Reducing Core Losses from Air Gaps

Core air gaps create flux fringe fields outside the air gaps, shown as 150 in the figures below.

In laminated or tape wound cores, ac flux fringe fields generate eddy currents where they intersect the broad surface of the lamination or tape, 117 & 118 in Fig. 1A.

With high ac flux, these eddy currents can generate significant losses in the cores near the gaps, as implied by the heavily shaded areas 122 and 123 in Fig. 1B.

With very low loss cores such as nanocrystaline, at high frequencies these gap induced losses can exceed all other loses combined.

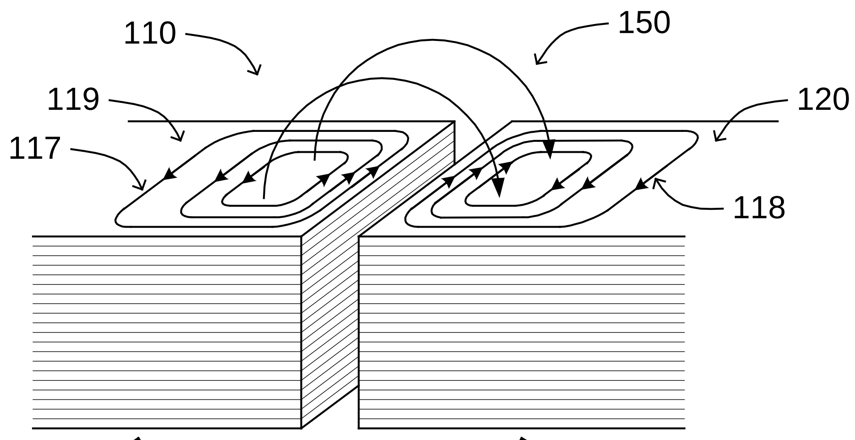


Fig. 1A

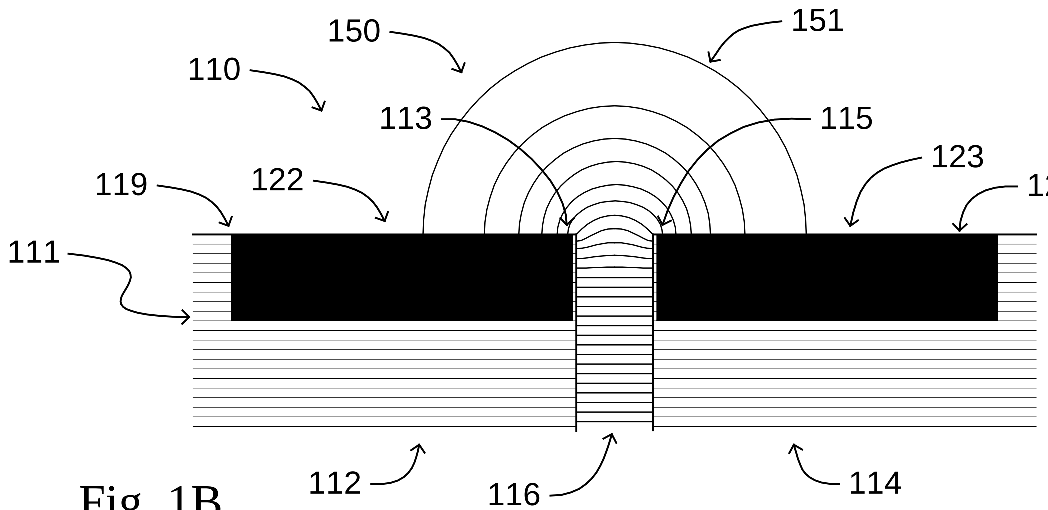


Fig. 1B

“Profiling” the Core to Reduce Gap Losses

These gap induced losses can be dramatically reduced by ‘profiling’ the broad surface of the cores near the air gaps, a shown below, so that the fringe field largely enters the edges of the laminations or tapes.

Since the fringe field drops off inversely with distance from the center of the gap, the exposed surface can be increased with distance from the gap.

The fringe field concentrates flux in the outer laminations or tapes, so this core profiling also results in a more uniform flux in the core, further reducing losses.

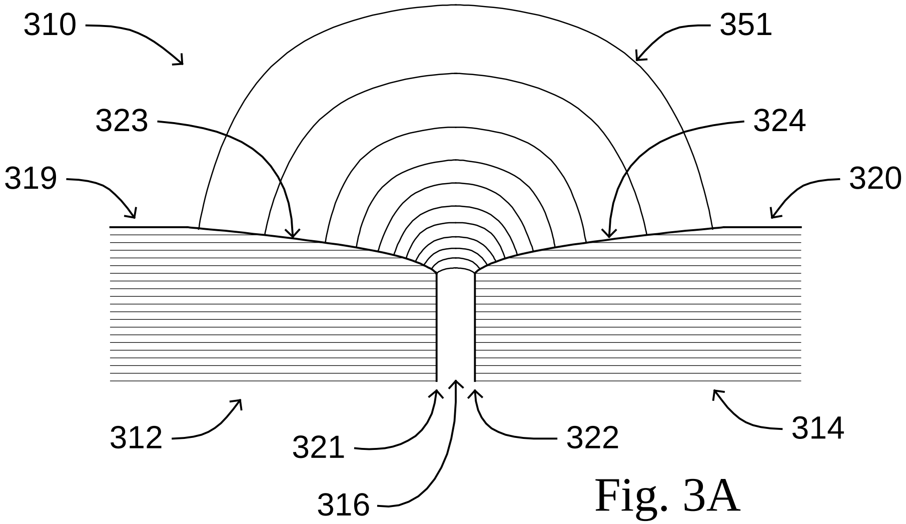


Fig. 3A

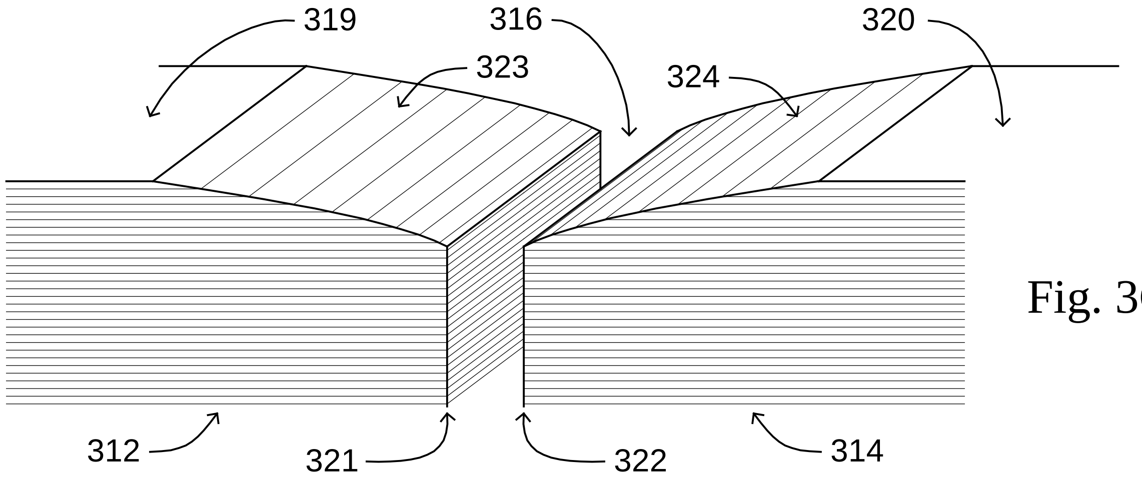


Fig. 3C

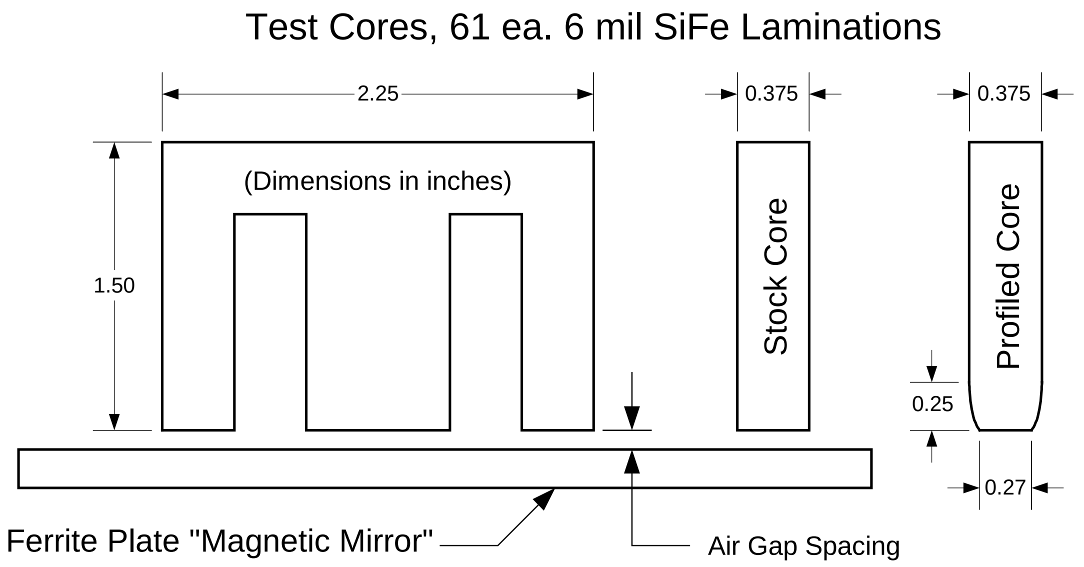
US Patent 8,466,766

Demonstrating the Effect of Core Profiling on Loss

It was originally intended to demonstrate the benefits of core profiling using very low "hysteresis loss" nanocrystaline cut cores.

However, the remaining suitable core was damaged in an attempt to align the two cut faces, so that the effect of gap length could be shown from near zero to large gaps. (Nanocrystaline cores can be very difficult to modify, for several reasons.)

With time running out, the best I could do was to make test cores out of SiFe 6 mil laminations:



The cores were loosely stacked, heated and epoxy impregnated to hold them together.

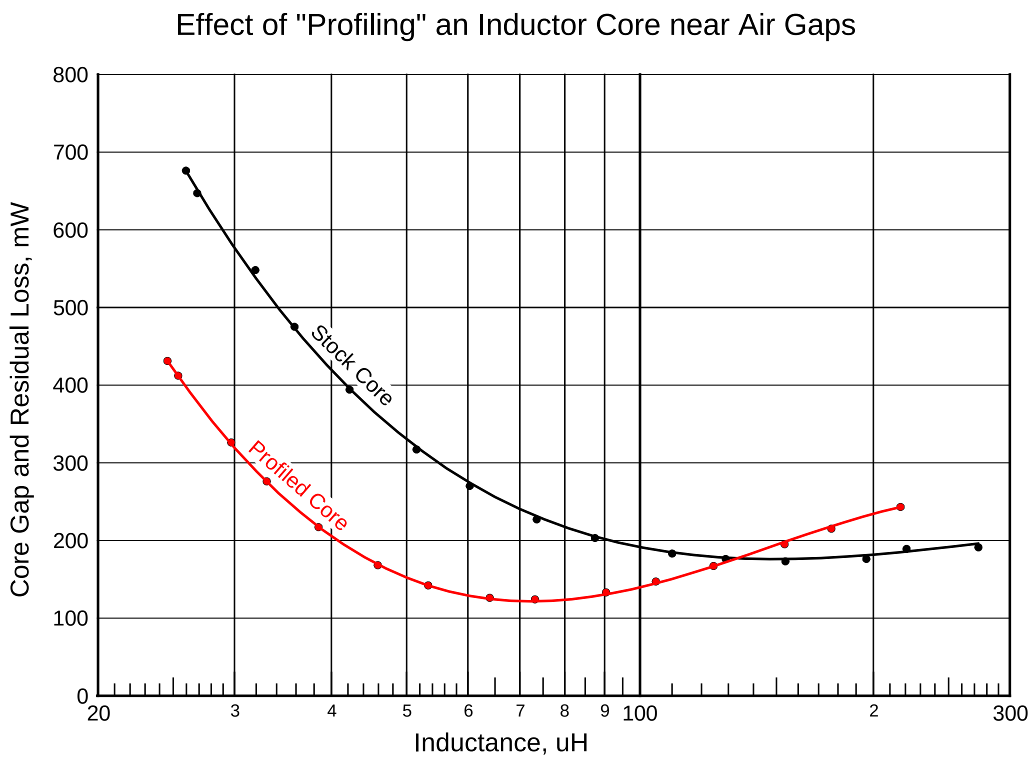
The test winding was 46 turns of 270/46 litz to minimize eddy current proximity effects at the 10 kHz square wave test frequency.

Tests were run with an Applied Parametrics Model 116A Core Loss Tester and a TEK PA 1000 Power Analyzer.

(Demonstrating the Effect of Core Profiling on Loss)

The winding voltage was maintained at 25 V average, for a core flux density of 247 mT.

The curves for “Effect of "Profiling" an Inductor Core near Air Gaps” presented at the Workshop presumed an estimated “ungapped” core loss of 850 mW, based on an observed ‘square wave’ component of the triangular magnetizing current:

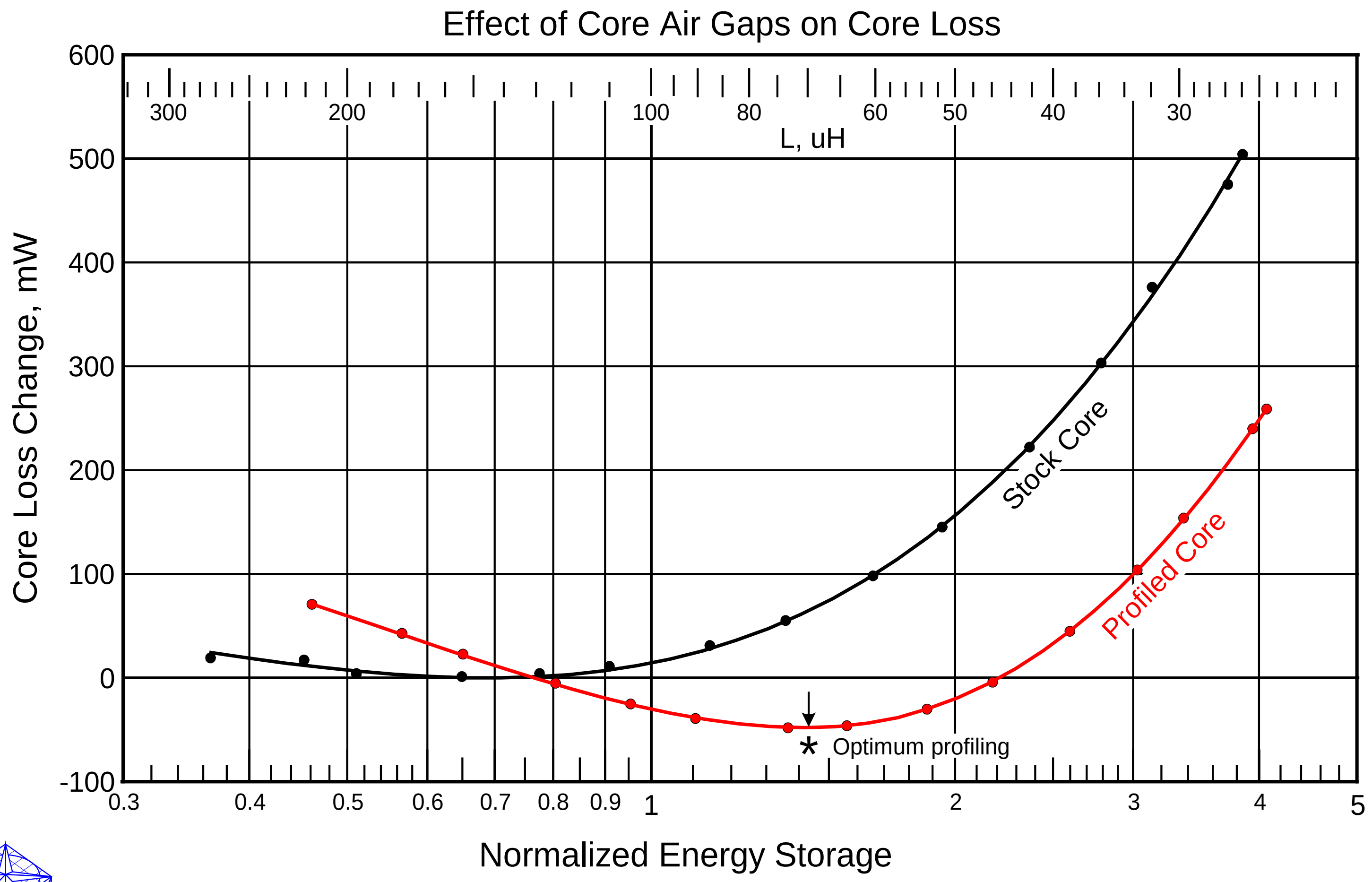


I have since measured the actual core loss with a complete core of E-I laminations, which was somewhat higher at 1,083 mW, when corrected for the reduced core volume with E laminations only.

I have corrected the curves for this and other effects, and redrawn them as a function of normalized energy storage, which is more meaningful than as a function of inductance.

(Demonstrating the Effect of Core Profiling on Loss)

These new curves are shown below. The "stock core" shows a slight increase in core loss with a small spacing from the ferrite "magnetic mirror", presumably due to an uneven face which causes a non-uniform flux distribution.



I was surprised that the loss in the profiled core actually drops below that of the stock core without a significant gap, by about 4% of the total ungapped core's loss, only about ¼ of which can be explained by the reduction of core volume from profiling.

As noted, the benefits of core profiling relative to other core losses would be far more dramatic with nanocrystaline cores.

Inductance v. Core “Gaps”, Stock and Profiled Cores

Profiled cores have a lower inductance for the same ‘air gap’ length, due to a smaller effective area at the gap.