Power comparison – String of beads equivalent cores

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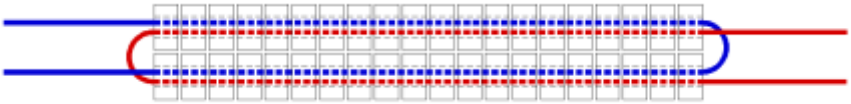
Background

The second item on the Phase III "Wish List" was to test a string of beads equivalent of the baseline core, as defined below (copied and pasted)

2. 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.



Ideally, for comparable inductance with one turn, the area should be 5 times and the magnetic length should be 1/5. The total volume should be the same. I could not find a combination using standard cores that fit the criteria, but 40 times R 40402 is very close on inductance and 87 percent of the volume. To make the volume equal, use 46 cores.

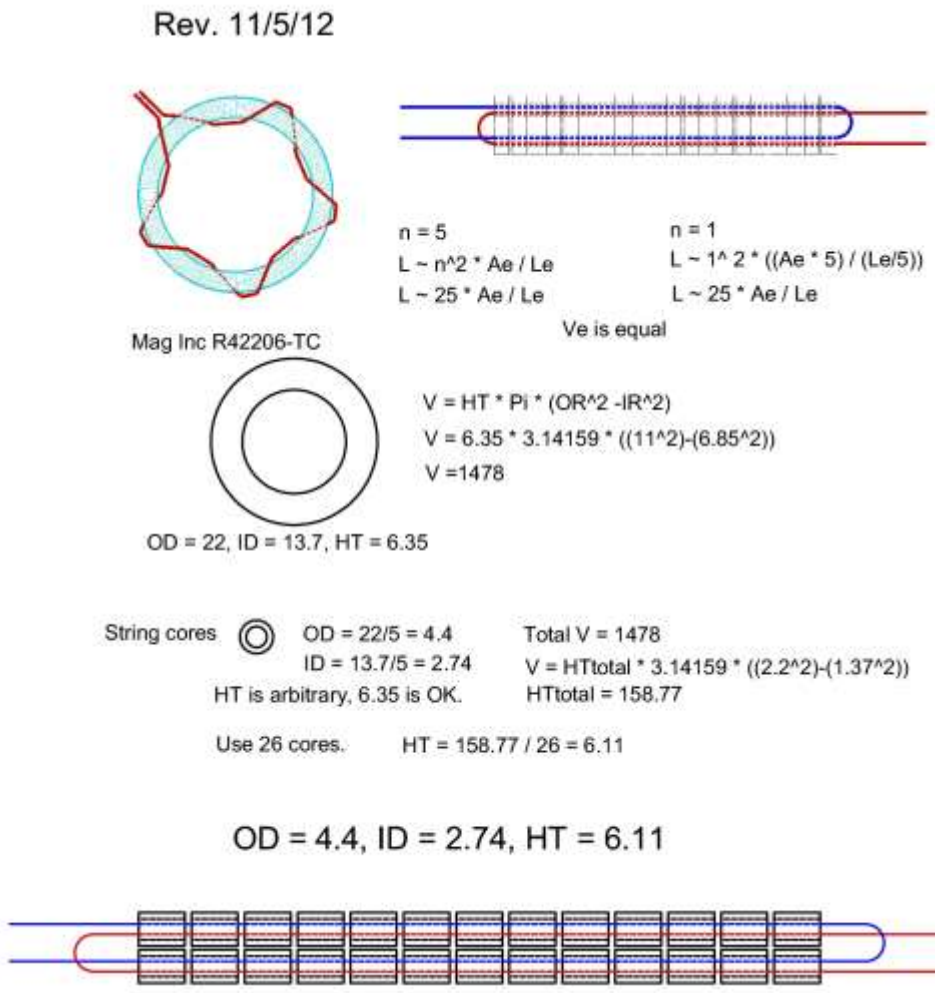
	R 42206		R 40402	
Ae	26.2 mm^2	x5 = 131 mm^2	3.08 mm^2	x40 = 123.2 mm^2
Le	54.1 mm	x1/5 = 10.8 mm	10.21 mm	
Ve	1441 mm^3		31.4 mm^3	x40 = 1256 mm^3

Check proportionate inductance:

$$\frac{5^2 * 26.2}{54.1} = 12.11 \approx \frac{40 * 3.08}{10.21} = 12.07$$

Theory

The ideal scaling for the beads is as follows.



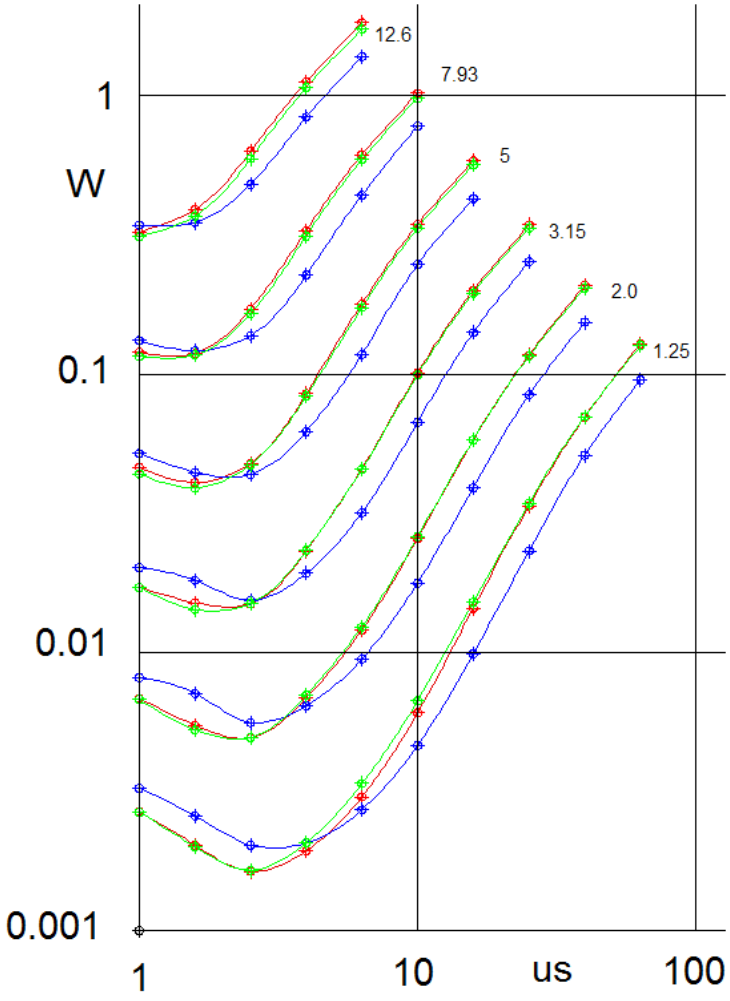
Compromise:

To avoid having to machine special cores, we acquired 50 cores from Magnetics Inc that were approximately correct, but not exact. As seen in the "Background", equivalent area suggested using 40 cores. Equivalent volume suggested using 46 cores.

Tests were run on strings of 40 cores and 42 cores. As far as is known, the suggested string of 46 cores was not tested.

Test results:

Using the "Herbert" curves for the square-wave tests on the three samples tested (runs-mi12-1x is a 40 bead string, runs-mi12-2x is the baseline large core with 5 turns, runs-mi12-3x is a 42 bead string), it can be seen that the core losses are substantially higher for the string of beads runs (red and green) at longer time periods (lower frequency). However, as shorter times (higher frequency, 500 kHz), there is a cross-over, and the string of beads has lower losses.



There is not much cross-over at the highest voltage test, but loss difference is more than is apparent because it is difficult to see small differences on a log-log plot of several decades. The 500 kHz test with 12.55 V is as follows:

mi12-1-041.csv	0.324 W
mi12-2-041.csv	0.342 W
mi12-3-041.csv	0.311 W

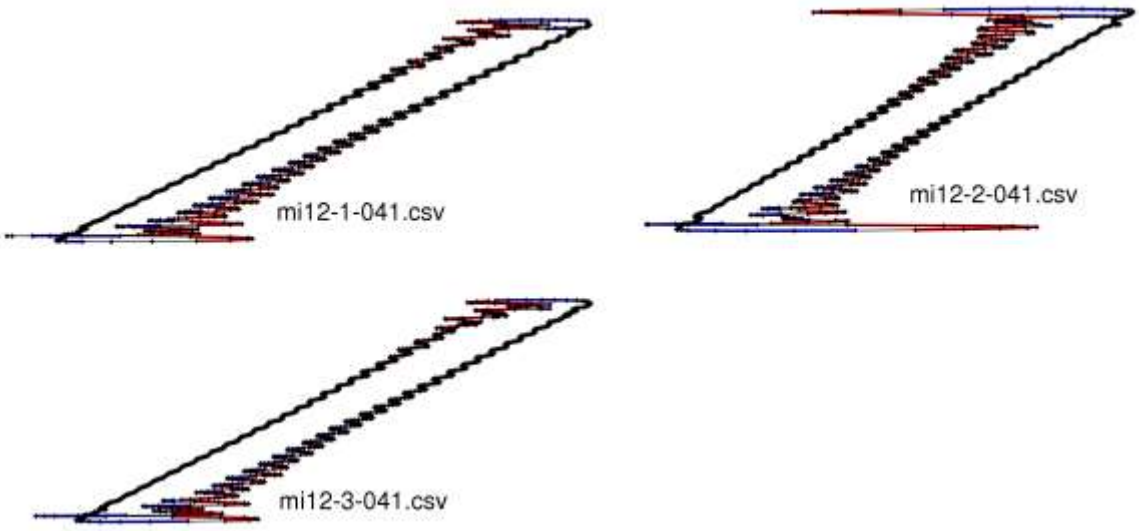
The differences are greater at the lower voltages, 7.55 and 5 respectively, of the curves below:

mi12-1-035.csv	0.119 W
mi12-2-035.csv	0.131 W
mi12-3-035.csv	0.115 W

mi12-1-028.csv	0.046 W
mi12-2-028.csv	0.052 W
mi12-3-028.csv	0.044 W

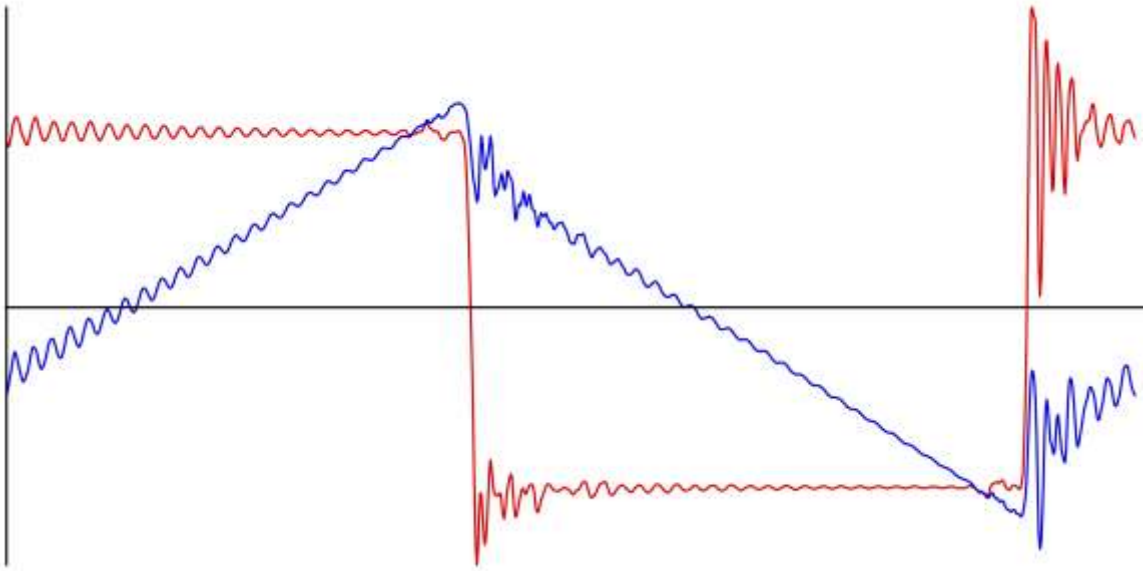
Hysteresis loops

The hysteresis loops for the -041 test runs are shown below:

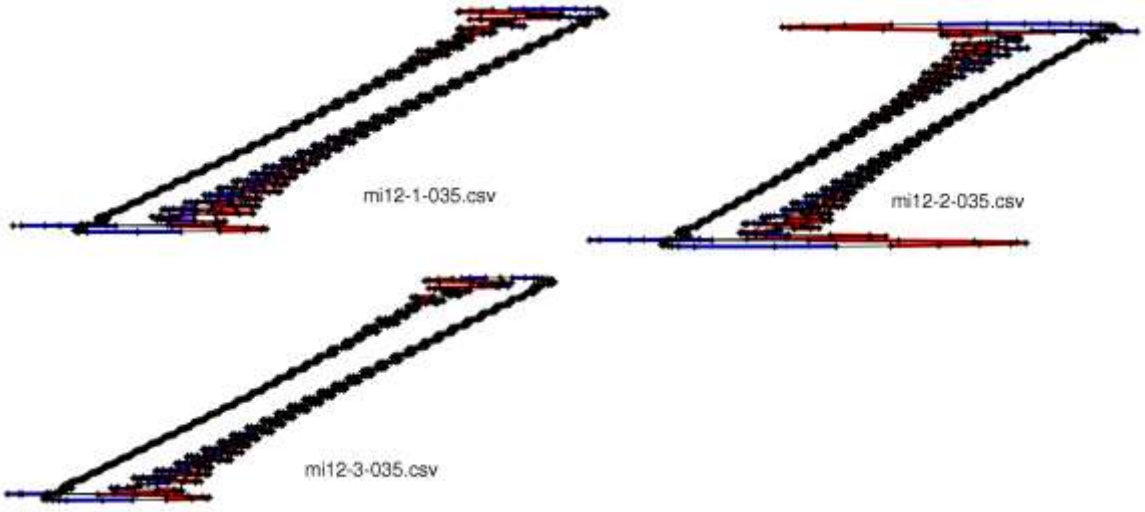


Below is a very much enlarged section of the top of the mi2-1-041 hysteresis loop. This drawing is made with four passes. First, the loop is traced as a fine black line. Then pointmarks are superposed, to give time stamps, one point for each datapoint of the test runs. Finally, the thicker red and blue lines are added. If there were an off-time, as in the expanded curves, there would also be a green section. Red is when the absolute value of the voltage is above 0.95 of average. Blue is when the absolute value of the voltage is below 0.95 of average.

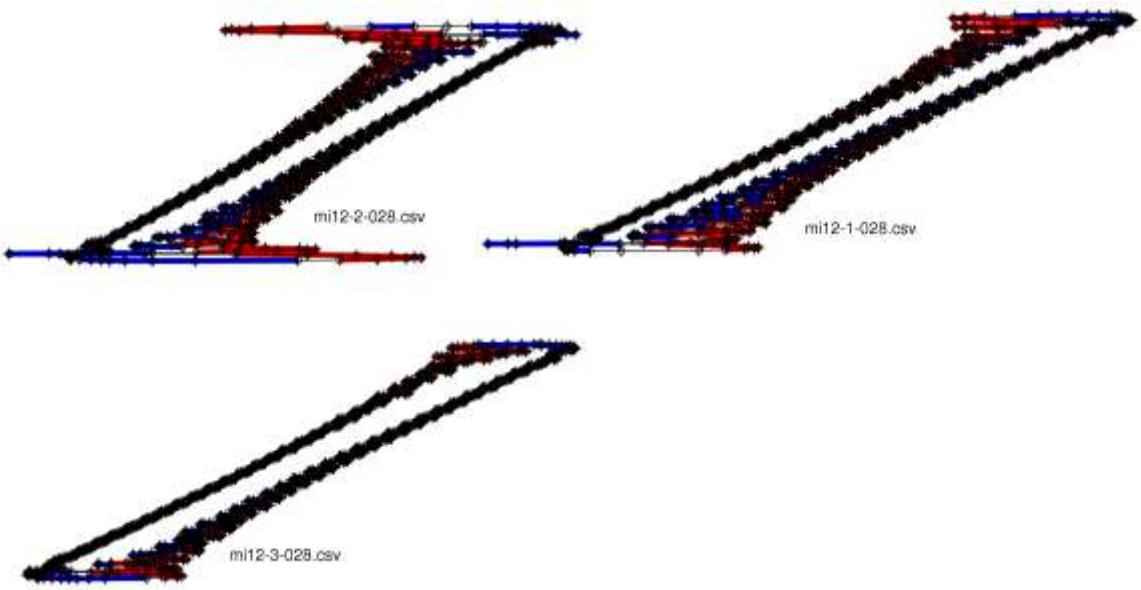
Below are the corresponding voltage and current curves for the mi2-1-041 data:



Here are the hysteresis loops for the -035 data runs:



Here are the hysteresis loops for the -028 data runs.

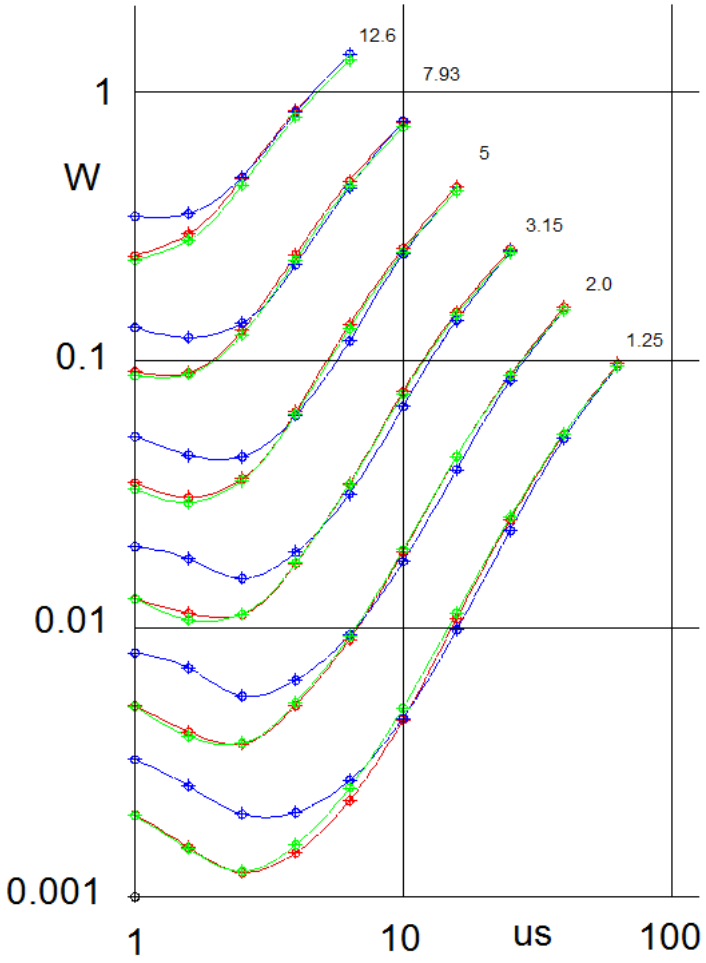


In all cases, the hysteresis loops for the baseline big core have much more ringing and a much higher initial current. I am speculating that the initial current spike is attributable to a capacitive phenomenon that is more prevalent in the larger core, but there are other possible explanations.

A much better analysis will be possible once the buck curve data are available. The low duty-ratio runs may very well exhibit the reduced losses of the short pulse width square-wave data.

Speculation:

I speculate that the correct way to design a string of bead equivalent core is to use sufficient beads so that the losses match at longer times (lower frequency). If that were done, it seems likely that the short time period results (high frequency) would exhibit very significantly lower losses.

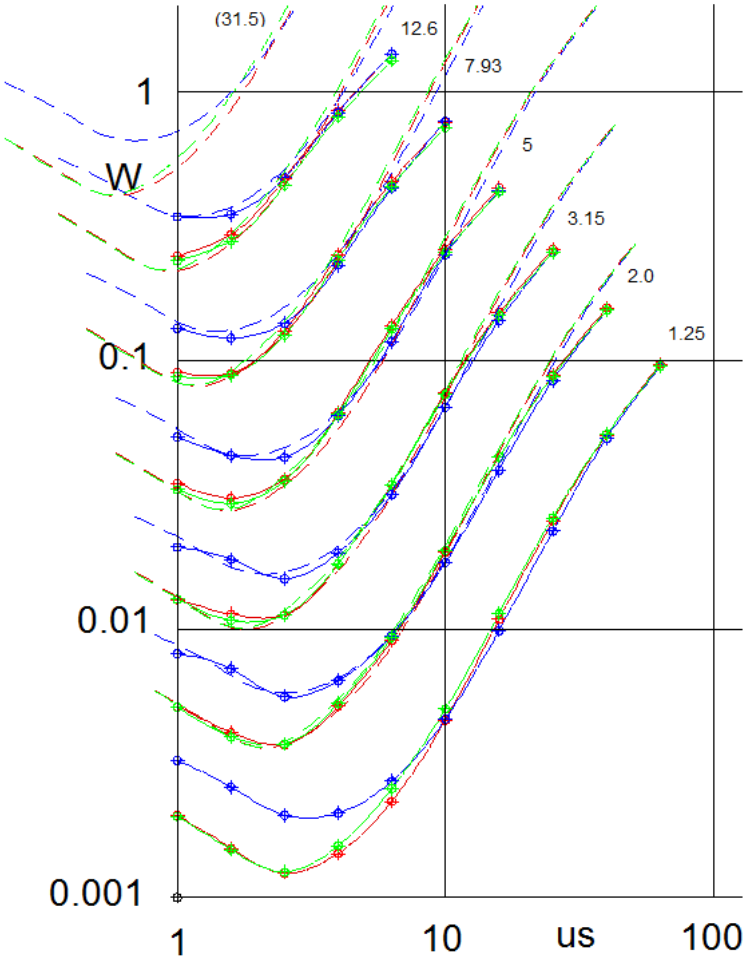


In the graph above, the red and green curves were selected in the CAD program, and moved down until the greater pulse-width (lower frequency) curves were fairly well aligned.

Because of the frequency limits of the test equipment, no data was taken with square-waves greater in frequency than 500 kHz. As pulse width is defined, this is 1 us in the graphs above.

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 power, they would be vertically displaced by the proportionate power difference, as it is a log-log curve.

Extending the curves:

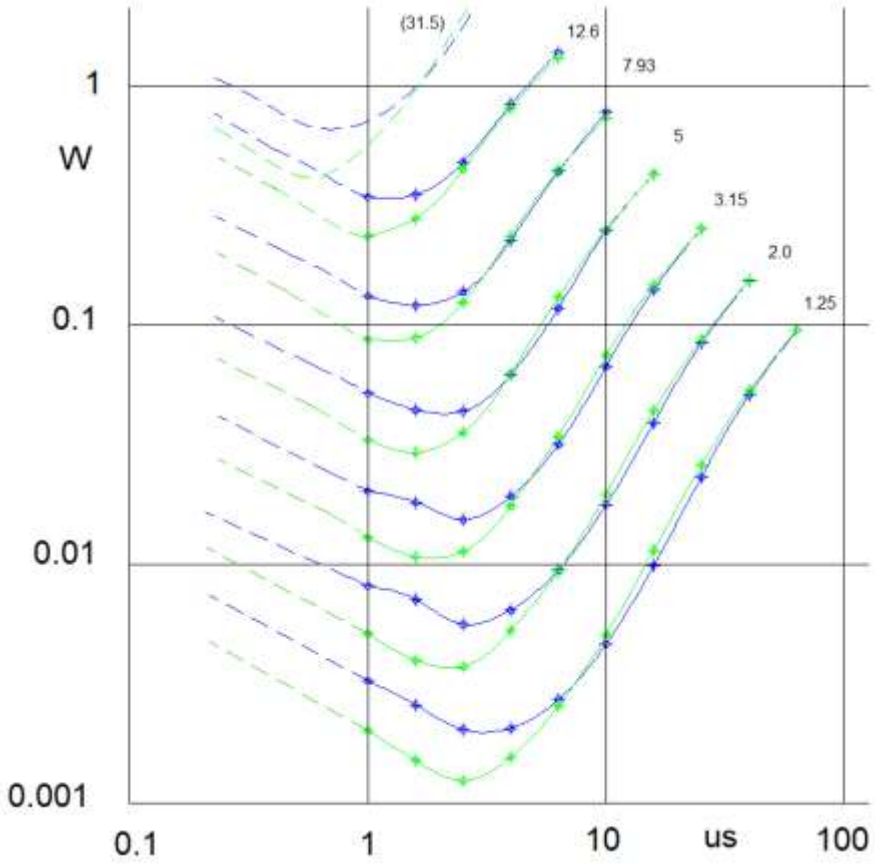


In the graph above, the 1 volt curves were copied, changed to dashed lines, then pasted on the higher voltage curves by eye to make the best fit. The fit is qualitatively fairly good for points for which there are data. Whether this is valid at shorter pulse-widths is highly speculative, but it may show the general shape of the curves.

An additional set of curves was pasted in above the others, using the relative spacing of the other curves. Again, this is highly speculative, but it may show the general shape of a curve with higher excitation.

Hypothetical curves, extended:

The hypothetical curves were cleaned up and extended using the same slope, giving the graph below.



While the above is highly speculative, it suggests that tests should be conducted both with a string of beads set having more cores and also at shorter pulse-widths (higher frequency).