THE PULSITRON
A COMPACT, HIGH-CURRENT ELECTRON BEAM ACCELERATOR

W. F. Crewson, J. T. Naff and C. H. Jones
Pulsar Associates, Inc.
La Jolla, California

Summary

A coaxial high current electron beam accelerator design is discussed. A novel feature of this design is that approximately one-half of the required energy is initially stored capacitively in a volume inside the beam. The cylindrical beam is accelerated with a Marx-like circuit.[1] After acceleration, the beam is focused between coaxial biconic conductors to a small cross section. The design incorporates features which have been discussed by others.[2-6] A specific accelerator module design storing 70 kilojoules and capable of producing beam currents greater than a million amperes at 1 million volts is described. The principal advantage of this design is that its compact size will make possible multi-module machines which will have an output far exceeding anything thought practical today.

Introduction

Interest in intense relativistic electron beams has increased rapidly over the past decade. However, the basic methods of generating such beams have not changed significantly over this time period. Several factors now indicate that a rethinking of beam generating techniques is required. The PULSITRON pulsed electron accelerator concept is the product of such an effort.

An intense relativistic pulsed electron beam is taken, for the present purpose, to have maximum electron energy in the range of 1 to 10 MeV, peak current in the range of 0.1 to 10 MA and a pulse length in the range of 10 to 1000 ns. All existing pulsed beam generator systems which deliver beams in these parameter ranges are of "discrete" design; all the energy is stored in one part of the system and is then switched to a single cold-cathode diode structure. This "discrete" accelerator layout has worked well for high-impedance beams, in the range of 20 to 100 ohms. In the regimes of lower voltage and higher current, however, the inductance of the energy store and the diode and switching structures has presented a strong limitation on the peak beam power obtainable.

An additional set of problems arises in the low-impedance regime; to the limitations imposed by the system inductance must be added beam instability problems such as those discussed by Lawson.[2] Lawson predicted that a space-charge neutralized electron beam, under certain special restrictions, would suffer current limitation given by

$$I_{MAX} = 17000\ \beta\gamma \qquad (1)$$

This relation can be rewritten in terms of the peak accelerating voltage (in MV) as

$$I_{MAX} = 34000\ V\sqrt{1+1/V} \qquad (2)$$

The predicted current limiting effect has been observed experimentally. However, strongly accelerated beams, such as those generated in present-day pulsed electron accelerator diodes, are often subjected to electric fields in excess of 1 MV/cm. The analysis does not apply under these circumstances, as Lawson points out. Complex beam instabilities have nevertheless developed in such diodes, even during the relatively short time duration of the pulse (typically, less than 100 ns). The most common instability has been self-magnetic constriction of the beam, causing the beam to collapse radially.

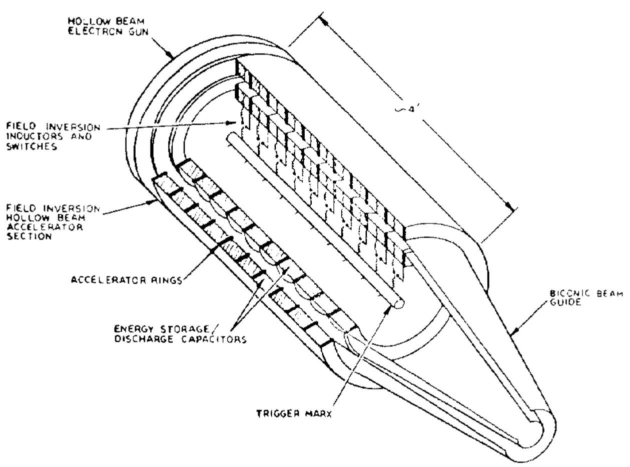
The PULSITRON design concept circumvents these problems, and is now described.

A One-MeV, One-Ohm Accelerator Design

The accelerator system shown in Figure 1 is a synthesis of ideas put forward during the past decade by several independent workers and groups. First, the concept of guiding a drifting electron stream around a central current-return conductor was suggested by Mr. J. C. Martin[3] of the AWRE in 1966. He proposed this arrangement to circumvent Lawson's critical current limit. The PULSITRON utilizes this concept, providing a return current path inside the electron stream. This stream is accelerated in the form of a hollow, cylindrical beam. The inner current return path is provided via a low-inductance array of capacitors, which stores half of the accelerating energy and delivers it to the surrounding beam. Secondly, in 1968, experiments by Yonas at Physics International[4] and Rostoker[5] at Cornell showed that the current limit could be overcome in special circumstances. A hollow beam propagating mode similar in some respects to that proposed by Rostoker has been incorporated in the PULSITRON design. Third, the concept of accelerating a drifting electron stream by passing it along the axis of a string of series Blumlein pulse generators was proposed by Hartwig[6] of the Lawrence Radiation Laboratory in early 1968. Hartwig intended this structure for synchronous acceleration of electron rings. However, the PULSITRON concept uses his basic "distributed" accelerator idea as a pulsed beam accelerator, for beam pulse durations in the 10-to-200 ns range.

The experiments of Yonas and others at Physics International have shown that beams exceeding the Lawson current limit could be guided in cylindrical pipes and would generally follow a curved conducting surface. The PULSITRON concept uses these data as a basis for proposing to guide the hollow beam between two converging coaxial metal cones, to achieve a large gain in power density. The authors of this paper have performed an equilibrium and stability analysis of a beam in this configuration, concluding that stable propagation should be possible in such a guide structure. If an axial magnetic field is applied to the guide, stable propagation is even more certain.

The operating sequence of the accelerator shown in Figure 1 is as follows. First, between adjacent conducting rings in the accelerator column, energy storage capacitors are shown. Each such capacitor comprises a series connection of two equal sub-capacitors, as shown in Figure 2. These sub-capacitors are oppositely charged so that no net potential difference appears between adjacent rings in the column. A low-energy Marx generator traverses the column along its axis and provides triggering impulses to a set of spark gaps as shown in Figure 2. When these spark gaps are triggered, one of the two sub-capacitors in every pair between the adjacent rings reverses in polarity. Ten capacitor sections are shown in Figure 1, and 20 series sub-capacitors, each charged to 50 kV, are included in these ten sections. When the reversal of voltage is complete, 100 kV potential difference appears between adjacent rings in the accelerator column, and a 1 MV difference appears between the extreme ends of the column. This field inversion process occurs in a time interval somewhat longer than the desired electron beam pulse length. Before the column voltage reaches its maximum value, the electron gun structure is triggered and launches a hollow electron beam into the energized accelerating column. This beam is injected at an energy of 100 KeV and is constrained to follow the desired trajectory by an applied axial magnetic field from a pulsed solenoid structure surrounding the electron gun (not shown). This is necessary since space-charge forces predominate over the beam's self-magnetic field at such low energies and would normally cause rapid divergence of the electron stream. After the beam has traversed three sections of the accelerating column, its total energy is approximately 400 KeV and the applied magnetic field is no longer necessary; the beam will be confined by the electrostatic focusing effect of the alternately converging-diverging field between adjacent rings (shown in Figure 2), and by its own magnetic field.



A one-MeV, one-ohm PULSITRON accelerator.
Figure 1

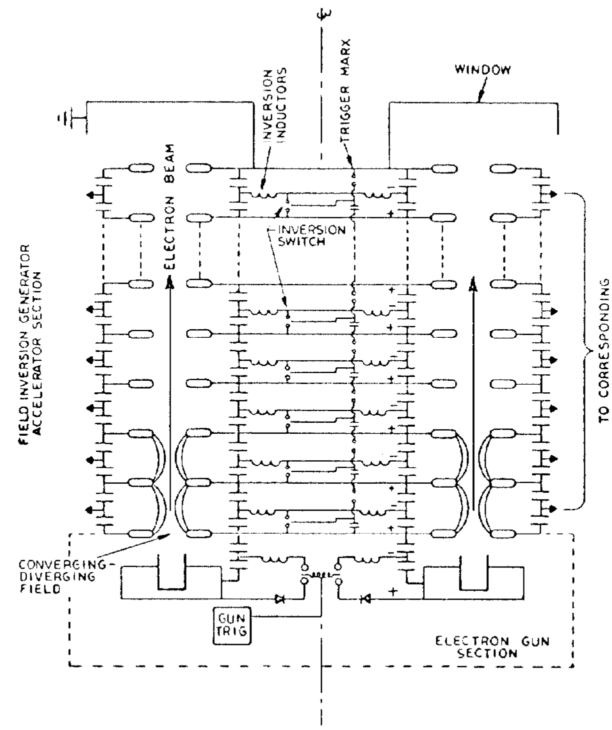
When the beam has traversed the column, it has achieved its full 1 MeV energy and is injected into the converging-cone beam guide for compression to higher power density.

As the beam accelerates down the column, equal return currents are induced in the inner and outer columns of energy storage capacitors. This is easily shown to be a condition of stable equilibrium. This circumstance is sketched in Figure 3. Performing an analysis along the lines of Lawson for this case shows that the new limiting current is given by

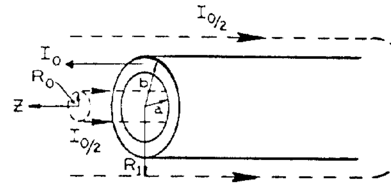
$$I_{MAX} = 34000\ V\sqrt{1+1/V}\ \ (2b/b-a) \qquad (3)$$

The limiting current indicated by equation (2) for a one-MeV beam is independent of beam dimensions, and is approximately 48 kA. However, the current given by (3) does depend on beam geometry. For the column dimensions indicated in Figure 1, this current exceeds two MA.

The inductive limitations encountered in "discrete" accelerator systems are largely circumvented in the PULSITRON since the volume of magnetic field external to the beam, which represents the beam inductance, can be made quite small in the accelerator column. This is a consequence of the low electric field at which the column operates; the storage capacitors can be moved quite close to the beam trajectory, since the column insulator geometry is non-critical.



A schematic diagram of PULSITRON accelerator.
Figure 2



Hollow beam with equal inner and outer return currents.
Figure 3

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