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MULTISTAGE PULSED-POWER ELECTRON ACCELERATORS

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Summary

Pulse power developments in high-current linear accelerators (RADLAC I) and low impedance water transmission lines (PBFA I) are reviewed. The design of Hermes III, a 1.1 MA, 15 MV linear accelerator based on these technologies is discussed and initial data on the development of this accelerator is presented.

Introduction

Requirements to improve intense gamma ray sources for studying radiation effects on electronic systems has made it necessary to develop a new type of induction accelerator. The pulse duration of this radiation source (>200 kR) must be less than 25 ns to achieve the required dose rates ($>9 \times 10^{12}$ R/sec). Since the dose is proportional to $V^{2.6}$, a 40 ns electron beam pulse rising in 20 ns will produce a 20 ns duration radiation pulse. The electron beam parameters required to produce this radiation are 15 MV, 1.1 MA, 40 ns; these are the design goals of Hermes III, a new radiation simulator. To achieve the high power and short pulse duration, a combination of the radial-transmission-line induction accelerator technology (RADLAC)[1] and the high power water-strip transmission line technology developed for the Particle Beam Fusion Accelerator (PBFA I)[2] will be used. In this report the status of these technologies is reviewed, and a conceptual design of Hermes III is presented and initial results of a program to develop this accelerator are given.

RADLAC Technology

If one attempts to achieve the design parameters with the standard oil-insulated Blumlein transmission lines that were used in Hermes II[3], the diameters become excessive. In the RADLAC program this difficulty was overcome by generating a fast rising current pulse with a relatively small, low-voltage (2 MV) diode and then increasing the beam kinetic energy with multiple accelerating gaps. The radial transmission lines serve the multiple purpose of forming the high-voltage pulse and transmitting it to the accelerating gap. The wave motion in these transmission lines provides the isolation usually achieved with ferrite cores in standard induction accelerators. The first successful demonstration of this type of induction accelerator was reported by A. I. Pavlovskii, et al.[4] It is reported that these accelerators have the capability of accelerating high beam currents (10-100 kA) to high kinetic energy (10-100 MeV) with average gradients exceeding 1 MV/m. A later report[5] indicates that a 13.5 MV, 50 kA electron beam has been produced with 14 water dielectric, radial transmission line modules. Beam current losses were less than 25% and the average accelerating gradient was 2 MV/m.

In addition to the high-current capability and the relatively high accelerating gradients, another attractive feature of linear induction accelerators based on pulsed transmission lines (PFL's) is that the development builds on the modular pulsed power technology that has been developed at Sandia National Laboratories for the Inertial Confinement Fusion Program [6-7]. Each module of these accelerators consists of moderate voltage (2-3 MV), oil-or water-insulated, low-impedance, PFL's arranged in parallel to supply very high particle currents to imploding pellets. The information gained in developing these ICF accelerators was used to form the basis of the RADLAC-I accelerator[1]. This device was successfully constructed and has produced a 9 MV, 25 kA, 12 ns electron beam.

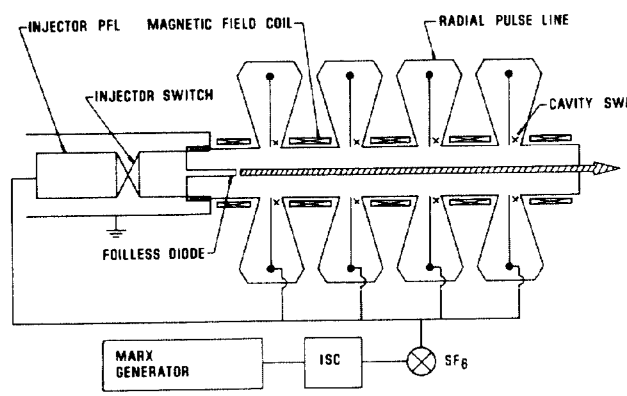

Fig. 1. Schematic design of the RADLAC I device, indicating the key accelerator components.

Figure 1 is a schematic outline of RADLAC I. The accelerator consists of an injector and four, radial-line accelerating cavities. The 9 MeV of beam energy was achieved with a 2 MeV injector and with each of the four cavities contributing 1.75 MeV to the final kinetic energy of the electrons. With such a short beam pulse duration and the requirement to synchronize the arrival of the accelerating pulse with the arrival of the beam, it was necessary for the jitter of the injector PFL and cavity PFL switches to be 1-2 ns. This rms jitter was achieved with two-electrode, oil-dielectric spark gaps[8] and very rapid (160 ns) charging of the PFL's. This rapid charging resulted from the use of an intermediate storage capacitor (ISC) in addition to a Marx generator.

The peak accelerating voltage in RADLAC I was limited by the peak design voltage of the ISC, the output voltage risetime, the particular cavity PFL design, and the vacuum-insulator flashover. The particular cavity PFL would produce an accelerating voltage that was 50% of the charging voltage if the beam appeared as a matched load. The accelerating

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voltage waveform is shown in Fig. 2. Radial pulse line cavities always produce bipolar accelerating waveforms. Ideally the beam would be energized on the second half cycle. The RADLAC-I experiments were conducted using the first half-cycle because of vacuum-insulator flashover at unexpectedly low voltages. The data indicate significantly stronger time dependence ($\sim t^{1/2}$) than do the unipolar data ($t^{1/6}$).[9]

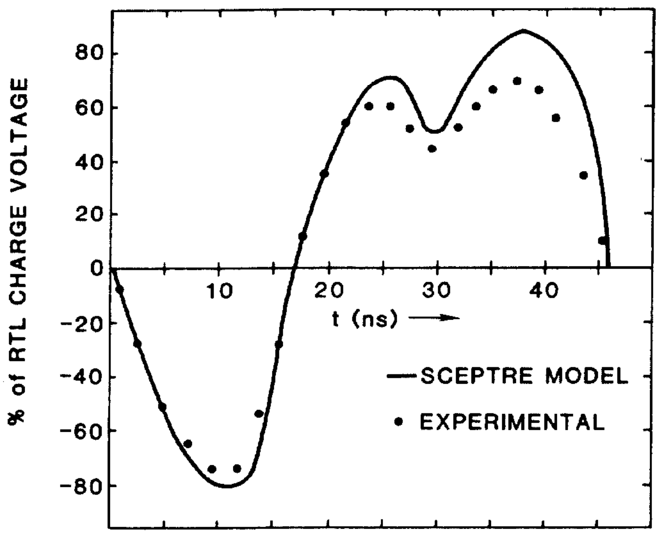

Fig. 2. A comparison of an open-circuit cavity voltage waveform with a SCEPTRE numerical model of cavity performance. The model assumes closure of all eight switch channels and uses an equipotential method to estimate the inductance and capacitance of the corner region.

Beam Considerations

The space charge potential created by the high-current beam as it propagates between the injector and the first accelerating gap limits the peak beam current of this type of accelerator. Thin annular beams are formed with a foilless diode[10] injector and propagated near the drift tube walls to circumvent this problem. The RADLAC-I injector produced 65 kA at 2 MV. Changes in beam diameter and accelerating potential limited the current to lower values for the full accelerator. Subsequent experiments with two of the cavities connected in an isolated Blumlein configuration resulted in the generation of 4 MeV, 100 kA beams[9]. Changes in beam and drift tube diameter and in the injector potential can be used to generate even higher current hollow beams.

Since the beams are operating near the space charge limit in the drift tube, a virtual cathode will form if the accelerating gap width is too large. On the other hand if the gap width is too small, field emission from the accelerating electrodes will load the cavity.

Figure 3 is a numerical simulation of a 2 MV accelerating gap with a 50 kA beam.[1] The numerical results indicate that the electron emission from the gap is suppressed by the beam space charge distortion of the normally-symmetric potential distribution in the gap. Although the beam loses energy as it enters the gap, a virtual cathode does not form. Another feature of the simulation is the formation of radial oscillations of the beam envelope due to the disruption of radial force balance. A solution to this problem is to maintain force balance by varying the magnetic field strength in the gap region.[11] A large variety of beam instabilities[11] have been investigated and none of these appear to be serious for accelerators with a small number (<10) of accelerating gaps.

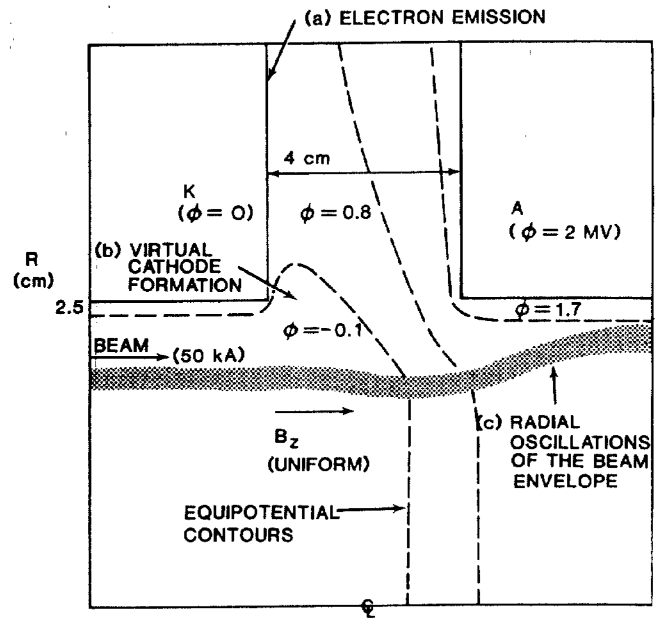

Fig. 3. Numerical simulation of a 2 MV RADLAC I accelerating gap with a 50 kA electron beam.

PBFA-I Technology

A low impedance voltage source (<2 Ω for 2 MV) is required to accelerate the 1.1 MA of electrons that will be needed for Hermes III. PBFA I is a 30 TW accelerator that was developed for the light ion beam fusion program.[2] In this accelerator 36 independent modules generate 2 MV, 500 kA, 40 ns electromagnetic pulses that are simultaneously applied to an ion beam diode. Each module has a 3.2 MV, Marx generator, an ISC, a PFL, and a magnetically-insulated transmission line. The PFL consists of two triplate transmission lines connected in parallel. The impedance of each transmission line of the triplate is 4 ohms. A 1 MV, 1 MA pulse with a 20 ns 10-90 risetime is produced from these lines when the 10 self-breaking, water-dielectric spark gaps close. By rapidly charging (170 ns) the PFL's, two nanosecond jitter in the closing time of each switch is obtained and all ten switches close each time.[12]

PBFA-I was originally designed to be an electron accelerator and was later converted to an ion accelerator to improve the target coupling in the ICF program. In order to make this change, it was necessary to invert the polarity of the output pulse. Since the dieletric strength of liquids are polarity dependent, changing the polarity at the dc power supply would require redesign of a large portion of the high-voltage hardware or a substantial reduction in the output parameters. To alleviate this problem, a unique pulse inverter was invented.[13] By the connection shown in Fig. 4, the pulse transmitted to the load is inverted and a small amount of energy (<10% of total) is propagated perpendicularly away from the crossover connection. Since the impedance seen by this external travelling wave increases rapidly, the losses are small. In the Hermes-III design, this type of inverter is used as a voltage doubler.

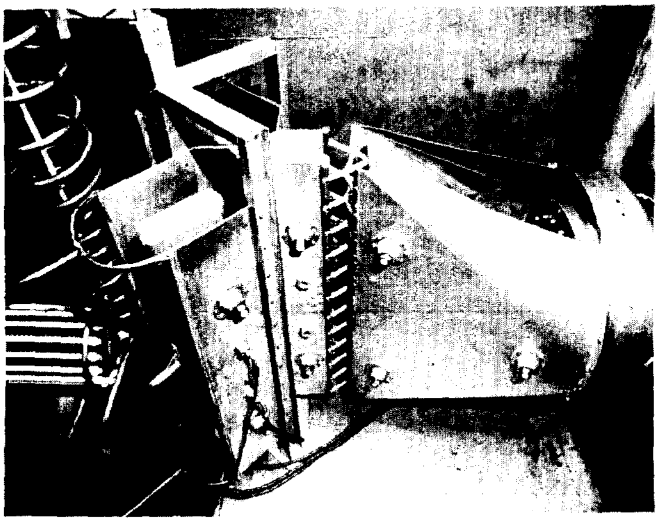

Fig. 4. PBFA-I Pulse Inverter

Hermes-III Design

The Hermes-III design consists of the PBFA-I intermediate storage capacitors, PFL's and pulse inverters and the RADLAC beam line technology. Figure 5 is a drawing of this design.

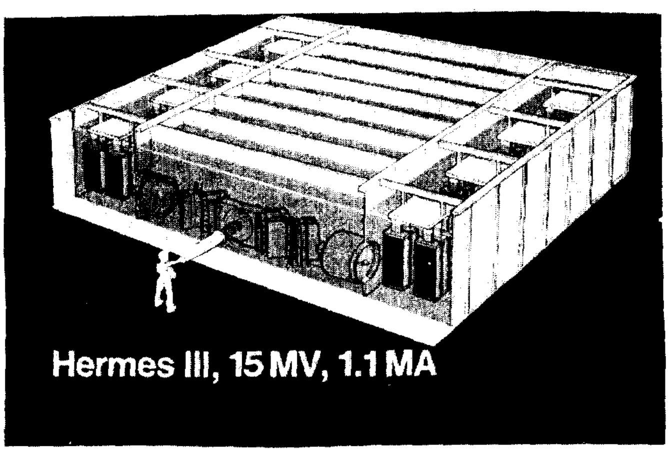

Fig. 5. Hermes III, a 15 MV, 1.1 MA linear accelerator.

It consists of eight 200 kJ Marx generators, 16 ISC's, 16 PFL's, and 16 pulse inverting convolutes. These inverters are located on only one of the transmission lines of the triplate (see Fig. 5) and have the effect of connecting the two transmission lines in series. Thus the output voltage increases from 1 MV to 2 MV and the output impedance increases from one ohm to four ohms. The beam line is fed by two of these combinations in parallel (one from each side) resulting in a 2 MV, 2 ohm source for accelerating the beams. The first two modules will be used to power the injector and the next six to post-accelerate the beams.

As indicated in the beam physics section of this paper, space charge effects limit the peak electron current that can be propagated through such an accelerator. In this application, a 5 cm diameter beam is desired and the magnetic guide field strength is limited to less than 20 kG. This restricts the peak current amplitude to 125 kA in a single beam. Thus, nine beams arranged as shown in Fig. 6 will be propagated through the Hermes III accelerator. Each accelerating gap will be buried in a coaxial hat as shown in Fig. 6 to prevent disruption of the beams by the forces due to the magnetic fields from nearby beams. Beams have been generated in single anode-cathode gap diodes with this configuration and operated completely independently.[14] An extensive series of experiments to develop the appropriate beam line hardware are being conducted.

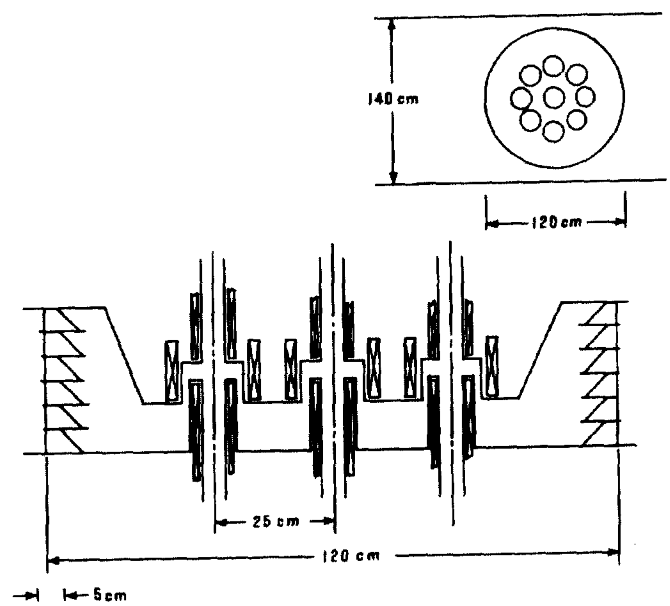

Fig. 6. Hermes III accelerating gap geometry for nine 125 kA beams.

MABE, Megamp Accelerator and Beam Experiment (see Fig. 7), is a new facility that was developed to be used for these beam experiments. Initially MABE was 1/8 of Hermes III and experiments were carried out with a single sided power feed to the vacuum diodes. A 3 MeV, 80 kA electron beam was generated in the first injector experiments. An accelerator consisting of this injector and two accelerating gaps has produced a 6 MV, 40 kA beam. Both the injected current and the final beam energy were limited by electromagnetic losses at the ends of the single-sided power feed transmission lines. A model of electromagnetic waves expanding radially and axially from the diode envelopes to explain these losses agrees with the experimental loss measurements.

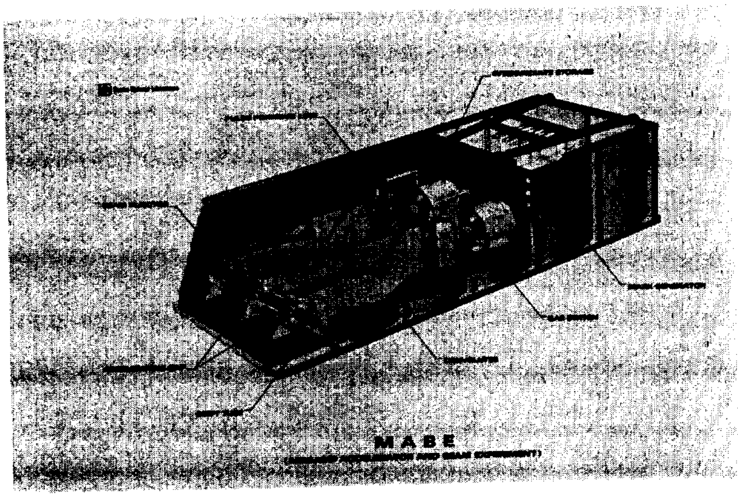

Fig. 7. MABE - Megamp Accelerator and Beam Experiment; cutaway shows one half of the accelerator.

MABE was recently expanded to 1/4 of Hermes III as shown in Fig. 7. The full accelerator is symmetric on both sides of the beam line. With double-sided feeds, the injector voltage can be increased to 4 MV, and based on the foilless diode theory, the full 125 kA beam current can be generated. The energy of this beam will be increased to 8 MV with the two accelerating gaps. Multiple beam experiments will follow shortly thereafter.

Conclusion

The requirement for improved radiation sources has led to the design of Hermes III, a 15 MV, 1.1 MA linear accelerator based on low-impedance, water-strip transmission lines feeding 2 MV accelerating gaps. An experimental program to develop this technology is underway, and a new 8 MV, 125 kA test facility (MABE) has been developed to conduct these experiments.

Acknowledgement

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