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IBEX FOILLESS DIODE EXPERIMENTS*

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Summary

A new high voltage isolated Blumlein accelerator (IBEX) has been designed and constructed. A new accelerator pulse-forming-line (PFL) configuration produces an output voltage pulse equal to the PFL charge voltage for a matched load (as in a conventional Blumlein circuit); however, the prepulse level is negligible and both sides of the diode remain at electrostatic ground potential. With a matched planar diode load, IBEX has generated a 4 MeV, 100 kA electron beam. In the present stage of experimentation, a foilless diode load is being used to produce 3-4 MeV, 20-30 kA annular electron beams with an applied magnetic field strength of ~ 10 kG.

Introduction

The most common PFL geometry for producing high voltage (> 2 MeV) electron or ion beams is an oil dielectric Blumlein.[1] When this type of structure is charged to high voltage, the time-varying flow of current through a grounding inductor produces a prepulse voltage that appears across the output diode load. Such a prepulse can generate plasma on the highly stressed cathode and anode surfaces of a foilless diode, resulting in serious disruption of diode operation during the main voltage pulse. In this paper, we discuss the application of a new PFL configuration that produces no diode prepulse for generating intense electron beams using a foilless diode load.

IBEX Description

IBEX is an accelerator[2] that employs a new pulse-forming-line configuration known as an isolated Blumlein. A photograph of this device is shown in Fig. 1. The PFL charging circuitry consists of a Marx generator, containing thirty-two, 0.7 μF, 100-kV capacitors, and a 3.0 MV, 7.7-nF water capacitor. The intermediate storage capacitor (ISC) energizes the PFL through a self-breaking SF_6 spark gap and a low inductance feed line.

The operating principles of the isolated Blumlein PFL have been described in a previous publication.[3] A schematic diagram is presented in Fig. 2. The structure consists of three concentric cylinders with diameters of 223 cm, 135 cm, and 81 cm. The intermediate cylinder is 406 cm long, and is charged to a negative 4 MV through a four-point symmetric feed at the rear of the PFL. Twelve self-breaking, point-plane oil spark gaps are located at the center of the PFL. Closure of these switches launches waves of inverted electric field polarity in both directions away from the switch in the inner coax. When the wave traveling in the forward direction reaches the diode, its electric field adds to the electric field associated with the outer coax producing a voltage pulse across the load.

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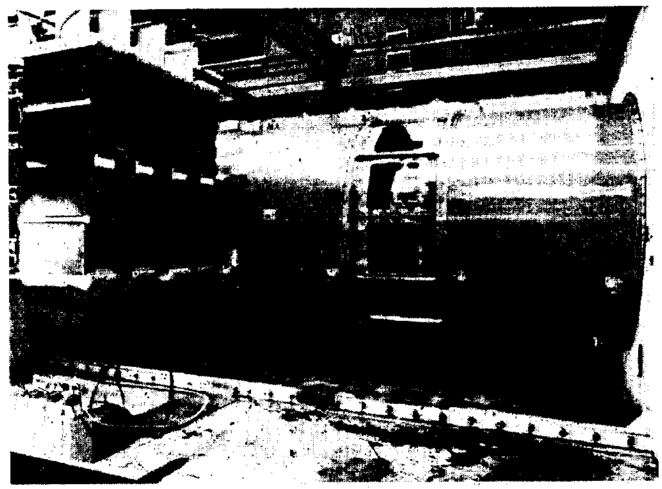

Fig. 1. A photograph of the IBEX accelerator hardware showing the Marx generator, the intermediate storage capacitor, and the cylindrical isolated Blumlein PFL. The oil switch access panels have been removed from the outer cylinder. The entire pulse power circuitry is immersed in transformer oil.

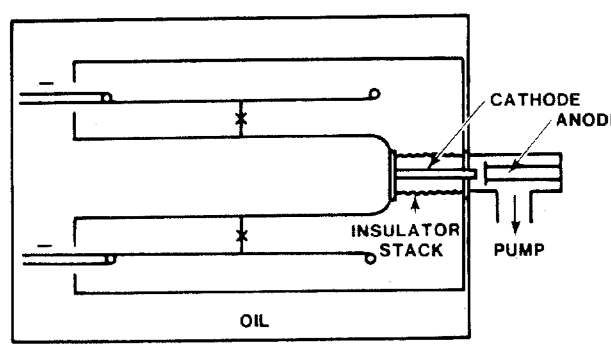

Fig. 2. Schematic diagram of the cylindrical isolated Blumlein PFL showing the symmetric charge line feeds, the oil switch location, the high voltage vacuum insulator stack, and a planar diode.

Note that this circuit produces an output pulse while both sides of the load remain at electrostatic ground potential, without the use of high magnetic permeability material. In effect, the upper and lower transmission line sections to the left of the switch in Fig. 2 provide the necessary inductive isolation at the expense of energy transfer efficiency. Note also, that such cavity structures can be cascaded in series to form a linear induction accelerator configuration.[4]

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Initial pulse power tests of IBEX were performed using a planar diode load, as schematically indicated in Fig. 2. The output diode voltage was monitored with a resistive voltage divider, while the beam current was monitored with a Rogowski coil. Typical pulse waveforms are shown in Fig. 3. Instead of a square shape, the output voltage pulse has a sloping top. This feature is due to extra energy entering the circuit after oil switch closure via the low inductance feed from the ISC.

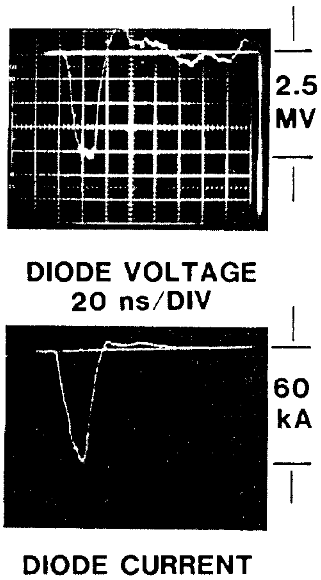

Fig. 3. Typical planar diode voltage and current waveforms during IBEX pulse power check-out testing.

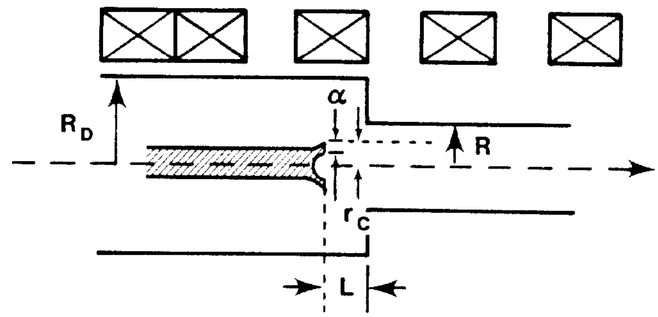

Fig. 4. Schematic design of the IBEX foilless diode structure.

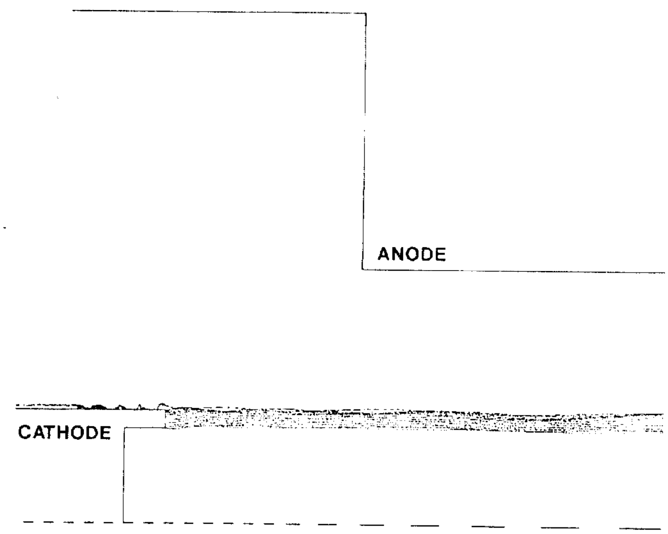

Fig. 5. Numerical simulation of the particle trajectories for the IBEX foilless diode for an applied field strength of 16 kG.

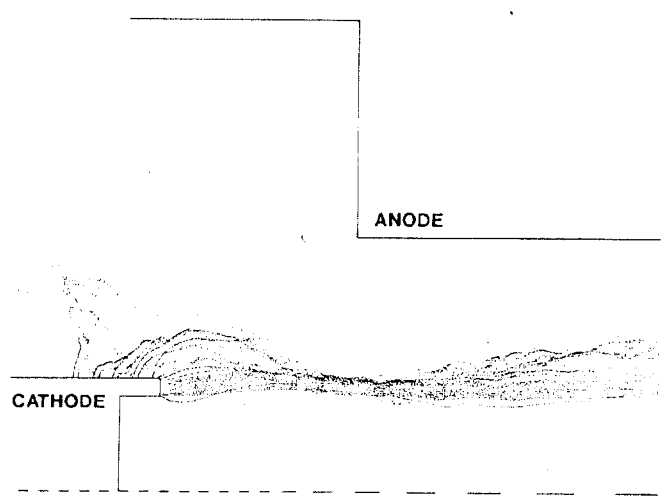

Fig. 6. Numerical simulation of the particle trajectories for the IBEX foilless diode for an applied field strength of 6 kG.

Foilless Diode Experiments

The foilless diode (Fig. 4) was constructed following the design procedures outlined in Ref. 5. Nominal design goals were 30 kA at a diode voltage of 4 MV. The applied axial magnetic field was supplied by a capacitor bank discharge through several individual "pancake" coils connected in series. The axial field profile was approximately constant throughout the anode-cathode gap; the peak field strengths could be varied from 6-16 kG.

In order to check the foilless diode design predictions, numerical simulations were performed using a quasi-static, two-dimensional, particle-in-cell code. Two different cases, at 16 and 6 kG, are exhibited in Figs. 5 and 6. The results for the higher magnetic field strength are in excellent agreement with the calculated estimate, while the beam current for the lower field strength somewhat exceeds the estimate. This difference is due to electron emission from the cathode shank. Such electrons have relatively large Larmor orbits and substantially increase the beam emittance.

Typical diode voltage and current signals for an axial anode-cathode gap of 3.2 cm and a peak magnetic field strength of 7 kG are shown in Fig. 7. The peak voltage and current levels are consistent with the design goals. Note, however, that the diode voltage trace no longer contains the signature of the ISC feedthrough voltage; the inductance of the foilless diode structure has substantially increased the pulse rise time over that of the simple planar diode structure.

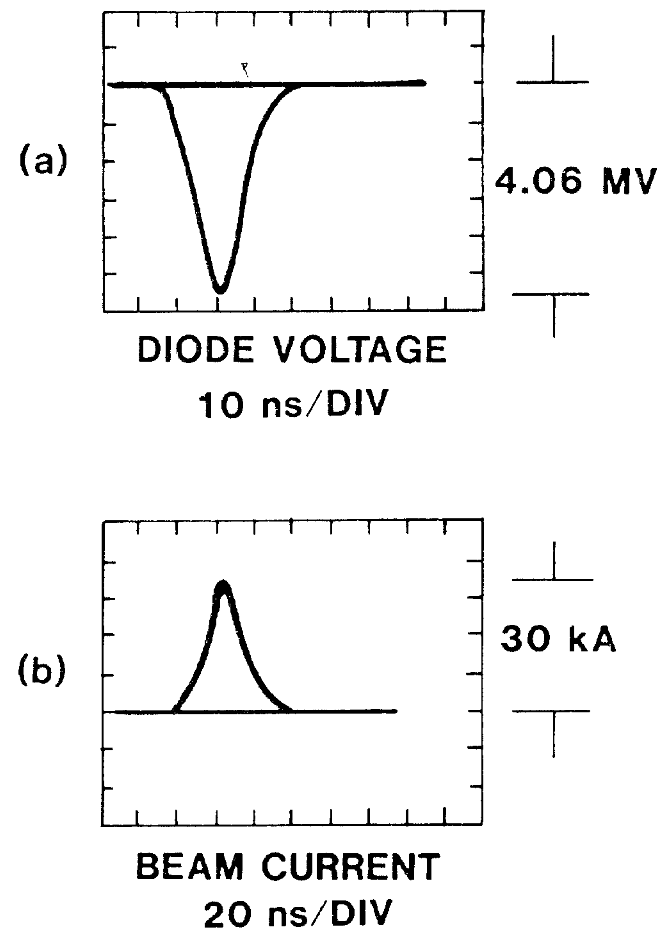

Fig. 7. Typical IBEX foilless diode current and voltage waveforms for an applied magnetic field strength of 10 kG.

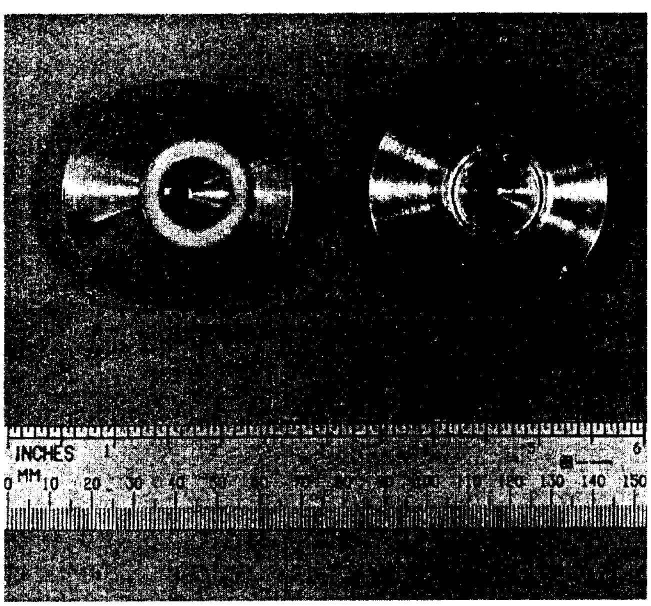

Fig. 8. Typical beam damage patterns at 18 cm from the anode plane. The witness pattern on the left is observed at 7 kG, while the pattern on the right occurs at 14 kG.

Beam damage patterns in brass targets placed 18 cm from the anode are shown in Fig. 8. For the case of 14 kG, the calculated Larmor orbits are less than the cathode annulus, and the resulting beam reflects the cathode tip geometry. For the 7 kG case, the calculated Larmor orbit radius is of the order of a few millimeters, in good agreement with the thicker beam damage pattern. The beam damage pattern was also observed as a function of distance from the anode. Correcting for target pinch effects,[6] the observed amplitude of azimuthally symmetric radial oscillations[7] was essentially negligible (< 0.5 mm).

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