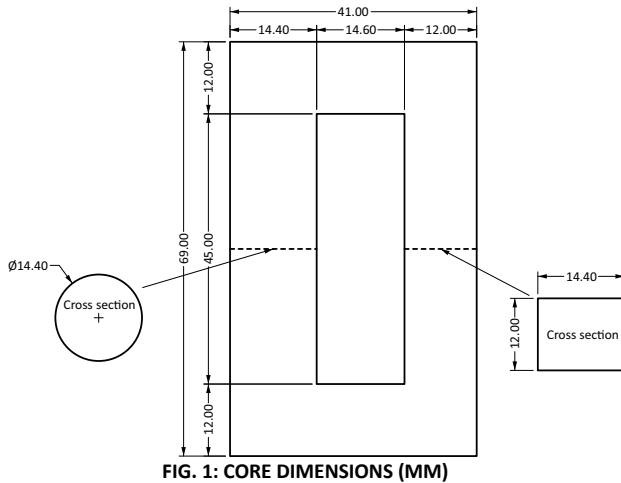


MEASUREMENTS OF INDUCTOR PROPERTIES VS. NUMBER OF TURNS AND AIR GAP

Lindsay Wilson 20/07/12

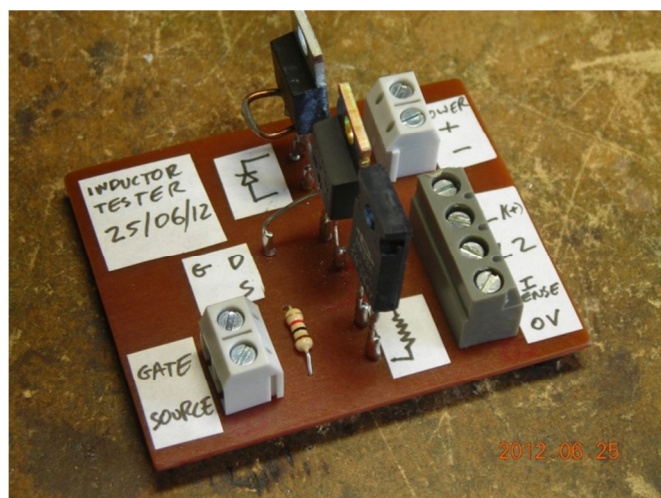
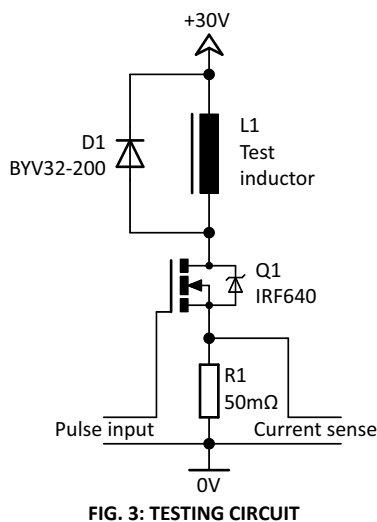
INTRODUCTION – CORE USED AND MEASUREMENT METHOD

The dimensions of the ferrite core are shown in Fig. 1 and a photo in Fig. 2. The core is from a standard TV flyback and was originally gapped by about 0.25mm.



A coil was wound on a 15.7mm diameter former using 1.2mm diameter wire. The coil was placed centrally over the join between the core halves. Inductance and saturation current were measured by applying a constant voltage pulse to the coil and observing the increasing current waveform with a sense resistor.

Fig. 3 and Fig. 4 show the circuit used to test the inductor.



For an excellent reference on inductor and core construction, including the effect of gapping, please see:

<http://info.ee.surrey.ac.uk/Workshop/advice/coils/gap/index.html>

INDUCTANCE AND INDUCTANCE FACTOR (A_L) VS. TURNS

The inductance was measured with different numbers of turns on the core. This was done for both an ungapped core and a gap of 0.06mm. The inductance is shown in Fig. 5. The *inductance factor*, A_L , measured in nH, is calculated from the inductance & number of turns and is shown in Fig. 6. The inductance factor is used in the equation $L = A_L * N^2$ to calculate the inductance from the number of turns.

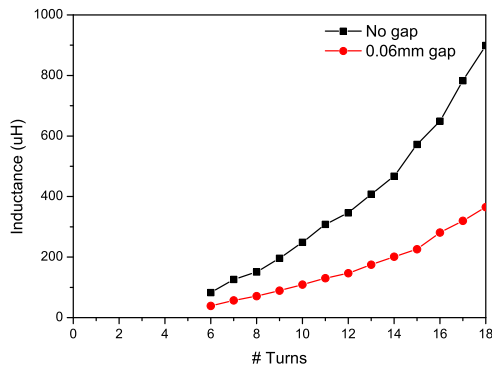


FIG. 5: INDUCTANCE VS. TURNS

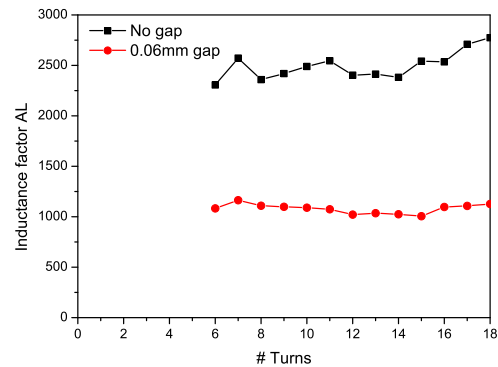


FIG. 6: INDUCTANCE FACTOR VS. TURNS

Unsurprisingly, the inductance shows a parabolic relationship to the number of turns, since the calculated value of the inductance factor is reasonably independent of the turns. The inductance is lower with a gapped core - A_L is around 2500nH turns⁻² for an ungapped core, and around 1000nH turns⁻² for a 0.06mm gap.

SATURATION CURRENT AND AMPERE-TURNS VS. TURNS

Fig. 7 shows the saturation current vs. turns. As the number of turns is *decreased*, the saturation current *increases*, since it takes a higher current to produce the same field strength inside the core. Additionally, a gapped core results in a much higher saturation current – nearly 3x, with only a 0.06mm gap. If we plot the *ampere-turns* required for saturation (obtained by simply multiplying saturation current by the number of turns), Fig. 8, we see that it is relatively independent of the turns – around 20 for an ungapped core, and around 60 for a 0.06mm gap.

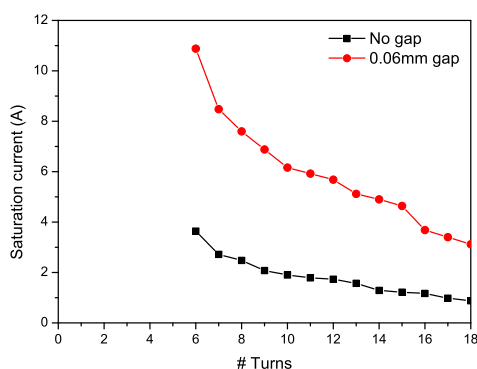


FIG. 7: SATURATION CURRENT VS. TURNS

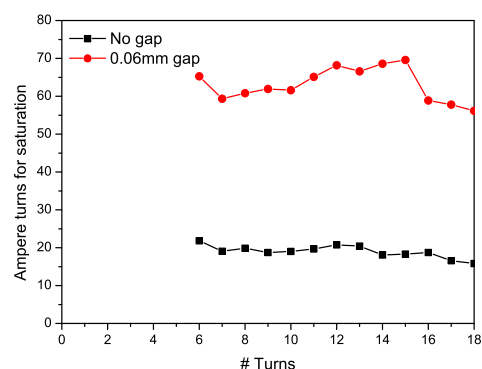


FIG. 8: SATURATION AMPERE-TURNS VS. TURNS

This is interesting – for a particular *core* configuration, it is the *ampere-turns* which determines when the core saturates. For example, if we had 100 turns on an ungapped core, the saturation current would be 20/100=0.2A.

MAXIMUM STORED ENERGY VS. TURNS

Fig. 9 shows how the maximum stored energy varies with turns. This is calculated from $E = \frac{1}{2} * L * I_{SAT}^2$. Ignoring the slight variation, which is due to uncertainty in determining the exact saturation current, the maximum stored energy remains constant, regardless of turns. In addition, the energy is *higher* with a gapped core – significantly higher, increasing from 0.5mJ to 2mJ with only a 0.06mm gap. This is because, although the inductance decreases with an air gap (in this example, by about 2.5x, see Fig. 6), the saturation current increases by about 3x, and since the energy is proportional to the *square* of the current, this outweighs the effect of a smaller inductance.

This is the second interesting point – the energy storage limit *does not depend* on the number of turns, but *only* on the core and gap configuration. Which makes some sense, because, after all, the energy is being stored in the core and air gap.

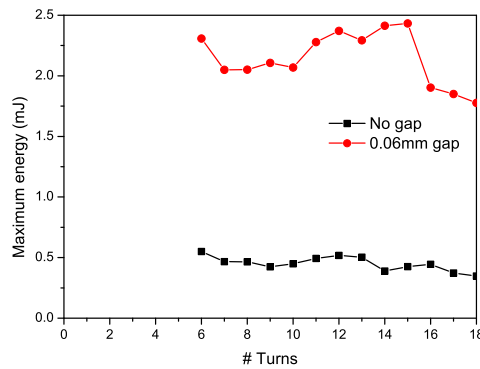


FIG. 9: MAXIMUM STORED ENERGY VS. TURNS

INDUCTANCE AND INDUCTANCE FACTOR (AL) VS GAP

Having seen the effect of the number of turns on various parameters, we now look at the effect of the air gap. In all the following graphs, the number of turns was constant at 18.5.

Fig. 10 and Fig. 11 show the inductance and inductance factor vs. air gap. As expected, both decrease sharply as the gap is increased (sort of exponentially), but the decrease slows above about 0.1mm.

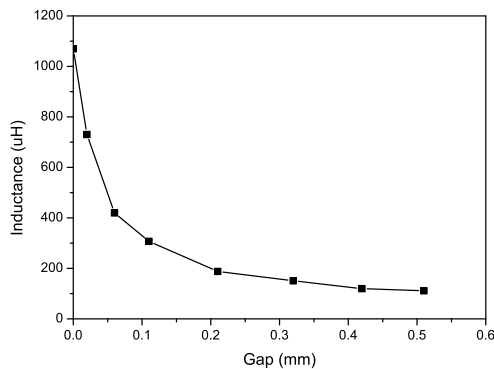


FIG. 10: INDUCTANCE VS. GAP

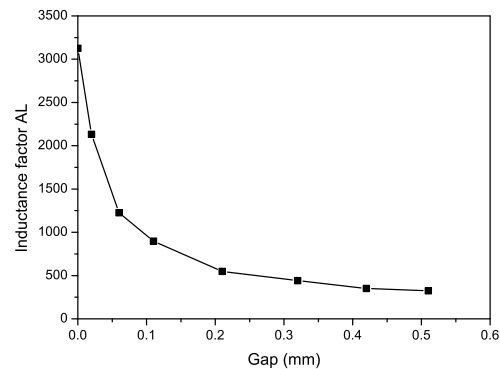


FIG. 11: INDUCTANCE FACTOR VS. GAP

SATURATION CURRENT AND AMPERE-TURNS VS. GAP

Next, Fig. 12 and Fig. 13 show the saturation current and saturation ampere-turns vs. gap spacing. Both increase approximately linearly. The increase is huge – for example, a 0.3mm gap results in a saturation current of around 10A – over twenty times the saturation current with an ungapped core.

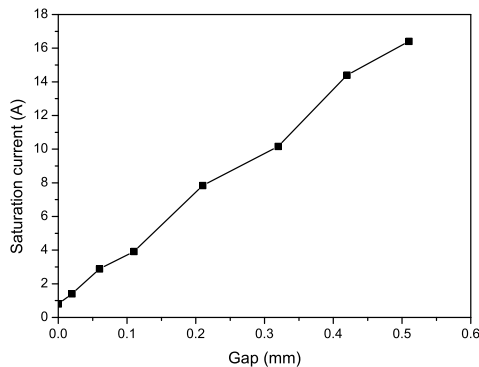


FIG. 12: SATURATION CURRENT VS. GAP

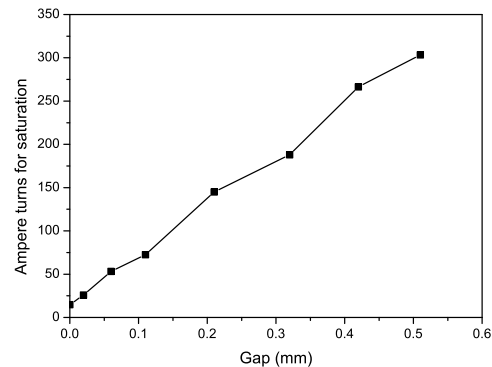


FIG. 13: SATURATION AMPERE-TURNS VS. GAP

MAXIMUM STORED ENERGY VS. GAP

Fig. 14 shows the maximum stored energy vs. the gap spacing. Again, since the effect of an increased saturation current is more significant than the reduced inductance, the energy limit increases with gap spacing. The effect is, again, dramatic – a 0.3mm gap results in around sixteen times more stored energy than an ungapped core.

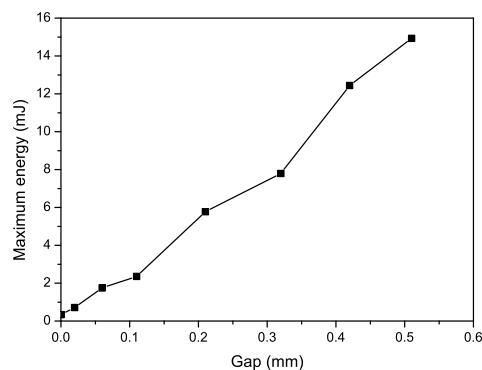


FIG. 14: MAXIMUM STORED ENERGY VS. GAP

CONCLUSIONS

Both the saturation current and maximum stored energy are independent of the number of turns and depend *only* on the core and gap configuration. As the core gap is increased, the saturation current increases approximately linearly, while the inductance factor decreases sort of exponentially.

I realize these results are probably obvious to people who know about inductors and magnetics, but I find it nice to have some experimental demonstration of them!