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Authors

Christofilos, Nicholas C.
Ehlers, Kenneth W.
Voelker, Ferdinand.

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THE ASTRON PULSED ELECTRON GUN

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N.C. Christofilos, K. W. Ehlers and F. Voelker

Radiation Laboratory
University of California
Berkeley, California

The design and construction of a pulsed electron gun, to be used in conjuction with the Astron program, is under way. The unit will consist of a million-volt pulse transformer and an electron source capable of supplying more than 100 amperes. An unusual design, with the transformer cores and windings in vacuum, is being employed. Design considerations necessary to meet the output requirements are discussed.

INTRODUCTION

A portion of the Astron program has been undertaken at the Radiation Laboratory in Berkeley. The Astron concept requires a pulsed source of well-focused high-current energetic electrons. The approximate values presently considered are 100 amperes of electrons with an energy of one million electron volts. A pulse length of 0.75 microsecond with a 0.25-microsecond rise time is desired. The repetition rate is variable, with a maximum of 60 pulses per second, giving a maximum duty factor of 4.5×10^{-5}. In order to have a useful beam, which in its final application is not lost to the walls, beam divergence must be held to a minimum.

For meeting these requirements in the most practical manner the pulse transformers seemed the most logical choice. Several types of designs were considered. The conventional type of pulse transformer with the cores and windings sealed in an insulating oil would be physically the smallest. However, the shunt capacity of the secondary seriously affects the rise time and pulse shape, and the increased dielectric constant of the oil would increase this capacity. Secondly, a transformer of this type would require the construction of a million-volt bushing which would serve also as a seal between the oil of the pulse transformer and the required vacuum in the region of the electron beam. This we were not anxious to attempt, owing to the long delays and high cost encountered in obtaining specially fabricated ceramics.

In order to minimize the shunt capacity of the secondary, it was decided to attempt a design that eliminated the use of oil and limited the use of high-dielectric ceramics. This consideration required placing the transformer windings and cores, as well as the electron source, in the vacuum. A sample core was obtained and tested, and it was determined that the vapor-pressure characteristics of the core and its impregnant were satisfactory; for the past several months the final design and construction of this electron gun have been under way.

METHOD AND APPARATUS

Figure 1 is a block diagram of the present transformer design. The energy-storage unit is a pulse line which is fed by a +25-kilovolt power supply. A variable-rate trigger unit discharges the pulse line by means of a ball gap, which for this application must pass approximately 60,000 amperes during the 0.75-microsecond pulse length. The switch connects the charged line to 20 paralleled two-turn primary windings driving 20 cores. If the characteristic impedance of the line is matched, 12.5 kilovolts appear across the primary (only one of which is shown in Fig. 1). The secondary winding is an 8-turn helix and is shown in cross section only as it passes through the core window. The 4-to-1 transformer ratio allows 50 kilovolts to be induced into the 8-turn secondary for each core through which it passes. A total of 20 cores is thus required to attain one million volts.

The secondary is wound from 2-3/8-inch o. d. stainless steel tubing. This permits cathode heater wires to be run inside the tubing in a bifilar manner. In order to eliminate magnetic field effects on the electron beam, the cathode is heated by a half-wave power supply. The transformer is pulsed during the part of the cycle when no current is flowing through the cathode heaters. Four kilowatts of heater power have been provided.

The cathode size was determined mathematically by working backward from the beam size desired at its maximum velocity. The electron trajectory was traced backward by noting the space-charge effects on the beam as it passes points of various velocities and charge densities. The result is a cathode approximately 5 inches in diameter.

To minimize space-charge effects at the edges of the beam in the low-velocity region where it is most detrimental, current is actually drawn from a cathode larger than 5 inches in diameter. This

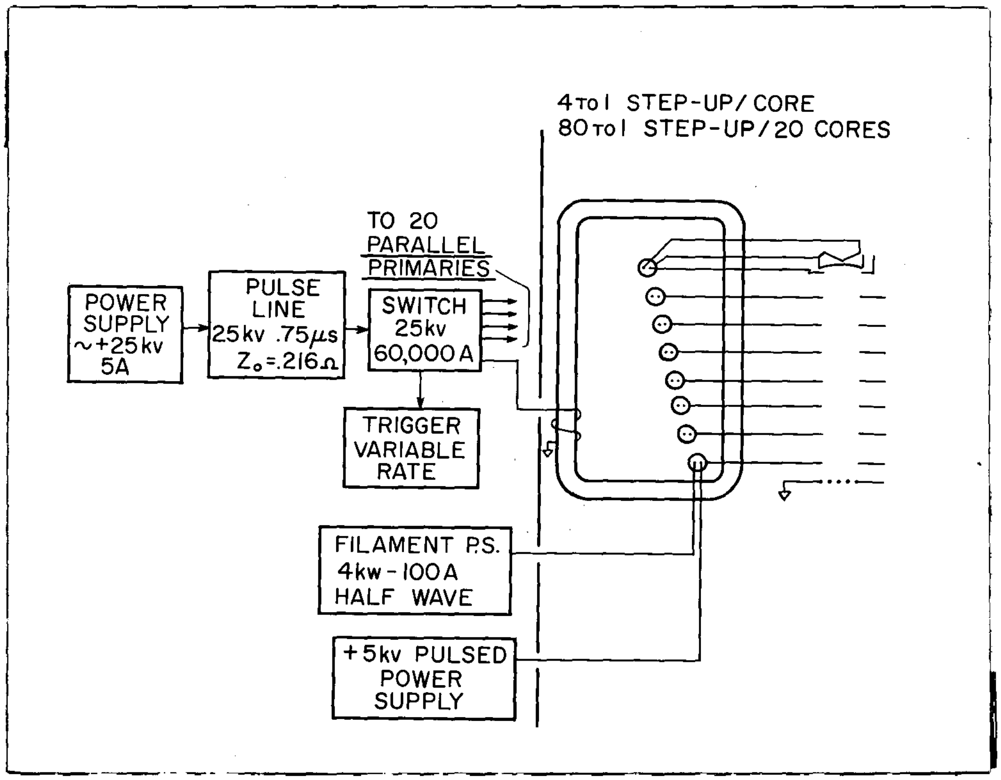
4 TO 1 STEP-UP/CORE
80 TO 1 STEP-UP/20 CORES
TO 20 PARALLEL PRIMARIES
POWER SUPPLY ~+25 kv 5A
PULSE LINE 25 kv .75 μs Z₀=.216 Ω
SWITCH 25 kv 60,000 A
TRIGGER VARIABLE RATE
FILAMENT P.S. 4 kw - 100 A HALF WAVE
+5 kv PULSED POWER SUPPLY

Fig. 1.

allows the beam edges to be defined after the electrons have acquired considerable velocity. A pulsed power supply of approximately 5 kilovolts will be provided for this purpose, and its connecting wire will also be fed through the center of the secondary tubing.

Beam formation will be accomplished with tailored accelerating lenses attached mechanically and electrically to the secondary turns.

Beam divergence or defocusing would be beyond the tolerances desired if the electron stream were allowed to pass through a simple iris acting as the anode. While in transit through the region of an iris, the electron stream would be subjected to a strong defocusing electric field normal to the beam. To reduce this effect, it has been determined that an anode grid is required.

Including the cores and windings of the pulse transformer in vacuum requires the size of the vacuum vessel to be reasonably large.

Figure 2 is a photograph of the vacuum vessel taken shortly after the vessel was mounted in position. The inside diameter of the tank is 7½ feet and the inside height 4 feet. The tank is mounted 5½ feet above the floor. This is several feet above the expected focal point of the beam, which will be directed toward the floor. The large magnet shown in the background is the one used for the original Calutron studies of electromagnetic separation of uranium. This magnet has been degaussed and is not in use; however, we are using its associated vacuum equipment. The vacuum equipment consists of two 32-inch oil-diffusion pumps with -40°C refrigerated baffles. Empty, this tank has been evacuated to 5×10^{-7} mm Hg.

The transformer cores weigh about 200 pounds apiece, thus requiring the use of the overhead crane for assembly.

A sample core wound of 0.002-inch laminations was obtained and tested electrically. These test data, when extrapolated, indicated that a pulse line capable of energizing 20 cores should have a characteristic impedance of about 0.2 ohm. Such a low impedance presents problems in design. A single lumped-constant line was ruled out, for in order to have sufficient sections to insure low pulse ripple, the inherent inductance of capacitors would be too large. An energy storage consisting of long, charged parallel plates immersed in a high-dielectric fluid was ruled out on the basis of cost plus the fact that no safe or satisfactory fluid with high dielectric constant and strength and with low loss factor was available.

Tests were run on RG-8-U coaxial cable to determine whether or not it could hold sufficient voltage to allow its use in a pulse line. These tests indicated that if the center conductor of the cable were made positive and voltages of the order of 25 to 30 kilovolts were used,

Fig. 2.

cable life of more than a thousand hours could be expected.

Our pulse line (Fig. 3) was thus constructed of parallel lengths of 50-ohm RG-8-U cable. Each roll, as shown in Fig. 3, consists of two parallel 250-ft lengths with a characteristic impedance of 25 ohms. Six rolls are needed per core and 120 rolls for the full 20-core operation. The total capacity of this line is 1.8 μf and the characteristic impedance is ~0.2 ohm. Although the line contains 60,000 ft of cable, the total material cost was slightly under $5000.

Each of the 240 cable ends is connected to the ball-gap switch unit (Fig. 4) by means of a fitting which is both oil- and vacuumtight. This switch is made up of four sets of gaps, each set feeding five cores. The center electrode of each three-ball set is the one triggered. The trigger transformers are mounted inside the case, which was vacuum-impregnated with 20 gal of transformer oil.

The case which surrounds the spark gap region contains sound insulation and decreases the gap noise by about 60 decibels. Starting jitter and jitter between gaps have been reduced to 60 mμsec by the addition of a strong ultraviolet light. Thus far, carbon has been used as the electrode material, and its performance has been quite satisfactory. Approximately 50 cfm of filtered air is passed through the gap region. This air serves to remove the gaseous and ionic by-products of the arcs as well as provide electrode cooling.

To prevent a mismatch of impedance, the same number of cables (240) is used to connect the switch to the primary windings.

Figure 5 is a view of the pulse transformer at its present state of development. In this picture, the cores and the 8-turn secondary are shown. Several primary windings as well as primary feed-through assemblies are also visible. The cathode will be mounted below the rounded shield cap in the center, which is the point of maximum potential.

The secondary winding is virtually self-supporting, but a number of disk-shaped insulators have been installed to insure proper turn spacing as well as to damp out mechanical oscillation.

At the present time, the pulse transformer is in the testing stage. With the assembly as shown in Fig. 5 the system has been evacuated to 3×10^{-6} mm Hg. With a water load of 6,600 ohms the secondary was recently energized to about 900,000 volts. The only sparking observed to date has been in the region of the secondary turn-spacing insulators, which at present are made of Epon. These insulators are being redesigned and fabricated of ceramic material.

Fig. 3.

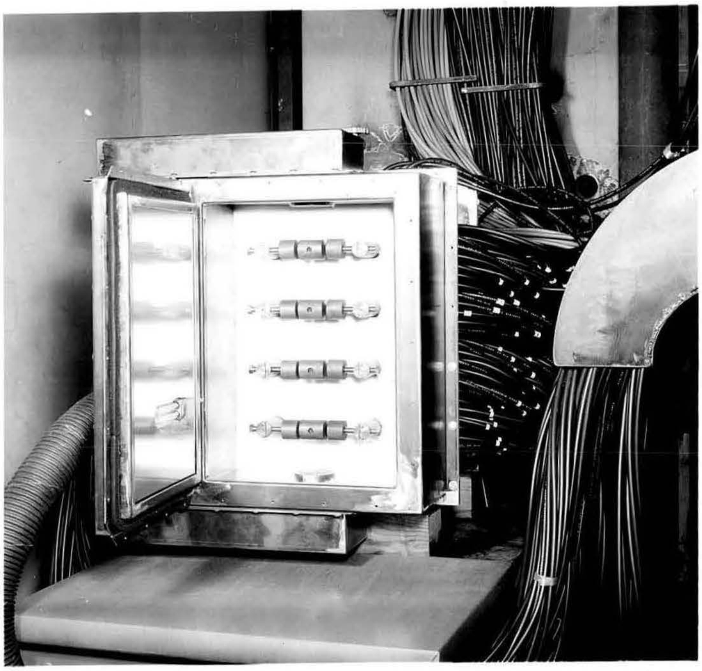

Fig. 4.

Fig. 5.

When the testing and voltage calibration are complete the cathode and gun assembly will be installed. The cathode (Fig. 6) was constructed with the aid of Eitel-McCullough, Inc. of San Bruno, California, and represents the largest ever attempted by this company. It is a nickel-matrix type and is 6-1/8 inches in diameter. In its construction a mixture of barium and strontium carbonates and nickel powder were pressed onto a nickel backing plate. A pressure of more than a million pounds was used; it was applied by the large hydraulic press located on the campus of the University of California.

To obtain the total beam current desired, a space-charge-limited cathode emission of only 1.4 amp/cm^2 will be needed.

In order to terminate more properly the accelerating electric field, an anode grid with a transparency of 66% has been constructed. Including the maximum beam losses as well as heat radiated from the cathode, the grid dissipation will be approximately 3 kw. For this reason the construction of a water-cooled grid was attempted. The grid, as shown in Fig. 7, is 5-1/4 inches square and is constructed of 88 stainless steel tubes 0.020 inch o. d. and 0.010 inch i. d. These tubes are separated by a spacing of 0.040 inch, and are connected at either end to a water manifold. Because of the small inner diameter the tubes will be cooled by means of a self-contained water system. This system contains adequate filters as well as a heat exchanger. With a 200-pound head, water flow through the complete grid assembly is about 1 gal/min.

When the pulsed electron gun assembly is complete, beam studies will be carried out. The x-ray flux in this test area will be extremely high, and plans for adequate shielding are now being made.

ACKNOWLEDGMENTS

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Fig. 6.

Fig. 7.

FIGURE CAPTIONS

Fig. 1. Block diagram of Astron pulse transformer

Fig. 2. Vacuum vessel

Fig. 3. Pulse line

Fig. 4. Spark-gap switch

Fig. 5. Transformer assembly

Fig. 6. Cathode

Fig. 7. Water-cooled anode grid