Magnetic Core Losses

The PSMA-Dartmouth Studies
Phase III Project

Phase III Supplemental Report: The String of Beads Experiment

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Summary:

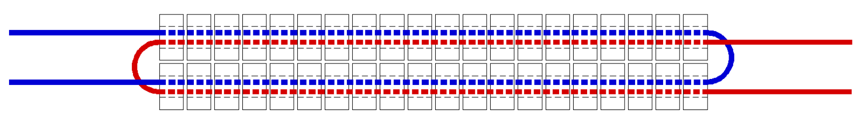
Due to extreme problems with the test equipment and a limited budget, very few productive test were run in Phase III.

Tests on a "string of beads" alternative to a single toroid provide a tantalizing suggestion that the high frequency losses may be significantly lower and that the "off-time" phenomenon may be partly mitigated. There are insufficient data to say more.

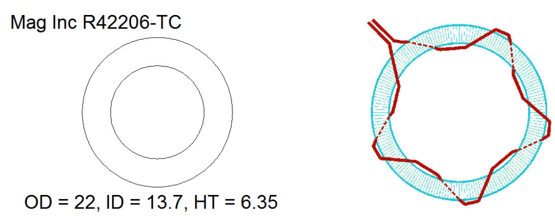
Winding Variations

We had more tests planned for winding variations, but only the string of beads tests were run. There are very little data, so it cannot be considered conclusive, but it is suggestive that a string of beads may have significantly lower core losses at higher frequencies (>500 kHz).

String of Beads test



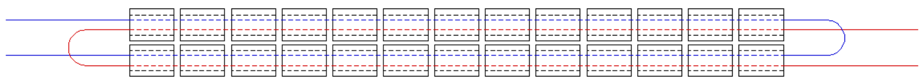
The objective: To further asses a core set with no radial component, and to assess eddy current and dimensional resonance effects, run a set of tests on a composite core comprising a string of small cores with single turn excitation and sense windings, designed to have comparable inductance and total core volume. Doing this exactly might require specially machined cores, but a reasonable approximation is 40 cores Magnetics Inc. R 40402.



The baseline core is a Mag Inc. R42206-TC with five turns. (There is also a five-turn sense winding, not shown.)

Ideally, for inductance comparable to a five-turn winding using onle one turn, the area Ae should be 5 times and the magnetic length Le should be 1/5. The total volume Ve should be the same.

If we keep the ID/OD ratio the same, and meet the above criteria, the ID and OD are divided by 5 and the height is multiplied by 25, so the area Ae is 5 times and the volume Ve is the same. The heiht of the individual beads is arbitrary as long as the total is correct. As an example, the arrangement below would work.



26 cores, OD = 4.4, ID = 2.74, HT = 6.11

We could not find a combination using standard cores that fit the criteria, but 40 cores of Mag Inc. R 40402 is quite close on inductance using the published values and 87 percent of the volume Ve. To make the volume Ve equal, use 46 cores.

	R 42206		**R 40402**	
Ae	26.2 mm^2	x5 = 131 mm^2	3.08 mm^2	x40 = 123.2 mm^2
Le	54.1 mm	x1/5 = 10.8 mm	10.21 mm	
Ve	1441 mm^3		31.4 mm^3	x40 = 1256 mm^3

Check proportionate inductance L:

$$L \propto \frac{n^2 * A_e}{L_e} = \frac{5^2 * 26.2}{54.1} = 12.11 \approx \frac{40 * 3.08}{10.21} = 12.07$$

Tests of a “string of beads” of 40 beads and 46 beads were proposed.

Test results: The results of this testing is very interesting, but the sample is so small that it has to be considered inconclusive.

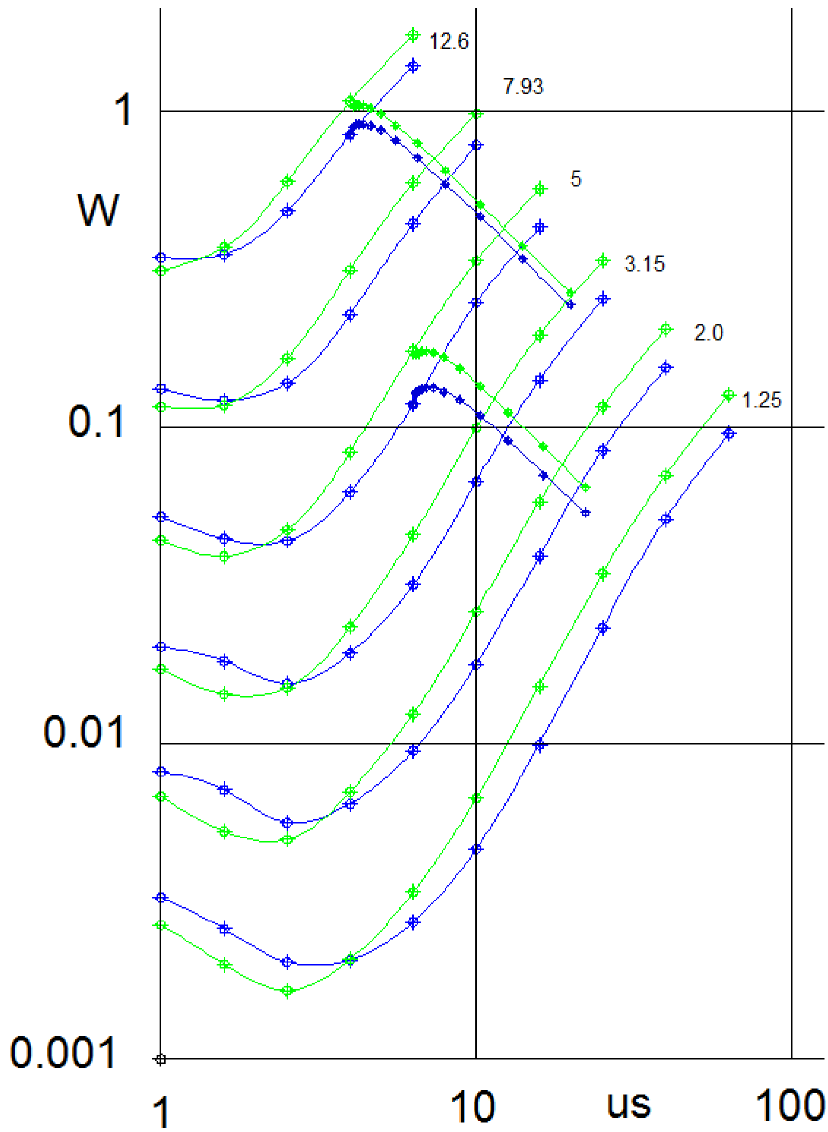
The first sample using 40 cores shows higher losses and some signs of saturation. This suggests that the effective core area Ae is too low, perhaps due to surface effects. Small cores are known to have a “skin” with different characteristics, which may reduce the usable area Ae. The volume Ve is also significantly lower.

Comparison of the string of beads to the baseline core showed that the string of beads has higher losses at lower frequencies. However, at higher frequencies, the situation reverses, with the string of beads having significantly lower losses.

A second sample using 42 cores was then assembled and tested, but the difference is too small to make much difference. The suggested string of 46 beads was not tested.

The graph below shows the core loss in W vs. pulse width for square-wave excitation at various excitation voltages, using the format from the Phase II Supplemental report. The reader may wish to review that report for a more comprehensive explanation, and to see graphs for many more materials.

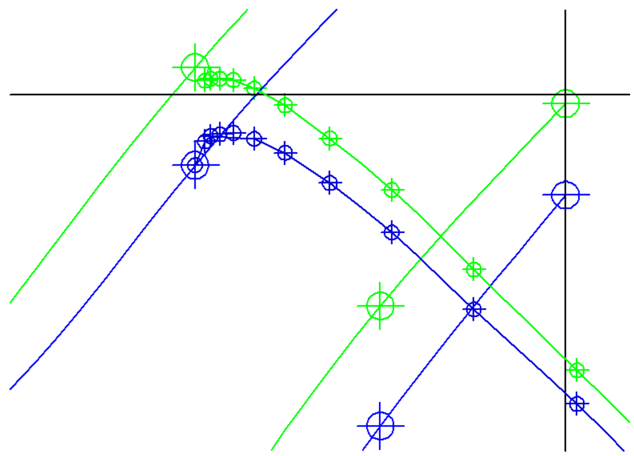
The baseline 5 turn core is blue and the 42 core "string of beads" is green. The curves that slope downward and to the right are the expanded waveform data. For the expand data curve, the pulse width is the same as the square wave curve from which it originates, but increasing amounts of off-time are inserted between the pulses. For the expand curves, the x-axis is one half of the period.



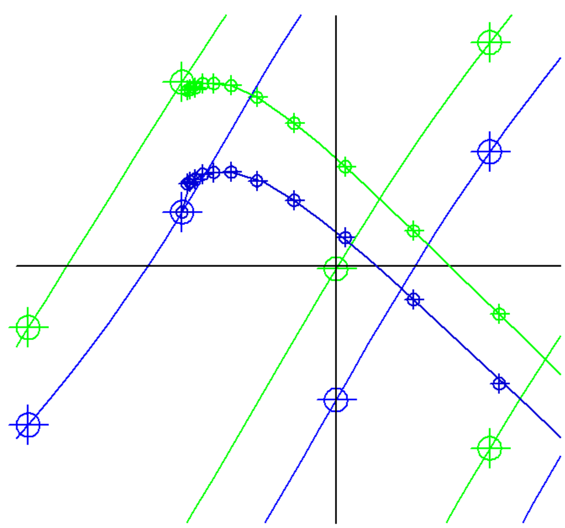
The blue curves are the baseline core, using the data from the mi12-2 run set.. The green curves are the 42 string of beads, using data from the mi12-3 run set.

The curves below are enlargements of the expand data curves from the graph above at the points where the expand data departs from the square-wave data. The first extends from the 12.6 V square-wave excitation curve, and the second extends from the 5 V curve.

It can be seen that with the five-turn reference core, mi12-2, the core loss rises significantly as the off-time increases, then it slopes down at approximately 45º. (If there were no off-time phenomenon, duty-ratio considerations alone would produce a straight-line 45 º down-slope.).



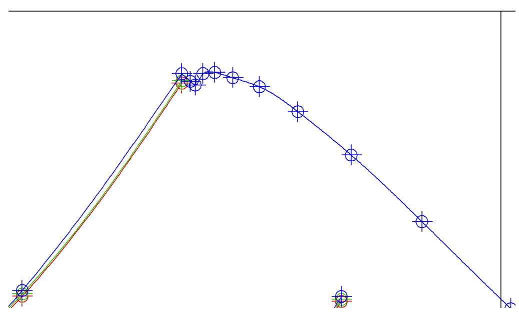
By contrast, the “string of beads” mi12-3 shows no increase in the average power.

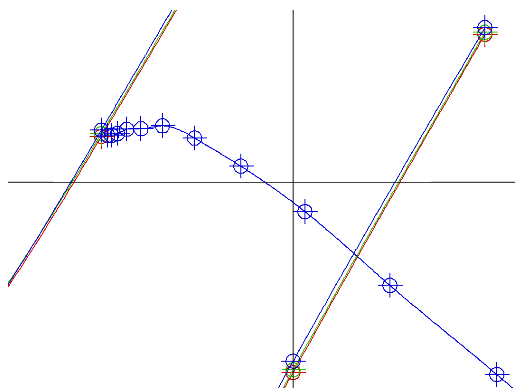


With so little data, it is speculative, but the data suggest that the off-time phenomenon may be somewhat mitigated using the “string of beads” configuration.

The above graphs are for F material. A similar enlargement of the expanded waveform graph using data from Phase II for R material shows that there may be as much difference between materials as there is between geometric arrangements. It is too bad that we cannot make similar comparisons with more materials.

The graphs below are from the Phase II mi01-3 run set.



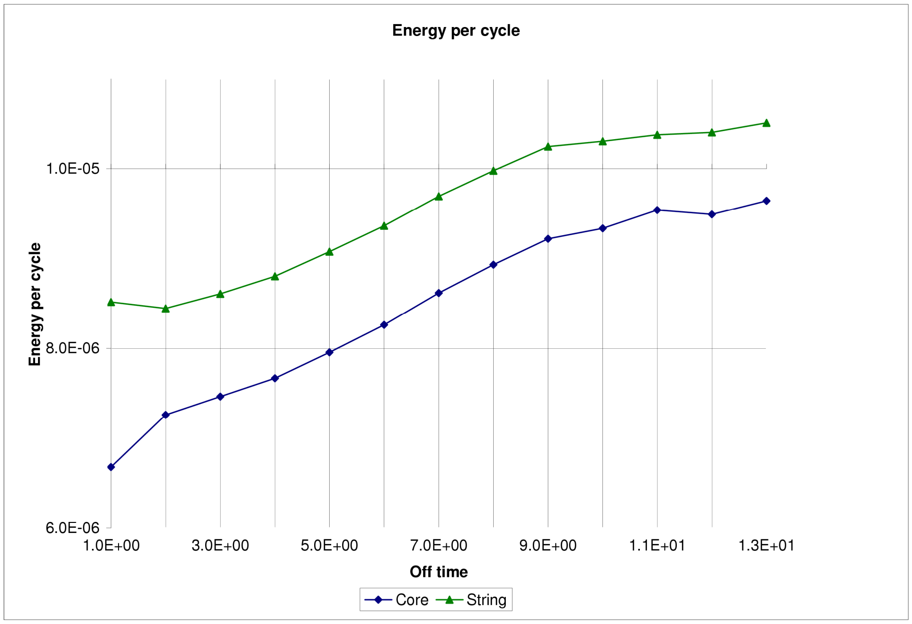


Loss per cycle for expanded waveforms

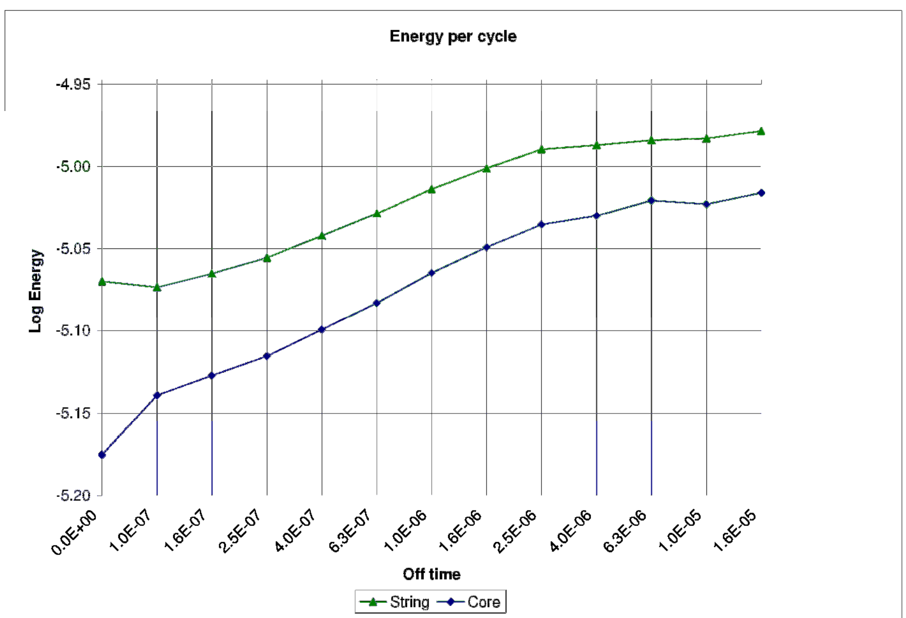
The graphs of energy loss per cycle with expanded waveforms, below, shows differences, but with very little data, it is hard to know if this is repeatable.

The graphs below show the loss per cycle vs off-time, the first as a linear-log plot, the second is a log-log plot.

[The x-axis (Off time) in not strictly logarithmic, as it has a point for zero off-time (the square-wave base-line), but the other time intervals of the test data are based upon a logarithmic progression.]



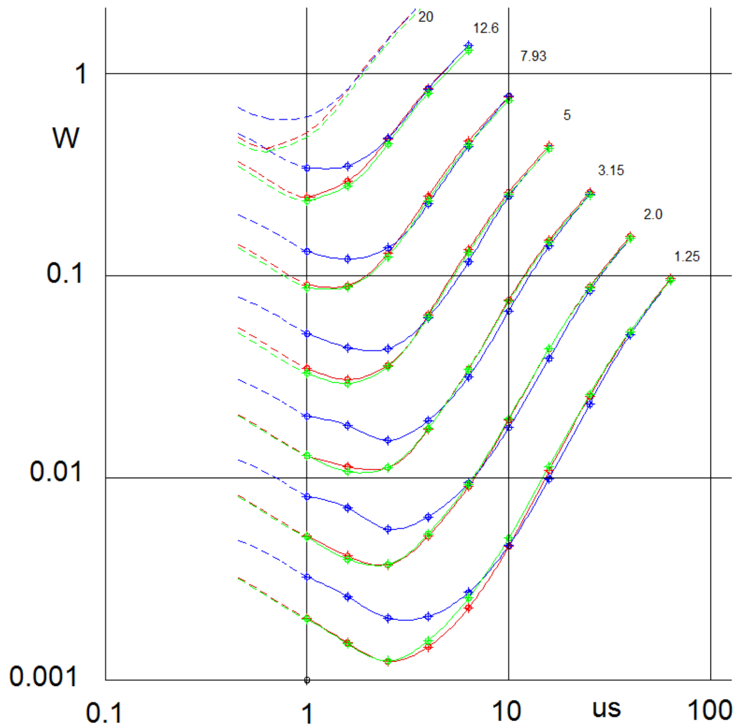
These data and graph show the energy per cycle for the core, in blue, and for the string of beads, in green. The pulse width is a constant 3.98 μs. Except for the first data point, the curves are quite similar.



This graph shows the same data, except the energy per cycle is shown logarithmically. On the log-log graph, the slope of the curve for the "string of beads" can be seen to be lower, particularly for small off times. With so little data, it is impossible to asses the significance of this. It may or may not be repeatable, but it suggests a lower proportionate increase in core loss per cycle with added off time for the "string of beads" configuration.

Speculation:

We speculate that the correct way to design a "string of beads" equivalent core is to use sufficient beads so that the losses match at longer pulse widths (lower frequency). If that were done, it seems likely that the shorter pulse width results (high frequency) would exhibit very significantly lower core losses.



If a string of beads were made with more cores, the flux density would be lower in each, suggesting that the losses would be lower as well. On the speculation that the curves would have the same shape but lower core loss, they would be vertically displaced by the proportionate power difference, as it is a log-log curve.

In the graph above, the red and green curves were selected in a CAD program, and moved down until the longer pulse-width (lower frequency) curves were fairly well aligned.

Because of the frequency limits of the test equipment, no data were taken with square-waves greater in frequency than 500 kHz. As pulse width is defined, this is 1 µs in the graph above. In the above graph, it was speculated that the curves would have the same shape, extended, if the frequency and voltage were increased.