilling of these holes.

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 si
	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.

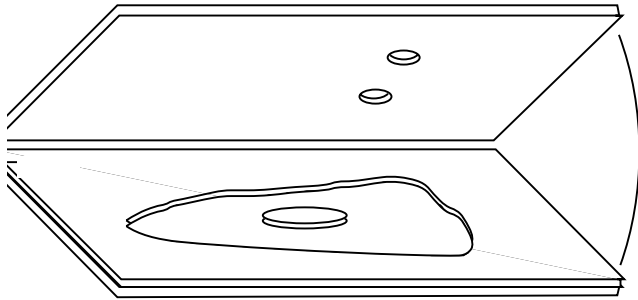
- Mark the mounting-hole centres 7+5/8" [196] away from the centre. Mark two centres on the offset line. The separation should be 11+1/2" [300 mm]. Mark the third hole's centre on the horizontal centre-line, opposite the offset line. Do not drill any holes yet!

- Draw arcs on these three hole-centres at 1+1/4" [30 mm] radius. These describe the

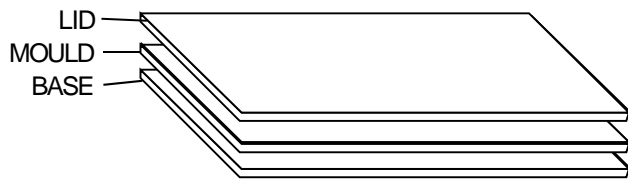
outsides of the mounting lugs. Finally use a ruler to connect the big circle to these new arcs with tangential lines so that the outside edge of the stator is a smooth shape. **Do not cut the mould out yet.**

Sandwiching the stator mould.

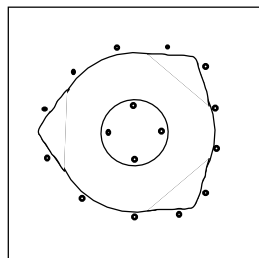
While being cast, the stator will be sandwiched between two smooth-faced boards: a base and a lid. Discarded kitchen cabinets or worktops are good for this purpose, or you can use thick composite board for strength, and add smooth hardboard for the finish.



- **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

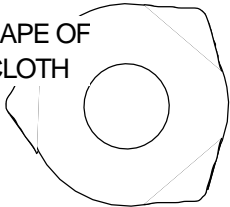
- Place the mould surround onto the base correctly and **screw it down**, using different holes (not the ones you drilled through the lid). Use the lid holes to position the central island on the base and then screw that down too. Cover the screw heads with polish and/or tape to prevent flooding with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

SHAPE OF CLOTH



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

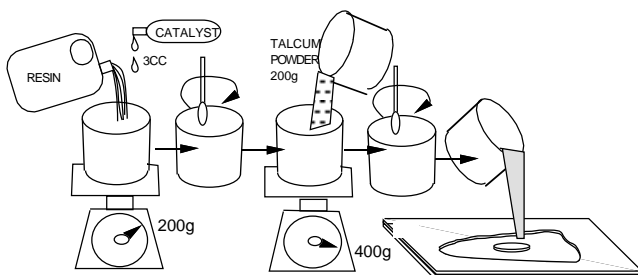
comfortably. Make provision for the wires where they exit the mould. Some small extra pieces of cloth can also be useful for strengthening the lugs (see later).

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.

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 magnet-positioning jig

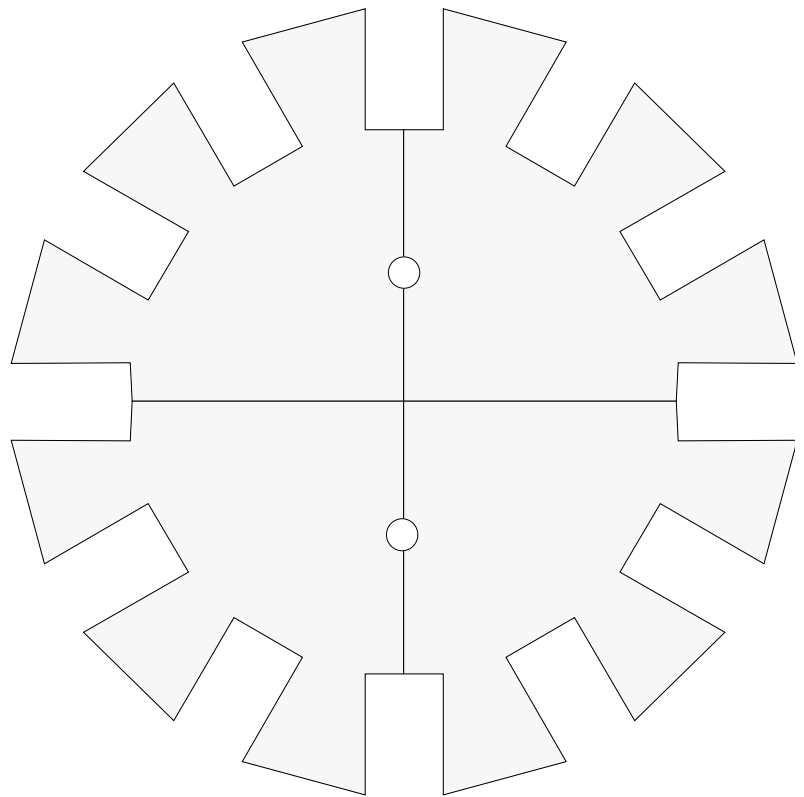
The finished jig looks like this

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

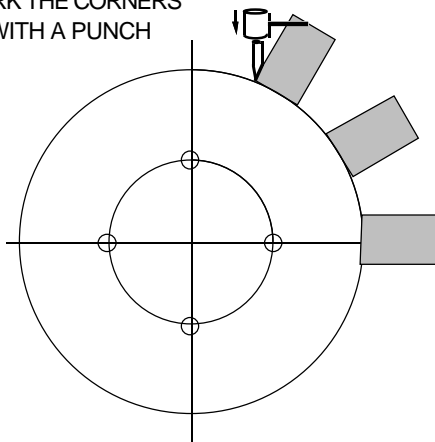
The magnet layouts are different for the two versions 'English' and 'Metric'.

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.

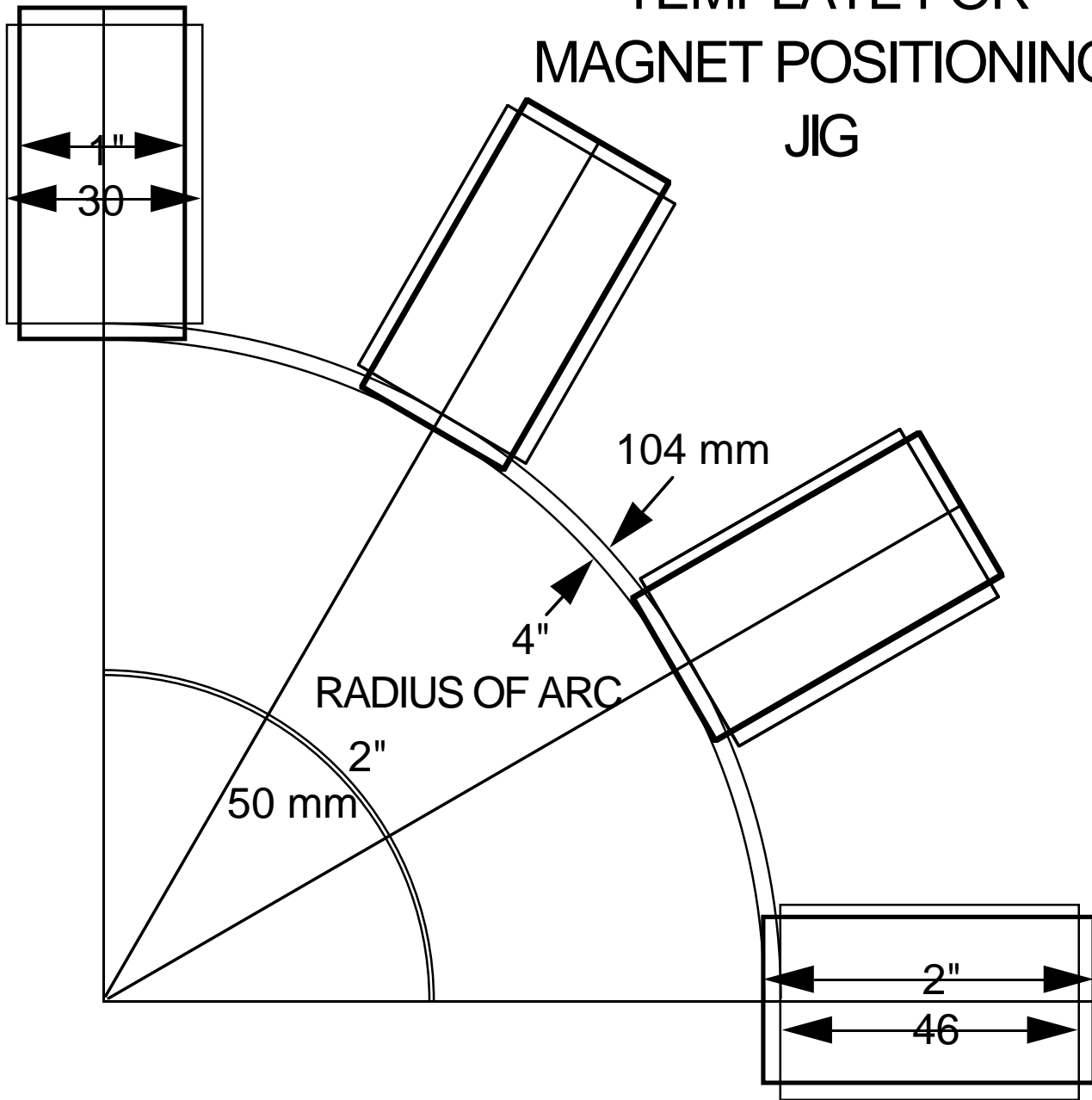
- Mark the centre of the board.
- Draw two circles with radius 2"[50 mm] and 4"[104 mm] respectively.
- Draw two lines through the centre of the circles at right angles to each other.
- Align the drawing exactly on each quarter of the jig and mark the corners of each magnet with a centre punch or sharp 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.



MARK THE CORNERS WITH A PUNCH



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			

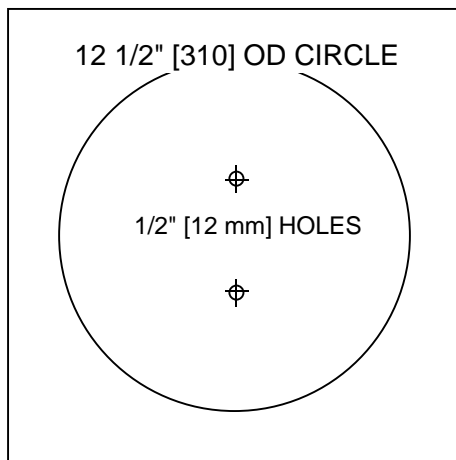
The magnets are mounted on 5/16" [8 mm] steel plates that have been drilled for mounting on the wheel-hub. We embed the magnets in resin to support them from flying off and to protect them from moisture that would cause corrosion. There is one mould for each rotor.

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.

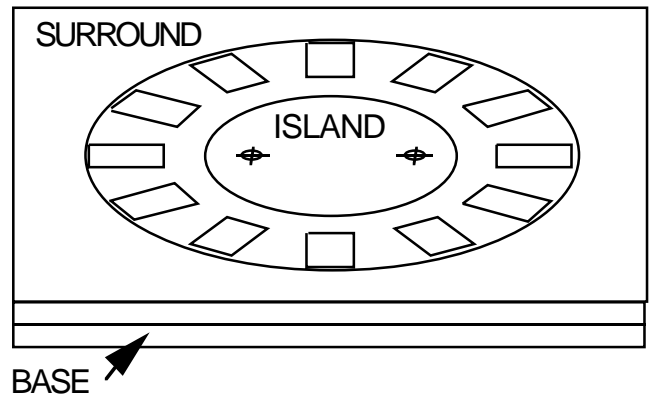
These bolts will later be used for positioning the steel plate, jig and island. Use the steel plate to guide the drill.

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.

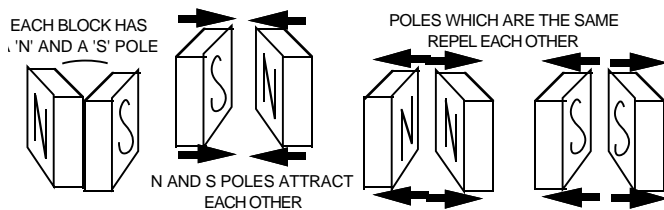
Check that the rotor disks have all the necessary holes drilled, and the front disk has tapped holes ready for the jacking screws.

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 very 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.

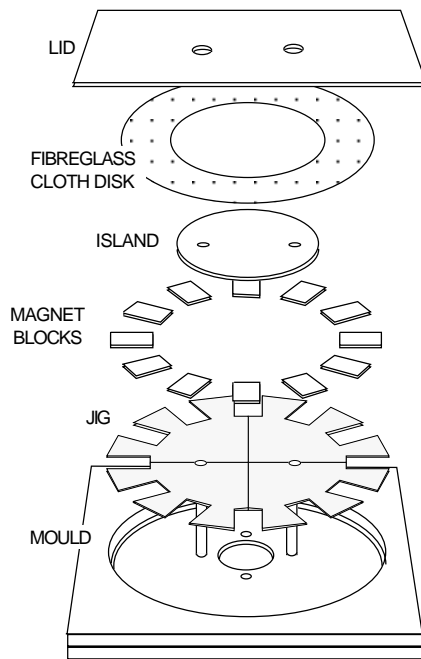
Paint this mixture over the area of steel where the magnet blocks will lie, and allow some to run over the edge of the steel disk (already in the mould).

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.

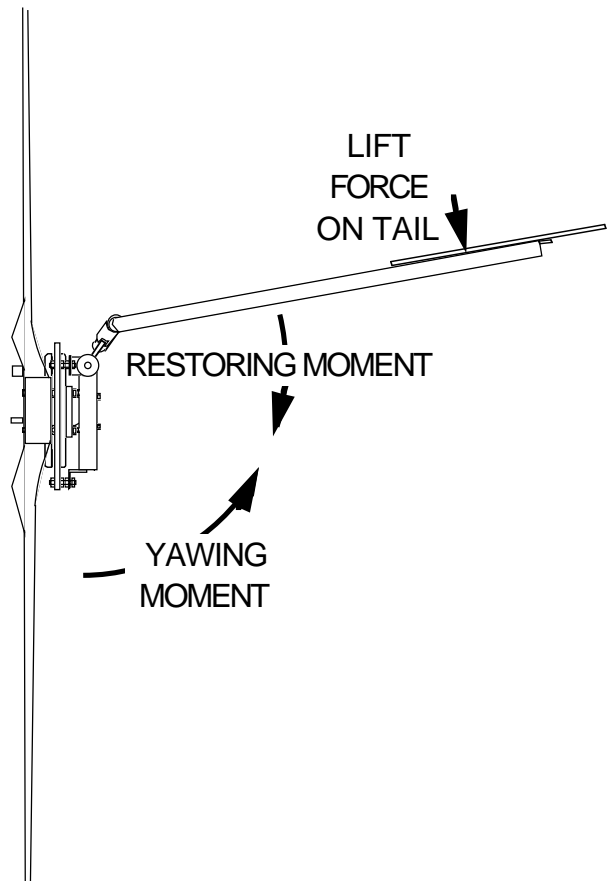
Do not use violent blows to release the casting in case you break the resin or a magnet. Use persistent tapping all around the edges and be patient.

FURLING SYSTEM THEORY

Why furl?

The power in the wind is proportional to the cube of the windspeed, so if the windspeed doubles, then it is eight times as powerful. We could design for the highest windspeed which could ever happen and harness its power, but then for 99.9% of the time our wind turbine would be under-used and probably not very efficient because it would have a huge, heavy alternator and relatively tiny blades.

If the windspeed increases beyond a certain point there is a danger of overload. The alternator and diodes may overheat, the blades may overspeed or the side loading on the mast or 'tower' may be too high. To prevent these things from happening, we fit the turbine with a furling tail.



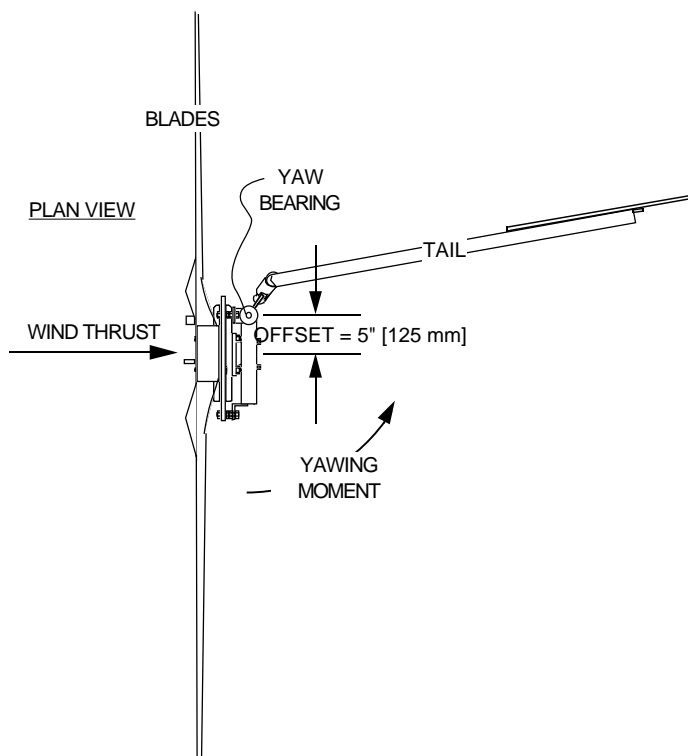
How the furling tail works

The wind thrust on the rotor blades is indicative of the amount of power being captured by the machine. When that thrust reaches a certain level, and the wind is getting stronger, we want to prevent the power increasing further. Ideally we would like to continue producing full power in higher winds, while avoiding overload.

We build the wind turbine off-centre, so the wind thrust (centred on the alternator) is always trying to turn the machine away from the wind. If it turns away at an angle to the wind, this reduces the frontal area and limits the power it can capture. The trick is to make it face the wind when it needs to and to turn away by the right amount at the right time.

The alternator is offset so that the wind thrust acts at a 5" [125 mm] radius from the centre of the 'yaw bearing' on which the whole machine swivels to face the wind. This means that the thrust creates a 'yawing moment' or torque about the axis of the yaw bearing. The wind thrust is always trying to turn the blades away from the wind.

In normal operating windspeeds, the force of the wind on the tail counteracts the yawing moment. When the machine tries to yaw out of the wind, the tail swings into a position where it produces a lift force. That lift force creates a restoring moment which balances the yawing moment and the machine sits there in equilibrium. We deliberately set the tail at a slight angle to the side opposite the alternator offset so that the equilibrium is achieved with the blades squarely facing the wind and catching the maximum power.

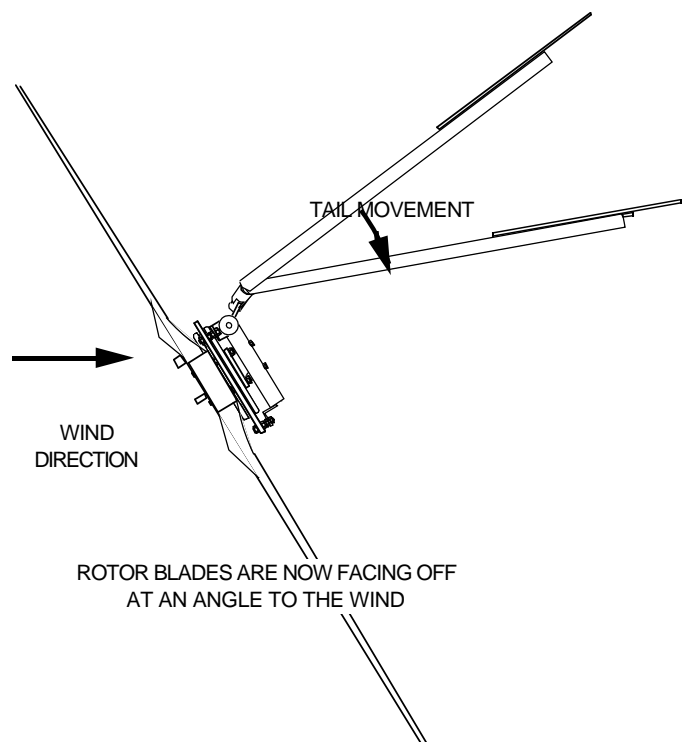


Controlling the thrust force

As windspeed increases, the thrust increases, and so does the yawing moment. However, the lift on the tail is also increasing and so the equilibrium of forces keeps the blades facing the wind.

The clever part of the furling design is in the way the tail is mounted. When the lift force reaches a certain magnitude, it moves the tail into a new position. In this position the blades can turn away from the wind. The thrust force is thereby reduced and a new equilibrium is established.

We could use a spring and a hinge to construct a tail mount that yields in this way. But experience has shown that springs vibrate, corrode and break. Instead we use an inclined hinge system which forces the tail to rise as it swings to the side. The weight of the tail itself brings it back down into the normal position. We can control the windspeed at which furling takes place by making the tail heavier or lighter.



Fabricating the tail hinge

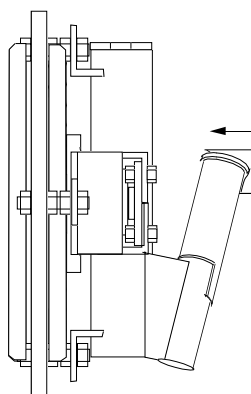
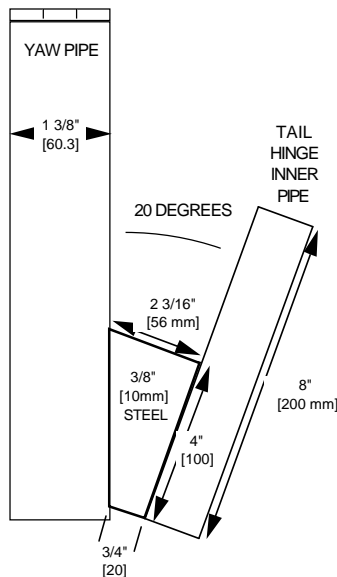
Materials				
Pieces	Material	Length	Diam.	Thick
1	Steel pipe 1" nominal bore	8" [200 mm]	1 5/16" [33.4] overall	1/8" [3 mm] wall
1	Steel pipe 1 1/4" nominal bore	4' [1200mm]	1 5/8" [42.2] overall	1/8" [3 mm] wall
1	Steel pipe 1 1/4" nominal bore	6" [150 mm]	1 5/8" [42.2] overall	1/8" [3 mm] wall
1	Steel disk		1 5/8" [42.2] minimum	5/16" [8 mm]
Pieces	Material	Length	Width	Thick
1	Steel plate	4" [100]	2 1/4" [56 mm]	3/8" [10 mm]
1	Steel bar	12" [300]	1 1/2" [30]	5/16" [8]

The tail hinge is made in the same fashion as the yaw bearing. It consists of a 1 1/4" nominal pipe slipped over a 1" nominal pipe.

These pipe sizes are used in both the 'English' and the 'Metric' versions.

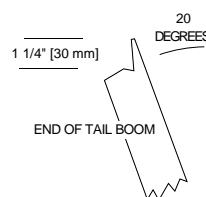
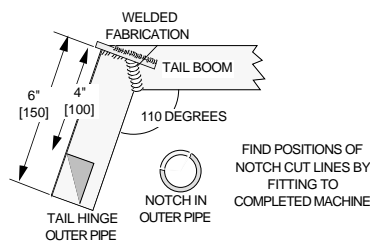
The smaller, inner pipe is to be welded to a shaped piece of 3/8" [10 mm] plate. The other side of the plate is welded to the yaw bearing. The resultant angle of the inner pipe is 20 degrees to the vertical.

TAIL HINGE SIDE VIEW



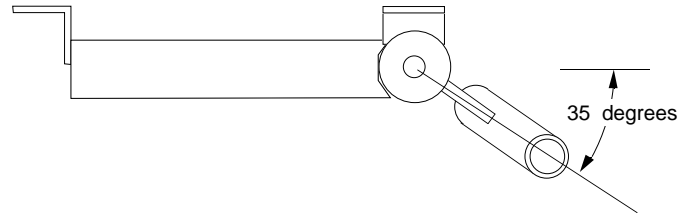
48" [1200 mm]

"INCH AND ONE QUARTER" NOMINAL BORE STEEL WATERPIPE



You can cut this plate out from 4" x 3/8" [100 x 10 mm] flat bar. The 20-degree angle is achieved by making one side of the plate 2 3/16" [57 mm] long and the other 3/4" [20 mm] long.

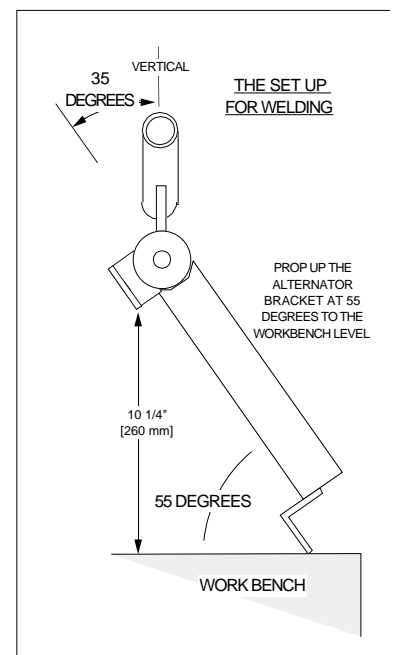
Weld the plate onto the 1" pipe first, and then weld it onto the yaw bearings as described below.



The hinge must be welded onto the yaw pipe in a diagonal position, as seen from above. The angle between the pipe and the rotor plane is 35 degrees in this plan view.

I find that the easiest way to achieve this 35-degree angle is to set the yaw assembly up on the bench with the alternator-mounting bracket at 55 degrees to the horizontal. Then I sit the tail hinge pipe and plate vertically on top of the yaw tube and weld it there.

Apply plenty of welds at both sides of the steel plate. The tail will put some critical loads on this part. Good quality welding is essential here.



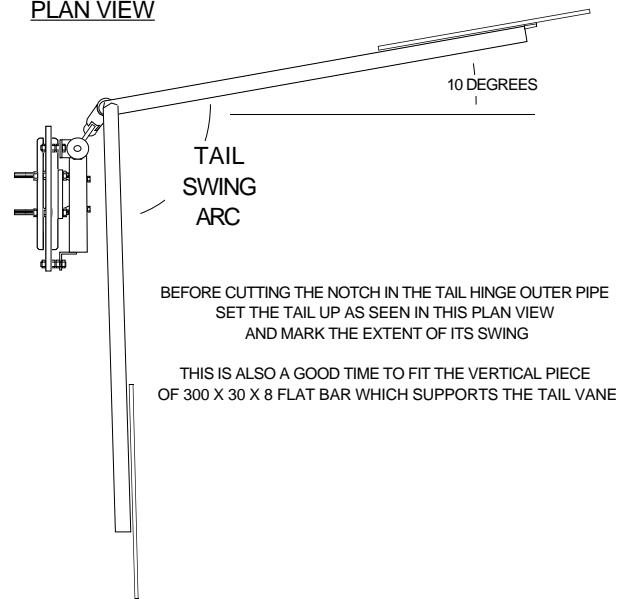
The tail itself

The outer part of the tail hinge bearing is a 6" [150 mm] long piece of 1 1/4" pipe, with a steel disk welded on top. The tail boom is a 48" [1200 mm] piece of 1 1/4" steel pipe, welded to this outer part of the tail hinge bearing. The overall diameter of these pipes is 1 5/8" [42 mm].

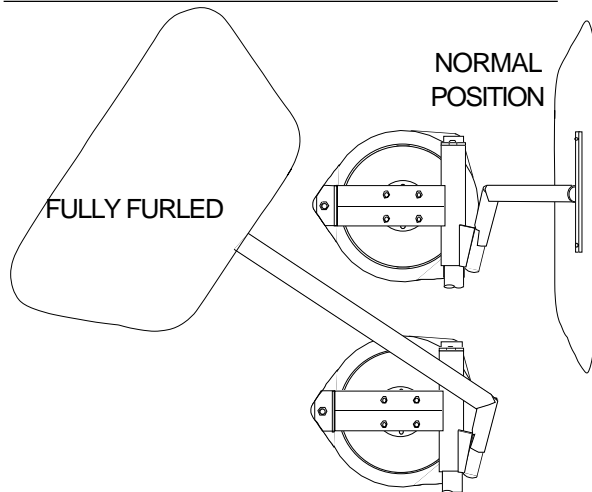
To prepare the tail boom for welding to the hinge bearing, set it up at an angle of 20 degrees off the vertical and make a vertical cut into the end, starting just inside the right hand wall (see diagram previous page). The depth of this cut is 1 1/4" [30 mm]. Now place it horizontally and cut square across the pipe to remove a piece and leave a 'bird's mouth' on the end of the pipe. This should now fit the outer part of the bearing at an angle of 110 degrees. Use an angle grinder to make it fit better and then weld it very strongly.

Set the wind turbine in a vice, or a dummy tower/stand with yaw bearing vertical. Drop the tail onto its bearing.

PLAN VIEW

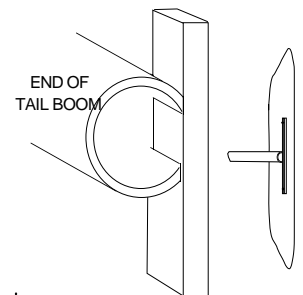


REAR VIEWS OF THE TAIL IN TWO POSITIONS



The tail vane needs a crosspiece at the end of the boom to bolt onto. I suggest something like a piece of flat steel bar 12" x 1 1/2" x 5/16" [300 x 30 x 8 mm]. Recess the flat bar into the pipe to create a flat surface on the windward side of the tail where the vane will sit.

Wait until the tail boom is on the wind turbine and its notch has been cut before you set up to weld the T piece on the end. This way you can set the T piece vertical. A vertical tail vane looks better (although it makes no difference to the way it works).



It will not go all the way home, because the steel plate gets in the way. You will need to cut a notch in the tail hinge outer pipe to accommodate the steel plate. The shape of this notch will also control the range of movement of the tail as it swings up and allows the machine to furl.

The tail should sit horizontally in its lowest position at an angle of about 80 degrees to the rotor blades, and therefore 10 degrees away from pointing straight back. At the top of its swing motion it comes close to being parallel to the blades but not beyond that point.

Use a hacksaw or an angle grinder to cut the notch. Try to make the corners smooth and prevent stress concentrations. The pipe may not butt neatly against the steel plate; the welds may get in the way. You may then have to add external pieces for extra strength and a more positive stop.

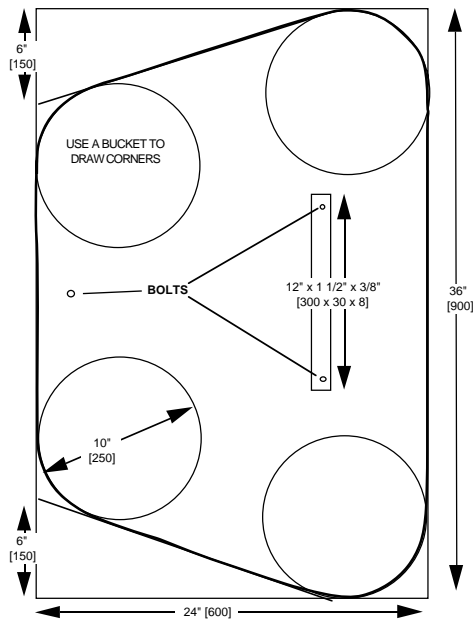
Cutting out the tail vane

You can make the tail vane any shape you like provided it is large enough. I suggest you use about 3' x 2' [900 x 600 mm] area.

Here is one way to make a tidy looking tail vane.

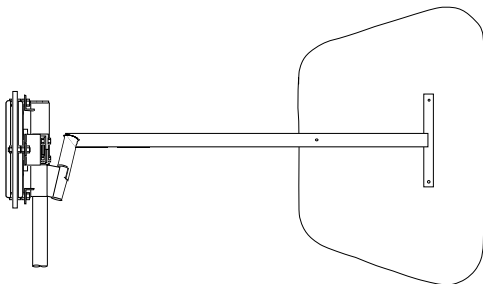
Materials				
Pieces	Material	Length	Width	Thick
1	exterior plywood	36" [900 mm]	24" [600]	3/8" [9 mm]
3	Bolts, nuts	2 1/2" [60 mm]	3/8" [M10]	

Start by making two marks at 6" [150 mm] in from the ends of one of the longer sides. Find a bucket or plate with diameter around 250 mm and use this to round off the corners of the other long side as shown. Draw a line from the marks you have made so it just touches the circles you have drawn. Finally use the same bucket or whatever to round off the new corners created by this new line.



Use a jigsaw to cut out the tail. Sand off the edges to remove splinters.

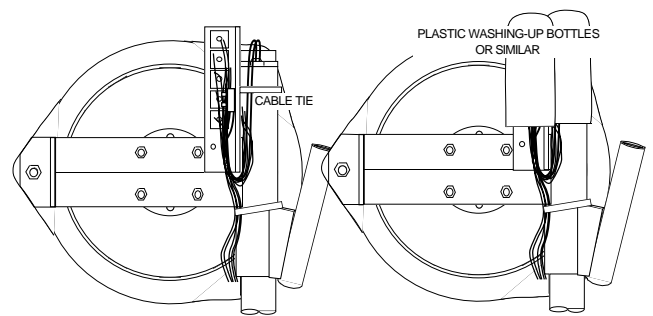
Mount the tail on the tail boom with three 3/8" [M10] bolts. One bolt passes right through the boom, and the others can be near the ends of the steel crosspiece you welded to the end of the boom.



Mounting the heatsink

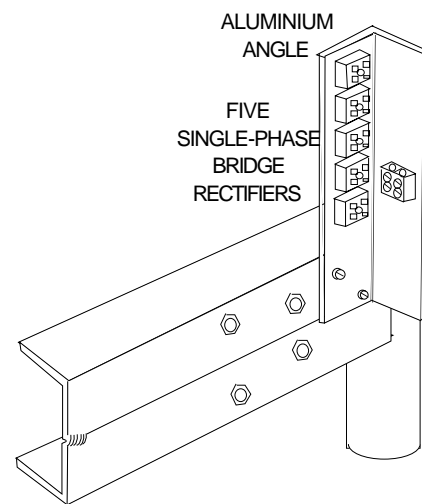
Materials				
Pieces	Material	Length	Width	Thick
1	Aluminium angle	12" [300 mm]	2" [50]	3/16" [5 mm]
2	Bolts and nuts	1" [25]	1/4" [6]	
6	Bolts and nuts	1" [25]	3/16" [5]	
5	Bridge rectifiers	35A 6-800V single phase		
1	Connector block			

The ten wires from the stator will supply AC output from the alternator. This has to be converted into DC for charging the battery. The bridge rectifiers convert AC into DC. They have to be mounted on a heatsink to keep them cool when handling high currents. For example piece of 2" x 2" x 3/16" [50 x 50 x 5 mm] aluminium angle would make a suitable heat sink. The length of the heatsink is 9" [220 mm].



Fit the heatsink to the alternator support bracket alongside but not touching the yaw pipe.

Bolt it on with 1/4" [6mm] bolts. The rectifiers are bolted to the heatsink with 3/16" [5-mm] bolts. A junction block for the DC wiring is also useful.

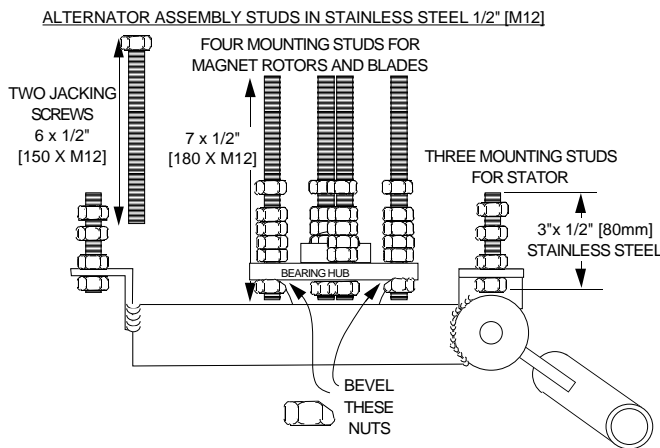


Assembling the alternator

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

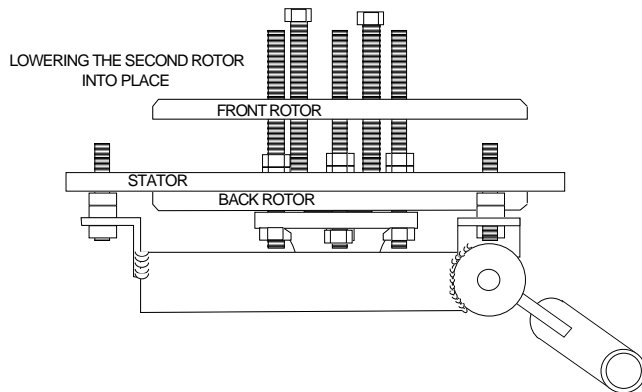
Spin two 1/2" [M12] nuts onto each stator-mounting stud, and pass the stud ends through the stator lugs. Add nuts to the back (with thread-lock). Squirt threadlock between the lug and the first nut above and tighten the nut down.

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:

$$\text{Frequency in Hz} = \text{rpm} \times \text{number of poles} / 120$$

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.

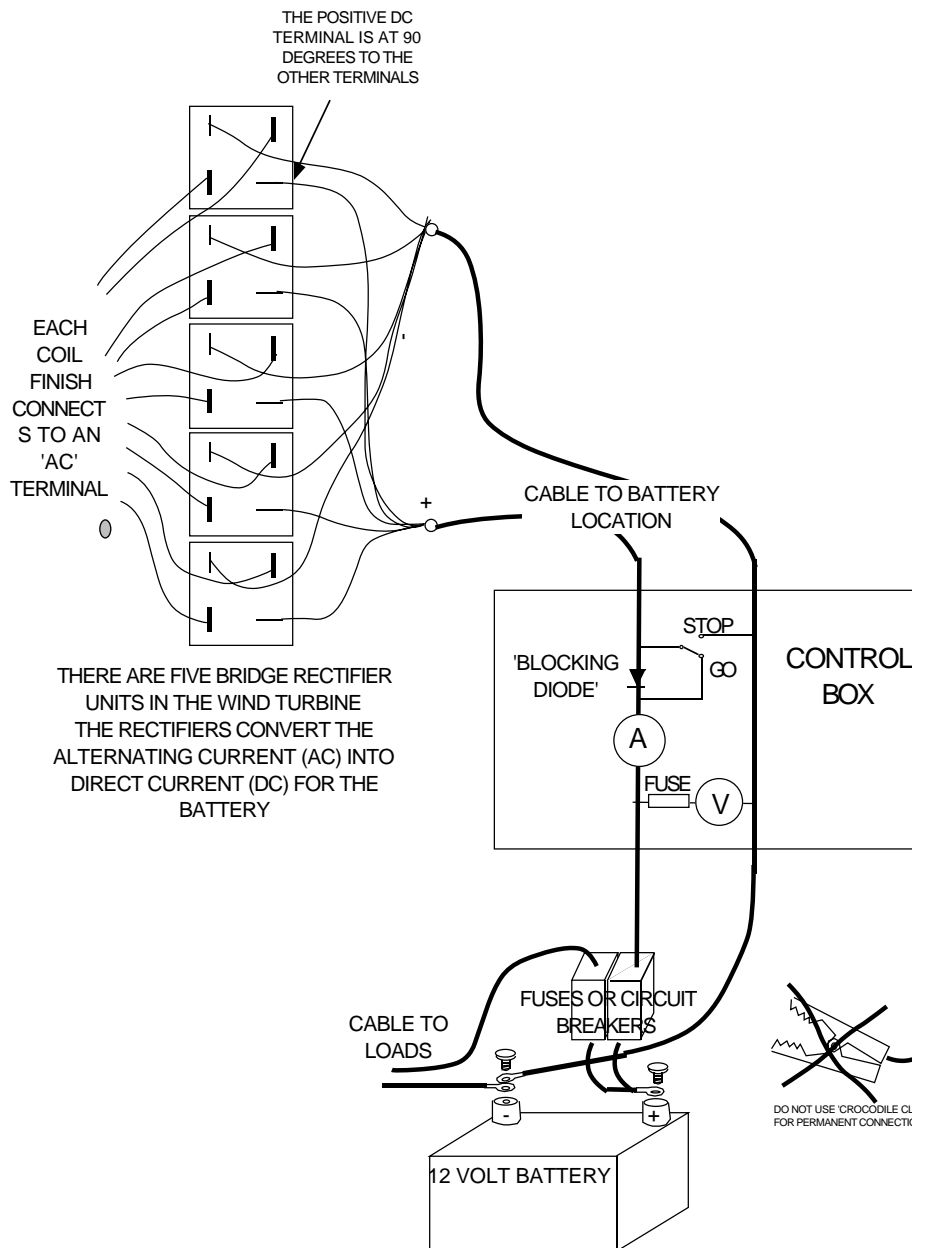
Connections

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.

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.

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 noise, 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%

Fitting and balancing the blades

When the alternator has been assembled and the machine is electrically ready for erection, it is time to fit the rotor blades. Set the machine up on a stand so that it is about 1.5 metres above floor level, and securely supported. Balancing can only be done in a sheltered place, so it is wise to fit the blades in the workshop rather than in the field.

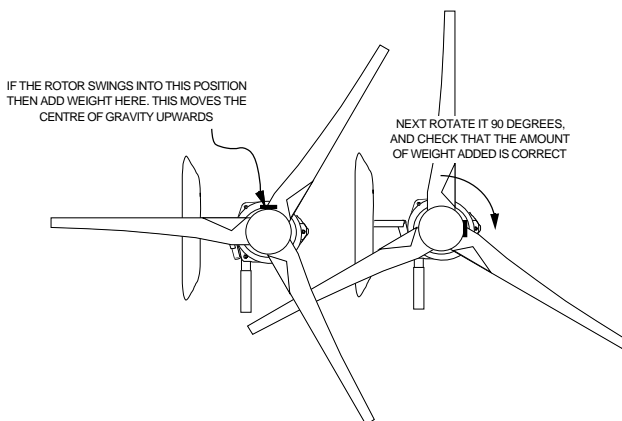
The rotor blade assembly is usually quite a tight fit onto the four M12 studs and may need to be driven on with mallet blows. Avoid extreme shocks to the alternator in case you damage one of the magnet rotor castings. AS soon as the tips of the studs appear through the front of the rotor, fit washers and nuts to them and use the nuts to finish pushing the rotor home.

Checking the tracking

When the blades are on, first check the tracking of the tips. Place a chair or similar object very close to one tip and rotate the others past the same object. They should follow each other through space within about 10 mm. If one blade is forward compared to the others, you can usually correct this by tightening the nuts hard on that side of the rotor. This crushes the plywood slightly and corrects the tracking. It is also possible to use shim washer but in practice it is very hard to find thin enough ones and get them right. Rubber washers (from inner tubes) can be used instead of crushing the plywood if you prefer.

Balancing the rotor

The goal of this procedure is to static-balance the rotor assembly. Dynamic balancing is not necessary for our



purposes. Provided the tips track each other then the dynamic balance will be fine once it has been static-balanced.

When first assembled, there is normally a conspicuous imbalance in the rotor. It will swing around into a preferred position. This is the position where the centre of gravity of the rotor is below the centre of the shaft (like a pendulum). Try deflecting it clockwise and anticlockwise and watch it return toward its preferred

position. It may not get there, because of friction in the bearings. Help it by tapping the alternator mounts. Carefully observe the position it likes to come to rest. Take an average.

Make a counterweight from a piece of lead flashing and fix it temporarily onto the rotor at a point directly above the centre when it is in its preferred position. The neatest place to fit this weight is usually in between the two plywood disks. Adding weight here will move the centre of gravity upward toward the centre of rotation and should help to balance the rotor. However it is hard to know exactly how much weight to add.

To calibrate the weight, you have to check again for balance. Rotate the rotor 90 degrees clockwise and observe whether it has any tendency to move right or left. Adjust the size of the weight until there is no tendency to swing in either direction. You can also trim the balance by moving the weight horizontally closer to or further from the centre. Moving it to the right will counteract a tendency to swing anticlockwise for example.

Fine tuning

Try the rotor in a number of positions, and vibrate the mounting in an attempt to make it move. At this stage you are looking for a very small imbalance. If you can find any tendency to move when it is in a particular position, then try turning it 180 degrees and see if it tends to move the other way. Add a very small weight to the side where it wants to rise. Adjust the size and position of this weight until there is no perceptible trend to rotate in either direction.

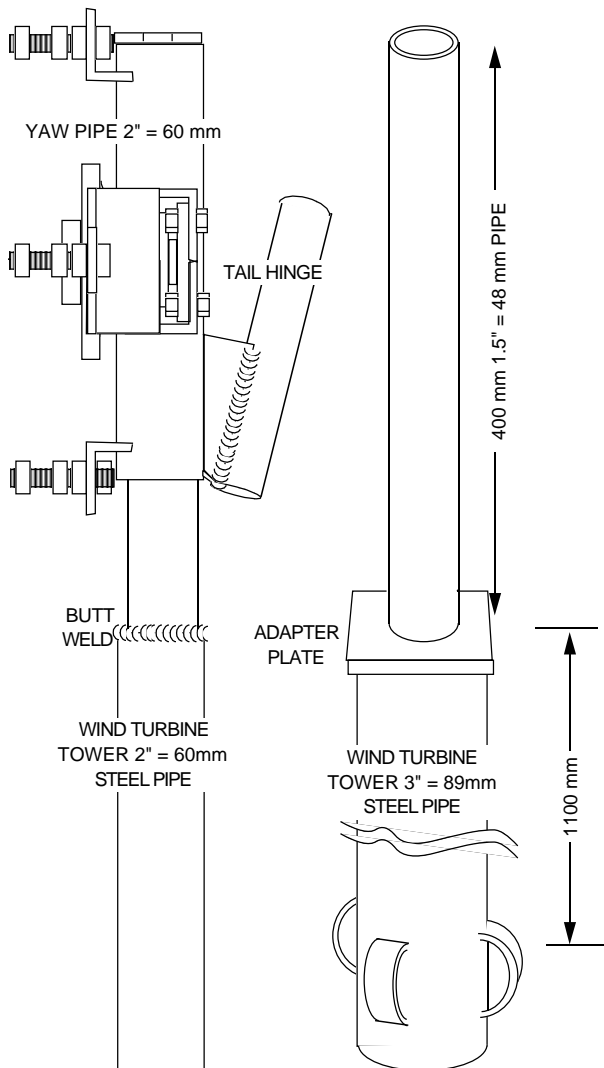
The above procedure will result in a smooth running rotor unless the bearings are exceptionally stiff. If you wish to fine-tune it still further, you can try the following. Hang a small weight (about 50 grams) on one of the studs. Choose just enough weight to start it turning. Hang the same weight on the opposite side and check that it starts in the opposite direction. If not then you may have to fix a little balance weight on that side. Do the same test with the rotor in several positions.

When you are happy that you have chosen suitable weights and positioned them correctly to balance the rotor, then screw the weights securely to the blades so they cannot fly off when the rotor is spinning fast.

ADDITIONAL INFORMATION

Guyed tower ideas

The mast or 'tower' is usually made from steel waterpipe. 2" pipe is sufficient, but larger sizes are also OK. The tower must be tall enough to take the wind turbine up and out of any turbulence, into a good clean wind. The higher the better is a good rule, but optimum height will depend on location. In a very open location a 20' [6 metre] tower might do. In many cases it will be necessary to go to 40' [12 m] or 60' [18 m] to reach clean wind. In the USA, 120' [36 m] are not uncommon. Making such a tall tower in lightweight pipe requires many guy cables.



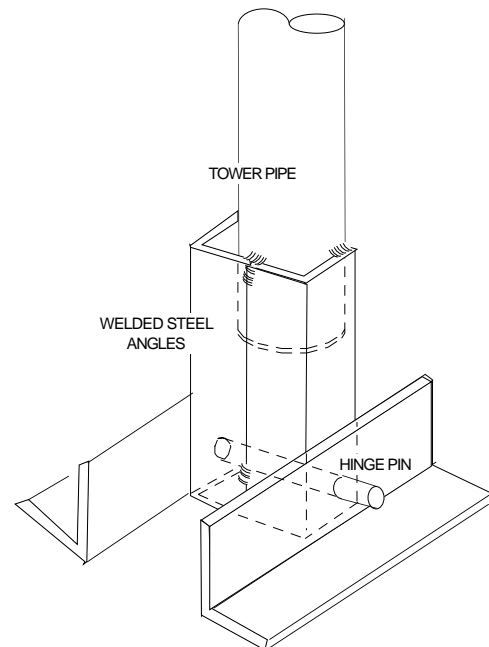
The tower top needs to consist of a 400 mm long piece of 1.5" pipe (48 mm overall). This will slip inside the yaw pipe. You can butt weld the 1.5" pipe directly to a 2" pipe, if your welding is good. If in doubt, then use pieces of flat bar alongside the join and overlapping to stiffen it.

If the pipe size is larger then use an adapter plate with a large hole in it for the wiring. A 50-mm hole would be

ideal, so that the smaller pipe can pass through it and be welded on both sides.

There are many ways to attach guys to the tower. One good solution is the slice short pieces of steel pipe in half lengthways, and weld them onto the side of the tower as shown. Then tie the guys around the tower, passing through the half-pipes. Make sure the guys are well clear of the blade tips, but not so far below them that the bending load on the tower is excessive in strong winds. Fit guys to the tower at approximately 4 metre intervals along its length. The top guys need to be strong; the others simply provide stiffness.

Guys are traditionally made from steel wire rope. Even galvanised wire rope has a limited life span, say five to ten years. Other options include fibre rope for a temporary installation, fence wire for low cost and durability (but beware - wires can snap!), or galvanised chain for real peace of mind on short towers.



The base of the tower can be hinged in a number of different ways. Steel angle can be used for this. Make sure that there is clearance for the wiring to emerge smoothly from the bottom in such a way that it is easy to check for twisting.

Controlling the battery charge rate

Lead acid batteries should be kept in a charged condition. In the case of a wind-powered system, you may have to wait for a wind to charge the battery. But be careful not to discharge the battery too deeply, or to keep it too long in a discharged state, or it will be damaged (sulphated) and become useless. Stop using a battery before it is fully discharged. If there is a problem with the wind generator, then charge the battery from another source within two weeks.

Charging the battery too hard will also damage it. At first, when the battery is discharged, it is safe to use a high current, but later the current must be reduced or the battery will overheat and the plates will be damaged. The best way to fully charge a battery is to use a small current for a long time.

Watch the battery voltage. If the battery voltage is below 11.5 volts, then it is being discharged too much. If the voltage is high (over 14 volts) then the battery charging current is too high. Use less current or more current in the loads to correct these problems. If there is no voltmeter available, then the user should watch the brightness of the lights and follow these rules: -

- Dim lights mean low battery. Use less electricity!
- Very bright lights mean too much windpower. Use more electricity!

A good way to use more electricity is to charge more batteries in windy weather, perhaps charging batteries from neighbours' houses.

There are simple electronic circuits designed to regulate the battery voltage automatically. They are called 'low voltage disconnects' and 'shunt regulators'. If the user is not willing to watch the battery voltage, then it is necessary to fit a disconnect and a regulator.

Shunt regulator circuit

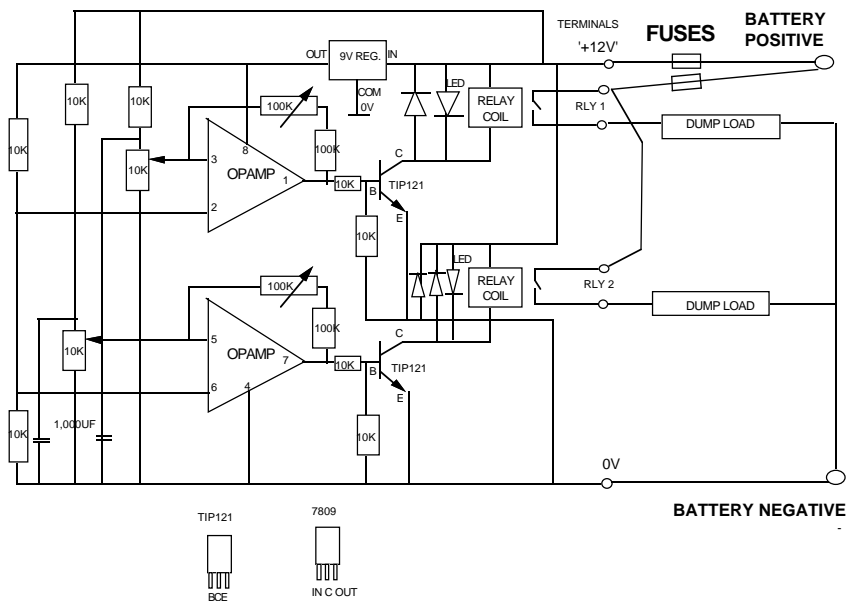
The diagram shows a simple 12-volt circuit. It is designed to switch loads on and off ('shunt' or 'dump' loads). It can also be used to disconnect user loads in the event of low battery voltage.

For a 12-volt machine you would need two of these circuits, and 4 @ 10 amp loads to regulate the charge rate.

A good alternative would be to buy a Trace C-40 controller. This has PWM switching on one big load, and it has two battery charging rates.

List of components required

IC dual opamp	LM1458
Transistor	TIP121 or 120
Voltage regulator	9V100mA
Preset potentiometer	10K cermet
Preset pot	500K cermet
Resistors	10K 0.25W
Resistors	100K 0.25W
Resistors	1K 0.25W
Diodes	1A
Indicators	LED 12V
Capacitors	1000uF 16V
Relays	12V 16A



Using polyester resin

Polyester is the plastic substance used in fiberglass work for building boats, car body parts, etc. Various things are added to it to make it work better for various jobs. Talk to your supplier and explain what the resin is to be used for. Your supplier should be able to help you.

Hardeners

There are two systems used to harden polyester resin, and each system uses two chemicals. For resin casting and most fiberglass work we use peroxide and cobalt. ('Car body filler pastes' use the other system.)

Cobalt 'accelerator' is a purple fluid. Your supplier will mix the right amount of cobalt into the resin. After it is mixed, the resin must be stored in the dark, or it will harden.

Peroxide 'catalyst' is a hazardous chemical. Avoid contact with skin. Store in a PVC container, in the dark, below 25 degrees C. Never mix it with cobalt (except for the cobalt already in the resin), or it will explode. Mix very small quantities (about 1-2%) of peroxide with resin or it will overheat.

Wax-free 'Air inhibited' resin 'B'

This type of resin is used for 'gel-coats' on boat moulds, where the resin is going to be built up in stages. We do not recommend using this resin for the alternator castings. Any exposed surface will remain tacky indefinitely. Ask for resin 'A', or better still 'casting resin'.

Thixotropic additive

A special powder of very light silica is often added to resin to make it thicker, so that it is easier to spread it with a paintbrush. This powder is not needed for casting resin. If it is already added, it does no harm.

Styrene monomer

Approximately 35% of the resin as supplied is styrene monomer. This is used for thinning the resin. It causes the smell. It is possible to add a little more styrene monomer (10%) to make it more liquid if desired.

Pigment

Pigment can be used to colour the casting, if a coloured finish is desired. Add pigment to the first mix, which will be on the outside of the casting. Add no more than 10% pigment to the mix. It is not necessary to add pigment to the resin. Without pigment, the casting is transparent and the coils are visible.

Fiberglass

The resin has almost no strength without fiberglass. It is available in sheets of 'chopped strand mat' (CSM). It is also possible to buy fiberglass cloth. This is useful for the magnet rotor castings. Add a little resin to the fiberglass, and press out all the air bubbles, before adding more resin.

Talcum powder

Talcum powder is a cheap filler that can be mixed with the resin after the peroxide has been added. It makes the resin mixture much cheaper, and a little thicker. Resin can be mixed with up to twice its own weight of talcum powder. The powder also reduces the heat build-up in large resin castings.

Mould preparation

Polyurethane varnish

Ordinary paint should not be used on moulds. Better to use nothing. If possible, use polyurethane varnish. This will prevent moisture coming out of a mould made from wood, plaster or clay. Smooth the varnish off with sandpaper before polishing it.

Polish

Polish the mould several times before using it first time. Rub all the polish off with a rag and then leave it some hours and do it again. Silicone polish is not compatible with PVA release agent. Use wax polish.

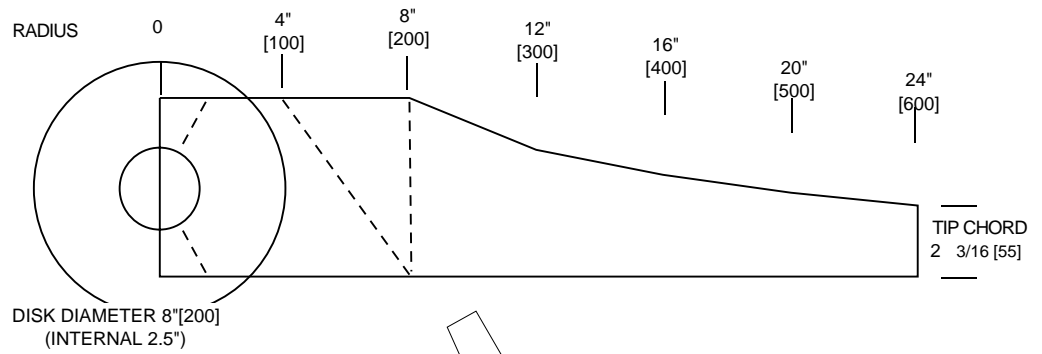
PVA Release agent

Moulds that are used many times will benefit from PVA release agent. Paint this over the mould before each use, and let it dry. It forms a sheet of PVA, which greatly helps to separate the casting from the mould.

Small machine supplement

Blades

Carve the blades in the same way as the larger machine blades but without the wedges. These blades are shorter and stubbier.



Dimensions in Inches

station	width	drop	thickness
1	6	0	1 15/16
2	6	1 3/4	7/8
3	3 15/16	3/4	9/16
4	3 1/8	3/8	3/8
5	2 9/16	1/4	5/16
6	2 3/16	1/8	1/4

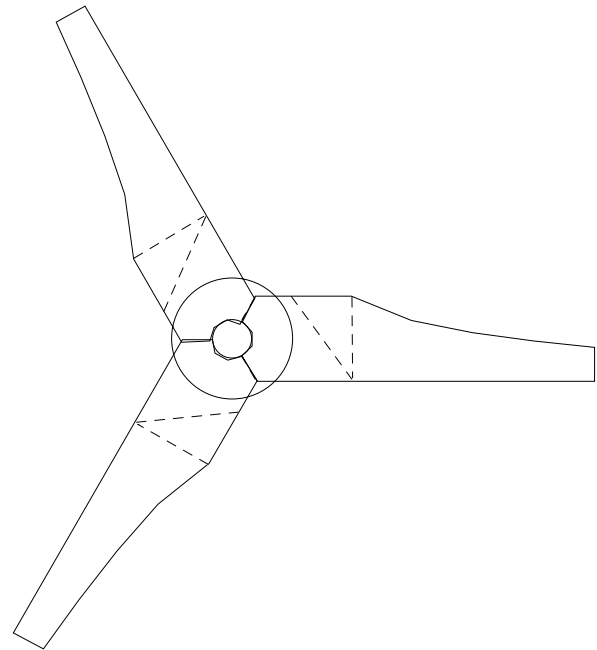
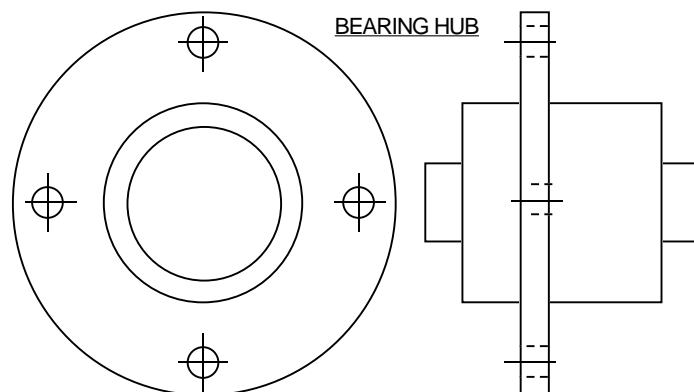
Dimensions in mm

station	width	drop	thickness
1	153mm	-	-
2	153mm	45mm	22mm
3	100mm	19mm	14mm
4	80mm	10mm	10mm
5	65mm	6mm	8mm
6	55mm	3mm	6mm

The hub needs a hole through it to fit over the bearing housing.

Bearing hub

Use a bearing hub for a trailer for the small machine. You can buy these in the UK from www.towsure.com



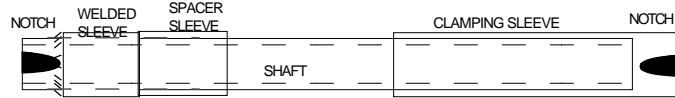
Materials				
Pipes	Material	Length	Diam.	Wall
1 shaft	Steel pipe 1" overall	11 3/4" [200 mm]	1" [25.4] overall	1/8" [3 mm]
2 sleeve	Steel pipe 1" nominal bore	1 1/2" [38mm]	1 1/4" [33.4] overall	1/8" [3 mm] thick
1 sleeve	Steel pipe 1" nominal bore	5 1/2" [140 mm]	1 1/4" [33.4] overall	1/8" [3 mm] wall
2 yaw & tail bearing	Steel pipe 1" nominal bore	6" [150 mm]	1 1/4" [33.4] overall	1/8" [3 mm] wall
1 tail boom	Steel pipe 1" nominal bore	18" [500 mm]	1 1/4" [33.4] overall	1/8" [3 mm] wall
2	Steel pipe 1 1/4" nominal bore	5" [150 mm]	1 5/8" [42.2] overall	1/8" [3 mm] wall
1	Steel disk		9" [230] minimum	1/4" [6 mm]
Pieces	Material	Length	Width	Thick
1	Steel plate	2" [100]	1 1/8" [56 mm]	3/8" [10 mm]
1	Steel bar	8" [200]	1 1/2" [30]	5/16" [8]

and in the USA from <http://www.southwestwheel.com/trailparts/hubs/hubs.htm>

The shaft

The hollow shaft is one inch overall diameter. This heavy wall tube may be hard to find. I have some if you need it. Use a 11 3/4" [300mm] length.

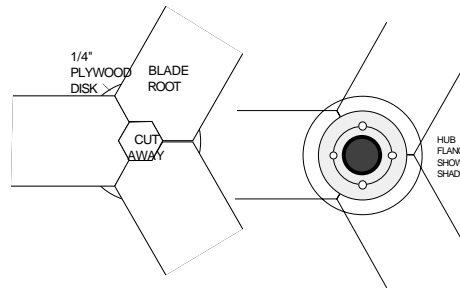
We cut 3 sleeve pieces to fit over the shaft. 1" bore pipe is good for this purpose.



At the stator end of the tube we cut a notch 3/4" deep so that the wiring from the stator can enter the tube and run back through the middle of the bearing.

Weld on a sleeve piece 1 1/2" [40mm] long. It ends flush with the face of the stator casting.

Between the stator and the bearing hub we used a spacer sleeve about 1 3/4" [45mm] long. Trial and error will help in sizing this spacer. Sizes will depend on the thickness of the blade roots for example.



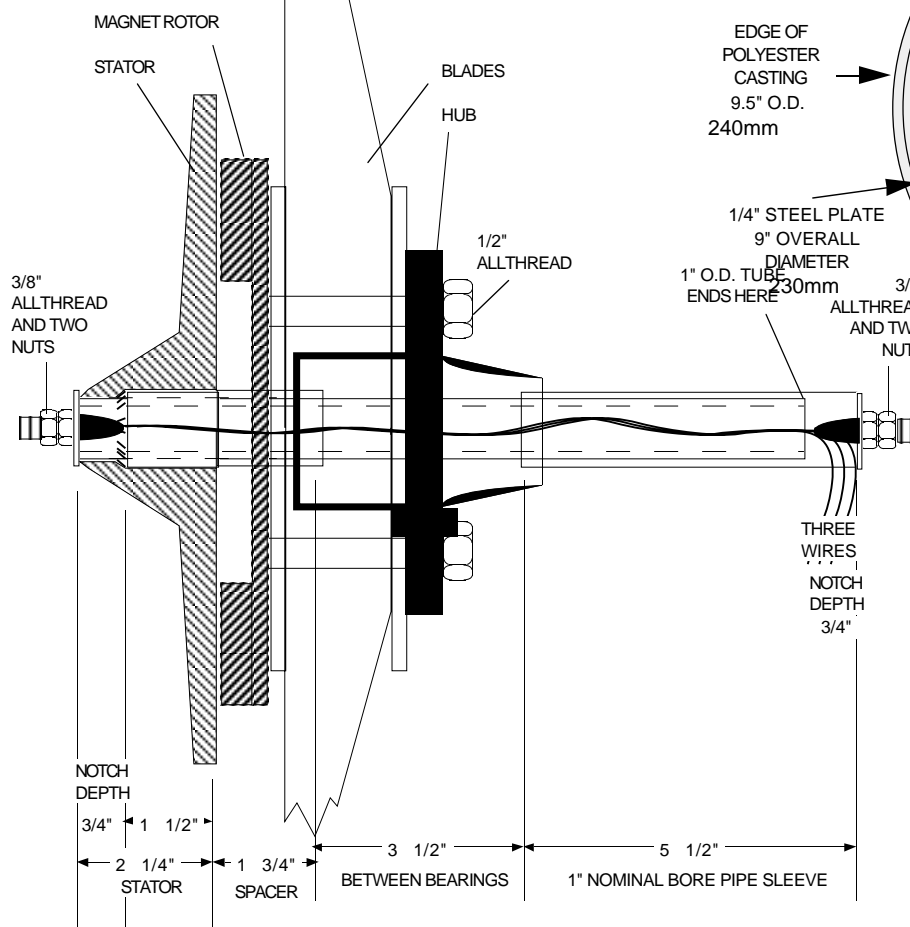
Behind the hub is another sleeve, which rests against the bearings. This clamping sleeve also forms part of the supporting frame of the wind generator

(see later).

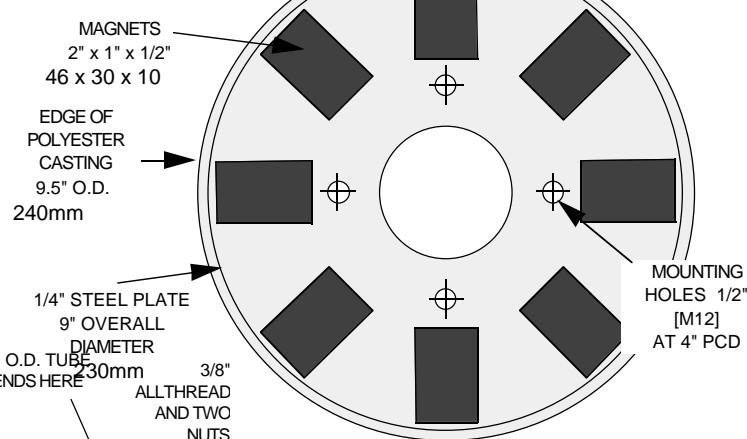
Drill the wheel stud holes out to 12mm. The US hub's wheel stud holes are just over 1/2" in diameter but the bore is near enough to suit the 1/2" allthread.

The steel disk at the back of the magnet rotor is 1/4" [6mm] thick and 9" [230mm] overall. It has a hole in the centre 1 1/2" in diameter. None of these dimensions

SECTIONAL VIEW OF 4' DIAMETER MACHINE



MAGNET ROTOR

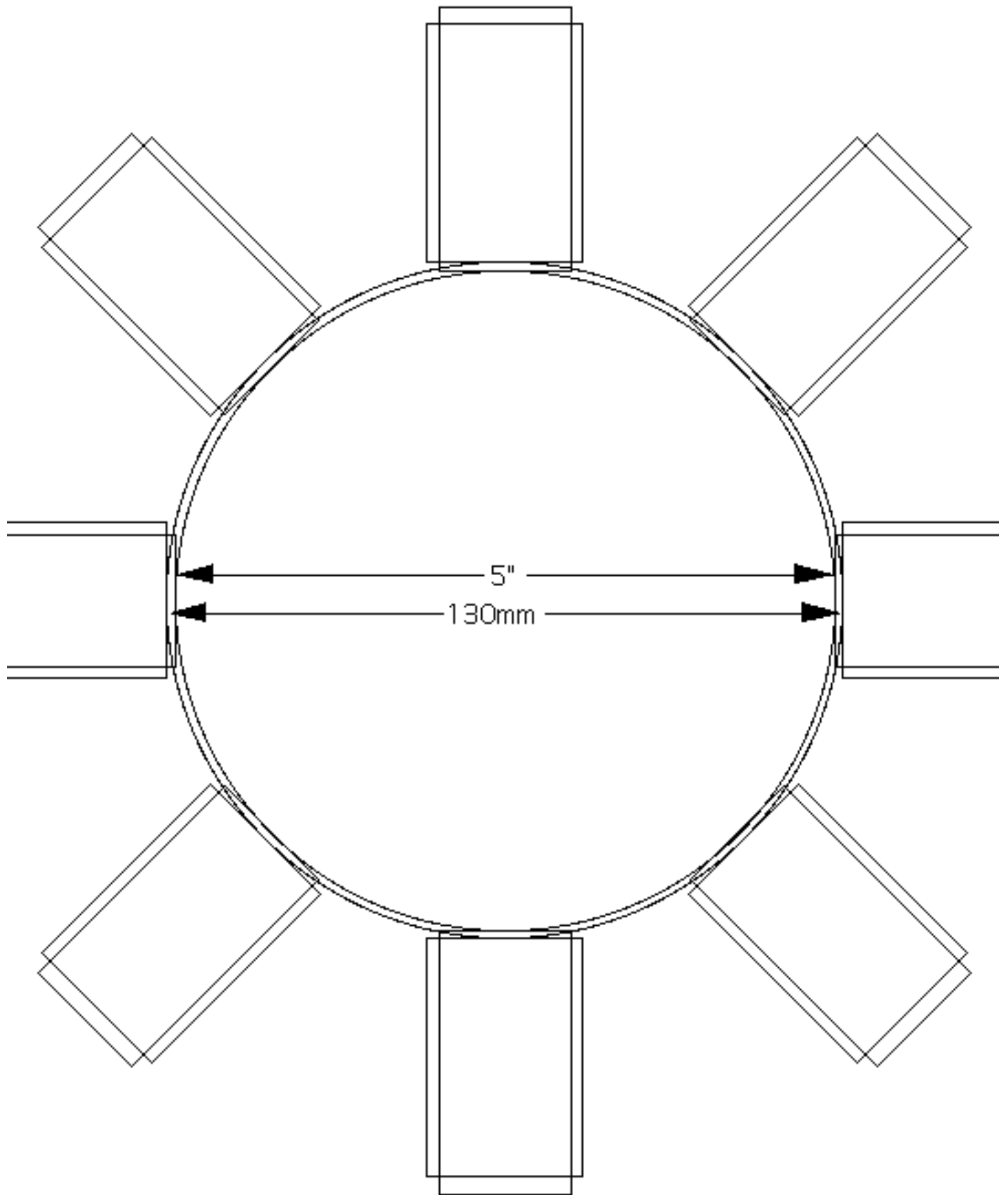


is critical.

The four mounting holes in the steel disk have to be tapped to receive the ends of 1/2" [M12] allthread studs. There is no room for nuts in this magnet layout. A smaller stud diameter would work equally well if it fits the wheel stud holes.

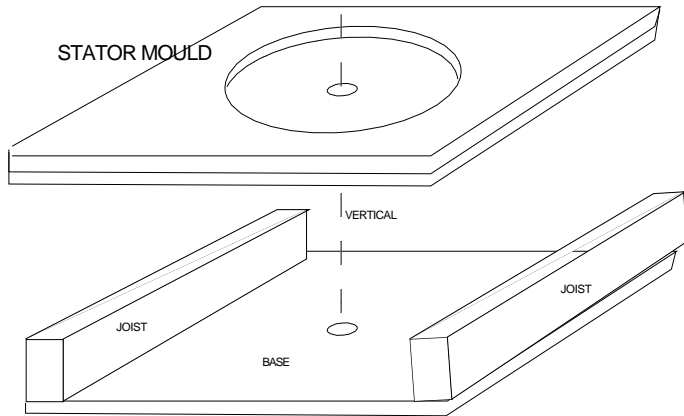
Rotor moulding

The magnet rotor is moulded in the same way as in the big machine. Use a magnet positioning jig to locate the magnets. They alternate north/south/north. No index marks are needed here. Keep the central part clear of resin, and stop resin from going into the threaded mounting holes.



Stator mould

The stator of the small machine must be moulded to the shaft squarely. When the stator is horizontal the shaft must be vertical. You have to be accurate or the magnets will not be able to come close the stator of the assembled machine and the output will be low.



The stator mould has a 1" hole at the centre through which the shaft must pass. First weld on the collar at the stator end of the shaft and then drop the 1" shaft through the hole. The shaft will also pass through a second hole in another board below the mould. The second board keeps the shaft square to the stator mould during the casting process.

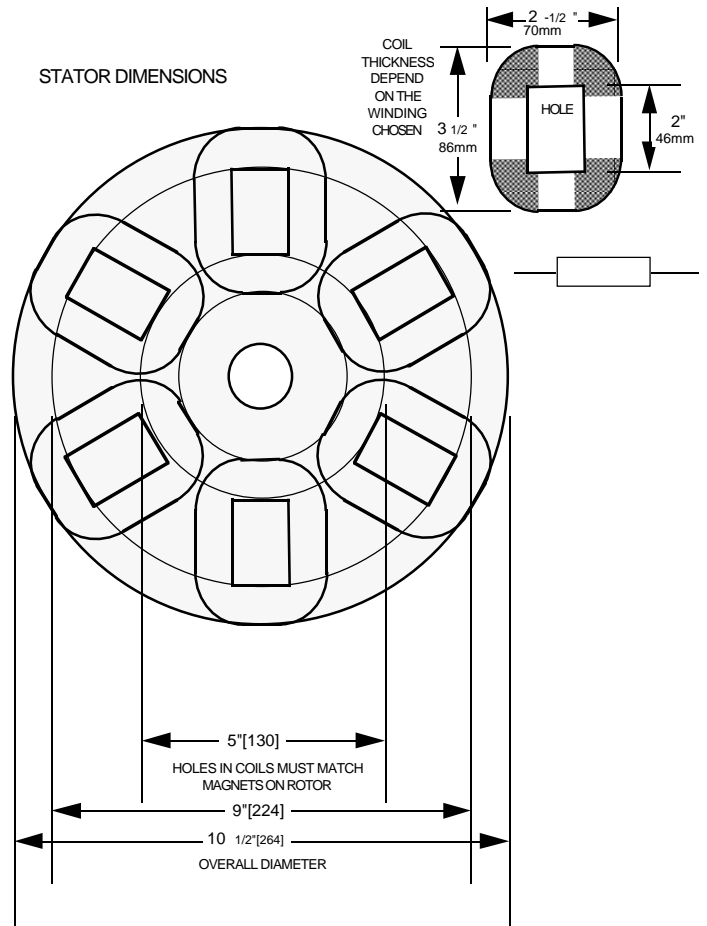
To set up the stator mould you have to first screw a couple of wooden joists (2 x 4's) onto the baseboard. Then fit the shaft. Move the shaft around until it is precisely square to the mould and then screw the mould to the joists.

Assembly of the stator

Solder the coils together according to the diagram on the right. Take great care to ensure that none of the coils are upside down. The wire should always run clockwise from the start to the finish (or always the other way, but no mixing of coil rotations).

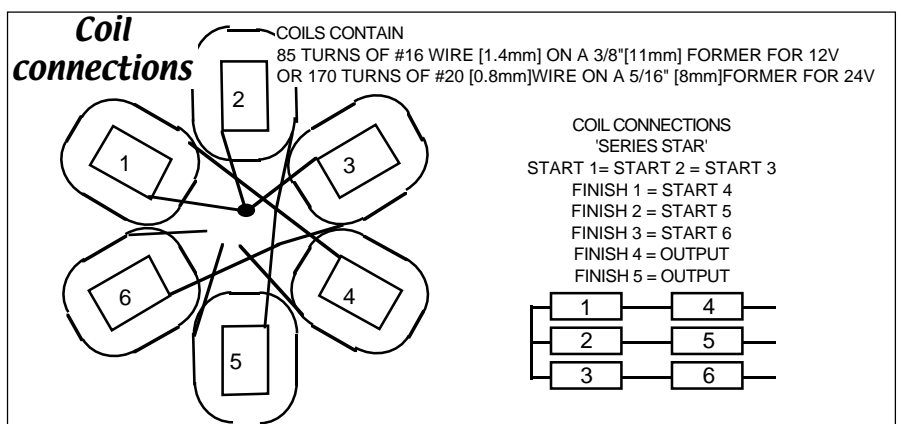
Bring the 3 flexible stranded wires out through the notch in the shaft and right down the hollow shaft to the other end. From there they will attach to larger wires leading to the ground and the rectifier at the battery.

Remove the wired up coil assembly and shaft carefully from the mould. Start the casting in the usual way with plenty of polish and then apply wet resin and a disk of fibreglass for strength. Replace the coils and shaft into



the mould. Pour on resin mixed with talcum powder. Apply more fibreglass to the upper side and then clamp a lid down onto the coils to press them firmly into the mould (except right at the centre).

At the centre around the shaft, add plenty of very thick mix and fibreglass to make a strong attachment between stator and shaft.



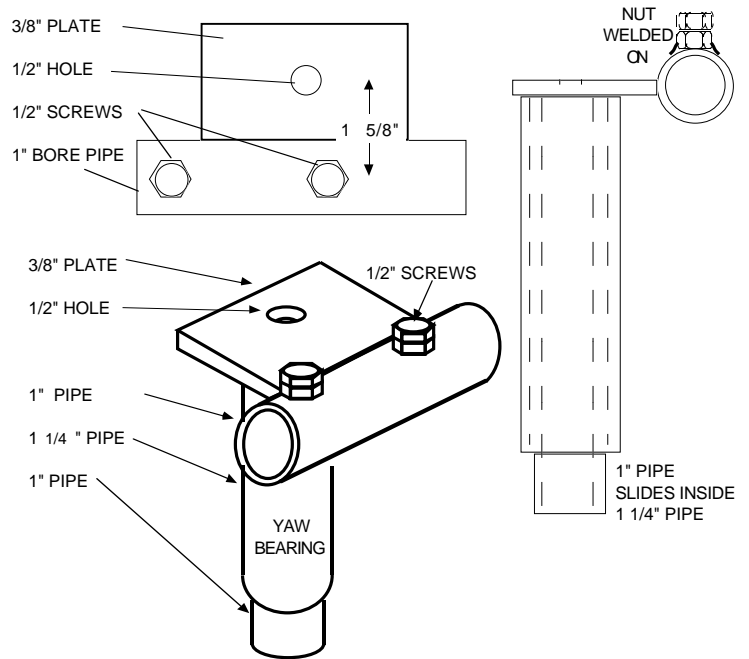
Remove the wired up coil assembly and shaft carefully from the mould. Start the casting in the usual way with plenty of polish and then apply wet resin and a disk of fibreglass for strength. Replace the coils and shaft into

The yaw bearing

The yaw bearing consists of a vertical 1" pipe inserted into a 1 1/4" pipe (just like the inclined hinge tail bearing). This works out lighter than the 1 1/2" yaw pipe we used for the larger machine.

The yaw bearing supports the sleeve for holding the back end of the shaft. This is the sleeve we referred to earlier. We welded two nuts to the top of it so we could screw down and clamp the shaft. We cut a notch for the wires to exit through the bottom at the rear end.

We welded this sleeve onto a piece of 3/8" thick plate. We put a 1 1/2" hole through the plate for wiring down the tower. Then the plate got welded onto the top of the yaw bearing. The space between the yaw bearing centre hole and the shaft centre is 1 5/8". This is the furling offset of the machine.



The tail bearing and tail

The tail furling system is almost exactly like that for the larger machine. However the sizes are smaller. The tail hinge bearing uses pipe sizes exactly the same as the yaw bearing:

5" long outer pipes in 1 1/4" pipe and 6" long inner pipes in 1" pipe

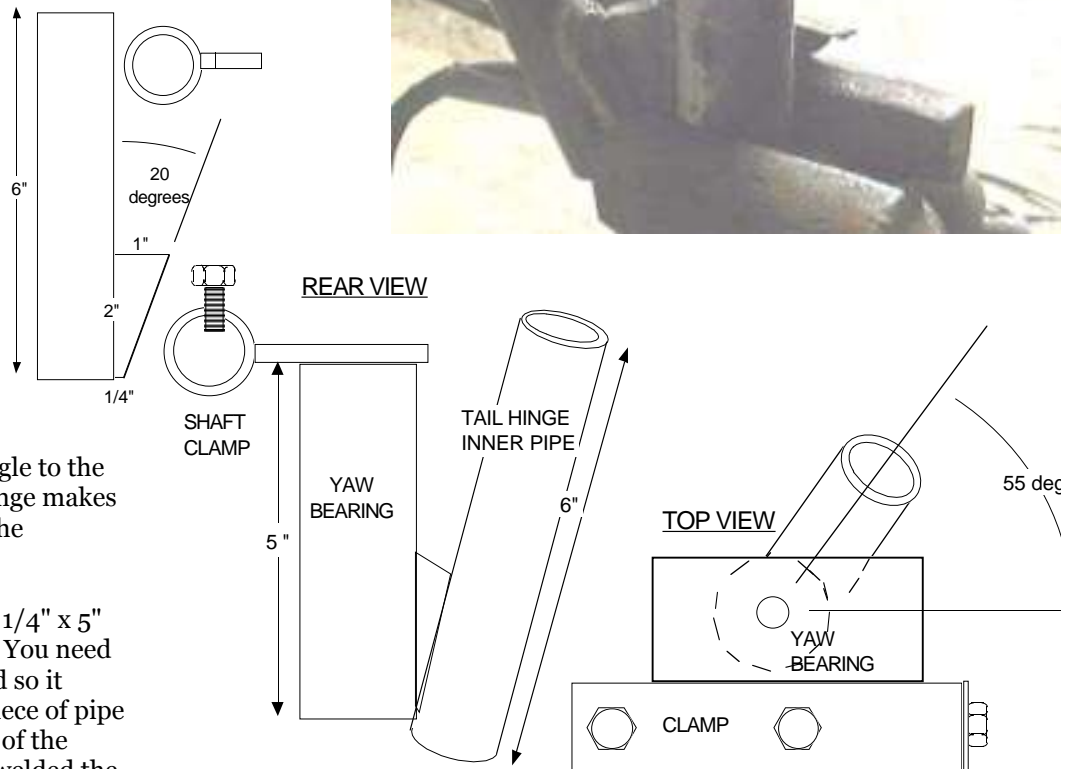
SIDE VIEW AND TOP VIEW OF TAIL HINGE INNER PIPE

The inner pipe is welded to a piece of thick plate with a 20 degree angle on it just as in the case of the larger version but the plate is only half the size.

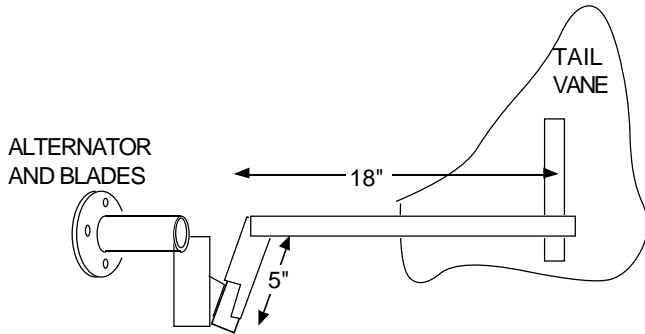
First weld the steel plate onto the side of the 1" x 6" pipe. Then weld the other edge of the steel plate to the side of the yaw bearing.

The hinge makes a 20-degree angle to the vertical. Seen from above the hinge makes a 55-degree angle to the axis of the alternator/blades shaft.

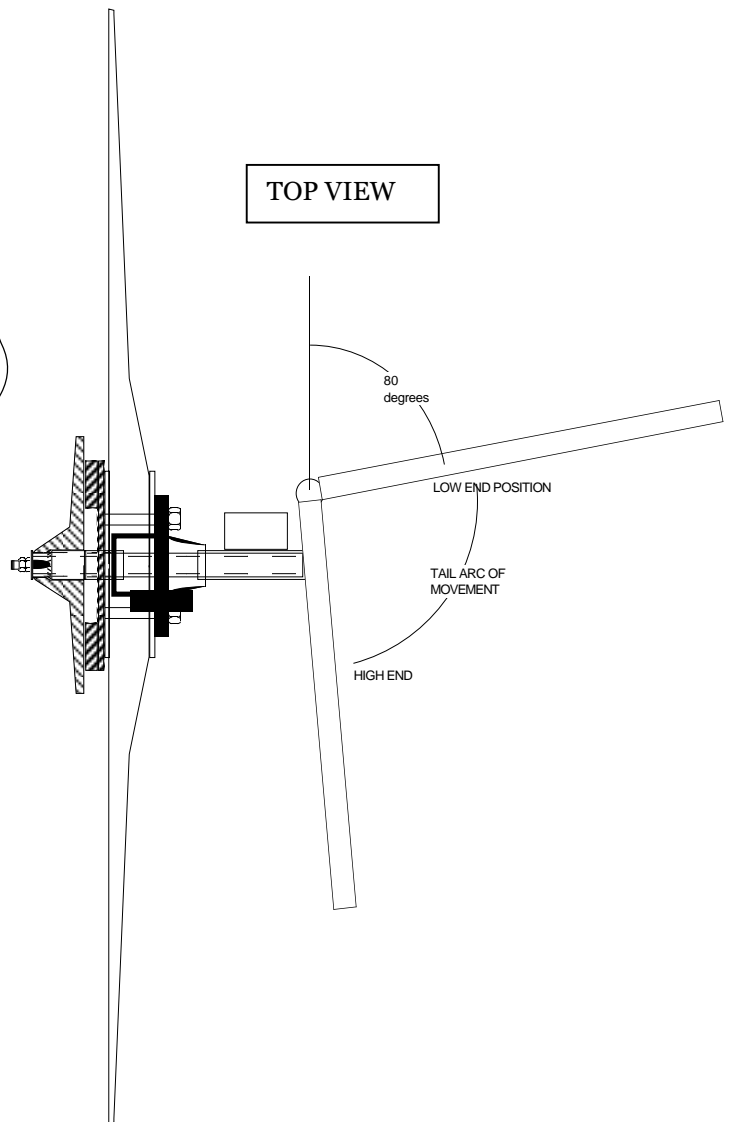
The outer part of the hinge is a 1 1/4" x 5" pipe that slides over the 1" pipe. You need to weld a plate across the top end so it turns freely. The tail itself is a piece of pipe 18" x 1" welded to the outer pipe of the inclined hinge. When you have welded the



tail onto the hinge you can set it up on the inner pipe and work out how to cut the notch. The notch allows the tail to swing through about 95 degrees from the low-end position up to nearly parallel to the blades.



When the notch has been cut and the tail swings nicely you can add the 'T piece' on the end and fit the vane. The T should be vertical in the normal (low-end) position of the tail. Weld it on flush by cutting a notch into the pipe first. I suggest a T made from 12" x 1" x 1/4" bar. The vane can be made from about 18" x 12" x 1/4" plywood.



Wiring up the battery

The best wiring system is to take all three wires from the wind turbine to the location of the battery.

Connect them first to a brake switch. You can use this to stop the wind turbine. A two-pole on-off switch rated for 20A at 12 volts DC is suitable for a 12 volt system.

From the switch, lead the wiring on to the rectifier and connect any AC wire to any AC terminal. You will need two bridge rectifiers to provide enough AC terminals.

Connect both negative terminals from the bridge rectifiers to battery negative and connect the positives to battery positive via a suitable fuse.

WIRING FOR SMALL WIND TURBINE

