INJECTOR FOR MARYLAND E R A PROJECT: DESIGN FEATURES AND INITIAL PERFORMANCE

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Summary

An injector has been built at the University of Maryland which produces a hollow cylindrical beam of relativistic electrons. The design uses a low-impedance pulse generator and step-up, transmission-line transformer to drive a high-impedance, field-emission electron gun. This paper reviews the design of the pulse generator and performance of the pressurized gas switches. The transformer and electron gun design is also described and results are given for the initial tests of the injector with a 2-MeV, 6-kA beam.

Introduction

An electron ring accelerator being developed at the University of Maryland requires a pulse generator and electron gun system to inject a beam of 5-MeV electrons into the ring-forming cusp geometry.[1] Since a current of 10 kA for 10 ns was thought to be adequate, the relatively low energy required suggested that a low-voltage pulse generator could be utilized with a step-up transformer to provide the high-voltage pulse. The design goal of a 5-MV output pulse could be achieved by a 1.5-MV pulse generator and a transformer gain of 3.5.

This injector system comprises an 8-Ω, water-dielectric pulse generator, an oil-dielectric transmission-line transformer, and a field-emission electron gun. These components are identified on the scale drawing of the injector shown in Figure 1.

Triggered pressurized gas switches are used to provide controllable and reproducible operation. A major concern in the development of the switching system was that the switch jitter be low enough to provide a short risetime pulse. The major concerns in the electron gun development are the hold-off voltage of the radial insulator and the operation of the gun as a high-impedance.

Blumlein Pulse Generator

The pulse generator uses a folded Blumlein circuit which consists of a pair of coaxial transmission lines. The intermediate conductor which is common to both of these transmission line sections is pulse charged by a 12-stage, 1-MV Marx generator.[2] The pulse is formed by discharging six pressurized gas switches arranged around the circumference of the outer transmission line. This pulse generator is contained in a 5 ft diameter water tank, shown near the center of the drawing in Figure 1. Electrical connections to the oil-filled Marx tank and transformer are made through 2 in. thick acrylic diaphragms on either side.

The use of the Blumlein circuit reduces the charging voltage required of the Marx generator. Water is used as the dielectric since it has a high dielectric constant giving the desired 8-Ω impedance and it has adequate dielectric strength when pulse charged. Positive charging is used so that the switches may be placed in the outer line for access by trigger cables. The maximum operating voltage of this generator is determined by the electric field strength on this positive conductor. The field is made more uniform by distending this intermediate conductor into two separate cylinders joined by a torus at the end, as shown in Figure 1. With this distended conductor, equal breakdown probability for the inner and outer lines requires that the generator be unbalanced with characteristic impedances of 5.5 Ω and 2.5 Ω for the inner and outer lines respectively.[3] With the 5 ft outer diameter, operation at 1.5 MV corresponds to a field of 90 kV/cm on the intermediate conductor. This is 70% of the breakdown field-strength of 130 kV/cm estimated by a formula of J.C. Martin.[4]

The shape of the intermediate conductor results in a varying impedance near the end of the two lines. No attempt has been made to calculate the true pulse shape resulting from this generator. The length was chosen sufficient to produce a pulse length of greater than 20 ns.

The switch mounting ring and the support structure design contribute shunt capacity in addition to that of the pulse-forming lines. The total capacity to be charged is 17 nF. With this capacity the 42-nF, 1-MV Marx generator presently used can charge the pulse-forming generator to 1.3 MV.

Switching

Originally SF_6 was considered for the switch gas because of its high dielectric strength. Tests with smaller, lower-voltage switches established that SF_6 filled switches could not be triggered from the cathode as required here. Further testing with mixtures of SF_6 and N_2 showed that the addition of a certain amount of SF_6 would increase the working voltage of the switch without severely deteriorating the fast switching characteristics of N_2. The resulting switch design had to be operated with a greater pressure and a larger gap space than originally anticipated. A mixture of 10% SF_6/90% N_2 is presently being used at 150 psi with a 5 cm gap. The inductance of each switch was calculated to be 150 nH.

The six switches are trigatrons with the trigger pin centered in and flush with the cathode. A fast-rising trigger pulse with a slope of about 5 kV/ns is applied simultaneously to all of the trigger pins through RG-220/U cables. The trigger generator is a small, 8-Ω, water-dielectric Blumlein generator. It is pulse charged to 150 kV in synchronism with the charging of the larger Blumlein generator so it can be command triggered at the desired time.

Detailed measurements of the switching times as a function of pressure and voltage for these particular switches have not yet been made. The switch performance has been checked by simultaneously observing di/dt signals from 6 independent pick-up loops placed close to each of the switches. The observed switch jitter was no more than ± 4 ns which was the resolution of the measurement.

The pressure housing for the switches are made of one inch thick wall MC901 cast nylon cylinders. Nylon, G-10 and Lexan were used as switch bodies in tests with a smaller switch. Of these materials, nylon was the only adequate one. The subsequent rapid failure of the cast nylon high-voltage insulator for the electron gun raises a question about the adequacy of the dielectric strength of larger pieces of this material. Until this question is resolved, the operation of the pulse generator is restricted to 1 MV.

Transformer Section

The desired injector beam current is 10 kA. In anticipation of some difficulty in inhibiting all of the electron emission from the cathode shank with the axial magnetic field, the transformer was designed for delivery of 20 kA at 5 MV. An ideal transformer design for this application would be two oil-dielectric transmission lines with characteristic impedances of 25 Ω and 80 Ω connected between the 8-Ω generator and the 250-Ω load. The three voltage increases experienced by a propagating pulse at the three impedance discontinuities would provide a voltage gain of 3.5. Such a transformer would have had to be long enough so that the transit time of each section was greater than half the pulse length. Propagation of a 20 ns pulse would require a length of over 4 m. This design was compromised by the possibility of a longer pulse and by the necessity for shortening the injector to fit it into available laboratory space. The design was thus changed to a single section tapered transmission line transformer with an input impedance of 28 Ω and output impedance of 70 Ω. The gain of the omitted impedance discontinuity is replaced by the gain of the tapered section. Pulses transmitted through the tapered transformer will show droop so the voltage gain at the tail of the pulse is less than that at the front.

The transformer section, as constructed, is shown in Figure 1. The transit time of 15.4 ns will permit pulses of up to 31 ns to be propagated without superimposed reflections. The measured width of the output pulse was greater than 31 ns in the initial tests. Further analysis is needed to determine whether or not the output could be made more uniform by eliminating the reflected pulse.

Electron Gun

A drawing of the electron gun, magnetic field coils, and iron cusp plate is shown in Figure 2. A 12 cm diameter annular beam is emitted from a circular ½ mil tantalum foil cathode protruding 2 mm beyond its mount. The cathode assembly is supported by a stalk centrally mounted in a 53 in. diameter radial insulator. This insulator configuration was chosen for mechanical stability and freedom from vibration so the annular cathode will remain centered on the magnetic axis of the accelerator. From the data of I.D. Smith[5] on the flashover on insulators under vacuum, J.D. Shipman Jr.[6] has developed a criterion for the design of radial insulators which allows the field to approach 370 kV/cm if the field lines make an angle with respect to the insulator of 50 degrees or greater. The field on the insulator surface was determined by a solution of Laplace's equation with a computer code. The field on the insulator was adjusted by the placement of the toroidal field shaping collar around the center conductor near where the electron gun joins onto the transformer and by the dished head of the outer vacuum chamber. The field angle was also improved by having the central conductor come through the insulator as a 60 degree cone. The calculated field in the final insulator design has a maximum value of 235 kV/cm at an angle of 50 degrees with respect to the surface. The field angles are smaller and the distribution was not as uniform as those used by Shipman in his designs. The field shaping collar helps to make the electric field more uniform over the insulator but at the expense of adding some additional shunt capacity. This capacity to be charged by the 70-Ω generator results in a minimum risetime of 13 ns. For rigidity and strength the original insulator was made of MC901 cast nylon. During tests of the pulse generator, the insulator failed internally. It is not known whether this was due to poor dielectric strength intrinsic to the material or due to defects produced in the manufacture of such a large piece. This insulator recently was replaced with a 4 in. thick piece of acrylic.

The cathode current of the injector will not produce a magnetic field about the shank of sufficient strength to trap electrons emitted from the shank.[7] The externally imposed magnetic field for the cusp must be relied on to trap any such electrons. Since both electric and magnetic fields are non-uniform throughout the vacuum chamber, a computer code was written to calculate single electron orbits in the combined fields. Most of any emitted electrons will be trapped and eventually find their way out the end of the tube. Electrons emitted from certain places on the cathode support will be reflected by an increasing field strength as they move forward and will be returned to strike the insulator. During operation with the clear acrylic insulator a few small trees have been observed which suggest that the insulator was struck by high energy electrons. Further calculations and experiments are needed to determine if this is to be a serious problem.

The cathode has been operated at 2.0 MV with a magnetic field of 2.3 kG and 3 inch anode-to-cathode gap. The effective load resistance was measured as approximately 240 Ω. With the beam stopped by a Faraday cup and current measuring shunt, 70% of the load current was determined to be in the forward beam. The full radial width at half-amplitude of the emitted beam at the anode surface was 3 mm.

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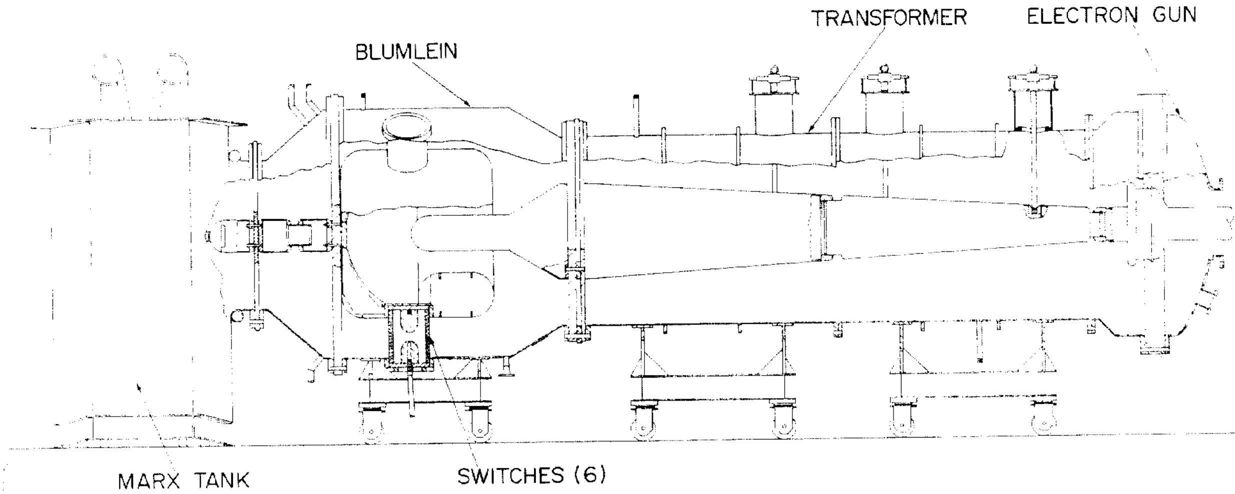

Fig. 1. Side view of injector system. The Marx generator is contained in the rectangular tank on the left. The pulse generator and transformer are contained in the cylindrical tanks shown cut-away.

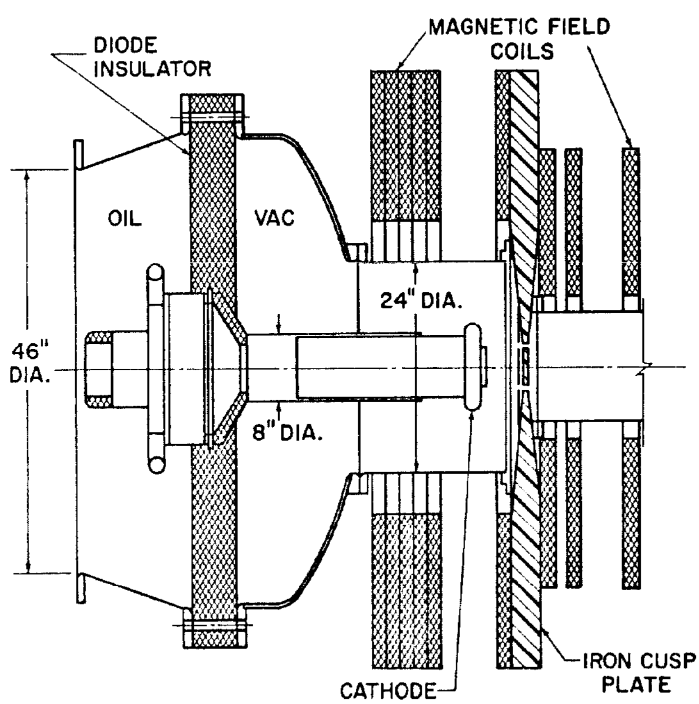

Fig. 2. Cross-section view of the injector electron gun and a portion of the cusp assembly.