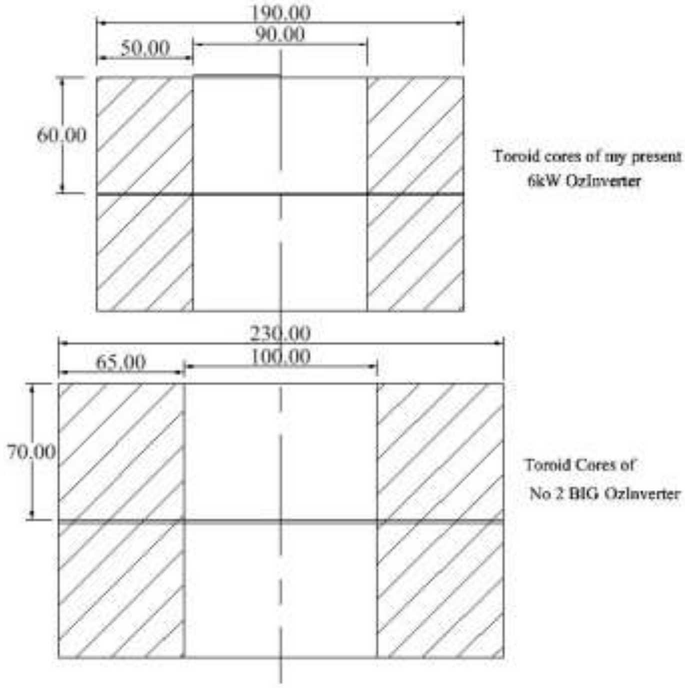
4. Making the Toroid.



The Concept.

Firstly,…. This is a working 'How To' book, so I will not get bogged down with constant technical stuff. Later in the book in the Technical Chapter you will find comments and fantastic information on the toroid from "Warpspeed" (retired toroid Engineer, Australia).

RECYCLING. ……….. For folk around the World who can not obtain New wound toroid cores at the correct size. …….. To save cost old salvage cores can be used. For a good 6kW the outside diameter should be about 200mm, the inside diameter, (the hole) about 100mm and total thickness when epoxied together should be about 120mm. The cores are normally spot welded at the start and finish of the coil. So its possible to unwind internally to get that 100mm diameter hole and then use the core strip to wrap tightly around the outside to build up the Outside diameter. If the old copper windings are about 1.8mm diameter then these can also be re-used, but treat with care when unwinding as the copper work hardens, and micro fractures will appear. Obviously the necessary calculations and examples shown below, may need altering with used/salvage cores, but once you have the correct size of core then you can modify the secondary number of turns using the TEST techniques I show later in this Chapter.

For a new toroid M427 or 27M4 specification, at 0.30mm thick silicone iron strip.

EXAMPLE 1. ………………… My No 1, 6kW OzInverter, 48vdc to 230vac 50HZ, works fine and does everything I wanted. The cores were 2off, 190mm outside diameter x 90mm centre hole and each core was 60mm high. These were stacked together, so the rectangle section through the core was 50mm x 120mm high.

4off /4 in hand, 1.8mm diameter at 118 turns Secondary, and 50mm/2, 14 turns, Primary.

EXAMPLE 2. ………………… My No 2, Big OzInverter, has cores 230mm outside diameter, 100mm diameter centre hole and each at 70mm high, stacked together that gives me a rectangle section of the core 65mm x 140mm high. That's just over 30% more core mass. See above drawing… …….

EXAMPLE 3, ………. **6kW Ozinverter, The optimal size of core,** for a good OzInverter that can run all day at 6kW is … **200mm outside diameter, … 100mm internal diameter,(the hole) …. and at 120mm thick,** about 22kgs**.**

'Oztules' technical explanations. Okay, with those of you with an enquiring mind, here is what is happening in the real world, from real working experiences, ie, empirical evidence. 'Oztules' explains……………………….

"The 8:1 ratio thing is a product of head room and the properties of a sine wave. Our 240vAC is really 340v with .7071duty cycle... to get our 240v rms ac.

So to make 240v AC from a DC source we need to handle the 340v part of the curve as well...... so our DC side needs to be .7071 of the expected AC wave generated in it or for 48v about 48X.7=33v.... so we need at least as low as a 33v primary to get to the peaks needed to make the sine wave....... now with losses in the switch, wiring, sags to cover high power surges etc, we need another 15% safety margin so we are reasonably assured of getting our 240vrms at all times.

So now we can see why we are using about 8:1 for our transformer. We are really winding a 48Vdc primary (30 odd volts AC rms sort of thing) to make 340v peak ac or 240v AC rms. (the rms is the root mean square... which is equivalent to the DC heating value..... so the power in 340v peak ac sine is equal to 240vDC in raw heating power (no power factor)... or 240vac as we call it for the mains. If you rectify and filter... you will measure 340vdc."

"Transformers are only as good as their cooling. That's what defines their power rating really. The little Chinese PowerJack toroid transformers in their own manufactured Inverters can do very impressive start ups, and short runs at very high power, but not for long. They will do the output they claim... but not for long. They limit the big figures to about 12 seconds (so it does not vaporise), peak for much less, and if you read the figures on the unit itself regarding what you can run, it is quite realistic... but way less than the headline figures.

The size of the transformer is a fair indication of it's power handling. I found 2800mmsq of steel is about 1 turn/volt (from memory). We only use bigger steel because we need bigger wire to keep the copper losses down... so we need to be physically bigger. A big core can also help with cooling, and evens out the transient temps as a heat bank.

The core size is not really a case of power: size..... if we had copper of zero ohms per foot of whatever size we had in our hand... then very high power transformers could be had very very small.
The magnetising current is fixed for frequency and voltage for a core..... you cannot saturate it unless you change the hertz or the voltage.... so core size does not dictate power handling.... sounds wrong I know

So what does? *It is the copper loss that causes us to use bigger cores... we need the real estate to use 3X 1.8mm wire and 90mmsq wire of the turns needed to do the job.*
The bigger the core, the less turns you need for the same frequency and voltage.... so for the same winding window we get more copper in there... we can make a bigger window and get more copper in there.... and we can see where this is going.... to get more and bigger wire in there, we need to use more core to get more real estate to play with... and better still .... less turns of it too.... so bigger wins.

If we had super conductor wire, then this would be mute. We could use any core for any voltage and freq (50-60hz etc), as the wire could be thinner than hair, and carry a 1000 amps, so we could have our 2000 turns on a tiny core, and handle huge power.... remember saturation is not from current or over loading... so once the core is magnetised for that voltage and frequency, all extra amp turns involved with the transforming process do not direct their extra amp turns into saturating the core, but rather using their MMF against each other, and inducing current into the other...but not the core... so if you look at the equations for core saturation.... no mention of current... anywhere.

The little Chinese Powerjack, (PJ) toroid's do the job, but their copper loss heats them up too fast to be useful for more than a kw or two, and their sag will be pronounced... so we use a bigger core to allow us to use sensible sized wire to keep the copper loss to a value we can handle heat wise.

Where does this get me???? well core size helps us get to our objective heat wise. If we used silver wire, our core could be smaller, as the R is less for the same power handling.... and losses are I^2R... we need R to be tiny for high currents.... or we burn up.
A big core handles no more power... but allows us to use much more copper to get the losses under control..... then the transformer as a whole handles more power for longer, or if we have enough cooling.... indefinitely.... ie oil cooled, forced air cooled etc.

I guess what I am trying to say is that core size is an indicator, but the copper is where the bulk of loss comes from, particularly in toroids, hysteresis loss is generally small for size, and eddy currents are small, as they use very thin laminate compared to EI ones. They tend to use high grade steel for toroids, as they are very expensive to wind to start with." 'Oztules'

EXAMPLE 2 ……. Calculation for the windings ……….The cores on the BIG OzInverter are 230mm outside diameter, 100mm diameter centre hole and each at 70mm high, stacked together that gives me a rectangle section of the core 65mm x 140mm high.

Oztules comments …… "*Lemme see...... I make that as about 9100mmsq cross section... so ... and here I can only go rule of thumb....9000/2800=3.25 So I figure about 3.25 volts per turn. …………* So the secondary windings will be 240v/3.25 = about 73 turns, and the primary ratio of 8 to 1 will be about 9 turns. So 260v/3.25 is 80 turns secondary, then , 8 to 1 ratio gives us 10 turns for the Primary.

EXAMPLE 2, continued ….. *How that would be worked out mathematically I can only postulate, but the* ***<u>in the real world measurements I have done, it would seem to indicate that roughly 2800mmsq of cross section at 50hz will yield about 1turn/volt.... so 9000mmsq would be about 3.25 volts/turn.</u>***

It is important to wind for a few more volts than we want, our saturation is further away... so say 240 or 260v for a 220v system gives us leeway and lower magnetising current ... from there about 1:8 primary : secondary.. and we have a workable start point.... that's how I tackle it.
Provide you have a crane close handy to hold the thing for you, it will be easy to wind.. big hole and plenty of room. It will be important to map out the wire sectors in advance.. or it will all end upon one side…… ***"We want the primary to be about 30 to 32v for the PJ style processors, and 28 to 30v for the 8010 chips for a nominal 48v system."*** *'Oztules'.*

So for the BIG OzInverter we start at a …. 38kg core, at 230mm OD, 100mm centre hole and 140mm thick/high. 80 turns of 6 off, 1.8mm diameter secondary and 10 turns of 1 off, 75mm/2 for the primary.

TESTING ……….. Big OzInverter toroid test, just using a 2.5mm2 test primary wire. ………… 234vac going in the secondary's 80 turns, after the step up light bulb process … and 29.4vac reading on the Primary. So our initial winding calculations are correct. Remember if in doubt a few more secondary windings will not hurt. See test procedure later in Chapter.

EXAMPLE 1 …….For the 6kW OzInverter, and its 22kg toroid core we have 118 turns on the secondary and 14 turns on the Primary, although having 15 turns would probably be better.
Here the 2 cores are stacked together and is 190mm OD x 121mm high x 90mm internal hole. At 90mm the toroid internal hole is tight for the 50mm/2 cable for your primary and you still want space for a holding clamp bolt, if you use 4 in hand of 1.8mm diameter enamelled copper for the secondary.
So… Example 1… Cores active cross section of 6050mmsq, and using 'Oztules' formula 6050/2800 = about 2.16v per turn.

240v/2.16 = about 111 turns for the secondary and therefore 111/8 = 14 turns for the primary. Allowing for 260v/2.16 = then we get 120 turns. After testing this particular toroid 118 turns on the secondary was adequate, with a 14 turn primary. Remember you are looking for a voltage on the primary of between "28v to 30v for the 8010 chips for a nominal 48v system."

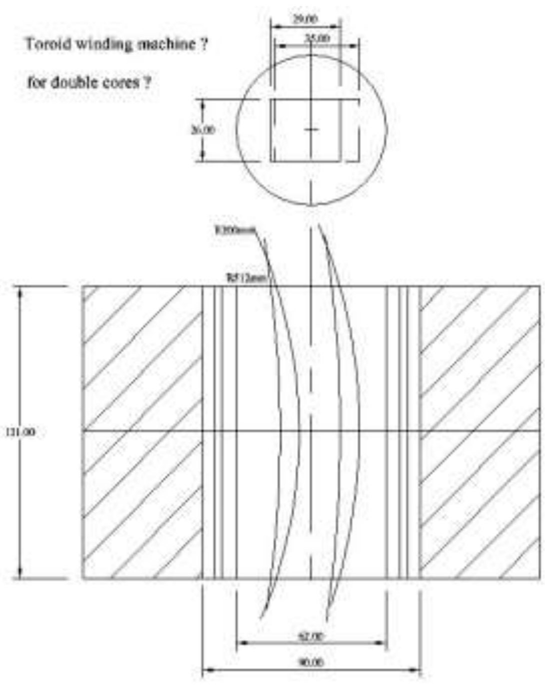
EXAMPLE 3 …….. **6kW OzInverter**, … Core 200 x 100 x 120mm = 6000sq mm = 6000/2800 = 2.14v per turn. 240v/2.14 about 112 turns for the secondary, therefore 112/8 = 14 turns for the primary. As the core was complete to the correct size, I used 120 turns on the secondary and 15 turns on the primary this gives me 29.2 volts. .

Reasons for this design of Toroid. Why don't we just buy a toroid transformer ready-made? Ahh, that's where this toroid design wins hands down,.

1. We double stack the cores, keeps the copper loss down, but increases the core mass so its cooler and can handle more. But, now's here the sting, the core centre is now too small, because of its double stacked height, for a normal commercial toroid manufacturing winding machine to get in. So this design has to be hand wound.

2. After each secondary winding, we Epoxy the winding before putting the next layer of Mylar insulating tape on. It's not too heavy coating, but this stops the windings from vibrating, rubbing together and eventually failing, it also helps with cooling.

3. As this design is hand wound, the Primary small number of turns can be the full size big diameter cable. This also helps significantly with keeping the toroid cool as this winding is open, and air flow can easily circulate around and through the toroid.




Bare toroid cores
for joining together

The bare toroid cores.

Shown here with removable Core inserts, to keep them circular when in transport. These two are to be stacked/joined together.

The cores themselves are made from Grain Oriented Silicon Steel (GOSS/CRGO). The cold rolled grain oriented steel, approx. 0.3mm thick, used in the production of toroid transformer cores consists of 3% silicon-iron alloy, M4.

Making the Toroid, Stacking & Joining the cores. Use a 80 grit flap wheel in a drill to remove the sharp edges on the cores outer and inner 90 degree edges, so the mylar insulation tape and the enamelled copper wire will not be damaged.

Epoxy resin, about 500ml total quantity should do for this toroid. That's Joining the cores, and on each of the secondary windings, and a little extra on the last secondary.


Toroid
Winding machine

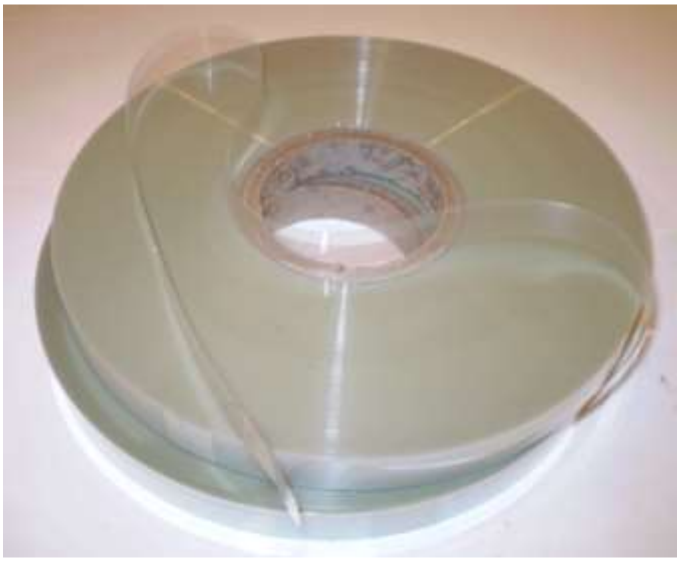

Toroid Heat
treatment Furnace

For these cores I use a thin'ish viscosity epoxy resin. The resin I used took about 24 hours to set solid, other types can set quicker. Temperature can alter the setting/curing process.
I put fiberglass matt strips around the core joints to strengthen the joint, then very lightly coat the cores with the epoxy.

Its best to keep the epoxy minimal, as according to the core manufacturers,… *"Magnetic Degradation Occurs Heat treatment machine when toroid cores are impregnated with varnish or epoxy. Light impregnated varnish +15%, Epoxy coated +40% degradation".*

At present my toroid makes no noise but the ferrite core just gently hums.


The 2 cores joined, but use minumum epoxy resin



Two rolls, 800m, 20mm wide, 55micron, Mylar non adhesive insulation tape.

Insulation winding tape. Mylar tape, or Molinex, Nomex, Non Adhesive, my observations…….

The trick is keeping it tight, and wrapping it right, let it go or drop the bobbin and a birds nest ensues.....

I obtained 20mm wide and 0.055mm thick, or 55micron, from the supplier of my toroid bare cores, the thickness was exactly correct.

The recycled PowerJack toroid I dismantled had super thin stuff, 0.040mm, that very easily broke, but I did managed to salvage most in small runs, I just used the adhesive backed Mylar tape to do the joins.

The Mylar tape I get from the USA......
http://www.ebay.co.uk/itm/181696004499?_trksid=p2060353.m1438.l2649&ssPageName=STRK%3AMEBIDX%3AIT
..... is 0.125mm thick, but i found that it is just too thick, Especially when its not flexible enough to allow the next winding of the secondary to fit down in the gap of the previous winding, especially on the internal centre hole windings. But it does come oval shape and goes down a 62mm diameter hole okay without having to unwind. And it is ideal for the last winding before the Primary goes on.

I half lap the Mylar tape on its self on the exterior of the toroid, and I do 2off complete wraps as a minimum, with the super thin breaking stuff I did 3off wraps, Waste not.

Don't forget the epoxy resin on each secondary winding before you cover it with Mylar tape. But test the secondary first, ***(see test procedure later in this Chapter).*** I like the thin viscosity stuff that I mix and lightly paint on. I have some thin Molinex sheet that I put under the whole toroid to collect any excess resin.

The following evening turn the toroid over, peel off the Molinex sheet, gently remove or roll flat any epoxy protrusions or excess. Then Mylar tape on the hardened, but still soft, epoxy resin coated winding, and then next copper wire winding goes on.

I use a small length of Mylar adhesive tape here its yellow colour, to hold the Mylar wrapping tape in position.

Firstly I wind the mylar tape onto a plastic spool or bobbin, this must fit down the inside hole of the core.

In the left photograph, the bare core is now wrapped with 3 layers of the 55micron thick Mylar insulation tape. The cut out area in the bench/ table is handy as you only need to rotate and move the toroid 5 or 6 times.

Winding the secondary.
For further information on how to wind a toroid, see ….
https://www.fieldlines.com/index.php/topic,148717.0.html

For my 6kW Oz inverter I used 118 turns of 1.8mm diameter enamelled copper wire, and did a total of four for the secondary. We are winding 4 in parallel, or what is called 4 in hand.
For my BigOzInverter I used 80 turns of 1.8mm diameter enamelled copper wire, and did a total of six for the secondary. That's 6 in parallel, 6 in hand.

Firstly cut a disc of card and equally space out your turns of the secondary. See below photos.
On this toroid on the first of the secondary windings, I used the adhesive Mylar yellow tape to give me guide positions where the first secondary winding should fit.

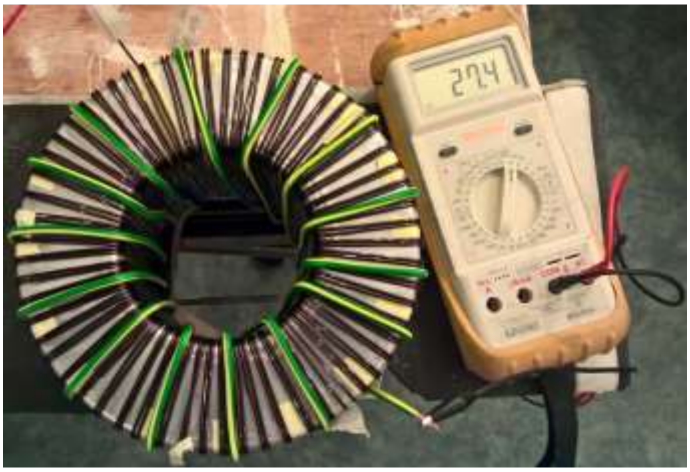
I do like 'Oztules' idea of putting 2 turns close to each other as this leaves a gap, and after Mylar winding, for the next secondary to fit into. So recalculating the spacing is made very simple on subsequent secondary windings.

When winding the toroid core. Keep the copper tight and use your finger to make sure it goes around each corner tightish. That's my battery electric screwdriver and arbour in the photograph; it's the right size, that goes in my small copper wire plastic bobbin. The battery powered screwdriver is very controllable for winding from the Big wire drum.

The enamelled or coated copper wire normally comes on a 200mm diameter, approx., plastic drum. A 5kg drum of 1.8mm diameter coated copper wire was plenty for the 6kW OzInverter.

I use the lock nuts to get a little tension on the drum so the copper winds onto the small plastic bobbin reasonably taught. Those other small wound coils in the photograph bottom right, are for my 3.7m diameter 48vdc, Hugh Piggott design Wind Turbines, which also uses 1.8mm diameter coated copper wire.

Remember …. One turn is when the wire passes through the centre hole.
Also remember that centre hole is a reducing diameter so the bobbin might need turning down each time to fit through.




The two above photographs show a complete solid core of 200mm diameter, a 100mm hole and at 120mm thick. This particular core has 120 turns on the secondary and receiving 240vac. . ***(See testing procedure further in this chapter).*** The first left photo …… shows 14 turns on the primary, and this gives us 27.4vac. The second right photo …… shows the 120 turn secondary with 15 turns on the primary, and giving 29.2vac. So this particular core has 120 turns secondary and 15 turns primary giving us the voltage we require between 28vac and 30vac.

Previously to obtaining the full size cores, I had been using stacked together cores at 200mm diameter, 100mm hole and at 120mm thick, but because there are several cores stacked the test voltage was different and resulted in a 118 turns secondary and a 14 turns primary.
So it is important that you test the secondary winding 118 turns, and add a temporary Primary winding of 14 turns, with some ordinary 10mm/2 single core flex . ***(See testing procedure further in this chapter).*** This will ensure that the secondary and primary winding number of turns is correct for the particular toroid core material. Please remember you are looking for a voltage on the primary of between "28v to 30v for our 8010 chip, for a nominal 48v system."

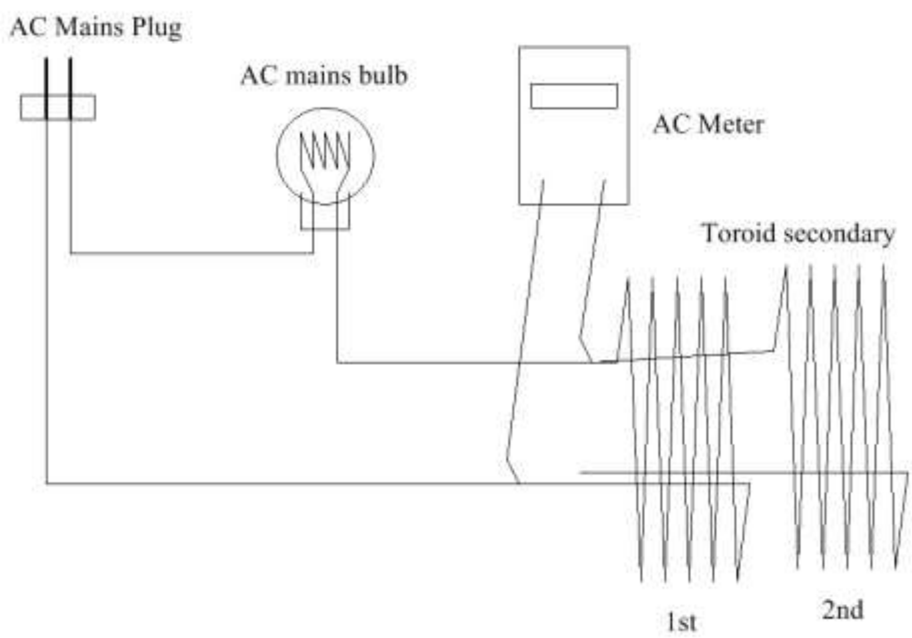
When you are happy with the winding number of turns then remove the temporary primary, and coat each secondary winding with epoxy resin just lightly brushed on. I normally only use about 25ml to 50ml of thinish epoxy lightly painted on each secondary winding. Let it set, then the mylar insulation tape goes on for the next secondary winding, and then repeat with 3 more secondary's repeating the epoxy.

With most resins you can use chalk powder as a thickener, mix it well with the epoxy first before adding the hardener. Try a little test batch with a little epoxy and see how you get on. Chalk also slows down the hardening process. I used about 25 to 50ml of epoxy on each secondary.

Also if you get the small plastic bobbin to unwind as in the photograph you can just roll it around the toroid reasonable easily, but remember to keep the winding taught.

The photograph right ….The second 118 secondary winding going on, between the spacing's of the first 118 turns secondary.

Once you have the second secondary on, then its time to test them so that they are the same, an extra turn or loss of a turn will show up, each of those four secondary's must be the same before we permanently connect them together.



The secondary basic test circuit.

WARNING THIS IS HIGH VOLTAGE

Here I am using a 20 watt 230vac light bulb and fitting.
Test the first secondary winding, switch off the mains leave the first connected as is, but now connect one of the test meter croc clips/connectors to the second wire that is sticking out from your second secondary winding. Reconnect the mains again and because the transformer is working the second will now have an induced circuit, and this should read the same voltage. If not, then remove or add a turn on the winding.

Do this test with each of the four secondary's you are adding, all should read the same voltage.

This photograph on the right shows what the voltage is reading on the multimeter.

Testing each secondary winding.

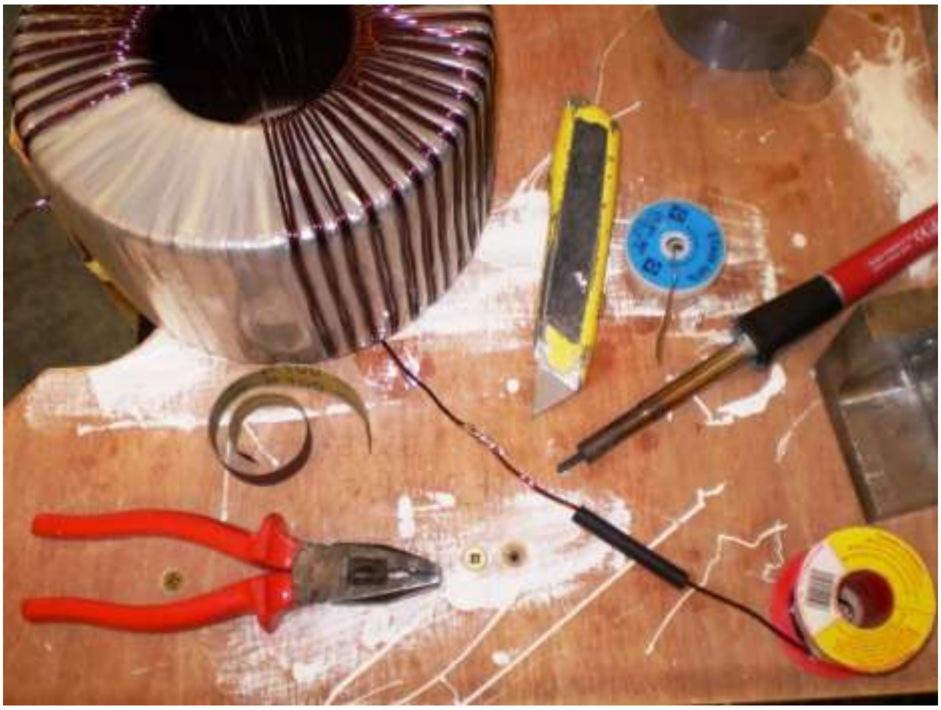
The below photograph shows the Blue cable coming from the mains plug is connected to both starts of the first and second winding of the secondary.

The Red cable in the below photograph is coming from the light bulb and is connected to the finish copper wire of the first secondary winding only.

In the photograph on the right the Red Croc clip of the multimeter is now connected to the finish copper wire of the second winding of the secondary.

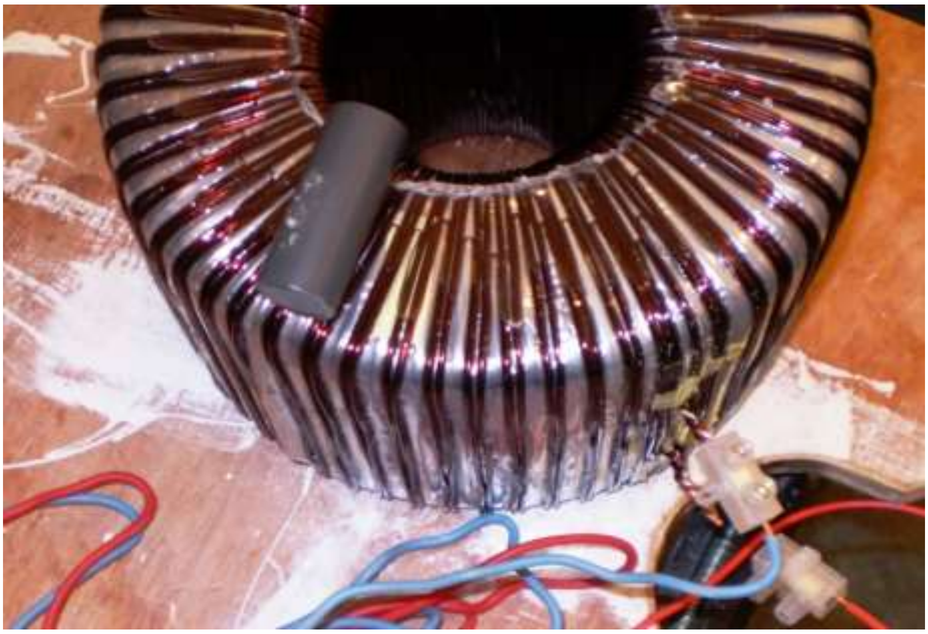
With the light bulb On, The toroid is now working and inducing a AC voltage in the second winding of the secondary. The voltage should therefore be the same.

Winding the secondary, continued..



As the bobbin diameter is reduced you may have to do joints in the secondary windings, here is my method that gives a permanent strong insulated joint.

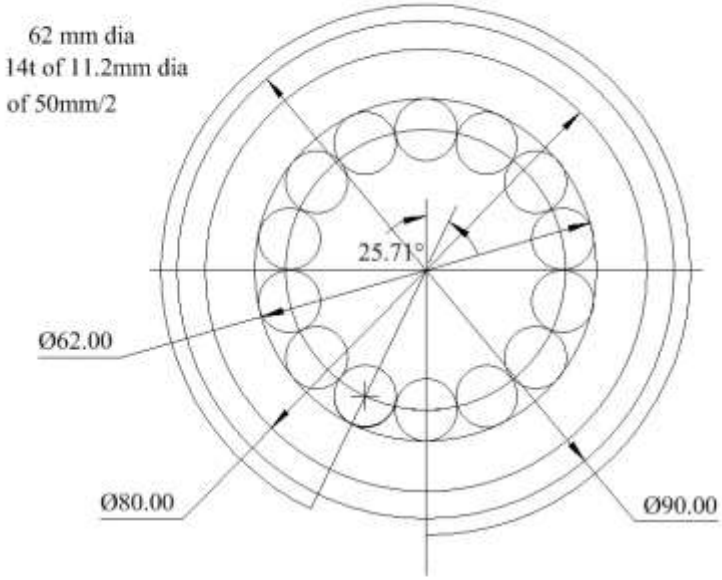
I clean the ends of the copper wire to remove the enamel by using the knife blade, ***(Note some enamel coating is very hard to remove, some its easy)*** , then remove any residual coating and clean with some emery paper. On the new wire I insert a piece of glue lined heat shrink insulation tube , sufficient to cover the joint. I place each wire end alongside each other and twist them, then do a good solder joint so the solder flows.



Allow to cool then slide the glue lined heat shrink tube up and covering the joint, and gently use the heat gun with hot air and the tubing will shrink and the internal glue will melt.

Above Right, here is the fourth secondary winding on and the appropriate epoxy went on the previous evening. Using a nylon roller to run round and push any epoxy flashings into the windings gaps. This photograph also shows the In and Out of all 4 secondary windings temporarily twisted together for testing purposes. Those 4 pieces of copper wire represent each of the four secondary windings, and each has got longer as the toroid diameter increases. These I use for getting the approximate length of wire for each secondary onto the spool/bobbin.

My spools/bobbins are now getting smaller as that centre hole diameter decreases because of the copper wire windings going through the centre hole are filling it.



Right … Here is a card template drawing with an original core hole diameter of only 90mm, to check to see if I can get the 14 turns off 50mm2 cable Primary neatly in the centre hole. As you can see at 90mm hole, the primary is very tight.

The above left photograph shows the first of the two final Mylar wrapping Insulation tape going on, after the final epoxy covering. I use that USA Mylar thick tape as the final Mylar wrap. Just do a quick check with the multimeter set for resistance for any shorts, we do not want shorts.
The 4 secondary windings are now joined in parallel, so each of the four start secondary's are joined together and the ends of the secondary's are joined together, just clean of the enamel coating and bare the ends and twist them together and add a little solder.

Winding the Primary

With this toroid we are using 14 turns of 50mm/2, 11.2mm outside diameter, 6m long, insulated stiff, copper wire. This type of cable is generally used as a hook up cable within trunking etc. It's the stranded stiff copper wire as it will bend and take a set around the toroid.

My trusty work bench is now attached with clamps to a car trailer.

I start at half the cable length, for this OzInverter it was 6 meters long but 6.5m would have given me a little more room. If it was 7 meters, then I could have another turn to 15. But 14 is still okay.

I use wood wedges and shaped wood blocks to keep the inside tight. But care must be taken to avoid damaging the Mylar and the secondary winding, and the primary cable insulation.

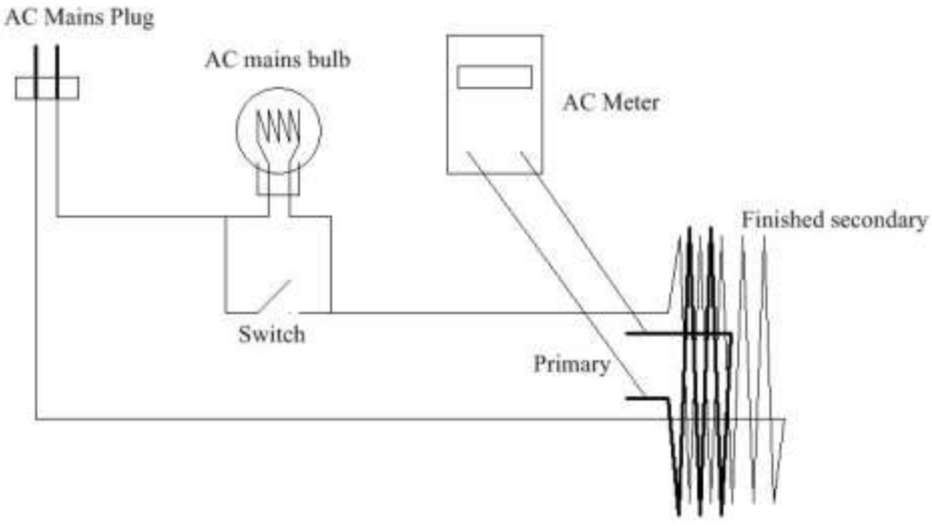
Using each end to pass through the centre and then pull tight on every corner, gently tapping with a wooden mallet so each turn stays in place. I use sash cramps to keep each new turn in place then start the next.

It’s a bit like wrestling with a rugby team. For this toroid, 14 turns of Primary it is.

Here I use copper solder sleeve connectors and glue lined heat shrink on the 50mm/2 cable, as I got the half way start point slightly out so I added/joined an extra turn.
Remember, a turn is when the cable passes through the centre hole.

Testing the Toroid Primary.

We are putting 230vac into the secondary and this will give us an AC reading on the primary, what we are aiming for is about 30vac. But if you just connect the secondary to the mains ac, the toroid has a huge inrush and this will blow the fuses on your mains ac supply.



Simple circuit for testing the Primary Output.

WARNING THIS IS HIGH VOLTAGE
Start the secondary windings using the already mentioned light bulb method.

Once the toroid is working, short the bulb out by closing the switch in the above diagram.

The secondary is now taking the full AC voltage, 236vac as shown in the below left photograph.

Now connect the multimeter AC to test the primary winding. What we are looking for is around 30vac, here on this 6kW toroid build we have 28vac. 28vac is acceptable as this allows, as Oztules says, "One more turn," (the primary), "would be better, but it will be fine as it is.... you will do better with flat batteries .. you have more head room."

The two photographs below, show the 8kW BigOzInverter toroid under testing, but here it has a temporary primary cable/wire. The 8kW BigOzInverter has a secondary of 80 turns and a primary of 10 turns.
Remember we want the primary to read between 28vac and 30vac, and the below photo shows 29.4vac, that's good.