

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.

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. 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.

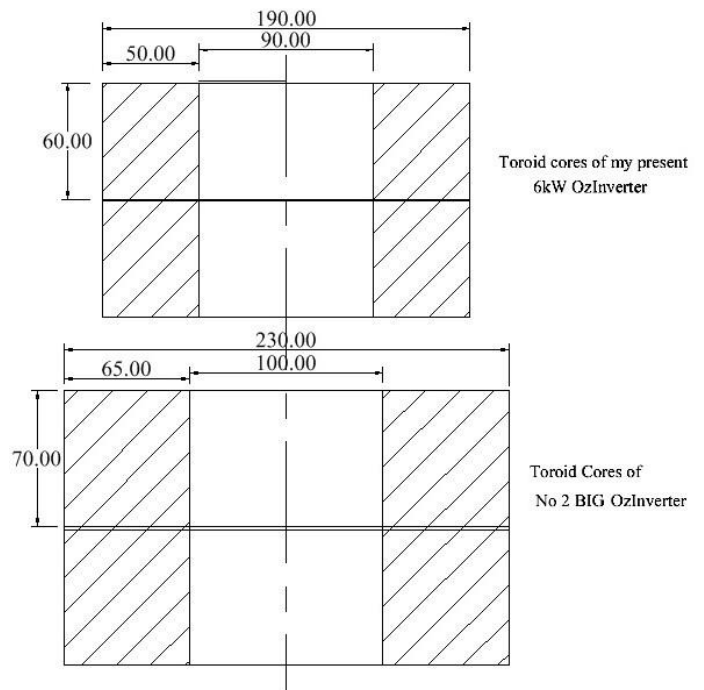
EXAMPLE 2. My No 2, OzInverter, has cores 230mm outside diameter, 100mm diameter centre hole and each at 70mm high, stacked together that gives me a rectangle section of the core 65mm x 140mm high. That's just over 30% more core mass. See above drawing... ..

'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 windingsThe 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 **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.**

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 1For 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.

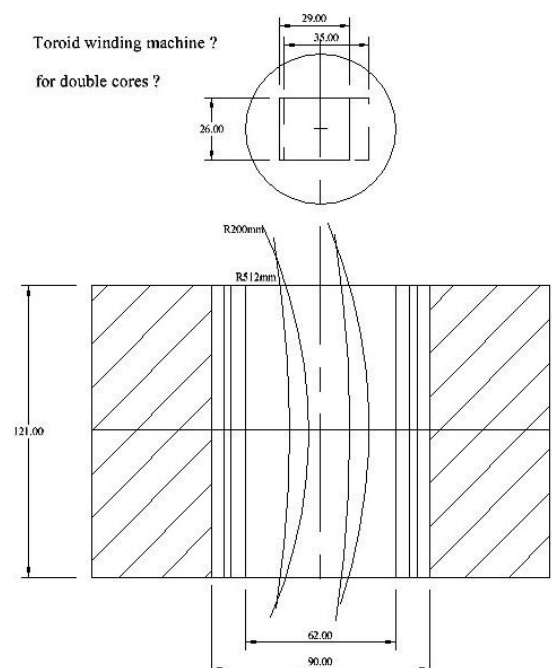
So... Example 1... Cores active cross section of 6050mmsq, and using 'Oztules' formula $6050/2800 =$ about 2.16v per turn.

$240v/2.16 =$ 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 6kW OzInverter, ... Core $200 \times 100 \times 120\text{mm} = 6000\text{sq mm} = 6000/2800 = 2.14\text{v per turn}$. $240v/2.14$ about 112 turns for the secondary, therefore $112/8 = 14$ turns for the primary. Again 118 turns on the secondary will be okay.

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,

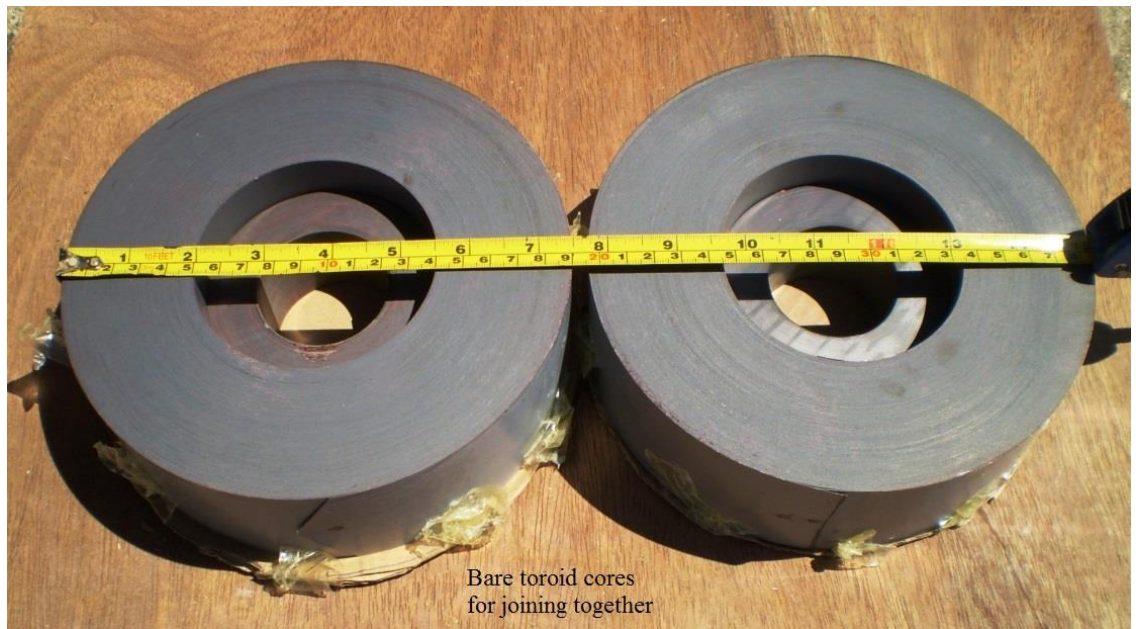
1. We double stack the cores, keeps the copper loss down, but increases the core mass so its cooler and can handle more. But, now's here the sting, the core centre is now too small, because of its double stacked height, for a normal commercial toroid manufacturing winding machine to get in. So this design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



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



Bare toroid cores for joining together

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



Toroid Winding machine



Toroid Heat treatment Furnace

windings, and a little extra on the last secondary. 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.



Joining /stacking 2 cores with glass woven matt and Epoxy resin



The 2 cores joined, but use mininum epoxy resin