

CONF-800640--11

TERAWATT POWER DIVISION AND COMBINATION USING SELF-MAGNETICALLY INSULATED TRANSMISSION LINES\*

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Abstract

Self-magnetically insulated transmission lines are necessary for the efficient transport of the terawatt pulses used in electron and ion accelerators. For some applications it is desirable to divide one transmission line into two, or to combine outputs of two or more lines into one, by means of self-magnetically insulated convolutes.

Tests have been made on a coaxial-to-triaxial convolute in which connections between negative inner and outer lines are made by pins passing through holes in the intermediate positive conductor. Measurements in the 2 MV, 400 kA, 40 ns pulse Mite facility indicate virtually 100 percent current transport through the convolute and the ability to vary the division of current between the inner and outer lines of the triax by choice of inner line impedance. These measurements, and results obtained with this convolute connected to the ion diode for which it was designed, will be presented.

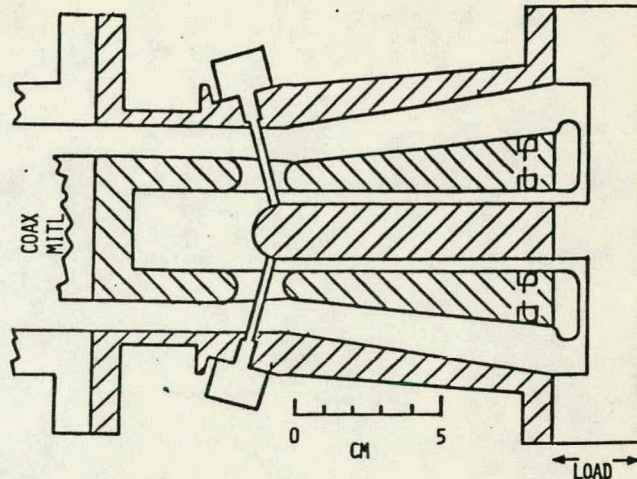


Fig. 1. Coax-to-triax convolute.

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Introduction

Transmission lines which use self-magnetic insulation can transport high voltage, high energy, short duration pulses over distances of several meters with energy propagation efficiencies greater than 90 percent.<sup>1</sup> In these lines, electrons field-emitted from the negative side of the line are prevented from reaching the positive side by the magnetic field of the current flow in the line. These electrons have a net velocity parallel to the energy flow along the transmission line, and carry a significant part of the line current. Stability and containment of this electron flow is one of the major considerations in designing a low loss magnetically insulated line.

Sandia National Laboratories Particle Beam Accelerator PBFA I<sup>2</sup> has 36 radially-converging, magnetically-insulated, triplate lines. Each of these lines incorporates a tapered section at the output which changes the configuration from triplate to coaxial. One ion diode<sup>3</sup> proposed for PBFA I requires a triaxial feed, so that the power appearing at the coaxial outputs of the lines must be divided into triaxial outputs. Tests of a coaxial-to-triaxial convolute with an electron beam diode, and preliminary tests with the ion diode have been very encouraging.

Coaxial to Triaxial Convolute

Physical Description

The configuration tested is shown in cross section in Fig. 1. The coaxial feed with a positive centerline is on the left. The negative outer housing is connected to the center rod by four pins (two shown) passing through circular holes in the positive line. A planar anode-cathode, electron beam load used for testing is shown on the right. The load impedance is varied by adjusting the A-K gap.

\*This work was supported by the U.S. Dept. of Energy, under Contract DE-AC04-76-DP00789.

The impedance of the coaxial line is 20  $\Omega$ . The dimensions of the triaxial section were chosen so that each leg has a constant 25  $\Omega$  impedance. In later tests, the diameter of the center rod was reduced from 1.84 cm to 1.32 cm, raising the inner line impedance to 45  $\Omega$  in order to test the effect on current division.

Current measurements in the triax section were made with B-dot loops shown schematically in Fig. 1. Other current monitors were located along the transmission line so that current transport efficiency could be determined.

Losses in this design could arise from two sources. One was the abruptness of the transition which might cause instabilities in the electron flow.<sup>1</sup> The other was that consideration of the magnetic fields produced by the current flows in the triax sections and down the connecting pins show that there is a line of zero B field 5 mm to 8 mm toward the load from each pin in the outer half of the triax line. Zero magnetic field implies a loss of magnetic insulation in these regions. In addition, the field gradients on either side of these regions are such that electrons would drift from the negative toward the positive electrode. The losses due to these effects were found to be negligible.

Testing of the coax-to-triax convolute has been done on the Sandia Laboratories Mite facility,<sup>1</sup> and preliminary testing with the ion diode has been done on Hydramite.<sup>4</sup> Each of these accelerators provides 40 ns pulses of 2 MV and 400 kA into a magnetically insulated transmission line that is essentially identical to those of PBFA I.

Test Results

Figure 2 shows the current transport efficiency obtained in shots on Mite with various A-K load gaps. The measurement accuracy is approximately  $\pm 10$  percent. Figure 3 shows the percentage of the total current carried by the outer line of the triax. The current transport efficiency is the total current measured by the B-dot monitors near the load divided by the current measured at the Mite line output.

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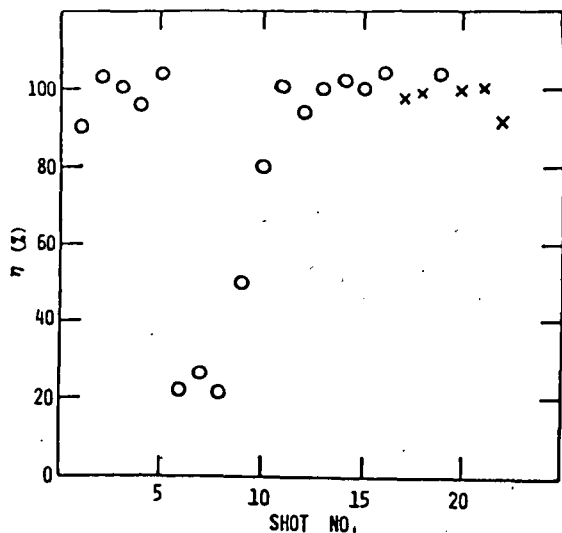


Fig. 2. Current transport efficiency.

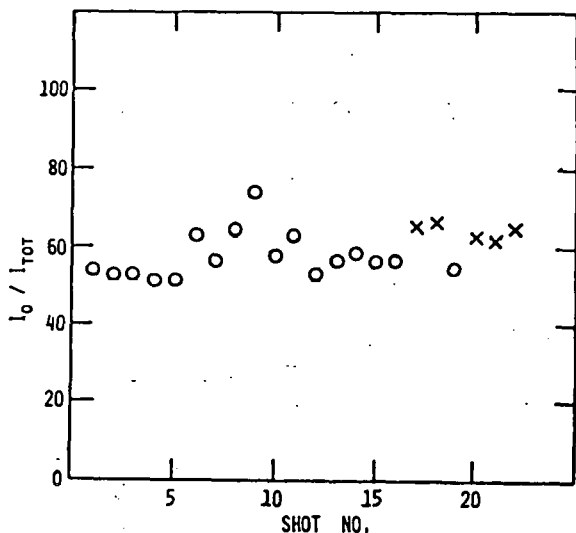


Fig. 3. Ratio of current in outer half of triax line to total current.

The low efficiency of shots 6, 7 and 8 were caused by a combination of poor current contacts and misalignment. These problems were corrected over the next few shots with a return to near 100 percent current transport. The losses in the low efficiency shots were located primarily near the junctions of the center rod and the connecting pins, as evidenced by damage to the positive line in this region.

The current division was approximately 55/45 outer to inner (except for the low efficiency shots) with the 1.84 cm center rod. Using the 1.32 cm center rod (crosses in Figs. 2 and 3) produced current divisions centering on 65/35, still with approximately 100 percent current transport.

The impedances of the loads tested on Mite were calculated by using the transmission line current with a short circuit load ( $I_{SC}$ ), the current input to the convolute ( $I_{IN}$ ), and the load current ( $I_L$ ) in

$$Z_L = Z_o (I_{SC} - I_{IN}) / I_L$$

where  $Z_o = 7.5 \Omega$  is the geometric impedance of the Mite triplate line. The load impedances ranged from a fraction of an ohm to  $2.9 \Omega$ . Since the matched output impedance of the magnetically insulated line was  $0.63 Z_o$  or  $4.8 \Omega$ , the Mite line was undermatched in these tests.

Using calculated load impedances and measured  $I_L$ , the values of  $I_L^2 Z_L$  were calculated for shots with  $Z_L > 0.3 \Omega$  and are plotted in Fig. 4.

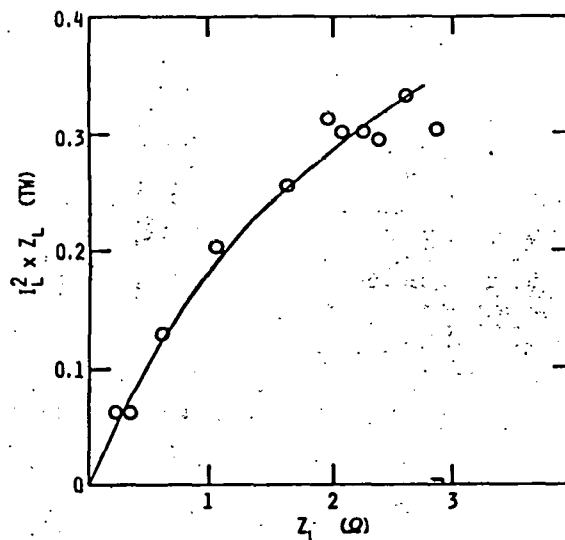


Fig. 4. Power to load vs. load impedance.

#### Testing on Hydramite

A particularly severe test of a self-magnetically insulated transition is operation into a high impedance load, since high impedance implies little current flow, low magnetic field, and poor magnetic insulation. The ion diode for which this convolute was designed has an externally applied magnetic field which retards electron transport across the diode A-K gaps, especially during the early part of the pulse.

If a loss region is established in the magnetically insulated line during the early, high impedance phase of a pulse, the loss region can become a low impedance load in parallel with the ion diode. Although the zero-B regions near the connecting pins did not produce loss with low impedance loads, they might cause losses with the ion diode because of the initial high impedance phase on the latter experiment.

While the results are preliminary, since testing is not complete, to date there has been negligible loss in the coax-triax convolute in operation with the ion diode.

#### Combination of Power Flows

Separation of a coaxial magnetically insulated line into a triaxial pair using a pin-hole convolute has been successful, and it is reasonable to expect that power combination using the same technique would also work well. A design is being developed for testing in the near future on the Proto II facility at

Sandia Laboratories in which a triple disk feed is convoluted into a double disk line using pins passing through holes in the positive center plate.<sup>5</sup> The magnetic zeroes and adverse gradients will be similar in location and magnitude to the tested coax-triax convolute and should have negligible loss in the proposed configuration.

#### Conclusions

A coaxial-to-triaxial pin-hole magnetically insulated convolute has been tested and found capable of operating with negligible loss with electron beam diode loads of zero to  $3 \Omega$ .

The convolute has been tested with an ion diode load, and preliminary data indicate negligible loss. The pin-hole convolute concept appears applicable to power combination as well as division.

Experiments with magnetically insulated transmission lines have been essentially one dimensional configurations. The tests of the coax-triax convolute, which have been successful in spite of potential loss mechanisms inherent in the three-dimensional transition, indicate that considerable latitude may exist in designing magnetically insulated devices.

#### References

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