

## Odd Transformer Notes

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Feb 2000

Jan 29, 2000

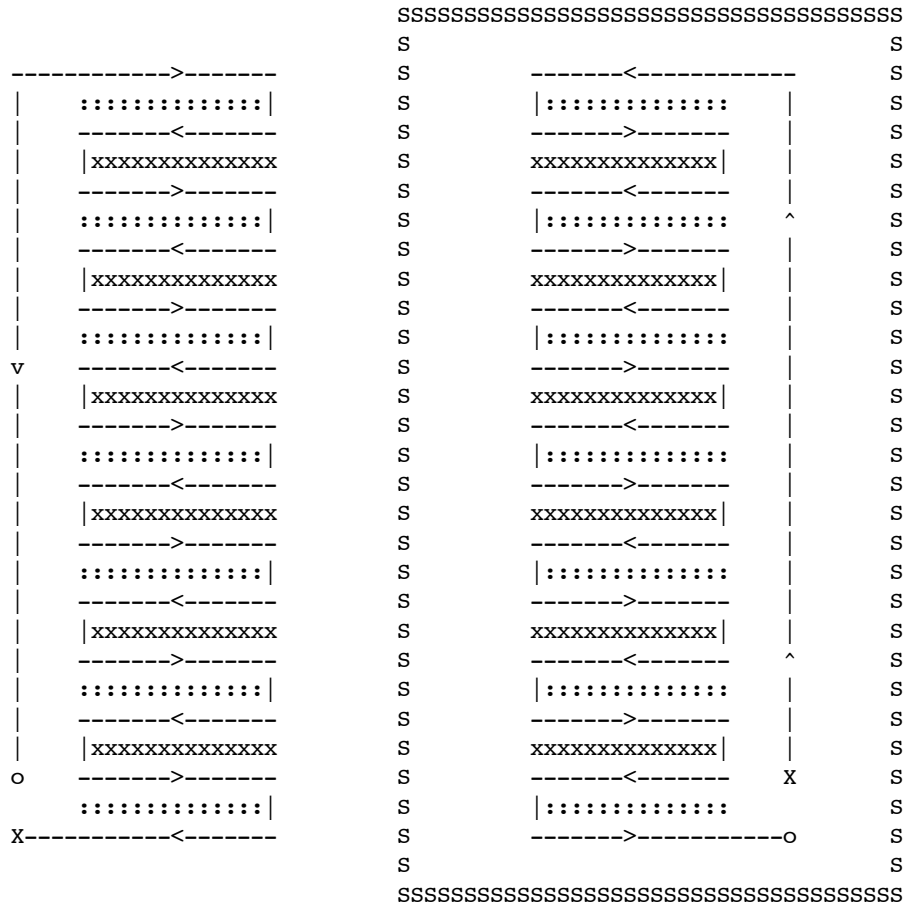
I'm going to build an odd transformer like that shown in Fig. 1 below, using 6 steel washers, 5" outer diameter, as shown. The steel washers make for poor transformer cores so it should handle only a few watts in the secondary, even if the primary windings were wrapped completely around the steel washers in the conventional manner. This transformer design is odd or unusual because the primary winding has zero turns around the steel washers used as core material. The field induced in the steel is all fringe field. The primary winding should therefore (unfortunately) have zero magneto motive force (mmf) and thus no coupling to the secondary, because  $n \cdot i = 0$ . However, the wide exposure of the fringe field of the primary coil to the washer should provide a strong magnetizing H field in the steel washers, thus producing a strong maximum field intensity B in each of the 6 cores. This creates the seemingly paradoxical situation that the odd transformer has zero primary turns, yet creates a strong flux in the core material.

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HIGH CURRENT SECONDARY?



- ::: - Insulating wood washers used as spacers
- xxx - Flat wide steel washers, each used as a core
- | - Copper windings
- SSS - Secondary "winding" - a straight copper conductor well insulated from cores and primaries
- X - Current into page
- o - Current out of page

Fig. 1 - Cross section of odd transformer

One possible resolution of this seeming paradox is that the zero (or nearly zero) mmf of the primary is quickly countered by any back flux produced by any

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current which is induced in the secondary, thus conserving energy. Therefore strong field intensity would only exist in the core material when the secondary is not in a closed circuit. The (likely) net effect is a weakly coupled primary and secondary. It is thus of interest to add a second secondary coil to the transformer to be used as a high impedance voltage sensing coil which can sense, by the voltage induced in it, the rate of flux change occurring in the cores when the main secondary coil forms either an open or closed circuit.

I figure that, just to get some experience with this hopefully novel situation, it will be convenient to do the wrappings in #12 wire, and drive the primary windings at about 10 amps. Much larger currents are feasible on a momentary basis, but the transformer should be able to handle 10 amps on a continuous basis unless the steel core material cannot be cooled properly. Unfortunately, due to the poor core material quality, most all the energy input will go to heat in the core material. I expect, based on experience gained testing the steel washers as cores with conventional windings, that the required primary voltage will be about 12 volts. It may be less due to the fact the odd primary geometry should have a low inductance compared to a conventional winding, due to having zero turns about the core, but this remains to be seen. I figure to get about 56 "turns" in the primary winding, as this fits through the 2.5" steel core holes in a single layer.

The 56 primary windings in this case will all be in series as a matter of convenience. However, they could be driven all in parallel to obtain a low impedance primary. Further, each winding as shown in Fig. 1 is in series between each of the cores. This could also be changed to make each (partial) turn about each of the 6 cores in parallel. In such a configuration the primary could be driven at very high  $dI/dt$  rates, thus at high frequencies, and with a very low primary/secondary turns ratio. This low impedance configuration, especially when used in conjunction with ferrite cores, might be useful for placing large high voltage pulses in the secondary.

Jan 31, 2000

The principle reason for interest in the Fig. 1 configuration is that, provided the wood ":::::..." is exchanged for the steel "xxxx...", and vice versa, the steel cores are then all within the primary current loops, and thus the transformer is normal. If the transformer were very long (lots of cores), and the secondary loop very wide, I don't think there would be any difference in the degree of magnetization of the most central steel washers in the stack, be they on the inside or outside of the coil. In other words, the cores should not see any difference in their magnetization depending on whether they are inside or outside the primary, since the field doing the magnetization is principally a fringe field and not the coil field.

It seems paradoxical that, as the size of such a device increases, especially the minor radius, i.e. the core diameter, the coupling of the secondary to the

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core appears to decrease, while the coupling of the primary to the core remains constant. It appears the coupling of the primary to the secondary is not equal to the coupling of the secondary to the primary - but that may just be due to my confusion.

Feb 4, 2000

The odd transformer was completed with 6 steel cores, 56 primary turns made of #12 wire, and 28 turns of #10 secondary wire (I could only get 28 turns through the 2" plastic core tube.) In addition, a 30 turn voltage sensing secondary made of about #24 wire was included.

The primary was made of 56 pieces of 33" long #12 wire joined together by twisting to make a 154' long primary. The secondary was made of 2 pieces of #10 wire, each 24.5' long, and having 14 turns of 21" #10 wire. The inductance of the primary was measured by meter at 0.83 mH, as compared to a normal transformer made with a single steel washer core, which measured 0.22 mH for 53 turns.

A 0.68 ohm 25 W resistor was placed in the secondary circuit in order to measure secondary current. The results are summarized in the following table:

	Secondary circuit closed			Secondary circuit open		
	-----			-----		
	Amps	Vrms	Vpk-pk	Amps	Vrms	Vpk-pk
Primary	9.96	2.59	7.80	9.98	2.59	7.8
Secondary	0.153*	0.071*	0.216*	0.00	0.139	0.424
Sense	--	0.153	0.464	--	0.162	0.488
Resistor	0.153*	0.104	0.320	0.00	0.00	0.00

\* - indicates calculated value

Sense at (0.153 V) for 30 turns is 0.00510 V/turn, which for 28 turns gives 0.143 V for the secondary.

$(0.104 \text{ V}) / (0.68 \text{ ohm}) = 0.153 \text{ A secondary.}$

$(0.153 \text{ A}) * (0.143 \text{ V}) = 0.0219 \text{ W secondary.}$

$(9.96 \text{ A}) * (2.59 \text{ V}) = 25.796 \text{ W input to primary when secondary closed.}$

$(9.98 \text{ A}) * (2.59 \text{ V}) = 25.848 \text{ W input to primary when secondary open??}$

$\text{Coupling factor} = (0.0219 \text{ W out}) / (25.8 \text{ W in}) = 0.000849$

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### CONCLUSION

The lack of coupling is remarkable. This low level of coupling might even be attributed primarily to the air core coupling of the primary to the secondary. This seems to bear out the notion that nearly all the flux is indeed included inside the toroidal primary coil, and excluded from the core material, or at least self-nullifying in the vicinity of the steel core material, which is topologically outside the primary coil surface. I would have expected the fringe field to be strong in the vicinity of the steel core material due to the strong surface distortion there, but apparently not.

An alternative interpretation might be that there is zero mmf, due to the total turns about each steel core being zero. However, this interpretation doesn't wash because the sense coil voltage does not vary much when the secondary coil is opened. This means that  $d\phi/dt$  does not change much, thus the core flux does not increase much even when there is no load on the secondary to reverse or negate the flux.

The only unusual thing noted in the experiment was that the primary current actually increased very very slightly when the secondary was opened. It was not a significant amount, and the current was gradually changing as the core warmed up, but the current increase in the primary upon opening the secondary was very repeatable.

It is notable that the small voltage rms values, computed by TEK TDS220 scope, are not very accurate. Comparing the secondary volts/turn to the sense coil volts/turn when the secondary is open shows a roughly 10 percent discrepancy, which should be a rough estimate of error for the low voltage values. This degree of accuracy is plenty sufficient to support the conclusion, namely that there is almost no electrical power output compared to power input.

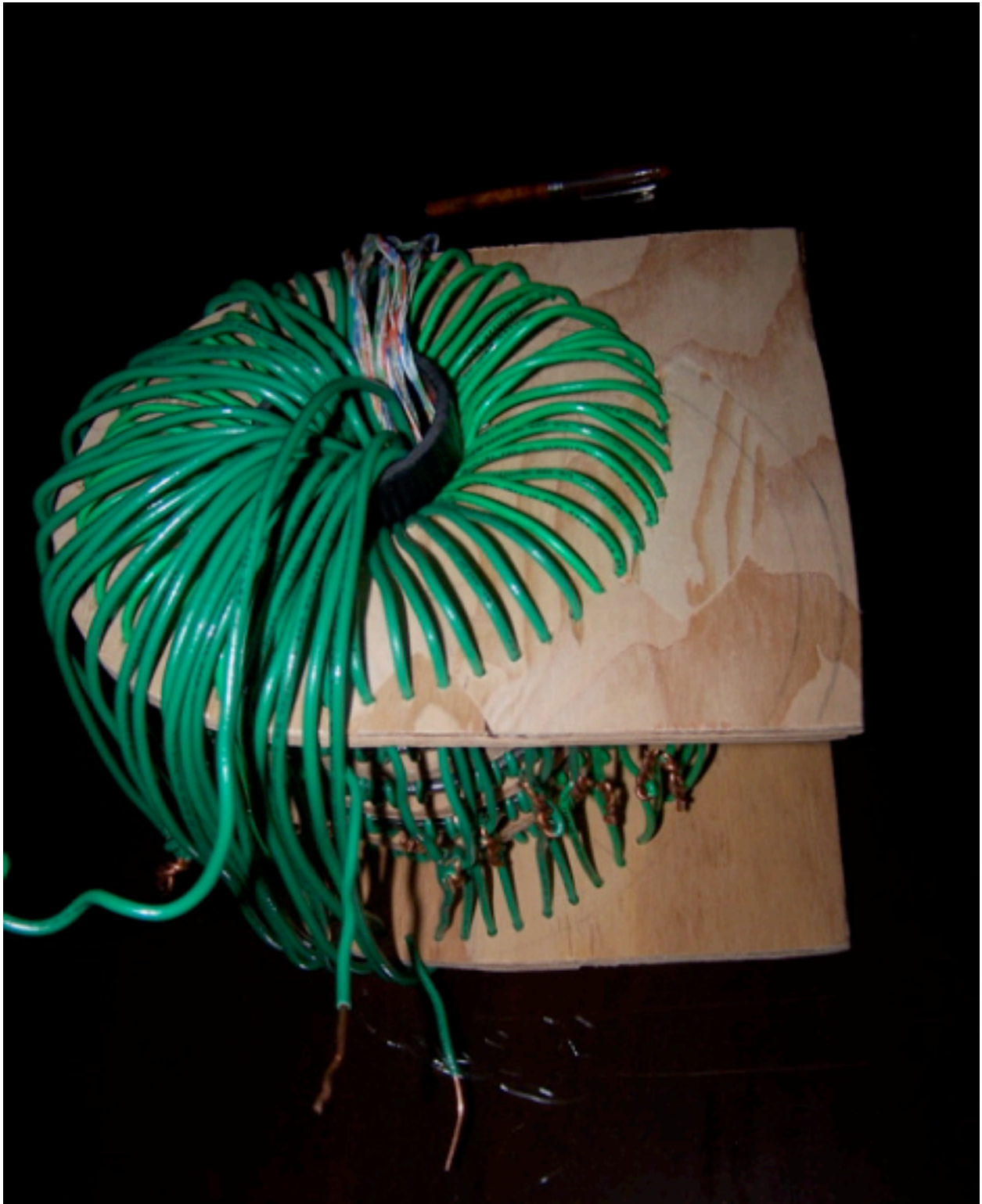
### PHOTOS

Photo 1 - Front and Side Views

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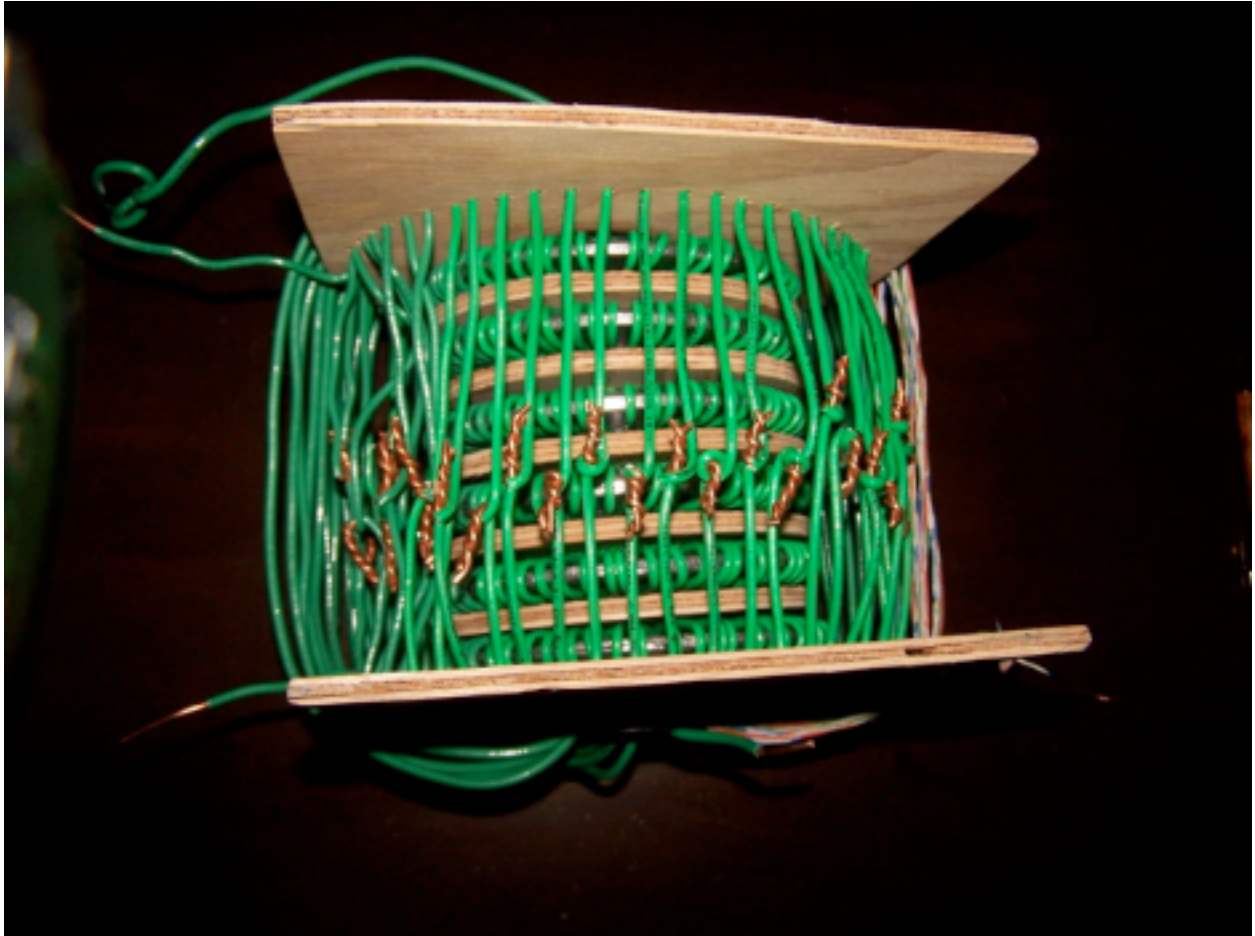


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Photo 2 - Bottom View



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Photo 3 - Top View

