THE CAMBRIDGE ELECTRON ACCELERATOR

Harvard University, Cambridge, Mass.

(presented by M. S. Livingston)

SYNCHROTRON DATA

Person in charge	M. Stanley Livingston	Person supplying data	M. Stanley Livingston

History and Status

Design study	1956	Completion date	April, 1961
Model tests	1956-58	Scheduled operation	
Engineering design	1957-58	Magnet cost	
Construction started	1957	Total cost	

Design Specifications

Magnet

Focusing, type	AG
Focusing, order	FOD
Field index, *n*	91
Bending radius	86½ ft
Mean machine radius	118 ft
Magnets, number	48 : 24 F, 24 D
Field, at injection	25.4 G
Field, maximum	7 600 G
Power input, maximum	~1 200 kW
Storage system	ring choke capacitor
Rise time	
Weight	Fe 298; Cu 49 tons (U.S.)

Aperture

Width	5.26 in.
Height	1.55 in.

Shielding	8 ft shielding wall, loaded concrete 150 lb/cu.ft

Design Goals

Particle accelerated	Electrons
Energy	6 GeV
Pulse rate	60/s
Output	1×10^{11} part/pulse

Injector System

Type	Linear Accelerator
Energy	20 MeV
Injector output	250 mA
Injection period	1 turn
Inflector type	Electrostatic

Acceleration System

Frequency	475.83 MHz
Accel. cavities	16
Harmonic number	360 RF cycles/turn
Orbit freq. final	1.32176 MHz
Gain at maximum *dB/dt*	860 keV/turn
Input to RF, maximum	400 kW

STATUS REPORT

The Cambridge Electron Accelerator is an alternating-gradient synchrotron designed to accelerate electrons to an energy of 6 GeV. It will operate at a repetition rate of 60 pulses per second, with an expected beam intensity of 10^{11} electrons per pulse, or a time-average beam of 1 μA.

The CEA laboratory and administration building, located on Harvard University grounds on a site adjacent to the Harvard cyclotron, was occupied in April, 1958. The ring tunnel of the accelerator, the power building at the center of the ring, and the external experimental building are nearing completion (see Figs. 1 and 2).

At the present time, detailed designs of most of the major components of the accelerator have been completed, and orders have been placed (*). Samples of some components have been received for test and study—these include magnet supports, magnet core blocks, clamps, end packets, coils, resonant capacitors, and a high power RF supply capable of providing half the RF power needs of the accelerator. Two prototype magnets have been assembled and measurements are in progress.

Magnet

The guide field of the synchrotron will be supplied by 48 magnets arranged in a ring. 24 are radially focusing and 24 are radially defocusing. The two types are placed in alternate sequence around the ring, with a straight, zero-field section between each pair of magnets. The sequence is : Focusing - Zero - Defocusing - Zero, repeated 24 times around a ring whose radius is 118 feet, measured to the orbit location in the magnet gap. Each of the 48 magnets consists of two similar 65.40 in. sections mounted on a single box-girder. Each half section is made of six 10.65 in. core blocks formed from stamped laminations of thermally flattened, Carlite-coated Armco A6 steel, bonded together by a thermally cured resin. (Pliobond).

The six blocks are located on precisely machined rails on the top girder surface, and are clamped together, between ¾ in. end packets of transverse steel laminations. Two straight half-sections are placed on the girder at an included angle of 176.25°, with a spacing between the two half-sections of about 2.76 in. Between each pair of magnets of different sign there is a straight field-free section about 50 in. long for radio-frequency cavities, pick-up electrodes and pumps.

Each of the 48 magnets is excited by four coils connected electrically in series, two coils above and two below the magnet gap, surrounding both half-sections of the magnet. Each coil has ten turns of conductor, for a total of forty turns per magnet, and the conductor consists of two 37-strand twisted copper cables. Copper tubing wound in a layer between the cable turns carries water for cooling the coils. Individual strands are insulated to reduce eddy current losses, additional insulation is provided around each stranded cable. Each coil is impregnated with bonding resin to prevent motions which could produce failure of insulation or fatigue embrittlement of the copper, and is encased in a high-voltage insulation wrapping (sinee Fig. 3).

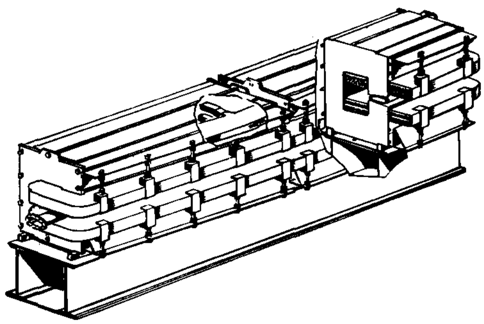

Fig. 3 CEA magnet sector.

Magnet power supply

The magnet circuit, which includes the magnet coils, the resonant capacitors and a ring energy-storage choke, is essentially a parallel resonant L_1-C-L_2 circuit with a high Q ($\sim$100).

The magnetic field will change from zero to maximum (7.58 kG for 6 GeV electrons) during each pulse. To accomplish this both direct and alternating currents are fed to the magnet circuit. The d.c. bias current is provided by d.c. supply No. 2. The a.c. component is provided by a pulsed system comprising a d.c. supply (No. 1), an $L-C$ filter and storage circuit, a pulse choke, and an ignitron pulser. The storage capacitor is charged by the d.c. supply and the ignitron pulser is fired to transfer this stored energy to the resonant capacitors of the magnet circuit once each cycle of the resonant circuit. The duration of the current pulse is shorter than the period of the magnet circuit, and is applied on the " down " side of the excitation cycle for the magnet. The filter

(*) A list of the components on order is appended.

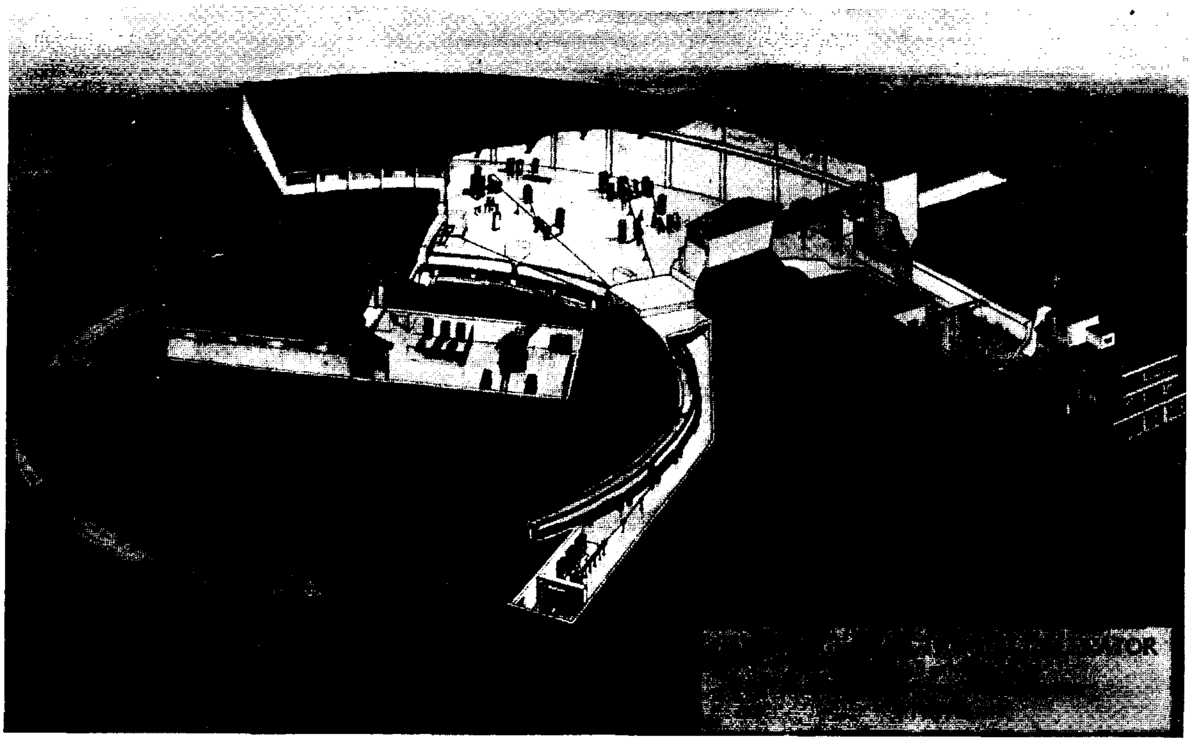

Fig. 1 CEA synchrotron and experimental hall.

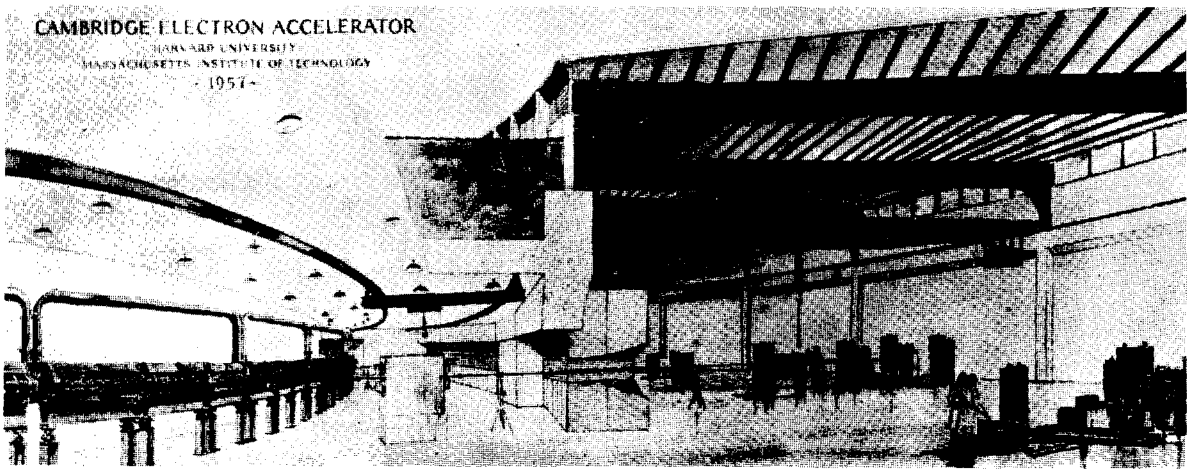

Fig. 2 CEA ring tunnel, shielding wall, and experimental hall.

choke provides for isolation of the storage capacitor from the d.c. supply. The prototype magnets are being powered by a smaller supply with a similar equivalent circuit. One prototype magnet serves as a storage choke while the magnetic properties of the other are being studied.

Injection

Electrons, after being accelerated to 20 MeV in a linear accelerator located in a spur tunnel, will be directed into the ring of the synchrotron through a system of focusing magnets. The particle trajectories will be deflected into the orbit by a pulsed electric field between inflector plates placed in a straight section (the injector). The linac operates at a frequency of 2855 MHz, the sixth harmonic of the RF frequency. Its specifications call for a total output current of 250 mA, a spot size of 0.5 in., an energy interval of 1.0 MeV, and a minimum of 210 mA within an angular variation of $\pm 3\times10^{-3}$ rad. The beam parameters must be maintained over a minimum beam-pulse length of 0.7 μs, which is the time required to fill the orbit.

The linac is being constructed by Arco. Most of the components are completed, and assembly and testing will start soon. From the performance of other linacs built by Arco, we expect that CEA specifications will be met.

A pulsed supply for the inflector plates is on order from Levinthal Electronics. Designs of other components of the injection system are in process and will await the results of a detailed study of the linac to be made after it is delivered to CEA.

RF system

The frequency of the RF accelerating system is chosen to be 1/6 of the linac frequency, or 475.83 MHz. The accelerating system consists of 16 copper cavities each consisting of two half-wave sections and each about 25 in. long and 16 in. in diameter, equally spaced around the accelerator ring and strongly coupled together by waveguide. High RF power (400 kW peak) will be supplied by a transmitter located in the power building at the centre of the accelerator ring, and will be fed through waveguide into the ring of RF cavities.

The theory of the strongly coupled RF system consisting of a ring of cavities joined by waveguide was developed by K. W. Robinson [1] and a 10 000 MHz model ring of six such cavities was studied experimentally at CEA by Barrington et al. [2]. The experimental results provided striking confirmation of the theory.

Several model cavities have been studied at low RF power levels, and one model has been excited to full power level. No objectionable discharges have been encountered with a clean cavity, so no difficulty is anticipated in maintaining the peak fields required in the accelerator (see Fig. 4).

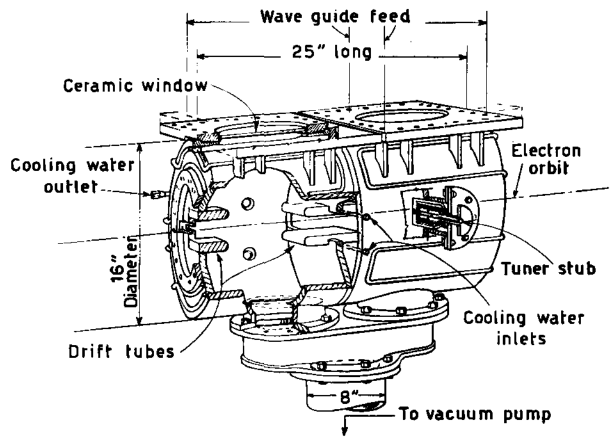

Fig. 4 CEA radio-frequency cavity.

An order for eighteen cavities (sixteen for the accelerator plus two spares) has been placed with Solar Aircraft which provides for the preliminary fabrication of a prototype cavity to be tested before production of the other seventeen.

I-T-E Circuit Breaker Company will supply the system of waveguide links which couple the cavities. Fifteen of the links each have a phase shifter, two utility slot sections for test measurements, two 11.25° *H*-Plane elbows, two 90° mitred *E*-Plane elbows, one expansion section, the necessary straight waveguide (WR 1800, 18.000 in. $\times$ 9.000 in.) and all necessary hardware for assembly. The sixteenth link will contain in addition one tee section for power feed-in and one extra 45° phase shifter. The waveguide for power feed will include three expansion sections and one utility slot section.

A transmitter developed and built for CEA by Levinthal Electronics has been used for cavity model tests at high power. This transmitter employs an

Eimac X-602 klystron, and two such transmitters could supply the required total power to the sixteen-cavity ring. After successful operation of the transmitter over a period of several months, the power tube failed and has been sent back to Eimac for replacement.

Single klystrons are now being developed capable of supplying the total RF power required for the CEA system. These developments are being watched with interest since, if such a tube becomes available in time, a single RF transmitter could be used to advantage.

Vacuum system

The vacuum chamber which fits between magnet poles will consist of a slotted, non-magnetic, stainless steel tube having a flattened oval cross-section, about 1½ in. high and 5 in. wide coated with resin for a vacuum seal. The slots, whose purpose is to reduce eddy-current losses, are ½ in. apart and are cut from alternate sides of the chamber. The steel tube will be wrapped with fiber-glass cloth which is impregnated and coated with epoxy resin, to form, after curing, a solid vacuum-tight wall. The tube is to be fabricated in forty-eight sections, to fit in the twenty-four open and twenty-four closed magnets. The design specifications of the chamber have been sent to possible suppliers with invitations to bid.

Ion-getter-type pumps appear to afford the best solution to the pumping problem. New models of evaporion and vac-ion pumps are being investigated, and a program is also under way at CEA to develop a pump particularly suited to the synchrotron requirements.

Equipment ordered

Component	*Date of Order*	*Delivery thus far*
Magnet core blocks	5/1/58	Prototype
Magnet girders	11/14/58	Prototype
Magnet girder jacks	6/20/58	All
Magnet jack supports	7/18/58	All
Magnet coils	3/6/59	Prototype
End packets	9/16/58	Prototype
Coil support brackets, End plates	2/8/59	Only prototype ordered
Magnet Power Supply :		
d.c. supply No. 2	3/31/59	
d.c. supply No. 1	3/31/59	
Filter choke	3/31/59	
Storage capacitors	3/31/59	
Ignitron pulser	9/22/58	
Ring choke core blocks	6/18/59	
Linear accelerator	3/27/57	Due 10/1/59
Inflector power supply	1/1/59	
RF power supply		Received
RF cavities	6/19/59	
Waveguide links	6/19/59	

LIST OF REFERENCES

1. Robinson, K. W. The RF system of the Cambridge 6-BeV electron synchrotron. Bull. Amer. phys. Soc., *4*, p. 269, 1959.
2. Barrington, A. E., Dekleva, J. and Rees, J. R. X-band analog of the Cambridge electron accelerator RF system. Bull. Amer. phys. Soc., *4*, p. 269, 1959.

DISCUSSION

STAFFORD : Would Livingston give the approximate dimensions of the experimental area?

LIVINGSTON : The experimental hall will accommodate six emergent beams from possible target locations located in free straight sections, which fan out across the large experimental area. This is a little over 100 ft in radial width and about 325 ft circumferential length at the midpoint. It is somewhat larger than a football field, and under a 40 ton crane.