Experimental control signals are individually buffered and distributed to experimental stations. A separate system is used to control injection timing and to produce the r.f. amplitude program.

Revision of the entire control system has eliminated numerous duplications of functions and components, particularly of power supplies, which were sources of failure. Silicon semiconductors have been used exclusively. Only one device failure has been experienced to date.

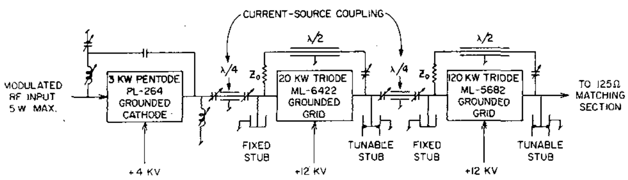

Fig. 3 - Tuning and coupling scheme, 250 kW linear r.f. amplifier, CalTech electron synchrotron.

The control circuit development was carried out in collaboration with J.H. Marshall and J.H. Mullins. Mechanical design and construction of the r.f. system was carried out by D. D. Sell with the help of the synchrotron crew under L. Loucks. Electronic sub-systems were produced by the electronics shop under the direction of L. Nesleny, and were made to work with the assistance of R. Severns.

It is a pleasure to acknowledge the help of J. H. Mullins, both in developing the double-tuned concept and in making both this and the previous r.f. system work in the double-tuned mode.

DISCUSSION

LITTAUER: Are you considering modulation of your linac iniector at the r.f. frequency, or is this not feasible at your harmonic number?

MALOY: Prebunching is not useful because injection is multiturn. The energy spread of the injected beam leads to virtualy complete smearing of the bunches by the time the r.f. is turned on injection of the beam with the r.f. on is not feasible at present because the inflector is not pulsed.

THE CORNELL 10 GeV ELECTRON SYNCHROTRON *

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About two and one-half years ago our group at Cornell proposed the construction of a 10 GeV electron synchrotron. Eventually, in April of this year, this proposal was funded by the National Science Foundation. In the meantime a study program had been supported by the same agency and included the construction of a number of prototype magnet units.

The basic features of the facility under construction are the following: the accelerator is to be of large orbit radius in order to minimize the radiofrequency power which must be supplied to compensate for the energy loss by synchrotron radiation. This leads to the possibility of using a magnetic guide field which has a low value of maximum field strength, low construction cost, and small sectional size. For 10 GeV operation, with a 100 meter orbit radius for the magnetic guide field, the field strength is 3.3 kG.

* Supported by the National Science Foundation, Contract No. C405.

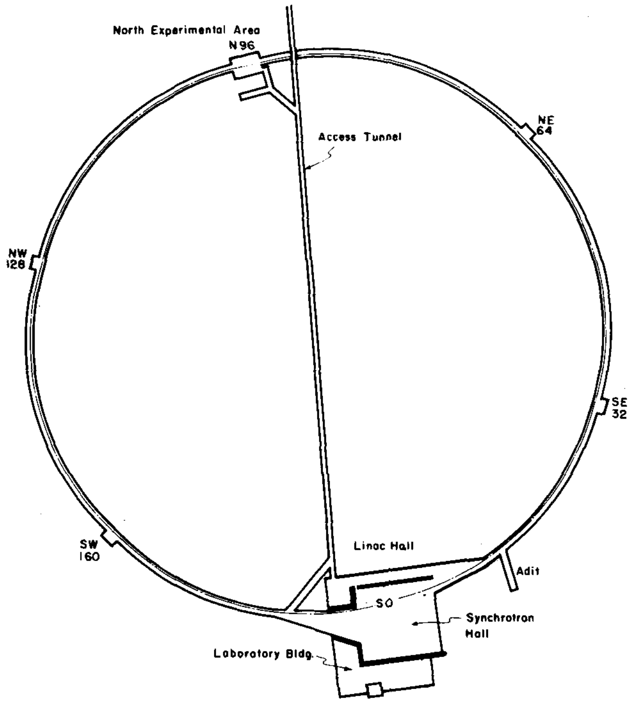

Fig. 1 - Plan of accelerator tunnel and laboratory.

The general configuration of the accelerator consists of 192 magnets arranged as shown in Fig. 1. Between four of the 60° arcs are 20-foot straight sections, and on diametric points are located two 40-foot straight sections. The 20-foot sections will be used for accelerating cavities while the 40-foot straight sections will be used for experimental facilities.

One of the long straight sections is located in the 100 × 100-foot experimental hall of the Laboratory Building. This building may be extended to increase the working area. In the same building is located the 200 MeV linac which is used for injection. There will also be support facilities including shops and offices in the same structure.

In the choice of the site, great importance was placed on having the instrument located within easy access of the existing Cornell Laboratory facilities, which included the operating 2 GeV accelerator. With the support of the NSF and the academic interests a site was chosen which was on the periphery of the campus within 10 minutes' walk of the existing Laboratory. The new Laboratory is located near the bottom and against the side wall of a gorge. The accelerator ring extends back into the wall of the gorge and 45 feet under a playing field adjacent to the gorge. The structure for containing the ring is obtained by actually tunneling under the bank using a tunneling machine. This tunnel has a cross section which is 10 feet in diameter, and the perimeter is approximately one-half mile, or approximately the size of the Brookhaven and CERN proton accelerators.

Diametrically opposite from the main experimental hall there is located a dome-shaped room 30 × 40 feet in dimension which, together with an adjacent apparatus room, may also be used as an experimental area centered about the other long 40-foot straight section.

The magnet construction is shown in Fig. 2. Here we see a cross section of one of the magnet assemblies mounted on a supporting I-beam. The magnet consists of approximately 11-foot lengths of laminations stacked together and bonded with epoxy. The magnets are formed in two halves and joined together in the median plane as shown. The profile of the laminations is shown in the figure, together with the exciting coils. The coils are made of cable which consists of a central water-cooled copper tubing surrounded by a number of insulated wires. Instead of using a donut structure for the vacuum tube, the entire magnet assembly is enclosed by a stainless steel jacket

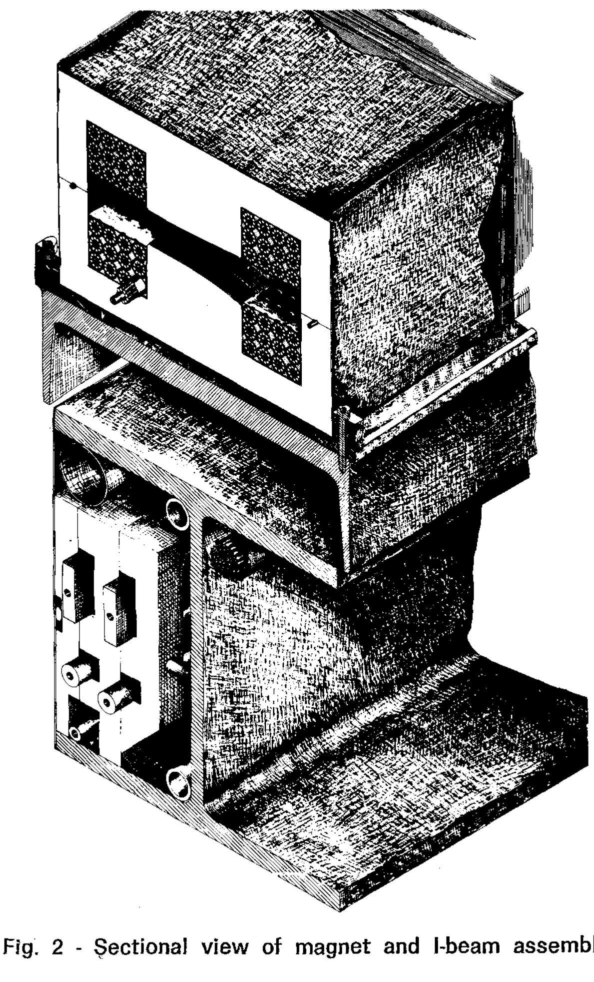

Fig. 2 - Sectional view of magnet and I-beam assembly.

TABLE I

Parameters for Cornell 10 GeV electron synchrotron

Nominal electron energy	10 GeV
Radius of curvature in bending magnet	100 m
Nominal repetition rate	60 cps
Nominal intensity	10^{11} electrons per pulse
Number of magnet units	192
Length of magnet units	3.43 m
Clear length between magnet units	0.25 m
Long straight sections	2 each of 12.2 m length; 4 each of 6.1 m length
Magnetic field at 10 GeV	3.3 kG
Injection field for 200 MeV	66 gauss
Gradient length, $x_o = B_o/(dB/dr)$	
Normal magnets	
Vertically focusing	23.167 cm
Horizontally focusing	23.223 cm
Magnets next to straight sections	
Vertically focusing	12.016 cm
Horizontally focusing	12.034 cm
Length of strong gradient	347.3 cm
Quadrupoles	
Length of quadrupoles	37.846 cm
Separation of quadrupole centers	144.526 cm
Quadrupole strength	3050 gauss/cm
Betatron oscillations per turn $\nu_r = \nu_v$	10.75
Magnet excitation power	800 kW
Linac energy	150-200 MeV
Linac frequency	2855 Mc/sec
R.f. frequency	714 Mc/sec
R.f. voltage per turn	10.5 MV
Average r.f. power demand	136 kW
Approximate cost of buildings, tunnel and accelerator	$ 12,000,000

which is welded vacuum-tight. The magnets are clamped to a supporting channel which is, in turn, supported on a heavy I-beam structure by positioning screws. Two magnet assemblies are mounted on the same I-beam structure. The I-beam structures are, in turn, supported by tables, one at the intersection of each pair of I-beams. Each I-beam is supported at one end by two vertical jacks and rods and constrained radially by a third jack and shackle. Another shackle adjusts the longitudinal position of the beam. The opposite end of the I-beam is supported on a ball point fastened to the succeeding I-beam. Each of the jacks are remotely operated and controlled, permitting optimization of beam intensity based on measurements of beam position and beam intensity.

The basic lattice pattern consists of alternate successive pairs of focusing and defocusing sectors, i.e. FDDFFDDF, of which one focusing and one defocusing magnet are located on each I-beam structure. Because the envelope of vertical oscillations varies with the type of magnet, optimization of cost with aperture may be obtained by making the vertically focusing magnet lenses with a wider gap than those will having vertical defocusing. The resulting gap is 1.5 and 1.0 inches, respectively. The width of the pole face is four inches. The usable horizontal aperture is 2.0 and 2.75 inches, respectively, again roughly a match to the envelope of oscillations. The number of coil turns per magnet is adjusted so that magnets of both types may be excited by equal currents in the coils. The final lattice configuration consists of basic units having the magnetic field index, x_o, i.e. $B_o/(dB/dr)$, given by the values 9.121" and 9.143". In addition, to compensate for the effects of the 20-foot straight sections, the magnets located on either side of the straight section are modified to have a section of its length with a strong gradient of opposite sign. This section will have values for x_o of 4.731 and 4.738 inches. These units are designed to provide a match for the straight sections following the method suggested by T. Collins, and permit a full 20-foot free space for the straight sections. The accelerating cavities will be installed in these space. To make a similar compensation for the long 40-foot sections, it is necessary to locate quadrupoles in the straight sections. Two quadrupoles are provided which are separated by about 5 feet centered in the straight sections. The quadrupoles may be designed to leave the beam plane unencumbered.

The magnet excitation circuit is shown in Fig. 3. The machine operates with a DC bias, using biasing chokes. The chokes and resonating condensers are distributed along the ring of the magnets, being supported from the underside of the I-beams. Each of the chokes has a winding for excitation, and is supplied by a heavy common bus running around the machine. The dc power supply is distributed in each of the long straight sections with one of them being regulated to keep the dc component constant. The ac excitation is

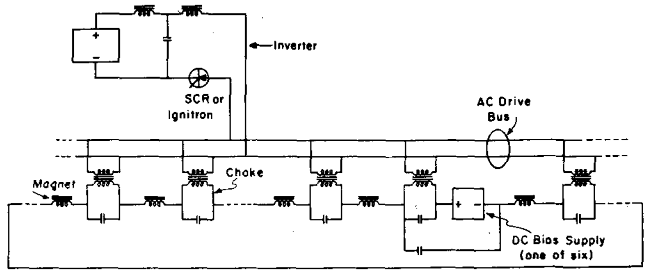

Fig. 3 - Magnet excitation circuit.

supplied by a pulsed power circuit. The total dissipation in the magnet excitation system for operation at 10 GeV is 800 kW, of which 396 kW are dissipated in the magnets.

The accelerating voltage will be supplied by 714 Mc cavities located in each of the 4 straight sections. For 10 GeV operation, 10.5 million volts per turn will be required. Each cavity will consist of 34 wave guide diaphragms and is driven by a klystron. The total input power for the system will be 136 kW.

Various quadrupole and multipole correction coils will be supplied, and the average gross field will be corrected by turns around the poles of the radially focusing magnet sectors.

Special magnets will be constructed for the purposes of injection and beam removal, utilizing an extension to the return yoke which increases gradually along the length of the magnet unit.

A multiplex system will be used which supplies both control and monitoring facilities for all I-beam units and straight section stations.

Radial and vertical beam positioning detectors will be inserted in numerous locations between magnet sectors.

Coils will be supplied for orbit distortion to force the beam on various targets as required, with alternations being made possible between successive pulses.

In Table I are given the principal parameters of the machine.

The current status is that the tunnel construction is under way. The digging of one 60-degree sector of the orbit has been finished. The first half of the tunnel is to be accessible at about the first of the year, followed in June by access to the linac room. About 6 months later the accelerator room will become available to us. We have completed a working unit of 8 magnet sectors and installed it in a mock tunnel. The laminations with the final profile will be available in about one month and the construction of the final magnet units and assemblies will begin.

DISCUSSION

KOLOMENSKY: Do you plan to use your synchrotron not only as an accelerator but also a storage ring in future?

MCDANIEL: Though we may use our machine as a storage ring, we would have to make serious modifications to the magnet and vacuum system, to guarantee the high vacuum which would be required for its use as a storage ring.

JONES: Why distribute the DC bias supplies around the magnet circuit? Don't the supplies now have to be above ground? Is the magnet circuit grounded at one point only?

MCDANIEL: By distributing the DC power supplies the ohmic drop in voltage is balanced by the power supplies voltage to reduce the average DC voltage between magnet coils and ground.

CHERENKOV: Do you have any estimate of scattering effect at a vacuum pressure of 10^{-5} torr, and for an accelerator radius as big as 100 meters?

MCDANIEL: Yes, we have made estimates of scattering effects. These show that for our injection energy at 10^{-4} torr there would be a 25% loss of beam and at 10^{-5} there would be a loss of only a few percent.

HARDT: By allowing two of the six long straight sections being of different length you introduce the very low superperiodicity of two. Please kindly confirme that no danger arises from this.

MCDANIEL: Yes, we have considered this question. I find no difficulty arising from it.

SCHAFFER: You could not say very much about the design parameters and problems of the system. Recently you changed the proposed frequency from the range of 475 Mc/s to 714 Mc/s. Is the main reason for this change to facilitate the construction of the accelerating units which are very long and therefore rather heavy?

MCDANIEL: Yes, this change was made primarily for mechanical reasons in order to reduce the size and weight of the units.

SCHAFFER: Will you provide traps on both sides of the cavities in order to improve the vacuum pressure inside them?

MCDANIEL: Yes, we expect to make special provisions to maintain a good vacuum in the radio frequency cavities.