HIGH CURRENT PULSED ELECTRON ACCELERATOR*

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The most important component required for the Astron experimental facility is a high energy, high current, pulsed electron accelerator. A thin cylindrical layer of high energy electrons trapped within an axially symmetric magnetic field is the key feature of the Astron thermonuclear device. The trapping magnetic field is constant in time. Therefore, it is not possible to inject electrons and trap the electrons in this field unless during the injection phase a part of the electron energy is absorbed by some friction process. This is accomplished by means of eddy currents generated on suitable passive circuits by the current of the injected electron bunch. This method has been described elsewhere. However, in order to achieve an effective loss mechanism the current of the injected electron beam must be over one hundred amps. Such high current beams are difficult to handle except if the electron energy is high enough so that the electrostatic repulsive force is compensated to great extent by attractive magnetive forces. Hence the electron energy required is 5 Mev or higher. Other requirements on the electron layer yield the same result. Therefore the parameters of the Astron electron accelerator are as follows:

Electron energy	5 Mev
Peak beam current	200 amps
Pulse length	.2 μsec
Repetition rate	30 to 60 pps

Furthermore the quality of the beam must be as high as possible in order to avoid transverse spreading during the injection pulse. The beam quality is usually referred to, in accelerator language, as the product of the random transverse momentum times the beam radius divided by the total momentum of the electrons. This quantity must not exceed, in the Astron accelerator, a couple cm radians. In addition the energy error or energy spread during the pulse must not exceed one or two percent.

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These rather strict requirements remove from the picture certain types of accelerators, as for example the Stanford type microwave accelerator. An electron beam of a couple of amps would be enough in such an accelerator to cause a much larger voltage fluctuation than the one allowed. A beam of one hundred amps will shift the resonant frequency of the cavity much more than the Q-curve limit. Some thought has been given to a microwave accelerator using a much larger cavity than the Stanford type loaded wave guide. This large cavity could be excited on a high order mode. The stored energy in the cavity would be large enough to limit the frequency shift caused by the high current beam. However, the energy fluctuation would be much higher than the prescribed limit. In addition about 40 klystrons, 20 MW each would be required to provide the power for the acceleration of the 200 amp electron beam. The parallel operation of this large number of klystrons coupled to a single cavity is rather questionable. Consequently this scheme was not pursued further. Some other alternatives did not appear satisfactory either. After reviewing a number of possible schemes it was concluded that the best solution was to employ a very old principle which although known for about 40 years, was never employed in a practical linear accelerator. This old principle is to use an accelerating induction electric field generated by changing the magnetic flux in a ferromagnetic material. A few years ago when electron accelerators were producing beams of one amp or less such an accelerator would have had an unacceptably small efficiency, for the excitation current required to pulse the ferromagnetic material was very large. However ferromagnetic materials of much better quality have been developed and are now commercially available. Consequently the required high current beam combined with smaller excitation current made this principle attractive for a practical machine, since an efficiency of over 10% is now possible.

A schematic diagram of the accelerator is shown in Fig. 1. The accelerator consists of a number of identical modular units. Each unit is a cavity loaded with a ring-shaped laminated silicon steel core. The primary winding is connected to a pulse-forming network through a high current switch. Since a large number of switches are required and the repetition rate is 30 to 60 pps it appears that hydrogen thyratrons are the best solution for the switching gear.

All the cavities are axially symmetric. They enclose an accelerating column built of ceramic rings sandwiched between metallic rings. These rings are electrically connected with the cavities and are shaped to shield the ceramic from scattered electrons. The electric field is generated across the gaps between the metallic rings.

The electric field (E_z) across these gaps at radius r_o can be expanded in a Fourier series,

$$E_z = E_o \sum_n a_n \cos (nkz)$$

where

$$k = 2\pi/s$$

and s is the distance between consecutive metallic rings. The free-space wave length corresponding to the pulse length is over one thousand times larger than the diameter of the accelerating column. Hence a solution of the Laplace equation is a good approximation to calculate the field distribution. Hence the solution for the axial electric field within the accelerating column is

$$E_z = E_o[1 + \sum_n a_n \beta_n I_c (nkz) \cos(nkz)]$$

where

$$\beta_n = [I_o(nkz)]^{-1}$$

All the higher harmonics of this solution are undesirable and they must be suppressed to a very small value. It turned out that it is possible by selecting the radius (r_o) of the metallic rings about twice the beam radius and the distance between rings three to four times smaller than the radius r_o, to suppress the higher harmonics to about 1% of the accelerating field. Thus a very uniform accelerating field can be achieved by proper selection of the dimensions of the accelerating column in comparison to the beam size.

A 5 Mev accelerator of this type is now being built at the Radiation Laboratory at Livermore. It is expected to be completed within a year.

A number of lenses are required along the accelerator to compensate for the electrostatic defocussing field of the beam. However at lower energy below 500 kev the defocussing forces are rather large and focussing by lenses is rather difficult, in this type of accelerator. Therefore the first section of the machine up to 700 kev is designed and being built in a somewhat different way. The first section which is referred to as the electron gun resembles a Pierce-type gun, to provide a convergent electron beam. The space charge is compensated by the gradient of the accelerating field so that there is no radial defocussing field. The beam size is larger in this section, namely at the cathode the beam diameter is 22 cm. The acceleration is provided by loaded cavities as described above. However, the metallic rings are larger and the applied electric field between the cathode and the anode is variable according to the space-charge law. A problem was with the anode hole. In order to achieve the prescribed beam quality it is required that the electric field be parallel with the electron trajectories. This is achieved by providing an anode which appears electrically as a solid plate. This anode is a grid of tubes of one-half millimeter diameter. These tubes are water cooled. Since a considerable amount of heat is deposited in these tubes the required water pressure is a few hundred psi.

An electron gun of similar type was built two years ago and has been operated successfully, in this respect, for more than a year. The beam quality is excellent. The beam diameter at the anode is 10 cm and the beam current 40 to 50 amps. In the new 200 amp electron gun the beam current density is the same as in the gun now in operation.

Simultaneously with the construction of the 5 Mev accelerator the other components of the Astron facility are now being built. The facility is expected to be completed by the summer of 1961. After the completion of the facility it would be possible to start experiments to evaluate the Astron principle either in establishing the E-layer or in trapping high temperature plasma.

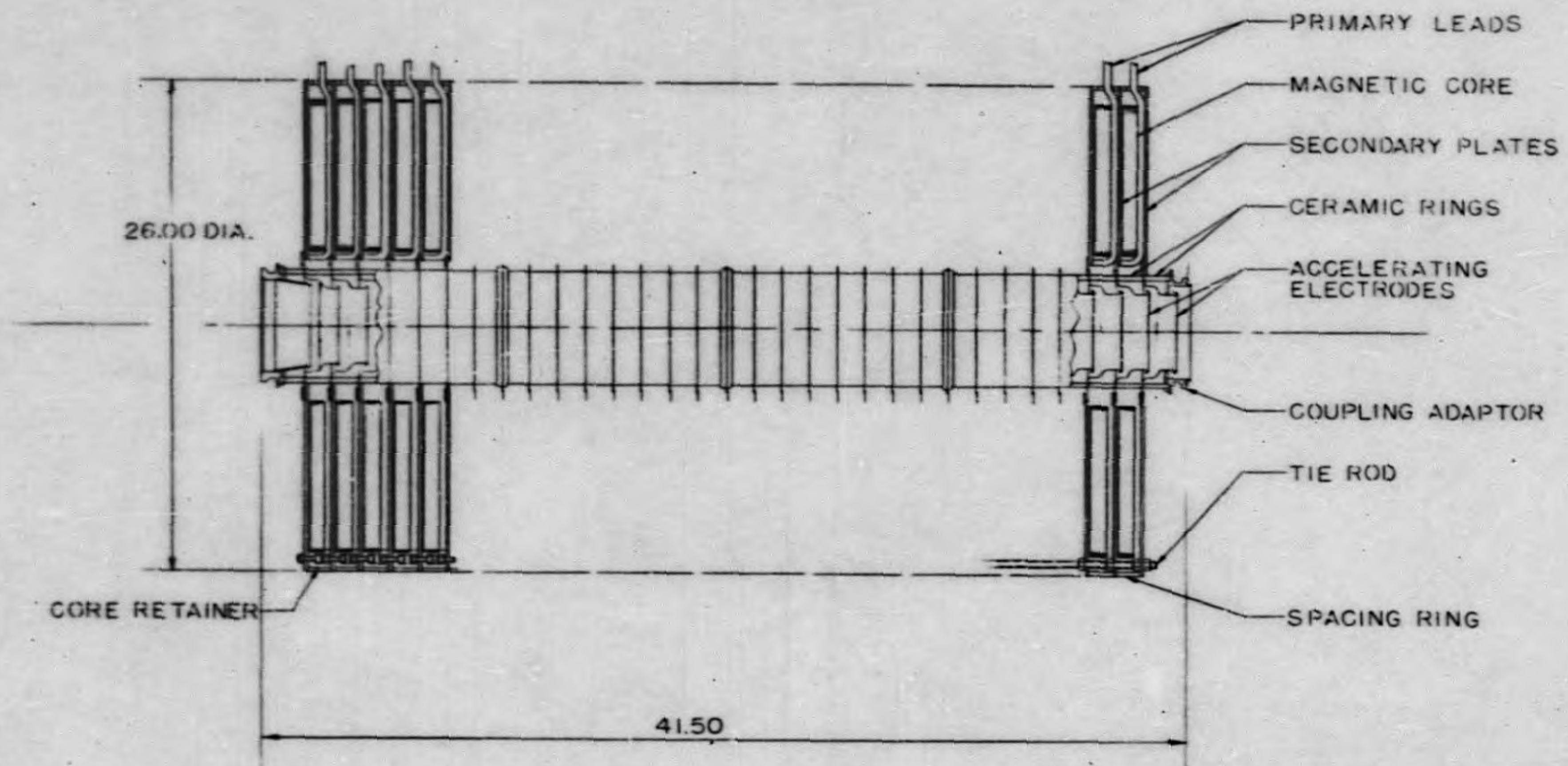

Fig. 1. Accelerating section of the Astron.

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