Brakedrum Windmill Plans

First devised in 1993, revised October 1999

CONTENTS

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PREFACE TO THE YEAR 2000 EDITION

This new edition of *Brakedrum Windmill Plans* is completely reformatted and contains many minor corrections as well as some significant new information.

For the first time since its initial release in 1993, this edition has been completely re-typeset from scratch. The previous editions were looking rather worn; they were maintained using "cut and paste" of the old fashioned variety that literally used scissors and glue! All of the diagrams have been redone, some improved significantly from the largely hand drawn figures in the previous editions.

The formatting also features a consistent method of giving measurements in both metric and North American units. Metric units always appear first, then equivalent North American units are given in square brackets following. In some cases British terminology that is unfamiliar to North American readers is also "translated" using square brackets as well.

Numerous minor corrections and clarifications have been made, based on questions asked by readers and found during proof reading. No doubt these will be of great benefit to people building these plans.

New information has been added regarding modifications for using the Ford 3/4 ton pickup truck, a common truck in North America. This information was furnished to me by Mr. Bob Budd, who has been teaching workshops on how to build wind turbines based on this design for several years.

In addition, a new section gives a mathematical model that can be easily programmed into any spreadsheet application. This model allows the ambitious windmill builder to modify design parameters of the alternator to suit individual needs. For example, one can determine the likely effect of changing the number of magnets and coils or turns of wire per coil in the alternator in order to obtain a desired output at a given speed.

A NOTE ON MEASUREMENTS AND CONVERSIONS

In some cases, North American conversions are rounded to the nearest commonly available size that will work properly. For example, M10 threaded rod is 10mm in diameter, but the near-equivalent 3/8th inch threaded rod is used as the equivalent even though technically 3/8th inches is only 9.6mm. In other cases where imprecise measurements are being described the discrepancy may be even greater. For example, when describing shaving off wood for a blade, I may say 'shave off about 1mm [1/16"]'. Even though 1/16th inch is quite a bit more than 1mm, it is still used because it's a commonly used measurement meaning "a little bit".

The one case where North American units are used directly in the text is when specifying pipe. This is because water pipe is commonly specified via its "nominal bore" size which is given in imperial units. For example, a pipe might be specified as "1.5 inch nominal bore". The outer dimension for such a pipe would be 48mm [nearly 2"]. We will specify both the nominal bore size as well as giving inner and outer dimensions in both metric and North American units.

ACKNOWLEDGEMENTS

Thanks to Elliot Bayly of World Power Technologies, and Gordon Proven of Proven Wind Turbines, for inspiration. Steve Wade of Wind and Sun Ltd. (UK), and Michael Eavis of Glastonbury Festival for motivation to produce the first machine. Robert Budd of www.windmill.on.ca for building a North American version. Steve Pendergrast of PicoTurbine.com for tireless diligence retyping the whole thing, and helping to clarify it.

FOREWORD, BY PAUL GIPE

Hugh Piggott's plans for turning a used brakedrum into a windmill is a welcome addition to the literature on small wind turbines. *Brakedrum Windmill Plans* is especially valuable because plans for building your own wind turbine have not kept pace with the technology. Most plans date from the 1970s—or even earlier.

Better yet, the plans in this booklet are for a wind turbine that really works from someone who lives with and depends on wind energy. The brakedrum windmill is a proven design that Hugh has operated at a remote, windswept headland in northwest Scotland since 1993. His site on the Scoraig Peninsula is so windy in fact that several commercial wind turbines failed within a few years (some, unfortunately, much sooner). Hugh's prototype of the brakedrum windmill in these plans has operated so reliably that he substantially increased its output within a few years after installation. And it continues to run to this day.

The beauty of these plans can be found in Hugh's use of conveniently handy scrap yard parts. The design is based on rear brake drums used by Ford trucks widely available in both Britain (the transit van) and North America (the F250 and F350).

Another plus is Hugh's elimination of slip rings and yaw bearings. Slip rings often bedevil the design of commercial wind turbines as well as home built machines. They're not necessary and seldom found on many wind turbines built in Europe. Hugh wisely avoided them, instead substituting a simple pendant cable. This greatly simplifies this design as does Hugh's use of pipe-on-pipe for a simple and hardy yaw system that allows the turbine to respond to changes in wind direction.

Hugh's brakedrum windmill also incorporates the durable "inside out" alternator design found in the popular—and successful—small wind turbines built by Bergey Windpower and World Power Technologies. With this alternator configuration there's no need to build a complicated hub that attaches the blades awkwardly to a small diameter shaft as in some other designs. Instead a simple plywood sandwich holds the blades tightly to the rotor and this assembly is mounted directly to the generator housing: the brake drum. In wind turbines it doesn't get more straightforward than this.

And like all reliable commercial wind turbines today these plans use "self-furling" to protect the product of your labor in high winds. Hugh's an expert on this technique to limit the speed of the wind turbine's rotor and the simple design found in these plans would be helpful to not a few commercial wind turbine companies who haven't quite mastered the art.

Brakedrum Windmill Plans includes detailed instructions for building the entire wind turbine, from carving your own blades for a 2.1 meter [7 foot] diameter rotor to building your own permanent-magnet, direct-drive alternator capable of generating real power. By following these plans you will construct a genuine wind turbine—not just a toy—that can reliably churn out 300 to 400 watts.

Brakedrum Windmill Plans is a great companion to Hugh's *Windpower Workshop.* Both are a valuable addition to any windmiller's library.

Paul Gipe
Tehachapi, 1999

MATERIALS YOU WILL NEED

Quantity	Item Description/Size	Notes
1	The rear hub from a Ford Transit double wheel van or Ford 3/4 ton truck.	Similar hubs may work, see section DISMANTLING THE BACK AXLE.
20	Block magnets, 64 x 32 x 20mm [2.5" x 1.25" x 0.75"]	See section SUPPLIERS.
1	Laminated core from a 5 horsepower electric motor, 203mm [8.0"] in diameter.	This is the part made from a stack of thin sheets of steel.
800g [1.75 pounds]	Enamel coated copper magnet wire, 0.75mm [20 AWG] thickness.	See section SUPPLIERS.
About 500g [1 pound]	Epoxy or similar resin.	See section SUPPLIERS.
Several sheets	Glass fibre surfacing tissue, or thin fabric.	
2	Single phase bridge rectifiers, rated at least 30 amps and PIV of at least 100 volts.	See section SUPPLIERS.
1	Piece of aluminum scrap, approximately 200 x 200mm [8" x 8"] to be used as a heat sink	for the rectifiers. Any shape will do. An old saucepan may work nicely.
1	Mild steel, flat 90 x 90 x 10mm [4" x 4" x 3/8"]	Used for mounting.
5	Mild steel, flat 125 x 25 x 6mm [5" x 5" x 1/4"]	For stator mounting lugs and horizontals.
1	Steel tube 6000 x 48mm overall x 4mm thick [20' x 2" black pipe or similar]	Pole for mounting.
1	Steel tube 250 x 60 mm overall x 4 mm thick [10" x 2.5"]	Used as a bearing.
1	Steel tube 150 x 43 mm overall x 4 mm thick [6" x 1.75"]	Tail bearing.
1	Steel tube 1,000 x 34 overall x 4mm thick [3' x 1.5"]	For tail.
1	Threaded rod plus nuts, 500 mm x 10mm diameter [20" long x 3/8" diameter]	
40	Wood screws, 50mm [2"] long	
3	Wood 1,000 x 100 x 50 mm [two by four, 40" long]	Must be knot-free, for blades. See section MAKING THE PROPELLER.
3	Wood 750 x 100 x 50 mm [two by four, 30" long]	Must be knot-free, for blades. See section MAKING THE PROPELLER.
2	Plywood, 300mm diameter disc by 12mm thick [1' diameter disc by 1/2" thick]	Marine or pressure treated plywood is required.
About 1/2 liter [1 pint]	Primer and gloss paint for wood parts.	
About 1/2 liter [1 pint]	Hammerite [Rust-oleum] or similar paint for steel parts.	

TOOLS YOU WILL NEED

TOOL	Comments/Notes
Socket spanners [wrenches], hammer, chisel, screw driver, pliers	
Wire brush, rags, petrol [gasoline]	
To clean auto parts.	
Hacksaw with good quality, new, blades	Sandvik blades recommended.
Angle grinder, electric drill and sharp bits	Cobalt bits recommended.
Pieces of 1mm [1/16"] aluminum sheet.	For shims between magnets during assembly. Thickness is approximate.
Scraps of plywood	For coil-former and cheek pieces. See section COIL WINDING MACHINE.
Former for clamping coils, made from 75 x 50mm [3" x 2"] timber.	See section HOW I DID IT.
G clamps [C clamps]	
Knife, soldering iron, multicore solder, tape	
Electric welder and steel welding rods, size 2.5 or 3 mm	
Wood working tools: saw, plane, spokeshave	To carve blades.

WHY DO IT?

I have been making windmills from scrap materials for twenty years. It cuts the cost and I like recycling. The biggest headache has always been to find a suitable generator. A generator for a windmill has to work at low speed, be efficient (not wasteful of power), and also be reliable and affordable. A tough spec.

Vehicle dynamos [DC generators] and alternators were the obvious first choice, but they need rather high speed (RPM) and are inefficient. I learned to rewind Lucas alternators, so they would work at low RPM, but the efficiency went from bad to worse, so most of the energy caught from the wind was wasted heating up the alternator.

The best bet turned out to be dynamos from buses or jeeps. A low speed 24 volt dynamo can be simply converted to a very low speed 12 volt dynamo, and these heavy old machines are rugged, efficient, and cheap. I have described how to make them into windmills in my booklet "Scrapyard Windpower Realities", first published in 1982, updated in 1992, but now out of print.

There are many successful windmills in operation based on these dynamos, but I have become painfully aware of the shortcomings. The worst thing is the performance in light winds. Here is the reason why:

> All generators require magnetism: they work by dragging coils of wire through a magnetic field. Vehicle dynamos and alternators use electromagnets, and these need about 40 watts of power AT ALL TIMES. So the first 40 watts of power you generate is used up energising the field coils, and only when the wind is stronger do you see an actual "profit" in terms of charging the battery.

Old dynamos are also harder and harder to obtain in good condition, and there are maintenance problems with the brushes.

The best type of generator for a small wind turbine is a purpose-built permanent magnet alternator (PMA). This requires no field coils to energise, and has no brushes to cause problems. There are scrap permanent magnet machines which can be useful, such as computer tape drive motors, washing machine motors, servos, etc., but I have found no reliable source. (See Suppliers at the end of the booklet for some sources.)

Buying permanent magnet machinery new is expensive, and I prefer to recycle, so I started making alternators built on wheel bearings. My first attempt is detailed in "Scrapyard Windpower". It was a rather laborious, welded fabrication of steel discs. Magnets glued on the faces of the steel discs (see figure 1) rotated past coils set in a stationary disc sandwiched between, as in the design used by Marlec for their Rutland wind turbines. It worked very reliably, but I felt that it had been too much hassle to justify building another.

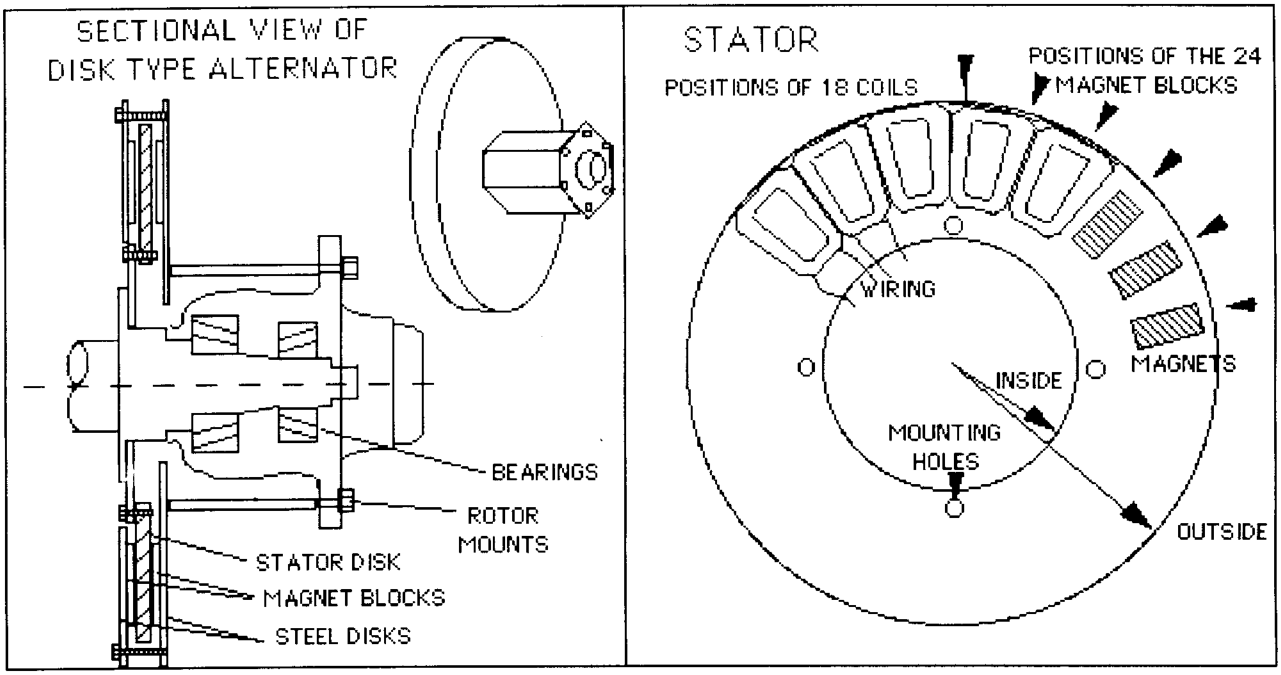


Figure 1

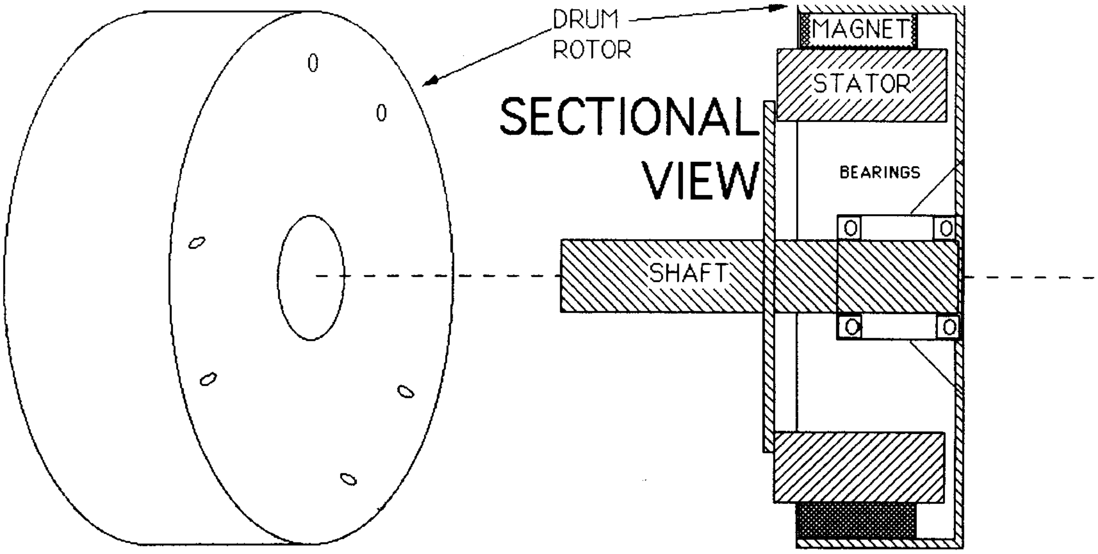
But over the years, quite a few people have built these, using the plans in 'Scrapyard' and I hope to produce a new set of plans for an axial design some day.

Small American wind turbines such as the Whisper and Bergey machines use a different geometry for their PMA. The magnets are glued to the inner surface of a cylinder (steel tube) which rotates. The coils which produce the output are wound on a stationary core of laminated iron material, with slots in its outer surface for the coils to fit into (see figure 2). The stationary part with the coils is called the stator. It seemed to me that a much simpler wheel-hub PMA could be built using a brake drum rather than steel discs, and following this American style. Long wheel base Ford Transit vans and 3/4 ton trucks have big brake drums on the back axle, and excellent bearings.

HOW I DID IT

Finding suitable magnets was not a problem. Hawnt Electronics in Birmingham gave the best quote, although I could have got smaller quantities from Magnet Applications at twice the unit price. Nowadays I would recommend CER-MAG in the U.K. (but see Suppliers at the end for other international sources). The internal diameter of the brake drum is 254 mm [10"]. The length is 64 mm [2.5"]. I chose magnet blocks 64 mm x 32 mm with thickness 20 mm [2.5" x 1.25" with thickness 0.8"]. The magnets are magnetized through the thickness, with poles on the large faces. Twenty magnets can be fitted around the inner face of the drum, bringing the internal bore down to about 212 mm [8.35"].

The big problem was finding laminate material for the core of the stator, to carry the coils. The core has to be made from thin laminates of soft iron stacked into a sold block. You can see them in transformer cores, or dynamo armatures. If you use solid iron, the changing magnetic fields would set up wasteful eddy currents in the iron, but the lacquer between the laminates prevents this. I wanted a core that fitted close up to the magnets, with only a small air gap, and slots to carry the coils, as in the American design. A small air gap allows the maximum magnetic field strength. But the diameter of the laminated material I needed was much bigger than standard sizes in scrap dynamos, and to have it purpose made would have added over a hundred pounds [about US $160] to the cost of each alternator.

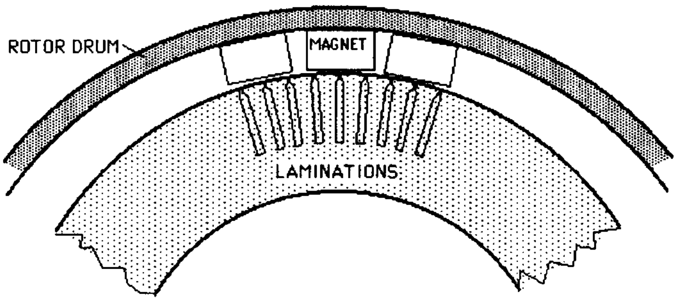


AMERICAN STYLE PMA BASED ON A ROTATING CYLINDER

Figure 2

For a while I almost abandoned the whole idea. I could see no way to make the stator at low cost. Then Gordon Proven of Proven Wind Turbines encouraged me to try a different tack.

NORMAL CHOICE OF SHAPE FOR LAMINATIONS IN THIS TYPE OF MACHINE



SHAPE OF LAMS WHICH ARE USED INSTEAD BECAUSE THEY ARE EASILY FOUND

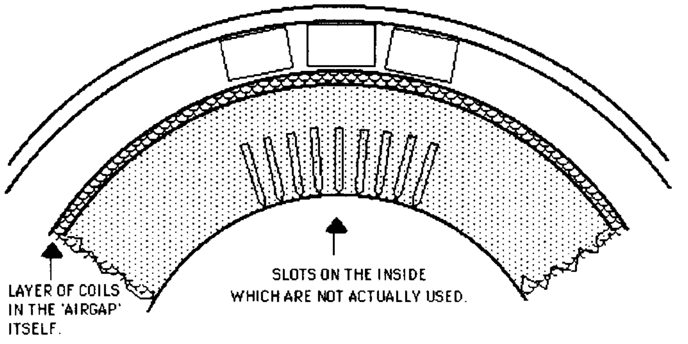


Figure 3

The way I did it in the end was using laminates from a very ordinary big 3 phase, 5 horse power electric motor. The laminates are the "wrong way out", with slots on the inner bore, and an almost smooth outer surface, diameter 203mm [8"]. Rather than placing the coils in the slots, I glued them on the outer face of the laminated core, in the 4.5mm [3/16"] gap between core and magnet faces. This gap is a rather large one for the magnetic field, and the field is weakened. Much of it also "leaks" straight from one magnet to its neighbor, to avoid jumping the gap. But the laminates were cheap (from a scrap motor). and the resulting alternator does work.

In fact the alternator was quite a success. For its weight, it is not as efficient as an alternator with the right sort of laminations and a smaller air gap, but it does have some advantages. For one thing, this sort of lamination is much easier to find. Also, the alternator starts up more easily in light winds than it would if the air gap were narrow. Machines with small air gaps have much higher magnetic drag, which holds the windmill back from starting up in light winds.

I glued the coils to the outside of the laminations with epoxy resin. I need a very thin layer of coils, so I used a G-clamp [C-clamp] to press them down onto the laminations. The wooden former shown is easily made by carving a hollow in the wood with an internal radius of 104mm [4.1"].

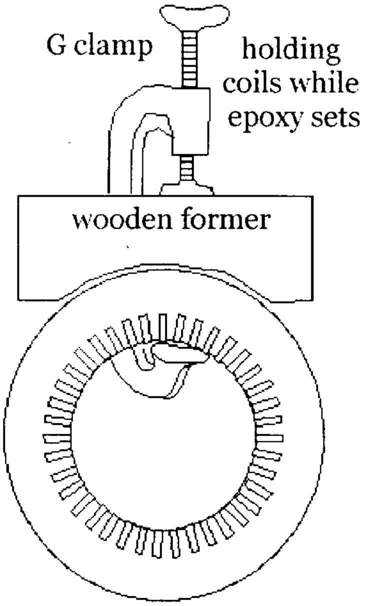


Figure 4

From past experience, the commonest problem with permanent magnet alternators is that the magnets start to rub the stator, so I allowed plenty of clearance, around 2mm [1/16"]. So only just over half of the air gap is filled with coils. You could get more power by making the coils thicker, but at the cost of lower reliability. I have never had a problem with the magnets hitting this stator, even when the bearings were quite slack.

The resulting windmill has been one of the best I ever built, and I immediately set to work and prepared plans so others could do the same. I actually built it for the low wind speeds of the Glastonbury Festival site in 1993, where it proved to be as good as the Marlec fm 1800 wind turbine in low winds.

After the Festival, I put it up on a hilltop site near my home, powering a neighbor's house. Here it had the chance to prove itself as a high wind speed survivor. The furling tail system protects it against over speed. At first we set the tail up to limit the output to 300 watts, but after a couple of trouble free years I added more weight to it, so my neighbor gets 500 watts (well actually rather less, as nearly half is lost in the cable to the house).

Here is some data for the alternator (connected 'star' ['Y'] for 24 volts):

Internal resistance:	4 ohms
Cut-in RPM:	200 RPM
320 RPM Output:	3 amps @ 30 volts = 90 watts
600 RPM Output:	9 amps @ 42 volts = 378 watts

See section PERFORMANCE at the end of the booklet for more details.

The technically minded reader will have suspected that there will be quite some heat generated in the windings when the alternator is putting out 9 amps. In fact the loss will be about 360 watts, so the alternator is only about 50% efficient at this point.

This is not wonderful efficiency, but the important thing is to be efficient in light winds, when power is scarce (and this alternator certainly is that). In higher winds, there is often power to spare, and also plenty of cooling to prevent the windings from burning out!

To milk the best output from the alternator, you should ideally load it with only a small current and use higher voltage in higher winds. The Marlec 1800 wind turbine has a special controller which does this (part of the reason why this windmill is so expensive). One solution would be to use star ['Y'] connection in low winds, and change to delta in high winds. Resistive loads (heaters, lights) will work with better efficiency from the alternator than battery loads because the voltage will vary.

But this is not the crucial issue, and in fact you will have a very good windmill even if you ignore the above considerations.

GENERAL NOTES

I should be very surprised if anyone follows these plans exactly, although this course of action would certainly give good results. In practice, it is most likely that:

- The parts which are obtained will vary slightly in size and shape from those suggested,
- Individuals will have their own ideas for simpler or better ways to suit their own skills and resources.

For example, I have made much use of electric welding, but for some it will be easier to bolt pieces of steel together and so avoid welding.

BLADES

I prefer to make blades from wood, but they can also be made from glass fibre and resin, or even from metal. Metal blades will tend to suffer from fatigue, and this danger should be recognised. Gordon Proven has a very interesting technique for making blades from polypropylene sheets, but I am not qualified to describe this properly.

I have used a 3-bladed propeller for this windmill, because they run more smoothly than 2 bladers and faster than 4 or more blades would. You could use a larger, 2-bladed propeller instead. The pitch of the blades would need to be finer (flatter) in this case. You could increase the diameter from 2.1m [7'] to 2.7m [9'] using a higher tip speed ratio (see my book "Windpower Workshop").

SPEEDING

The alternator can be run through a belt drive to obtain higher speed, and so more power, from the same machine, if this is considered worthwhile. Belt drive or other gearing is not only more work to make, but will introduce friction, which may make starting difficult in light winds.

The windmill described here cuts in at a very low wind speed, for battery charging applications, where a reliable, slow charge is most desirable. It is at its most efficient when it cuts in, but is fairly inefficient by the time it delivers 300 watts, directly driven by a propeller, and wired as described here, for low speed cut-in.

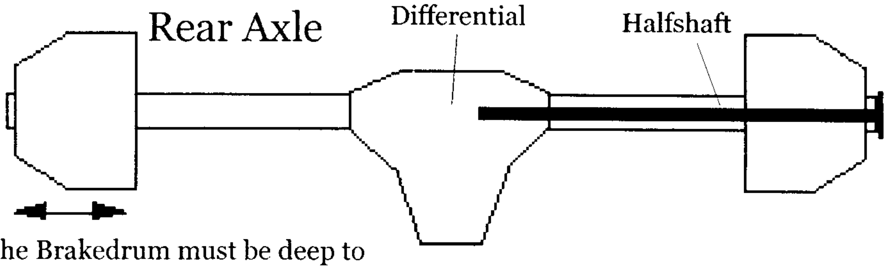
Higher outputs could be obtained with good efficiency by running it at higher speed, and either rewiring the coils in parallel groups, or operating at a higher voltage. There is a trade-off between speed and power which you can use: more speed allows the alternator to handle more power, but also brings more problems with noise, wear, fatigue and vibration. A better approach to getting more power would be to use a larger brakedrum or fabricate something with larger diameter. It's all up to you, but I am available to give advice on the phone or in answer to letter, email, or FAX inquiries.

GETTING PARTS

There is a list of suppliers included (see section SUPPLIERS), to help you find the parts you need. If you find cheaper sources (I am sure they exist) perhaps you would let me know, and I shall pass the information on to others. If there is anything you really cannot get hold of (laminations may be a problem) then I may be able to help out. The Ford 3/4 ton truck brakedrum can be used with different dimensions for magnets and laminations. See section MODIFICATIONS FOR FORD 3/4 TON TRUCK.

DISMANTLING THE BACK AXLE

What you need is a big brake drum from a Ford transit long wheel base van or similar. There is a Bedford with the same size brake drum, and there will probably be other makes. Front wheel hubs usually have disc brakes these days and so are not suitable for this design of alternator. You need "fully floating" bearings on the hub, i.e. the hub must be supported by two bearing races, even after the half shaft is removed. In the case of the transit, there are two tapered-roller bearings.



The Brakedrum must be deep to accommodate the windings.

Figure 5

The first step is to remove the half shaft, which carries the drive from the gearbox out to the hub. This is done by removing the six small nuts near the centre of the hub, and simply pulling the circular flange which is actually the end of the shaft.

Next you need to remove the outer bearing race, which is retained by two large thin nuts. The outer nut (which has been revealed by removing the half shaft) is locked by a tab bent outward from a washer behind the nut. Knock this tab backwards with a screwdriver or punch, driven by a hammer, so that the nut can turn. The nut is undone (anticlockwise) by placing a chisel against a corner, and driving it around with a hammer. Lift out the washer, and remove the second nut in the same way. Now the bearing race is free to come out, but it may not wish to. The easiest way I know to persuade it is to refit the half shaft back-to-front (sticking out, not in) and tighten two or three nuts. Pulling and waggling the shaft should release the bearing. When it comes out, keep it clean. It will need to be washed in petrol and repacked with grease (in moderation) before refitting.

Section through hub showing tapered roller bearings

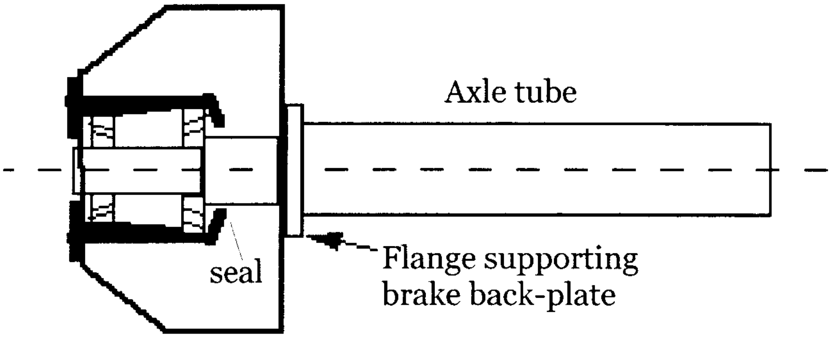


Figure 6

Now the whole hub and brakedrum can be removed from the axle, but it may still be retained by the brake shoes and the seals. Ensure that the handbrake cable is released. Keep waggling and pulling the half shaft. Some hammer blows may also be needed to release the brakes.

The brake parts can be removed as a whole by undoing the four nuts which retain the brake back plate to the axle. These may need penetrating oil, or even some heating, as they will probably be corroded. A piece of pipe on the end of the socket wrench will give you more leverage (and you may also bend your wrench!). Again, some hammer blows may help to crack the rust and let in the easing oil. Having removed the brake parts, knock out the screws which held them with a hammer.

The seal on the inner end of the hub can be removed from the hub using a hammer and screwdriver to prise it out. Maybe there is a more sophisticated method but this does work ok. Take care not to damage the inner bearing race. The purpose of this seal was to keep the oil (which comes from the gearbox to lubricate the bearings) out of the brakes. The seal causes a lot of friction, and you do not need it.

You can saw off the axle tube wherever you want, using a sharp hacksaw blade, in a few minutes. It is not that hard to do! Take it slowly, use the full length of the blade, and pay attention to keeping it square. I cut it off quite close to the brake back plate, but if you plan to bolt the windmill together rather than weld it you can leave the flat bracket (which normally meets the leaf springs) attached to the end you are using. For a small fee, the scrap merchant will probably cut it off with oxy-acetylene at the point of sale, and this would save you from transporting the incredibly heavy axle home at all.

DISMANTLING THE ELECTRIC MOTOR

Induction motors are the commonest motor in the world and you can easily find one in a scrapyard or similar location. I have only done two of these, but in spite of some differences in age and general appearance, they had exactly the same kind of laminates in the core, so I think it is commonly used. You need a big (3 phase probably) motor, and the body is usually of cast iron/white metal, with fins. The quickest way to see the laminates is to remove the cover on the terminal box where the wires enter, and perhaps the whole box. You can then estimate the radius from the axis of the shaft to the outer face of the core. This radius should be about 102mm [4"].

Start by taking off the cover from the fan at the back, and remove the fan from the shaft. It may be held in place by a roll pin which can be driven out with a punch or a nail with the tip sawn off. Then remove the screws holding on both the ends. The ends should come away, bringing the rotor from inside, and leaving only the motor body. Now you can see the copper windings, fitted to the core within the body. You need to remove the outer frame from the core, or vice versa. The core is retained in the outer frame by a locking pin which is not easy to locate, so the simplest method I know is to destroy the outer frame (the bit with the cooling ribs on it). If you have an angle grinder, cut the frame from one end to the other, at the thinnest place, which is where the wiring comes through. Having split the frame, it may spring open or it may need to be levered open until it releases the core, or snaps. The casting is not strong.

To remove the copper windings from the core, first shear off the ends of the coils with a sharp wood chisel, working tangentially (around the circle rather than inwards, or the coils will move into the gap and jam up). When the ends are neatly cut off, you can punch out the copper wires form the slots with a piece of 6mm [1/4"] rod, leaving the laminates ready for use.

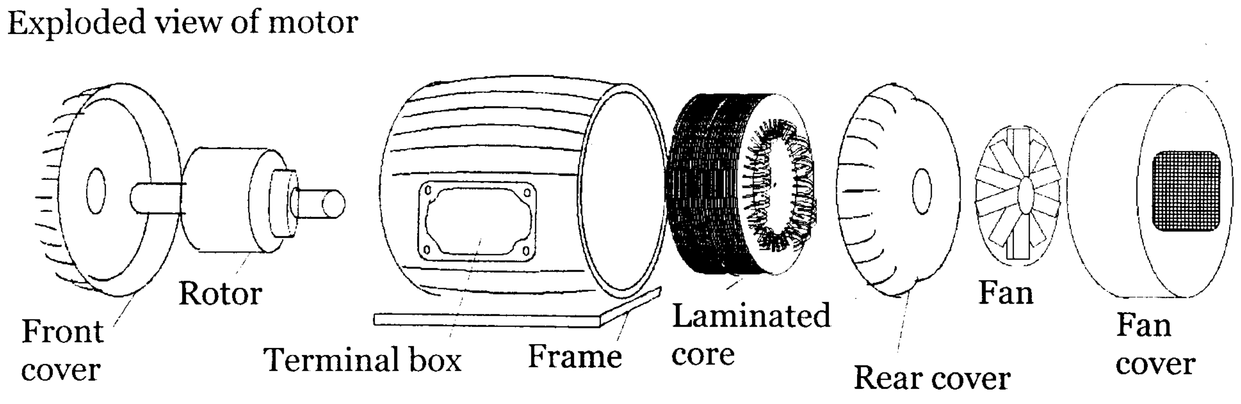


Figure 7

FITTING THE MAGNETS TO THE BRAKE DRUM

The hub and brakedrum will need to be cleaned up thoroughly, to remove all grease and grime, especially from the inner face where the shoes rubbed and the magnets are to be fitted. A rotary wire brush in a drill chuck is good. Beware of asbestos dust from the brakes: this should not be inhaled.

Place the blocks around the inner face of the drum evenly and note the space between blocks. It should be around 1mm [about 1/16" to 1/32"]. You will need shims of some non-magnetic material to place between the blocks as you lay them or they will slip together (they are attracted). Aluminum sheet is ideal, it can easily be obtained as aluminum flashing material at any hardware store.

If you want to shape the magnets, this can be done with an angle grinder, using a stone-cutting disc. The magnets are flat and the drum curved, so they do not fit perfectly, but shaping is not essential.

The magnets must be clean (no magnetic debris attached). Sticky tape is good at removing rubbish, as is plasticine.

The magnets must be fitted alternating first with north inside, then with south inside, and north against the drum. (Of course, it does not matter which is north as such). The blocks will naturally stack with north against south. As you take them off the stack, TURN EVERY SECOND ONE OVER. As you place it on the drum it should be attracted sideways to its neighbor and should and not be repelled. When the inner face of the drum is coated with resin the magnets slip around fairly easily and they will slide together. Hence the need for the shims. You actually only need about 4 shims because after a while you can start robbing shims which you used earlier and re-use them. Once there are magnets on each side of any given magnet, it will no longer tend to shift. When you get to the end you can adjust the spacing so it is as even as you can get it. Performance will not be adversely affected by any error which you can easily see.

The epoxy resin I use is intended for boat building in wood (SP Systems 106). You mix it at the rate of five of resin to one of hardener, and it takes plenty of time to set (maybe an hour you can safely work in). Avoid mixing a large amount in a pot, or it may heat up and set too fast (going "exothermal"). It helps to add powder to the mix before applying it, to thicken it, otherwise it will dribble away. "Colloidal silica" is a good powder, but again, do not inhale this. There are other thickeners which will do just as well, such as microballoons, or aluminum powder. Iron "weighting powder" or "magnetite sand" could possibly be used with epoxy to make a core without laminations. But this is not relevant to the job at hand.

Clean resin from the fingers at once with a dry rag or paper. It can be removed from the skin with solvents such as meths, but this tends to carry it into the skin as well, and can cause an allergic reaction. Resin is nasty stuff, do not touch it if possible, or better yet wear impervious gloves.

WINDING THE COILS

You will need about 800 grams [1.75 pounds] of enamel coated copper wire. The enamel prevents the wires from shorting out, and must not be damaged. I used 0.80mm [about 20 AWG] wire, because that is what I had, and it gave good results. I used 24 turns per coil. A smaller number of turns of thicker wire, or a larger number of turns of thinner wire would give more current or more voltage per coil respectively. Power output (volts x current) is not affected by the size of wire chosen, but the RPM speed at which it will charge a given battery voltage will be affected.

More power can be obtained by making the coils physically bigger (wider) and using more turns of wire. This is possible to do, since there is good clearance between the magnets and the coils. But if the magnets do touch the coils then you have problems, so I suggest you keep the coil size close to the 2.5mm [a bit under 1/8"] which I used.

See figure 8 which shows the coil winding machine and former. You need to build something like this. The tricky bit is getting the crankshaft (made of M10 [3/8"] threaded rod or similar) to drive the coil former and cheek pieces. Nuts are required on the shaft, which can be tightened against the pieces of ply. You start winding the coils by twisting the end of the wire around the retaining nut and passing it into the notch in the front cheek piece. Hold the wire in one hand, keeping a gentle tension on while you crank the machine with your other hand. The coil should be wound neatly in layers to get tight packing.

Before removing from the coil former, the coil has to be tied up. You can simply put a loop of wire around each end, but because the coil is wide and thin, it tends to be distorted this way. I suggest as follows:

Either:

1) Use a hot glue gun to solidify the ends of the coils, leaving enough flexibility to shape them later, or
2) What I did was this:
    a) Wind 12 turns
    b) Pass short pieces of wire inside the ends of the coil
    c) Cross them over outside the ends of the coils
    d) Wind the next 12 turns
    e) Twist the ends of the short pieces together outside the coil, so that it grips the coil in a figure eight.

The core should be as thick as the magnet blocks are long, 64mm [2.5"]. Simply split off as many laminates as you need to make 64mm [2.5"] thickness, from the core which you extracted from the electric motor. The core must be coated in a thin layer of resin and surfacing tissue or something to prevent sharp edges which might damage the enamel on the wires.

When you have wound six coils, you can glue them to the core. Mark the core in five places for accurate positioning of the coils around the circumference (five equal intervals of 72 degrees, easily found by dividing the 635mm [25"] circumference into 5 equal 127mm [5"] arcs). Place the coils in two heaps of three on the core, overlapping as shown in figure 9. The ends of the coils need to be manipulated to pass each other without causing bumps which would foul the magnets.

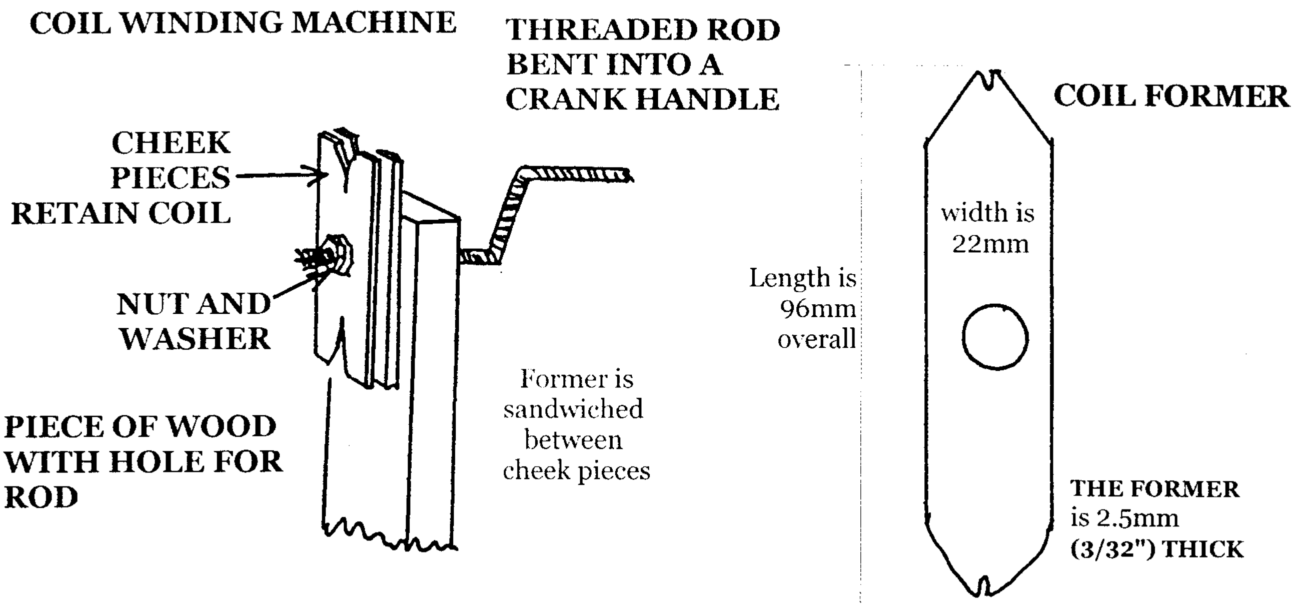


Figure 8

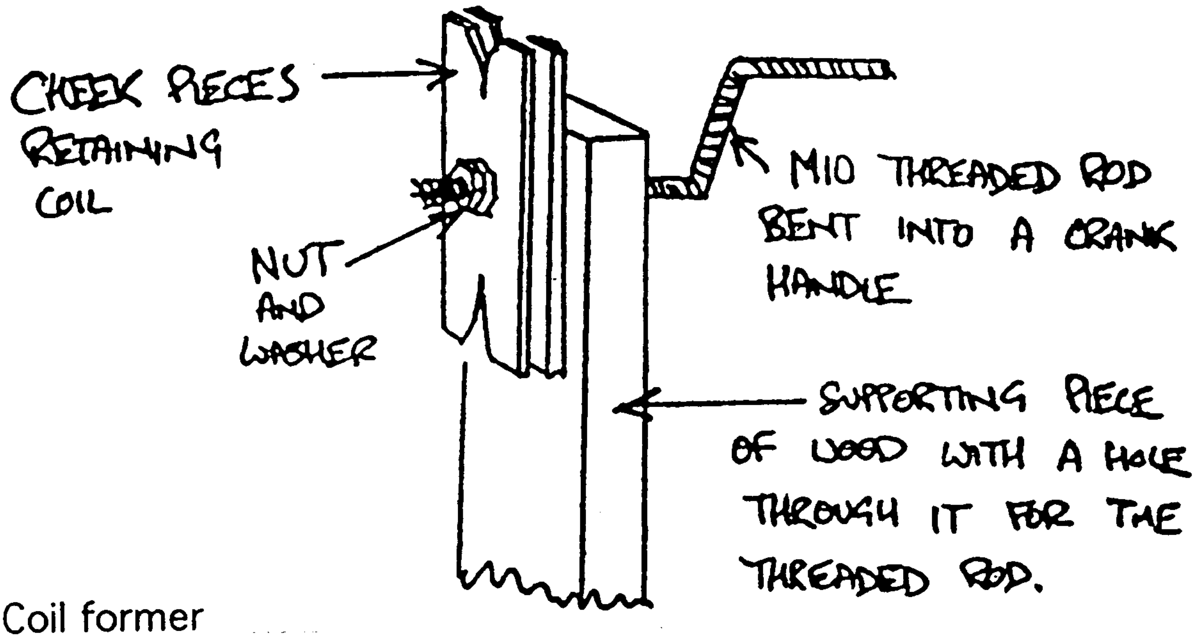
When you are happy with the shape of the coils, mix some (thickened) resin and tip it onto the coil groups. Lay on some surfacing tissue, and press down the wooden former. The inner radius of the curve on the former should be 104mm [4 1/16"]. The surface of the former needs to be greased to prevent it sticking to the job., Or maybe you could use polyethene. Anyway, as the clamps tighten the former down onto the coils, resin squirts out the ends. This should be encouraged to soak into the end windings in such a way as to set them solid. But ensure that you can still see which end of the coil is which when you come to connect them up. You need to be able to see whether the coil runs clockwise from one end to the other (see below). Now wash your hands.

CONNECTING UP THE COILS

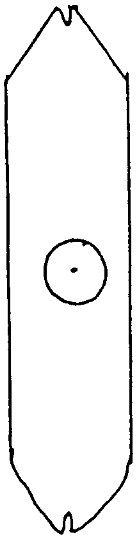
When I talk about the start and the finish of a coil, it does not matter which is which, provided you always follow the same rule. For example, looking at the coil from the outside (it is hard to look at it from the core side anyway!) the wire runs clockwise from the starting tail to the finishing tail. This rule defines the start and the finish. You can say anti-clockwise instead, provided you apply the same rule to all thirty coils.

The coils fall into three kinds according to the timing or “phase” of the AC power produced. There are ten of each kind. You will need to take every third coil, and connect them in series (finish of one to start of the next) as show in figure 9:

COIL WINDING MACHINE

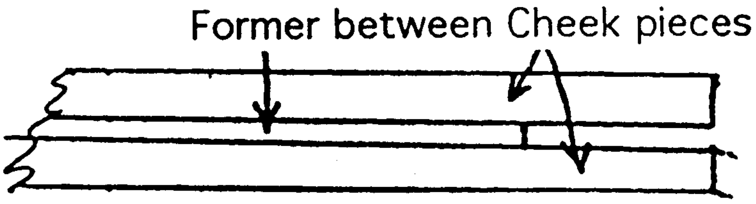


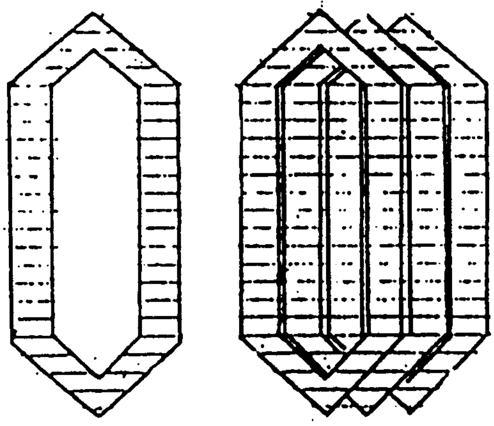
Coil former
(actual size)



Thickness = 2.5mm

The former is attached to one cheek piece, which in turn is locked to the shaft.

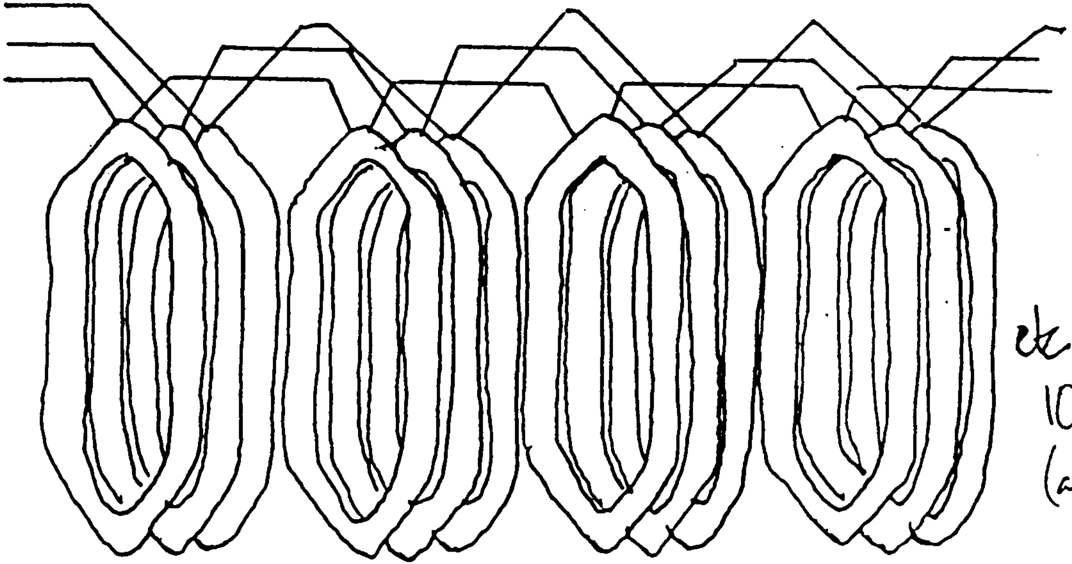




The coils are overlapped in groups of 3 like this.

There are ten groups of three coils each, in all.
Glue them to the core in pairs (six coils at a time).
This makes five gluing sessions.
Use a G-clamp and a wooden former as shown
Others have succeeded in gluing all thirty coils at once, using a band around the whole thing.

The coils fall into three kinds according to the timing or "phase" of the AC power produced. There are ten of each kind. You will need to use take every third coil, and connect them in series (finish of one to start of the next) as shown below:

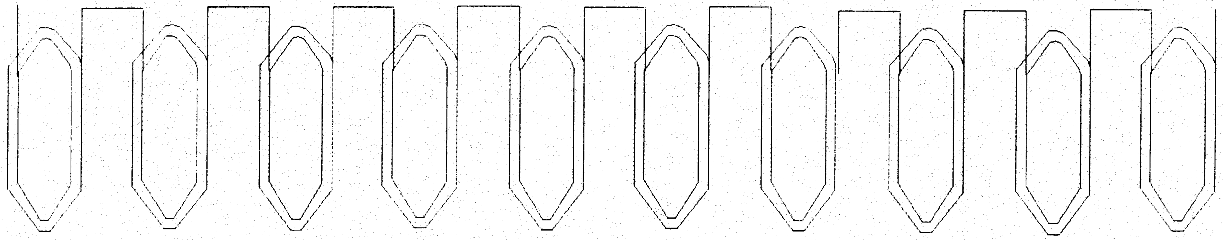


etc to 10th group (all the way)

The tails of the coils must be meticulously cleaned with a sharp knife to remove ALL the enamel coating, then twisted together tightly and soldered with a hot soldering iron, and resin core solder. Insulate the joins with tape (self amalgamating tape is best) or heat-shrink sleeving.

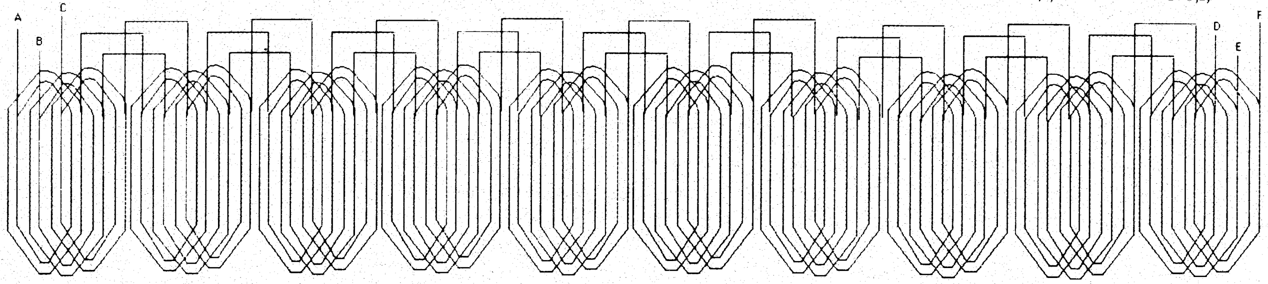
COIL CONNECTIONS

HERE ARE ALL THE COILS IN ONE PHASE, SHOWING HOW YOU CONNECT THEM TOGETHER - FINISH OF ONE COIL GOES TO START OF NEXT COIL - IN SERIES



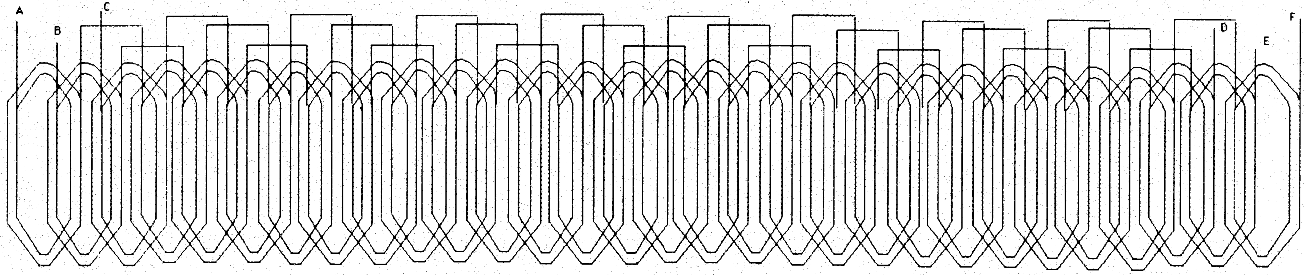
HERE IS HOW YOU SHOULD CONNECT THE COILS FOR ALL THREE PHASES - JUST THE SAME, BUT THE COILS THEMSELVES OVERLAP

IN THE FIRST EXAMPLE, THE COILS ARE HEAPED UP IN GROUPS OF THREE, SO YOU CAN GLUE THEM ON IN STAGES AS DESCRIBED - THE STARTS ARE LABELLED A,B,C AND THE FINISHES D,E,F



FOR DELTA CONNECTION (12 VOLTS) CONNECT A TO B, C TO D, AND E TO F.
FOR STAR CONNECTION (24 VOLTS) CONNECT B TO D AND TO F (NEUTRAL POINT).
IN BOTH CASES, CONNECT A, C AND E TO THE RECTIFIER

IN THE SECOND EXAMPLE, THE COILS ARE ARRANGED EVENLY, AND WOULD NEED TO BE GLUED UP ALL AT ONCE (SOME PREFER TO DO IT THIS WAY)



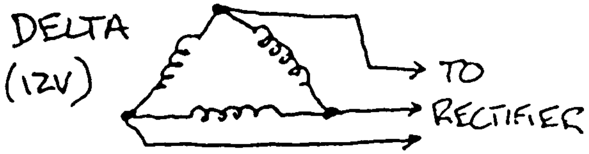
FOR DELTA CONNECTION (12 VOLTS) CONNECT A TO F, B TO D, AND C TO E.
FOR STAR CONNECTION (24 VOLTS) CONNECT D TO E AND TO F (NEUTRAL POINT).
IN BOTH CASES, CONNECT A, B AND C TO THE RECTIFIER.

Figure 9

The tails of the coils must be meticulously cleaned with a sharp knife to remove ALL the enamel coating, then twisted together tightly and soldered with a hot soldering iron, and resin core solder. Insulate the joins with tape (self amalgamating tape is best), heat-shrink sleeving, or "liquid electrical tape".

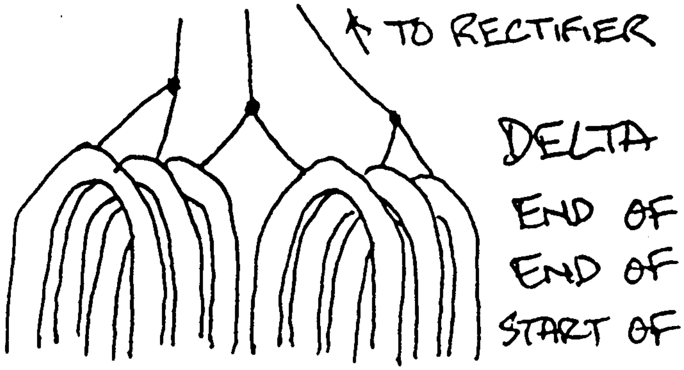
You can crank the alternator around and measure the voltage from a set of coils using a multimeter. At 60 RPM (one revolution per second), a set of ten coils produces around 3.5 volts AC. This tells us that at 180 RPM it will produce 10.5 volts AC. The DC rectified voltage will be about 30 to 40 percent higher than the AC voltage depending on current draw, so the turbine would "cut in" at about 180 RPM for a 12 volt battery charging application.

Check the outputs of each group of coils: they should be the same voltages at the same speeds, or you have got some coils reversed. This will leave you with six ends: the starts and finishes of the three series groups of coils. To make a 12 volt machine, these three groups of coils should be connected in "delta" (start of one goes to finish of the next and so on), whereas a 24 volt machine can be produced by connecting them in 'star' ['Y'] (one tail from each coil group goes to a neutral connection, and the free tails go to the rectifier). In figure 10, each coil group is shown as a single coil for simplicity.



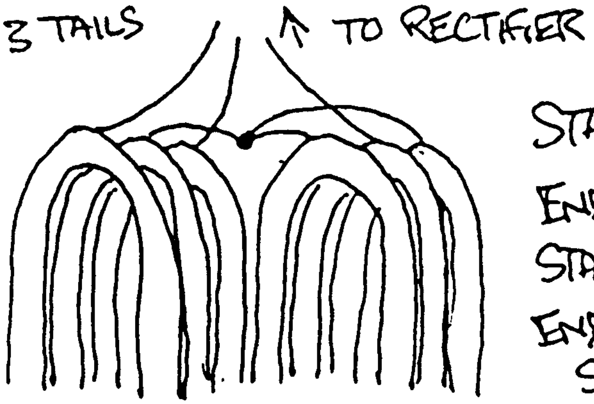
Just to make life more confusing, the second group of coils, which is made up of all the coils in the middle of the overlapping heaps of three, must be reversed. In other words the start of this group and the finish must be reversed. The actual wiring diagram which results from all this is shown next:

CONNECTING THE SIX ENDS OF THE GROUPS



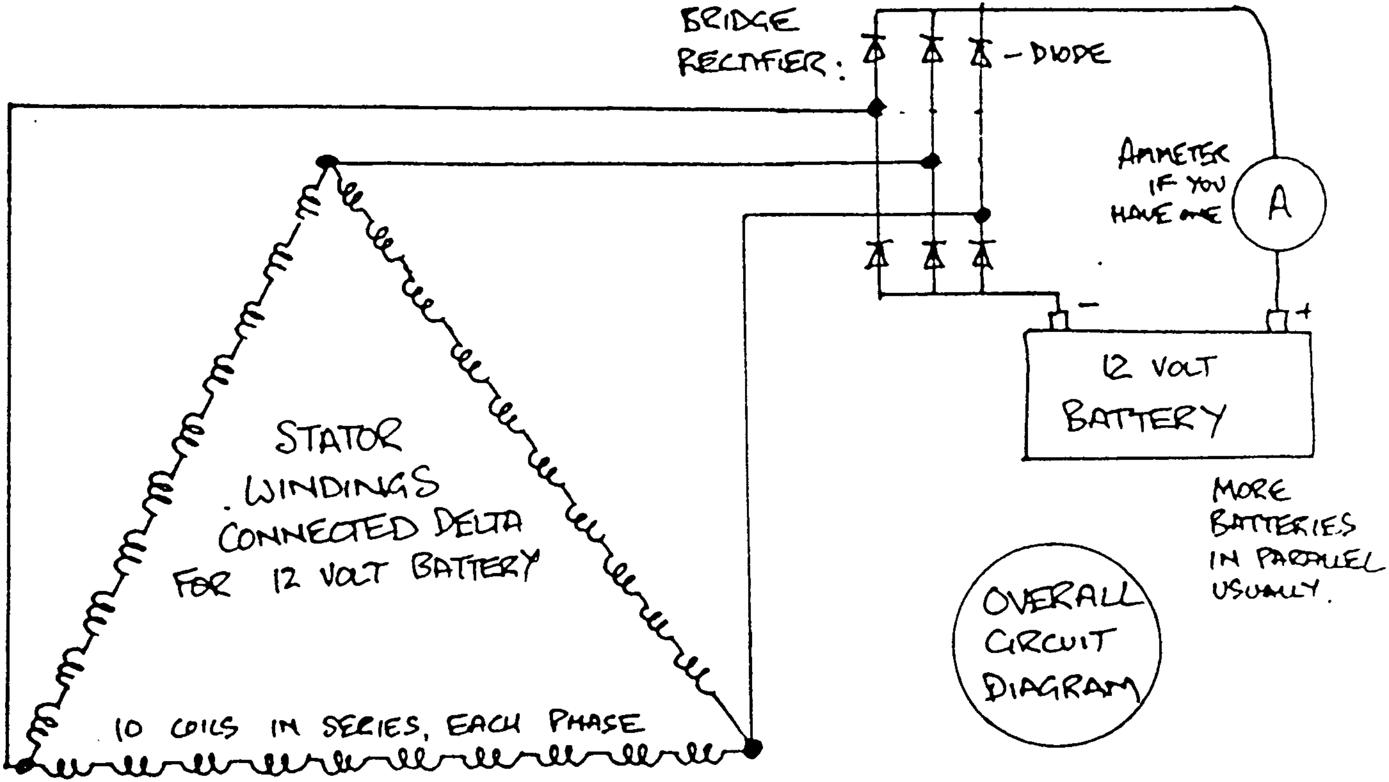
DELTA CONNECTION (12VOLT)

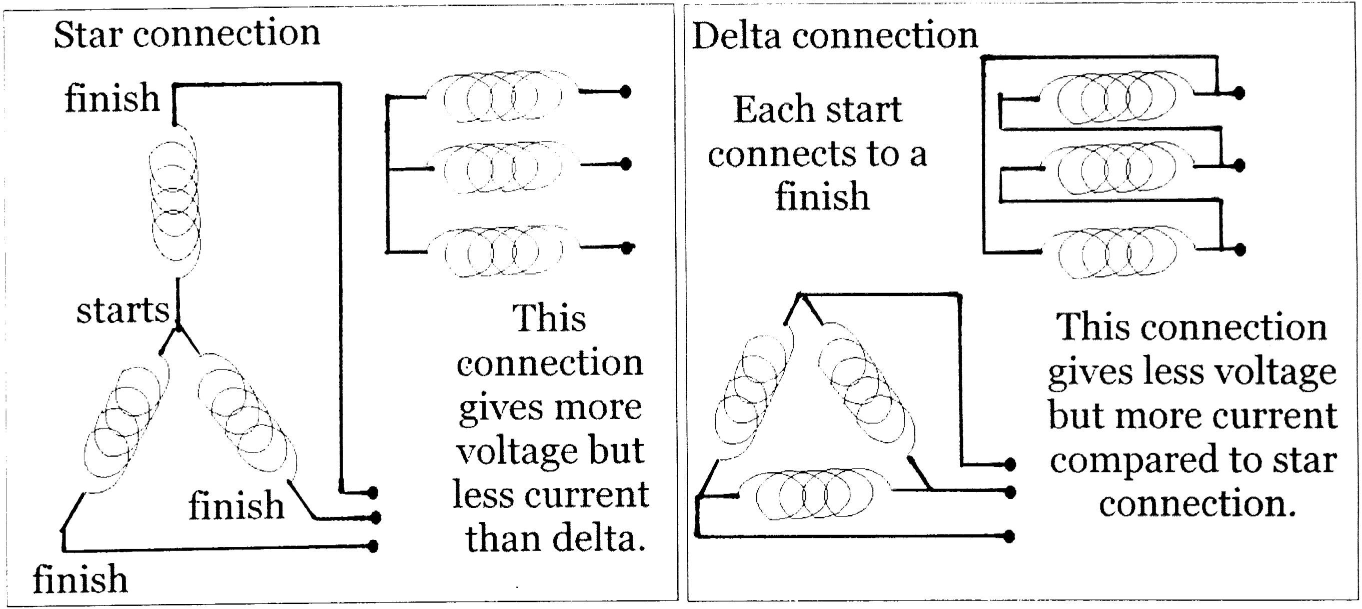
END OF GROUP ① TO END OF ②
END OF GROUP ③ TO START OF ①
START OF GROUP ② TO START OF ③



STAR CONNECTION (24 VOLT)

ENDS OF GROUPS ① AND ③ TO OUTPUT
START OF GROUP ② TO OUTPUT
END OF GROUP ② JOINS
STARTS OF GROUPS ① AND ③


BRIDGE RECTIFIER:
- DIODE
AMMETER IF YOU HAVE ONE
A
-
+
12 VOLT BATTERY
STATOR WINDINGS CONNECTED DELTA FOR 12 VOLT BATTERY
10 COILS IN SERIES, EACH PHASE
MORE BATTERIES IN PARALLEL USUALLY.
OVERALL CIRCUIT DIAGRAM


Star connection

This connection gives more voltage but less current than delta.

Delta connection

Each start connects to a finish

This connection gives less voltage but more current compared to star connection.

Figure 10

If you want to glue in the coils in heaps of 3, as I have done, rather than all 30 coils at once evenly spaced, then there is a complication. The middle coil of the heap is too close in its timing or 'phase angle' to the others in the heap. This needs to be corrected by reversing the start and finish of this middle phase. Follow the instructions for coil connection in figure 9, which uses letters for the wire tails.

WIRING TO THE BATTERY

The tails which go to the output should be flexible cable leading to the bridge rectifier, probably through some sort of connectors and a cable to the house. I find that the blade and receptacle type of crimp connectors are very handy for this sort of situation. The wiring is simply fed through the centre of the yaw bearing and goes down inside the tower, exiting near the base of the tower. I normally support the pole such that its bottom opening is clear, which allows easy checking for twisting. You could also drill a hole.

Some readers will no doubt be horrified that there are no slip rings used in this design. In my experience there are few sites where you will experience problems with a cable hanging down the middle. I have had more problems with brushes and slip rings (few enough but some) than I have with free hanging cables in the tower centre. There are some turbulent sites and some very free yawing machines where I have had problems but they are few and do not justify the hassle of fitting slip rings as standard. Slip rings have to be of very good quality or it is not worth doing them.

You can connect wiring to the rectifiers with these same crimp-on receptacle connectors (or solder them). The rectifiers are square blocks which must be bolted to a piece of aluminum to dissipate the heat they produce. There are four terminals on each. One terminal is at right angles to the other three. This is connected to a battery (+). The one diagonally opposite to it is connected to battery (-). The remaining connectors take the AC wires from the windmill. Since we have three wires (3 phases) we need two rectifier blocks, and there is one spare AC terminal: useful if damage occurs due to lightning or suchlike. It does not matter which AC wire goes to which AC terminal. See figure 11.

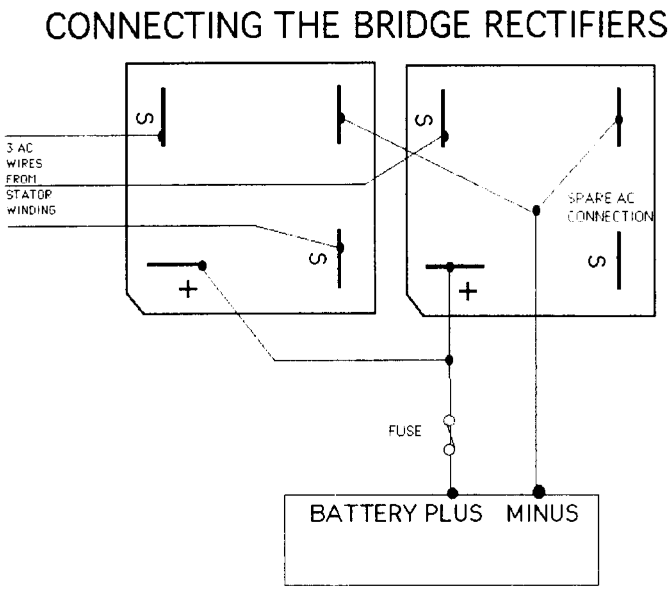


Figure 11

MODIFICATIONS FOR FORD 3/4 TON TRUCK

The following table lists modifications to make when using a Ford 3/4 ton truck instead of a Ford van.

Item	UK Version	North American Version
Vehicle	Transit Van, long wheel base version	Ford 3/4 ton truck, E or F, 250 or 350
Internal brakedrum diameter	254mm [10”]	306mm [12”]
Number of magnets	20	16
Magnet length	64mm [2.5”]	76mm [3”]
Magnet width	32mm [1.25”]	51mm [2”]
Magnet thickness	20mm [3/4”]	25mm [1”]
Air gap diameter	212mm [8 5/16”]	251mm [9 7/8”]
Lamination diameter	204mm [8”]	245mm [9 5/8”]
Lamination stack thickness	64mm [2.5”]	76mm [3”]
Coil former leg length	76mm [3”]	76mm [3”]
Coil former overall length	96mm [3.75”]	90mm [3.5”]
Coil former width	22mm [7/8”]	33mm [1 9/32”]
Coil former thickness	2.5mm [3/32”]	2.5mm [3/32”]
Number of coils per phase	10	8
Phases	3	3
Total number of coils	30	24
Wire size	0.8mm diameter [20 AWG]	0.7mm diameter [21 AWG]
Wire turns per coil	24	36
Nominal voltage, delta	12V	21V (usable at 12V)
Nominal voltage, star [‘Y’]	24V	36V
Propeller diameter	2.1m [7’]	2.8m [9’ 2”}

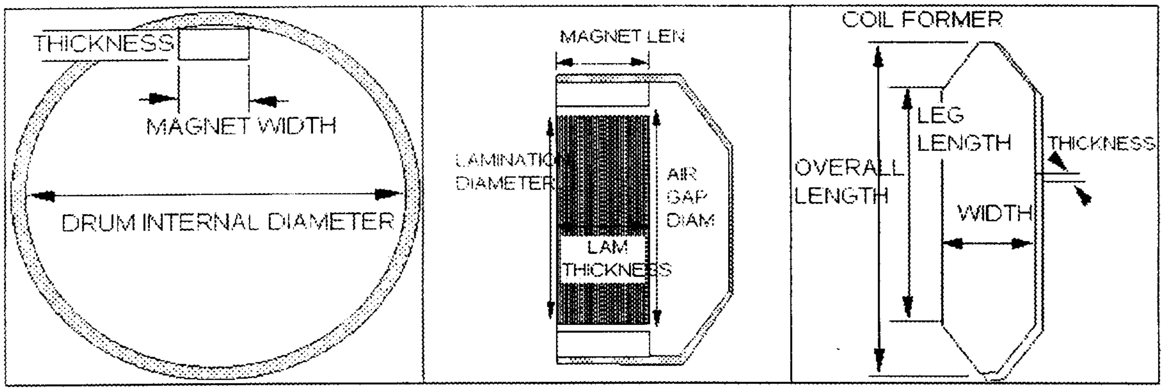


Figure 12

MATHEMATICAL MODEL OF BRAKEDRUM ALTERNATOR

The following mathematical formulas will help those of you who wish to modify the parameters given above. It should be kept in mind that these models are only approximations of what you will find in practice. You can easily program these formulas into a spreadsheet. A downloadable spreadsheet containing these formulas is available from PicoTurbine.com (see section SUPPLIERS at the end).

INPUT VARIABLES

These are things you need to know in advance which will affect the performance:

Description	Variable Name
Number of magnets in the rotor (must be an even number)	N
Length of each magnet, in mm	L
Width of each magnet, in mm	W
Battery voltage (system voltage)	VBAT
Turns of wire per coil	T
Speed of rotation, in RPM	RPM

ASSUMPTIONS

1. I assume that the stator winding is 2.5mm thick, in a total gap of around 4mm.
2. The magnets need to be 20-25mm thick, and at least 32 mm wide.
3. I assume there are 3 coils for every 2 magnets, and coils are in 3 phases.
4. Coils are connected in star [‘Y’] rather than delta grouping.
5. Common sense needs to prevail when playing with these numbers. For example, if magnets become too wide they will not physically fit around the brakedrum unless they are curved, etc.

OUTPUT VARIABLES AND FORMULAS

Description	Variable and Formula
DC voltage output, open circuit, in volts	VALT = N^2 * L * W * T * RPM / 150000000
Internal resistance of alternator, in ohms	R = (L+W) * N * T^2 / W / 8640
Total current produced, in amperes	I = (VALT-VBAT)/R
Total power generated, in watts	P = VBAT * I (watts)
Power lost in windings, in watts	LOSS = I^2 * R
Wire diameter, in mm	DWIRE = 0.7 * (W / T)^0.5

Notes:

1) You need to add your cable resistance to internal resistance R for a true picture of resistive losses. This affects the current output as well.
2) Your spreadsheet will give negative values of current, I, at low speeds. This should be treated as zero current. If you wish, you can use the IF operator of your spreadsheet to set to zero. For Microsoft Excel, for example, the statement would look like this assuming you have named the cells VALT,VBAT, and R: IF(VALT-VBAT<0, 0, (VALT-VBAT)/R)

MAKING THE PROPELLER

Whilst I am aware that many people are apprehensive about carving their own propeller out of wood, I still strongly advocate that you try this method, as it yields much better results than bent pieces of metal. Making molded fibreglass blades is a tricky operation and very laborious for a one off job. If you do not feel you can successfully make blades yourself, you could purchase the blades from a wind turbine blade supplier. See section SUPPLIERS at the end of this booklet for some sources.

You will need some sharp tools: a plane, a spokeshave [plane-like tool with handles on each side], chisel, saw and ideally, a drawknife, which is great fun for ripping out great hunks of wood. Sharpen the edges with an oilstone, at the correct angle (work up towards the edge rather than back from it). And remove any rag [loose threads of steel at the edges] which may result, by stropping the edge to and fro until it breaks off.

I usually clamp the wood onto a bench with a G-clamp [C-clamp], or clamp it to a waste piece of wood, which in turn is firmly gripped in a vice. This allows me to turn it around to the best working angle with ease, and hold it rock steady. If it vibrates, and the tools judder, try cutting slightly crabwise, angling the blade diagonally to the direction of motion. Obviously you will need to cut with the grain for best results. Power tools may be useful but they create a lot of dust, and it is difficult not to cut too much off at once.

Reasonably knot free ("clear" is the technical term), straight grain wood is necessary for a satisfactory job: if you buy it new, then Oregon pine is a good choice but very expensive. Old bed frames can be a good source of propeller wood or even old building timber or church pews. In what follows I assume you are using 100mm x 50mm ("two by four") timber, but you can piece the same shapes together with any starting size once you understand the principle.

You need a total of over 5 meters [16.5'] of 100mm x 50mm ["two by four"] timber, cut into six pieces, 3 at 1000mm [39"], 3 at 750mm [30"]. Each blade is then built up by gluing two pieces together, overlapping as shown in figure 13:

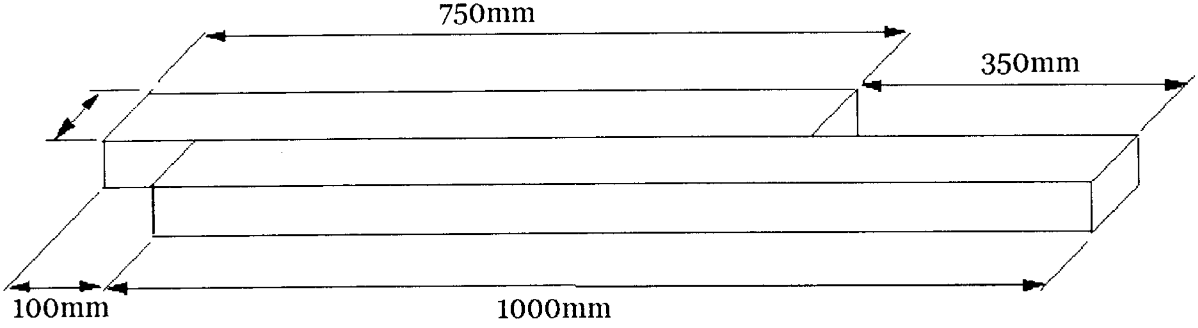


Figure 13

If you do not have enough wood, you may be able to work out a way of producing the final shape by cutting what you have into triangles. Use the same epoxy as for the alternator job. Other glues may be ok, but epoxy is definitely very suitable. Clamp the pieces together very firmly while the glue sets.

Each of the operations which follow will start by marking the correct measurements onto the work piece at each of a series of "stations". There are 7 stations including the tip, spaced equally at 150mm intervals from the centre of the propeller. Mark the stations on the work piece now, using a square to draw a line right around the piece as shown in figure 14. (Note that the actual centre of the propeller assembly is beyond the wood of this one blade. Measure stations from the tip.)

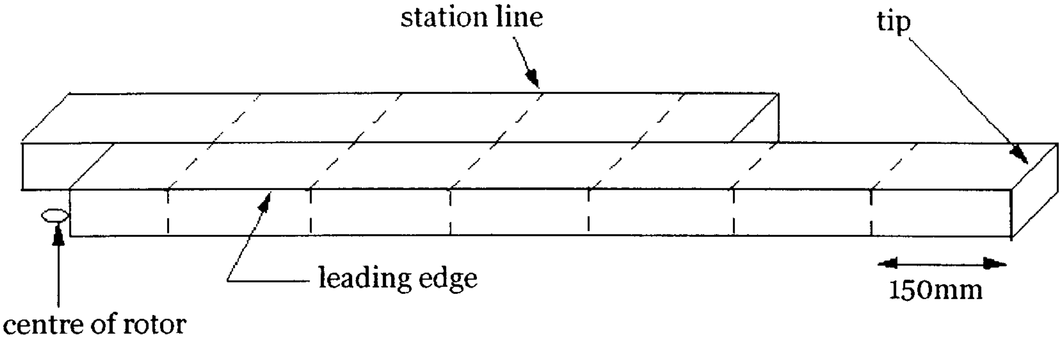


Figure 14

Next you will need to produce the correct taper: i.e. get the blade "chord width" right at each station. In all that follows, the leading edge remains untouched, as a sort of reference line. Measure the width from the leading edge at each station, join the dots with a line, and cut away the surplus wood, as shown in figure 15:

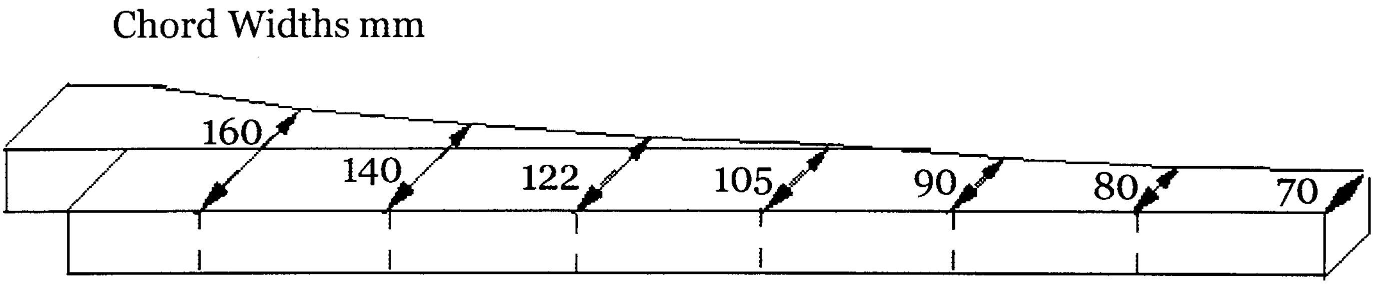


Figure 15

Turn the blade on edge, and work down to the line to an accuracy of plus or minus 1mm [about 1/32"], and keep the cut face square to the "top" of the wood (see figure 16). Where there is more than 10mm [3/8"] of wood to remove, it may be easiest to cut through the waste across the grain with a saw and then chop out chunks with a chisel, along the grain. Or you can use a band saw if you have access to one.

The next job is to put the correct angle on the blade, so it will catch the wind and run at the right speed. This is variously known as the weather angle, setting angle, or pitch of the blade. The angle is measured relative to the "top face" of the piece of wood: the one shown facing you in the above figures.

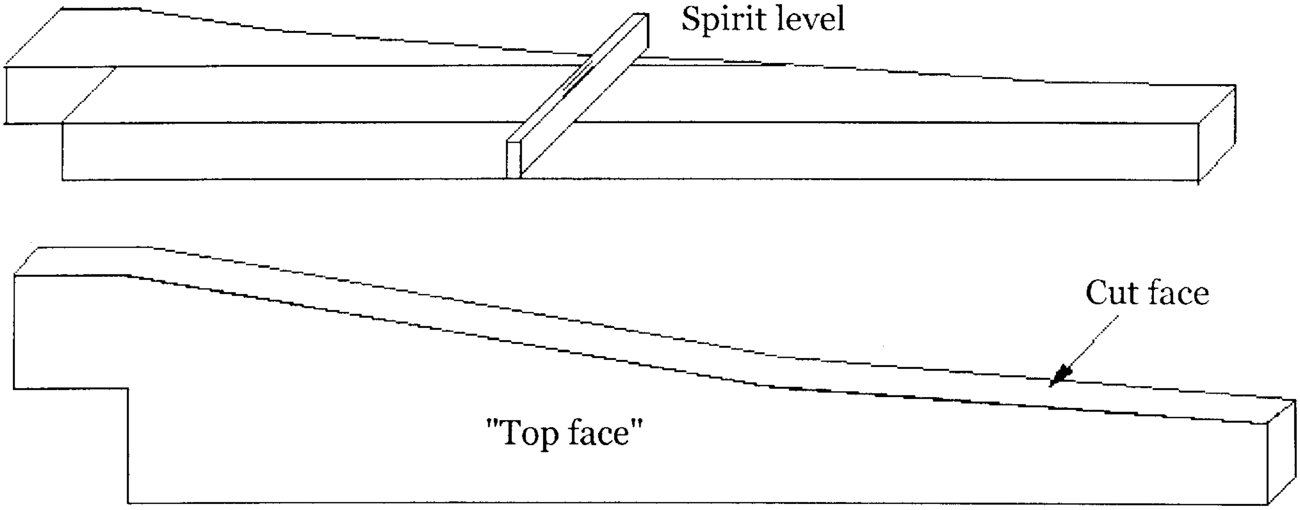


Figure 16

Before going any further, check for warp on this face, as this will affect the angle produced. You can check for warp by laying the work piece on a level surface, with the top face horizontal. Place a spirit level *across* this top face at each station in turn. At each station the bubble should sit at the middle of the glass. If there is a tilt at some of the stations then you will need to compensate, either by planing the top surface carefully level, or by measuring the error and compensating for it in what follows.

Turn the wood up on edge again. Draw your square lines at each station on the newly cut face, as shown in figure 16.

Now we need to draw a line to mark the position of the trailing edge of the blade on the newly cut face. At each station, measure the prescribed amount (see figure 17 below) from the "top face" along the newly drawn lines on the cut face. Mark a dot on each line at the correct distance from the top face. Join the dots, to produce the trailing edge line of the blade, as shown in figure 17:

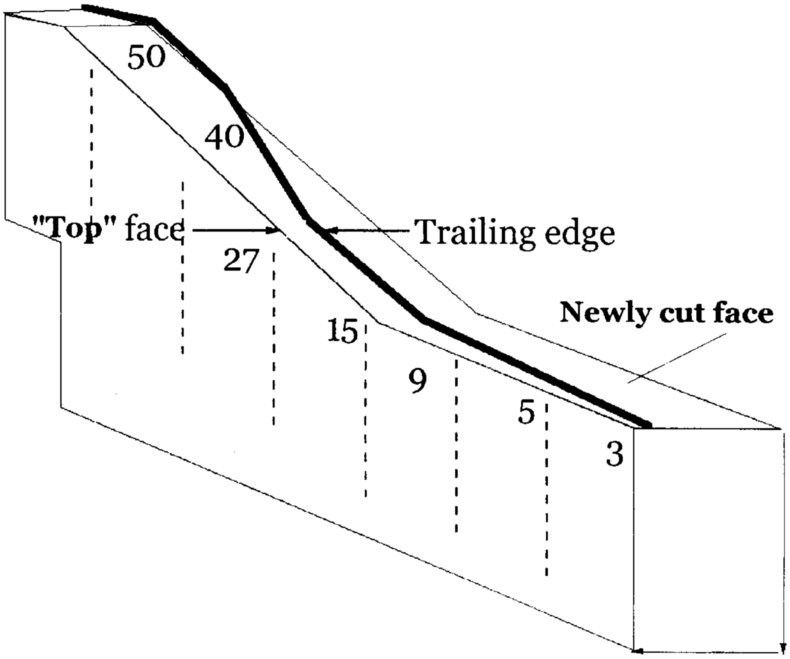


Figure 17

The trailing edge line is shown in bold in figure 17. This line is all that will remain of the face of the wood when you have finished the job. Now it is time to tackle the windward face (front) of the propeller blade. For simplicity, I recommend a flat front face, although some people cut them concave. When I say flat, I mean that the line between leading and trailing edges is straight. The face itself is not flat, but twisted, due to the strange curve of the trailing edge.

First mark the top face as shown in figure 18, which shows (hatched) the part of the top face which should be left alone:

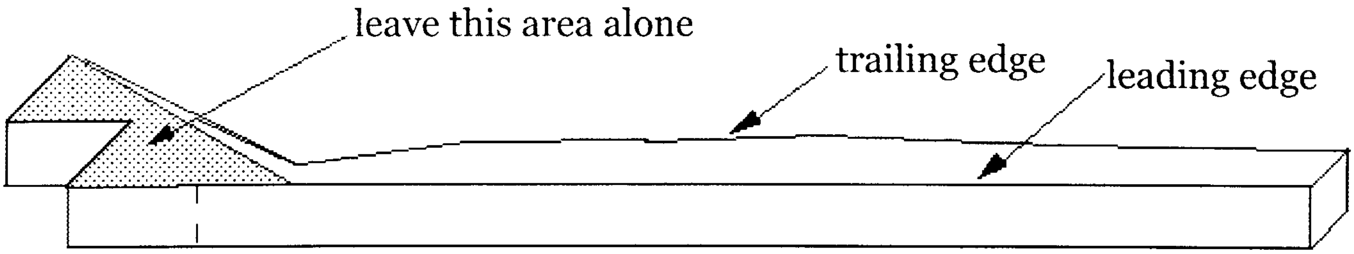


Figure 18

Now you have to cut away all the wood above a line between the leading and trailing edges, to produce the flat, twisted, front face referred to above. Figure 19 is a *cross-sectional* view of the fourth station, to show the part of the wood which must be removed (marked "CUT").

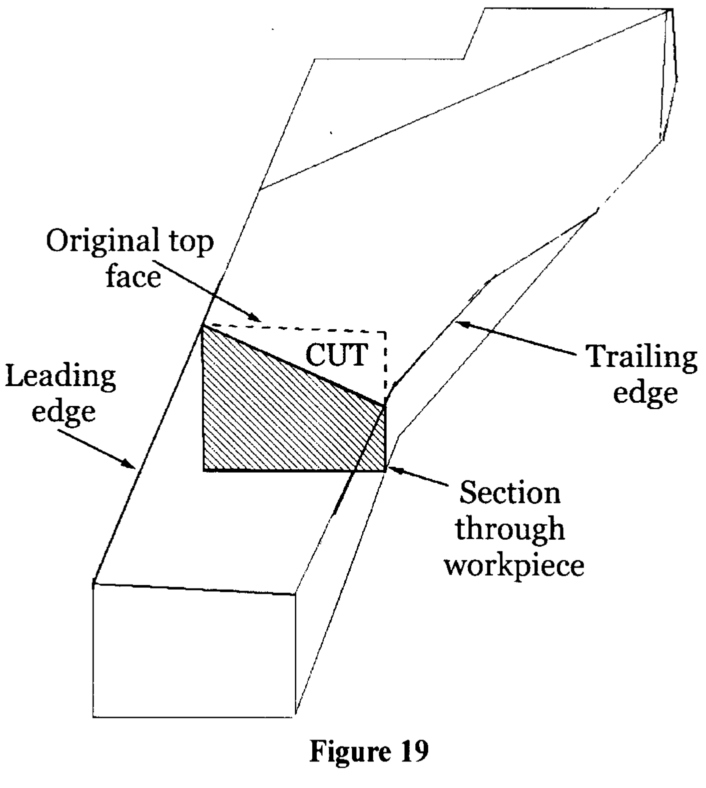


Figure 19

Having cut the front face, the next step is to make the blade the correct *thickness*. The thickness is related to the chord width (see figure 15). Near the root, the thickness should be about 15% of the chord width. It drops to about 12% of the chord width at the tip. The actual thicknesses I recommend are shown in this table:

Station:	1	2	3	4	5	6	7
Thickness:	50mm	20mm	18mm	16mm	14mm	12mm	9mm

You must measure these thicknesses from the front face, in a way similar to marking out the trailing edge in figure 5. Do it at both the leading and trailing edges, and make two lines running the length of the blade, on opposing faces as shown in figure 20:

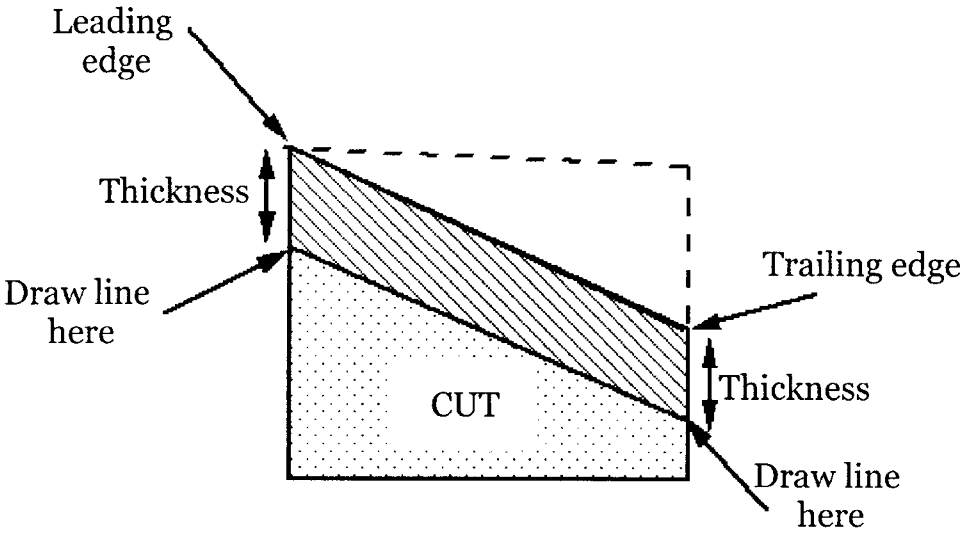


Figure 20

Turn the work piece upside down, with the front face downward. Now cut away the portion marked "CUT", working down to the two lines you have just drawn. It may be helpful to use calipers for accurate measurement of the remaining thickness, especially near the tip where precision is required.

You will be left with a blade which is the correct width and thickness, but has a crude rectangular/parallelogram cross-section. This now needs to be made into an aerodynamic shape. I normally leave the front face flat, but the back face (away from the wind) has to be convex (bulbous), and the trailing edge needs to be sharp, for minimum drag.

Shave wood away from one side of the most recently cut face to sharpen the trailing edge. The correct angle for the trailing edge is obtained by cutting away about 40% of the back face into a bevel down to the trailing edge as in figure 21:

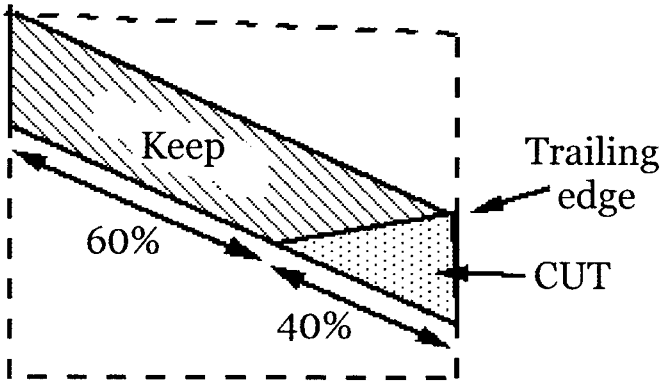


Figure 21

Finally you need to round off the sharp corners on the back of the blade, to produce a smoothly curved airfoil shape. I do this by eye really. Draw a line on the back face about 25% of the width back from the leading edge, and leave this line untouched, or you will lose your thickness. Figure 22 shows the general idea:

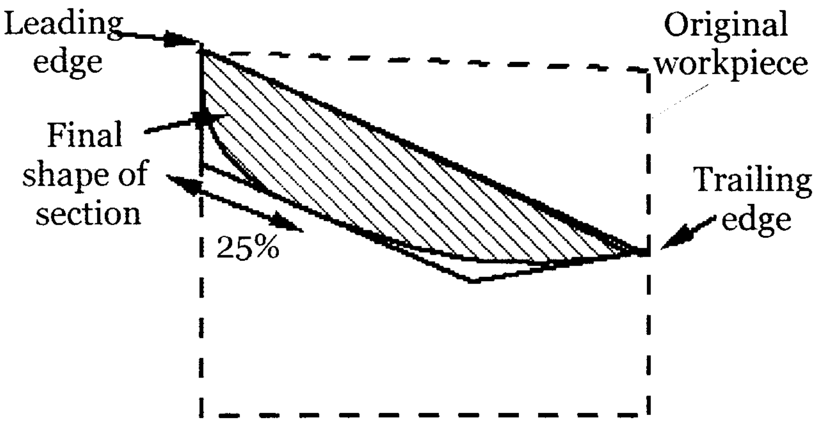


Figure 22

There is usually some debate about the best shape of the leading edge. I tend to keep it rather too sharp for some people's taste; maybe it should be more bulbous. In any case the wind generally wears this bit out of all recognition after a couple of years.

You should now have three lovely propeller blades. Normally I remove the leading edge with a plane to a depth of about 3mm [1/8"] and rebuild it with a mixture of epoxy and powder, to provide a tough setting paste. This has to be applied with a butter knife, and filed off when hard to make the original shape again.

I do recommend painting the blades thoroughly. I use Woolworth's non drip gloss on primer, and coat them thickly, sanding smooth with waterproof abrasive paper after the fourth coat. Painting should follow the next bit: assembling the whole rotor at the hub.

The way the blades fit together is shown in figure 23. The centre of the prop is 50mm [2"] back from the line of each leading edge, and 50mm [2"] from the end of the longer piece of wood, in the original construction (see figure 14). Position the blades so that these centre points coincide, and the angle between any two leading edges is 120 degrees. The easiest way is to measure the distances between tips and make them all the same. Fitting them together will require the removal of some wood (a triangle at the root) from the pieces you glued on the sides (see figure 13). I leave this until last, because these pieces are useful for clamping up during the carving phase of operations.

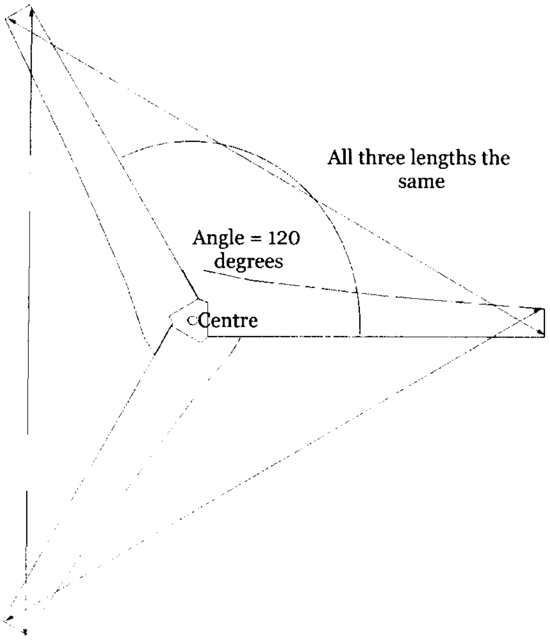
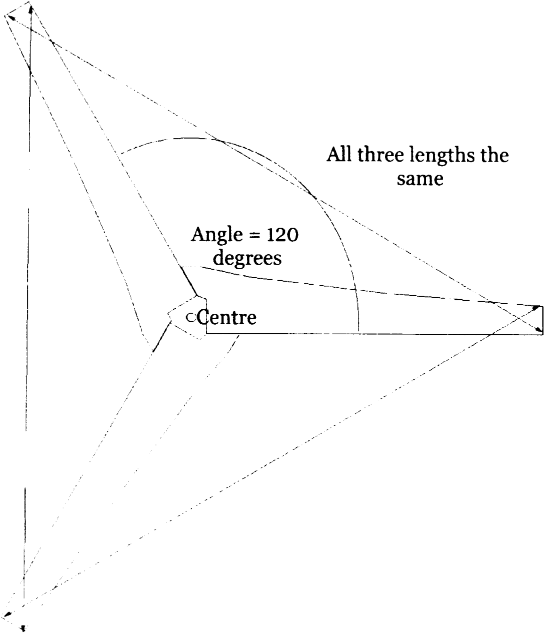


Figure 23


All three lengths the same
Angle = 120 degrees
Centre

When you have the blades all fitting snugly as described, cut two hexagons out of sturdy plywood (minimum 9mm [3/8"] better 12mm [1/2"]) as shown in figure 24:

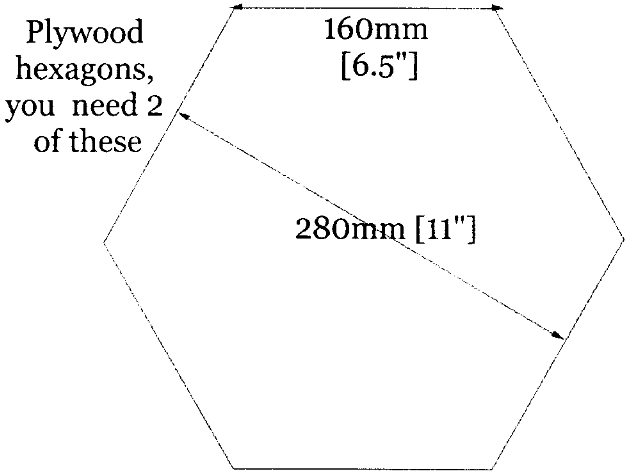


Figure 24

Sandwich the centre of the propeller between these two hexagons and fasten the whole together with a pattern of 50mm [2"] wood screws. I used 36 screws in all. Obviously you need to position the blades carefully before you start driving in screws.

If you will never need to take the propeller apart again (for easy transport or painting for instance) then it may be an idea to use epoxy as well as screws in the assembly of the hub.

The propeller is now complete, but it still needs to be balanced and fitted to the brakedrum alternator. Balancing is just a matter of making sure that the centre of gravity of the propeller assembly lies exactly on the centre of the shaft of the alternator. First find the centre of gravity of the propeller as follows:

Mount a sharp "knife-edge" about 300mm [1'] long horizontally in the jaws of a vice or similar. Balance the back of the propeller hub on this knife-edge. Sit the propeller dead level, and release it gently. If it tips, move it in the opposite direction a fraction and try again. Finally you should reach the point where it can hardly decide which way to tip. Press down firmly and slide it to and fro on the knife-edge to mark this position. Rotate through 60 degrees or so and repeat the process. Rotate a second time and cut a third line on the underside of the hub. When you have three lines, all passing below the centre of gravity of the propeller, turn it over and check that all three scratches meet at one point. This is the centre you need to use. It may not be the exact geometrical centre of the propeller, due to differences in density or whatever, but it is the centre you must use. If you do not like it, you can move the centre by attaching weights (e.g. pieces of lead screwed on), and repeating the process. The back of the hub will get a bet messy and you will find the line hard to interpret after a while.

Having found the centre, you can interface this with the mounting to the alternator. I mounted the prototype propeller by drilling and tapping two M10 [3/8"] holes in the front of the hub. One was in a hole previously used by a small screw which holds the brakedrum to the hub. The other hole I put exactly opposite. Precision is necessary for correct balance of the propeller. The holes are not flush with the surface of the alternator but I filled the gap with nuts and washers. See figure 25.

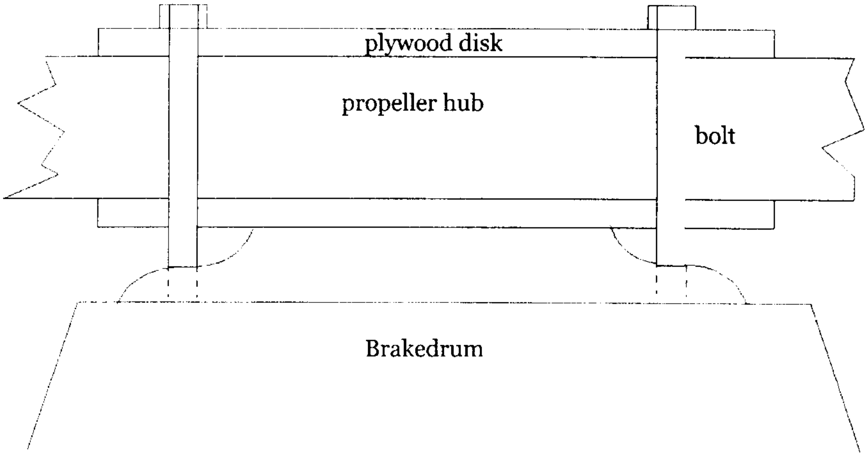


Figure 25

When drilling the two 10mm [3/8"] holes in the propeller hub assembly, use the centre of gravity as the mid-point between holes. This will ensure correct balance.

The studs for securing the half-shaft need to be removed or ground off. I tried drilling them out at one point, but found them very hard indeed. You can seal the front end bearing against entry of moisture, using silicone sealant or mastic. Put a bead of sealant around the hexagonal face where the propeller sits on the alternator before applying the propeller. When the propeller is correctly attached, the tips should follow each other exactly through space, as the blades rotate. If you find that the tips are more than 3mm [1/8"] in front or behind each other, then it will be worth shimming the propeller slightly to correct the tracking.

PUTTING IT ALL TOGETHER

We now have an alternator and a propeller attached to it. It only remains to explain how I mounted it on a pole as a workable wind turbine. The mounting which is described in what follows has the following functions:

1. Holding the alternator up securely on the tower top,
2. Keeping it facing the breeze, and
3. Protecting it from overload when the wind is too strong (the mounting allows the turbine to turn away from the wind).

I built this mounting from scrap steel, using an electric arc welder. It is no doubt possible to achieve a satisfactory result without welding, but it will look awkward, with bolts and pieces sticking out, and it will probably be more work. Provided the important dimensions are the same, then a successful result can be achieved.

My first step was to cut through the axle tube with a hacksaw. I recommend the use of *new* Sandvik (or similar high quality) hacksaw blades, and this will be found to take only ten minutes or so work. If you are going to bolt it together, you may wish to leave the bracket on the axle tube, which took the leaf spring suspension. I cut through closer to the wheel end (in fact about 30mm [2.5"] from the back of the brake back-plate flange). To connect the alternator to the mounting, I welded four pieces of M10 [3/8"] stud to the axle tube, such that they project beyond it thus:

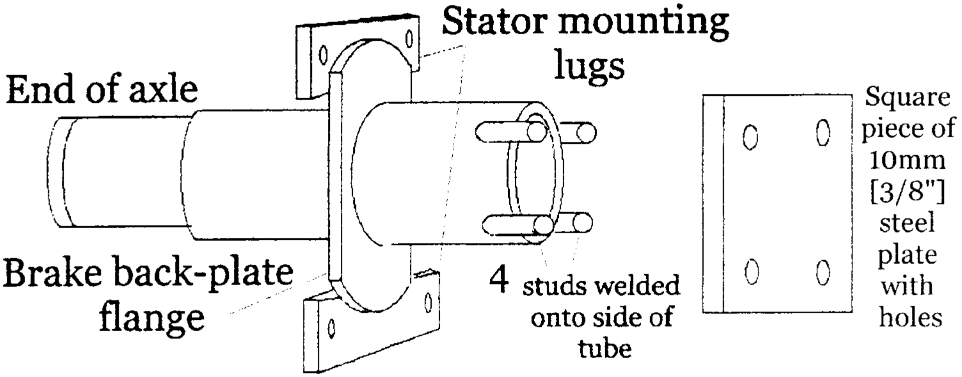


Figure 26

Actually, to be honest, before I welded them I found a piece of square 10mm [3/8"] plate with four holes in exactly the right places, and I used these holes to support the studs while welding. Lovely coincidences like this happen sometimes, but I expect you will need to drill your own holes in a piece of plate or piece(s) of heavy steel angle. Or you could simply weld the tube itself onto the mounting.

The tower is a piece of 1.5 inch nominal bore water pipe (48.3mm [1 29/32"] overall diameter). This is the standard size for scaffold tubing, and although it is rather smaller than Marlec use for their wind turbines, it is strong enough, as I have used it for years on machines this size. It does need to be well guyed (or otherwise supported) at a point just below the propeller tips, so as to be stiff enough.

The bearing which supports the wind turbine and allows it to rotate and face the wind is simple in the extreme. I have used car front wheel bearings, which are very good, but lots of hassle. They tend to corrode up anyway unless you do a very good job of stopping the rain from running in. For this job, I just used a piece of 2 inch nominal bore (60.3mm [2 3/8"] outer diameter) steel water pipe, which can be a fairly neat fit over the smaller pipe. I cut a 250mm [10"] length of the 2" nominal bore pipe, and welded a small piece of plate over the end. I drilled a 12mm [7/16"] hole in the centre of the plate, for the flexible cable from the windmill to the ground (it goes down through the entire supporting tube, and out through another hole drilled near the base). When well greased, this slips quite nicely on the top of the smaller tube. Both tube ends have to be cut accurately square.

The piece of square plate to which the alternator bolts is in turn attached to this 2" nominal bore steel pipe, at around the mid-point. It is set up such that the face of the plate is approximately tangential to the tube, and the centre of the alternator is 90mm [3 3/8"] away from the centre line of the tower. These dimensions are important, and are shown in figure 27:

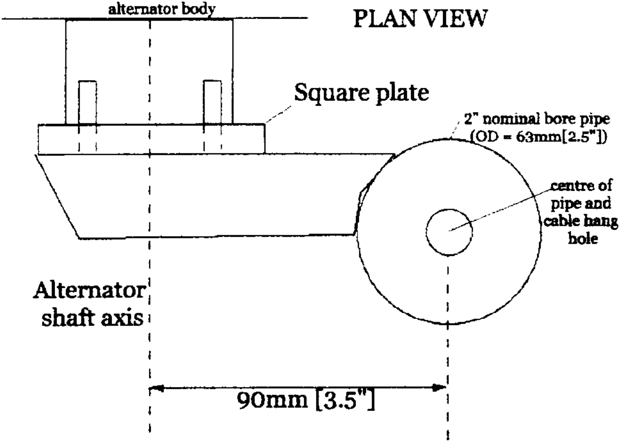

alternator body
PLAN VIEW
Square plate
2" nominal bore pipe (OD = 63mm[2.5"])
centre of pipe and cable hang hole
Alternator shaft axis
90mm [3.5"]

Figure 27

The square plate is connected to the pipe by three pieces of steel about 100 x 25 x 10mm [4" x 1" x 3/8"] in size, running horizontally. Care must be taken so they do not interfere with the operation of the spanner [wrench] which you use to secure the nuts on the ends of the alternator mounting studs. Figure 28 shows what they look like from behind.

The alternator axis should be about 90mm away from the centre axis of the tower tube, so that wind pressure on the propeller will try to turn it away from the wind. If it is less, then this action will not be sufficiently positive. If it is more than 90mm [3 3/8"] then you will need a bigger tail.

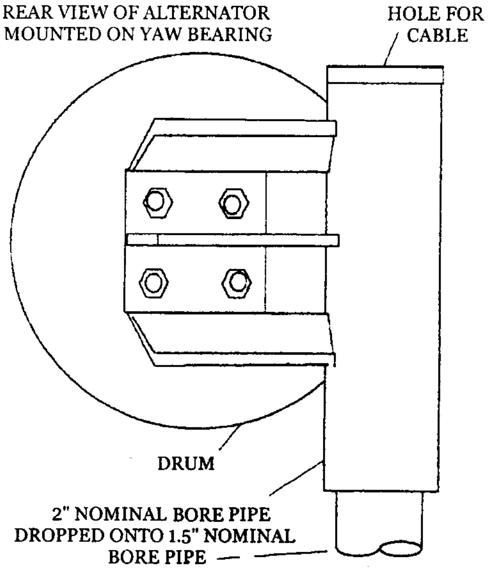


Figure 28

Now we have a windmill which is supported and can rotate to face the wind. We need a tail to make it face the wind. We also need to allow it to face away when the wind gets too strong. This will prevent over speed, with consequent erosion damage to the blades, overheating of the alternator, and vibration fatigue of the whole structure.

The tail must be designed to hold the windmill into the wind until the wind pressure exceeds a certain limit. After that, the tail must yield, allowing the windmill to turn away from the wind. The action needs to be proportional, so that we continue to generate power, but do not expose the windmill to undue stress. Figure 29 shows what is intended.

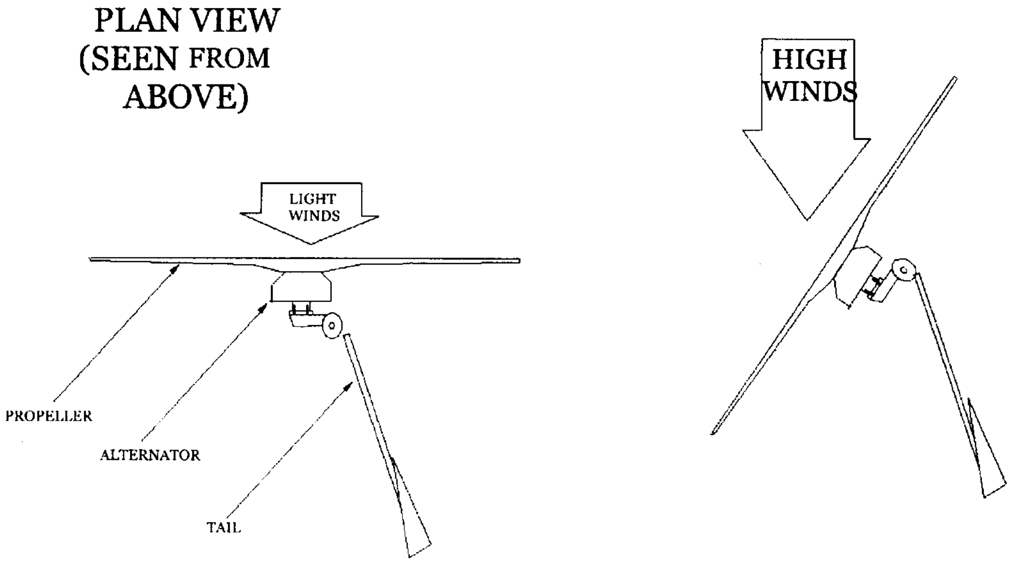


Figure 29

I have a great deal of experience in the design of these tails, and the tail on this windmill, while it is not the absolutely optimal system for best energy production in all wind speeds, is simple and reliable, and will keep the machine working without falling apart.

The tail is a piece of plywood (aluminum sheet always fatigues) bolted onto a steel boom. I used a triangle of plywood, but the shape is not very critical provided it is large enough: at least 0.25 square meters (2.5 square feet). The overall length of the tail is 1250mm [just over 4 feet]. Another important feature of the tail is its *moment of weight.* This is the combined weight of the tail and boom, multiplied by the distance from its centre of ravity to the root where it attaches to the windmill.. In this case, the weight was 4.4 kg [9.7 pounds], and the distance was 0.6m [2'], giving a moment of weight of 2.6 kg-m [19 foot-pounds]. (Engineers use a different unit of force, the Newton, but kg-m will do us fine.) I suggest you use the same moment of weight, plus or minus 10%. However, please recall that I increased the moment of weight in 1994 to 3.6 kg-m [26 foot-pounds], as mentioned in the section HOW I DID IT.

The moment of weight is what makes the tail hard to hold up from the root. We can use this moment of weight to control the whole windmill, by mounting the tail on an inclined hinge, so that it falls down into place, but can be lifted away by strong winds to allow the windmill to yaw out of the wind.

Here is how you construct the included hinge. Once again, a simple bearing is used: a piece of 1-1/4 inch nominal bore water pipe (outer diameter 42.4mm [1 21/32"]) fits neatly over a piece of 1 inch nominal bore pipe [(outer diameter 33.7mm [1 11/32"]). We start by attaching the smaller pipe (1 inch nominal bore) to the main windmill mount at the correct angle, and this is hard to describe.

Cut a piece of one inch pipe about 150mm [6"] long. It is to be welded to the small plate on the top of the 2 inch pipe used as a main bearing for the windmill, such that:

- It does not obstruct the hole for the cable exit.
- It is angled 27 degrees from the vertical.
- View from ABOVE, it makes an angle of 45 degrees to the windmill proper.

See figure 30.

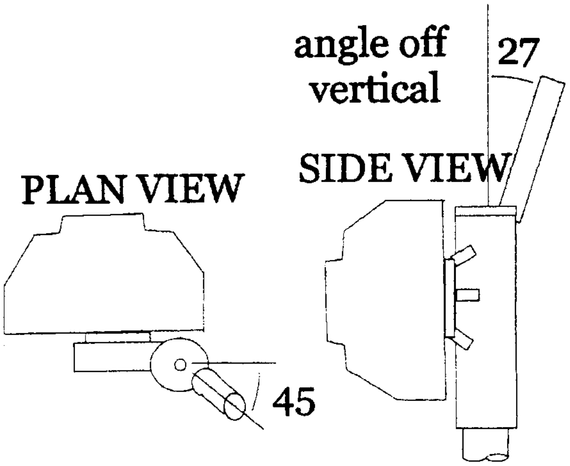


Figure 30

Now we cut a shorter, 125mm [5"] piece of the larger size pipe (1-1/4 inch nominal bore). Weld a small piece of plate across the top so it can be dropped onto the 1 inch pipe just described. We need to limit the range of movement of this outer pipe to about 100 degrees. This is done by welding a flange to the smaller pipe, and cutting a slot in the large pipe, so it can only rotate by that much, as shown in figure 31.

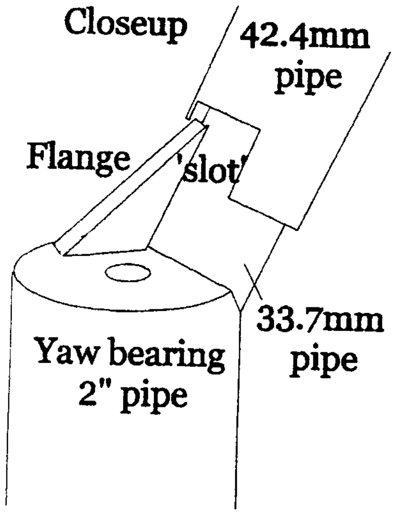


Figure 31

When all this is set up, you can weld the tail boom (could be another piece of the 1 inch pipe: I used a patent shelving support material) onto the larger, outer pipe so that it hangs horizontally outward when the outer pipe is rotated fully anticlockwise.

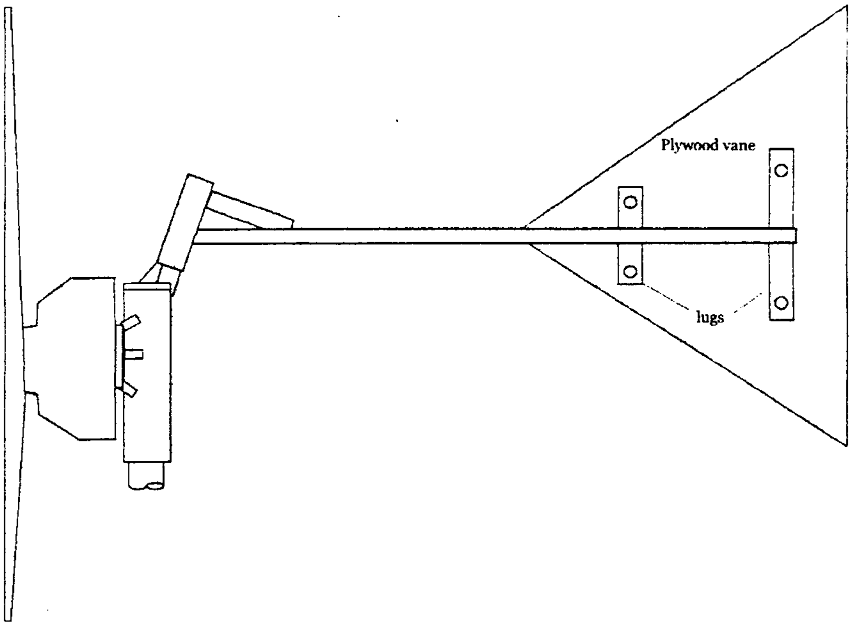


Figure 32

Conditions when you tack weld the tail boom on should be as follows:

- Boom is horizontal.
- Outer pipe is fully anticlockwise rotated
- Tail boom as seen from ABOVE should be almost square to propeller but cocked 10 degrees into the wind as shown in figure 29.

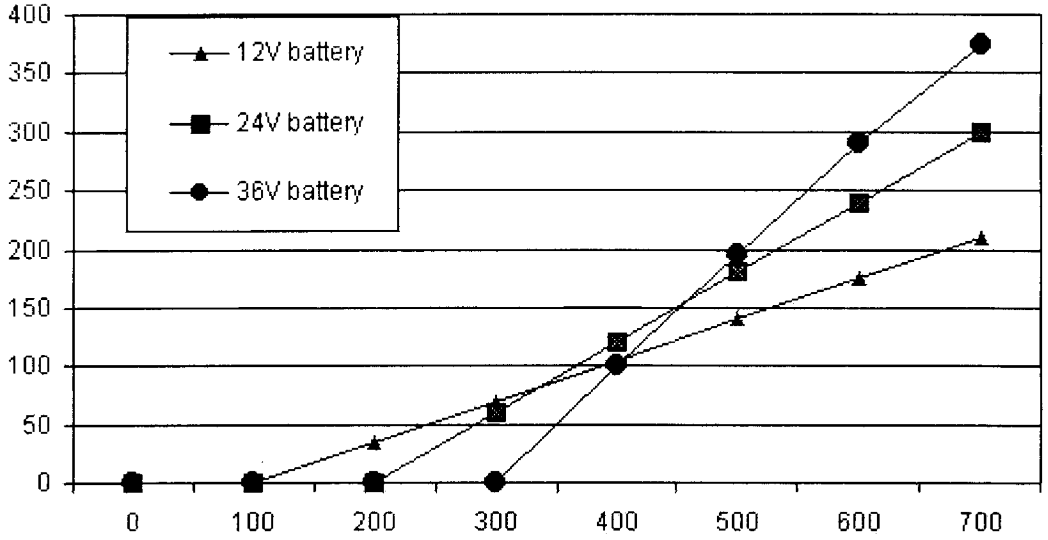
This is a highly stressed point if there is vibration, and good welding is essential at the tail root. Next fix the plywood support brackets (pieces of steel with holes in) such that the ply is neatly vertical on the horizontal boom. When you swing the tail around it should fall back into position under the action of its own weight. Check that it cannot swing as far as to hit the propeller blades, when at the top of its swing.

To increase the output in high winds, add weight to the tail. To make it turn away sooner, make the tail lighter.

When you have finished, paint all the steel work with Hamerite [Rust-oleum] or similar metal paint, and the ply with suitable paint for wood.

I hope that covers everything. If not, please give me a ring, and I shall try to explain some more.

PERFORMANCE CHART



This chart shows the pros and cons of different battery voltages for a given alternator winding. It is approximately based on performance of the star connected, 24 turns per coil winding given in this booklet. External cable voltage drop is ignored.

Connected to a 12 volt battery, the cut in RPM is lower, but the maximum power output is also lower. 24 volt operation does not start until the speed reaches 200 RPM, but after that, the power output soon exceeds the 12 volt performance curve. The higher the battery voltage, the less power you will lose in heating of the stator, too.

You could also change performance by altering the number of turns per coil. Volts increase with turns, so by rewinding with 100 turns (instead of 24), for instance, you could get 100 volts output, with the same wattage as the 24 volt graph above. This might be useful for long cable runs and for powering heaters, but it could also be lethal, so take care!

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U.K. Suppliers

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Enameled copper wire 250g 0.71mm product code YN83E crimp receptacles product code JH82D	Maplin Electronics plc Freepost, PO Box 3, Rayleigh, Essex, SS6 2BR (01702) 554 000
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Carved Wooden Blades	Lake Michigan Wind and Sun (414) 837-7534 email: lmwands@aol.com
Blades, small wind turbine alternators	World Power Technologies (218) 722-1492 www.worldpowertech.com

Canadian Workshop

Courses on building a wind turbine from recycled parts based on the designs in this booklet are given by Mr. Bob Budd, RR#2, Goderich, Ontario Canada. Tel: 519-524-6729 or email to ramdesign@odyssey.on.ca, web site: http://www.windmill.on.ca

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