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CESR - AN ELECTRON POSITRON COLLIDING BEAM FACILITY AT CORNELL†

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Summary

A proposal to modify the Cornell 12 GeV electron synchrotron facility to produce colliding beams of electrons and positrons was submitted to the National Science Foundation in May 1975. Subsequently, approval for design and prototype work was given and funding for the project is being requested by the NSF. Our goal is to complete this facility modification by October 1979. The status of the design and prototype work is described in this presentation.

Basic Concept

The central idea is to install a single ring storage ring for electrons and positrons within the existing synchrotron tunnel, the synchrotron and its linac acting as injector for the storage ring.[1] Initial operation of the storage ring will be at beam energies of up to 8 GeV with a design luminosity at 8 GeV per beam of $10^{32}\text{cm}^{-2}\text{sec}^{-1}$. The design is such that operation can be extended to 10 GeV by the addition of rf power. Collisions of the single bunches of electrons and positrons will take place in the present north and south synchrotron experimental areas. In the south experimental area the tunnel will be widened slightly to accommodate a bulge in the storage ring orbit. This bulge pulls the storage ring orbit away from the synchrotron to give a 5.3 meter separation between the machines at the south collision point. Elsewhere, the ring center lines are separated by 1.4 to 1.6 meter. A straight section of 7 meter is provided for physics apparatus at each collision region. Fig. 1 is a schematic plan view of the south segment of the machine showing the linac, synchrotron, storage ring collision area and planned synchrotron radiation experimental area. Adjacent to the bulge are two long straights each divided into three 7 meter sections, providing space for rf acceleration equipment and some wiggler magnets. The remainder of the ring, being inside the existing tunnel, is constrained to conform to the geometry of the synchrotron. Thus, in addition to the 7 m interaction straights and the rf straights associated with the bulge there are four 6 meter straights corresponding to the rf straights of the synchrotron along with six short instrumentation straights obtained by allowing the storage ring to seesaw slightly in the tunnel. Table I gives the principal parameters of the machine.

Table I

Design Luminosity (8 GeV)	$10^{32}\text{cm}^{-2}\text{sec}^{-1}$
No. of Interaction Regions	2
Quadrupole Spacing at IR's	7 m
South IR Pit Dimension	8x8x4 m
No. of electrons per bunch	1.5×10^{12}
Circumference	768.429 m
Maximum bending radius	87.85 m
Minimum bending radius	32.573 m
RF Power at 8 GeV	2 MW
Magnet power at 8 GeV	1 MW
Clear Aperture	50x90 mm

Lattic and Optics

Given the bilateral symmetry enforced by the required geometry and experience at previously built storage rings, flexibility of the optics has been a primary criterion in our design. The main windings of the normal bending magnets, the high field magnets in the bulge and the interaction region quadrupoles are in series. 15% trim windings on the interaction region quadrupoles and high field bending magnets are independently powered to adjust the collision betas and compensate for iron characteristics and magnetic history effects. Each of the normal lattic quadrupoles and sextupoles is independently powered for maximum flexibility. Families of operating lattices, linear and non-linear, have been explored using a locally developed fast optimizing method.[2] Usable lattices with tunes varying from 7.4 to 13.4 are known and E^2 luminosity dependence has been theoretically achieved with both eta mismatch and wiggler excitation, separately and in combination.[3, 4] Operation at energies as low as 1.5 GeV per beam and as high as 10 GeV per beam appear possible.

In Fig. 2 typical theoretical envelope functions and the component disposition for one half the ring are presented. The south interaction point is at the extreme left.

The geometry of the ring is such that only eight focussing and nine defocussing quads of the 49 in each half ring generally have the same current. Thus the concept of main lattices and matching sections is not very useful for describing the CESR lattice.

To control chromaticity, sextupoles are placed adjacent to most quadrupoles in the ring. While the sextupoles are all independent it has been found by tracking program calculation that two different values suffice for controlling chromaticity without sacrificing stability for particles at the edge of the physical aperture, 50mm vertical, 90mm horizontal.

Horizontal orbit corrections are effected by extra turns on one pancake of the bending magnet coil. Vertical corrections are made with an extra coil pair included in the sextupoles.

Magnets

Fig. 3 is a plan view of a normal half cell. To make efficient use of the available space, the bend of each half cell is comprised of two core blocks mounted at a slight angle with one-another to minimize the sagitta effect, the cores being linked by common four pancake coil. Pole and coil details are shown in Fig. 4. The core blocks are stacked from 1.5mm thick laminations of Armco steel with tapered end packs. The assembly is stacked, keying to the gap itself, compressed and bound together by welding on a steel, C shaped, .5 inch thick, shell as shown in the figure. Fig. 5 is a photo of a magnet core with two coils in place, mounted as it will be in the tunnel. The core blocks are supported by a common pillar at their junction. The outer ends are supported on tables which also bear the quadrupole-sextupole combination, pumps and instrumentation or auxiliary equipment units. Quadrupoles of three different cross-sections will be used. The interaction region quadrupoles have a bore of 12 cm, all others have a bore of 8 cm. The majority of the normal lattice quadrupoles are constructed

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in two pieces, each piece being stacked from stamped laminations with iron and coil cross-sections as shown in Fig. 6. At injection and ejection points, quadrupoles of extra large field aperture are required. In these places a four piece quadrupole with poles broader than the normal two piece lenses will be used. Fig. 7 is a photograph of the prototype for this lens with measuring coil in place. Edge cooled, tape wound coils are used for all normal quads to provide the high impedence required for individual excitation. The sextupole cross-section is shown in Fig. 8.

Magnet Power

Bending magnet power will be provided by three "Transrex" supplies in series, two on voltage control, the third on current control from a special transductor. Power for the quadrupoles will be provided by two Meaker supplies which drive busses girdling the ring. Transistor switching regulators connected between the bus and individual lenses set each quadrupole operating level. Regulation is by means of a second harmonic type transductor with synchronous detection. A prototype unit has been operated at a stability of better than .01% per day.

Vacuum System

Details of the vacuum system are given in a paper to appear in these proceedings.[5] The vacuum system is designed to maintain a pressure of 10^{-8} Torr during operation at full current. The main vacuum chamber is formed by a two compartment 6061-T4 aluminum extrusion. Expansion joints between the 30 ft. long vacuum pieces will be designed to minimize higher mode losses. Extensive tests of both sliding contact joints and elliptical, matched, bellows are in progress and a final decision will be forthcoming shortly. Beam position detectors and pumping ports will be integral with the vacuum chamber. Fig. 9 is a photo of the vacuum chamber with distributed pump protruding. While it is anticipated that discharge cleaning will be used, we are prepared to use bakeout with heating generated by passing current directly through the chamber or by externally applied heating elements a la the early PETRA design. For high energy operation 140 l/s auxiliary sputter-ion pumps, will be provided in every cell. i.e. every other straight. For very low energy operation these will be supplemented by smaller ion pumps in the alternate straights.

RF System

At 8 GeV, 100 mA per beam, 1 MW will be required by synchrotron radiation loss and 700 kW additional will be required to drive the cavities to 12 MV peak at 500 MHz and supply the higher mode losses into cavities and vacuum chambers. The rf power will be provided by six to eight 250 kW klystrons or four 500 kW klystrons per market conditions at time of order. In the power calculation a factor of two bunch lengthening due to potential well broadening is assumed. The 500 MHz operating frequency was chosen on economic and tube availability grounds. Fig. 10 is a photograph of the partially assembled cavity unit. In designing this cavity, particular attention was paid to the suppression of multi-bunch, beam-cavity instabilities. CESR, because its injection method, will need to operate in both multibunch single bunch modes. For this reason each individual cavity cell is strongly coupled to a transmission line which is resonant at the fundamental and strongly absorbtive at all other frequencies. Essentially no coupling is permitted along the beam line. The cavity shape is perturbed to assure strong coupling to all significant higher modes. 56 cells corresponding to 16.8 meters total active length are required. The 56 cells are broken into four subunits. Details of the cavity design are given in a paper in these proceedings.[6]

Injector System

In one injection method alternative, multi-bunch beams of positrons will be produced in the linac consisting of the original Cornell linac augmented to 8 sections by addition of components from the CEA linac. Successive 60 bunch trains from the linac are accelerated in the synchrotron and transferred to the storage ring, one on top of another, at close to the desired operating energy. After accumulation the bunches are extracted one at a time and coalesced using the vernier phase compression scheme.[7] Single bunch extraction of the 42ns spaced bunches is accomplished by a spark gap switched ferrite core magnet. To avoid harmful interaction between beam and magnet, this kicker is placed off to one side and shielded from the beam fields by a metalized ceramic vacuum chamber. The metalization thickness about 12 ohm/sq., is such that the beam fields are contained within the chambers while allowing about 90% of the pulsed magnet field to enter.

Fig. 11 is a photograph of a prototype of this magnet with a section of ceramic vacuum chamber inserted. Details of the magnet design and performance are given in a paper in these proceedings.[8] Pulsed bump magnets with ferrite cores and using a similar shielding scheme will also be used. More details of the injection scheme are given in the CESR Design Report.[9]

Control System

CESR's control system is centered on computers, all personnel safety interlocks however, being hard wired. The organization of the computer system is simplified both by vertical division (into virtually autonomous functional groupings) and by horizontal layering by level of sophistication of control tasks. The semi-autonomous units are linked to a common console computer which is also linked to the laboratory central time sharing computing system. To gain experience, the linac has recently been converted to computer control. Fig. 12 is a photo of the computer unit panel for the linac with its multifunction knobs and switches and television displays. A histogram of accelerator vacuum is displayed at the top with values of variables controlled by the knobs shown below.

Program

As prototype and development of the injection scheme, we will install positron injection and extraction equipment in the synchrotron, the positron transfer line and 6 cells of CESR lattice in the tunnel. The lattice section will include the fast ferrite kicker and bump magnets, thus allowing us to study positron manipulation bunch by bunch. We intend to complete this phase of our work by October 1977 so that upon the anticipated availability of funds at that date we can proceed to full construction without delay. Construction time will be two years or less.

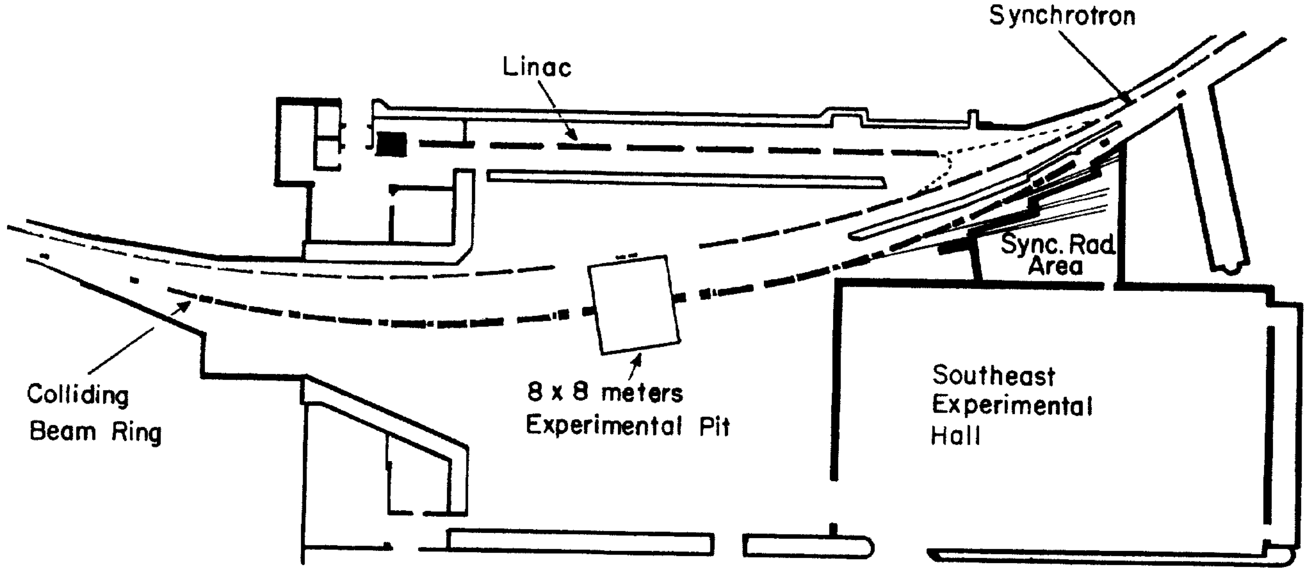

Fig. 1. Plan View of South Interaction Area

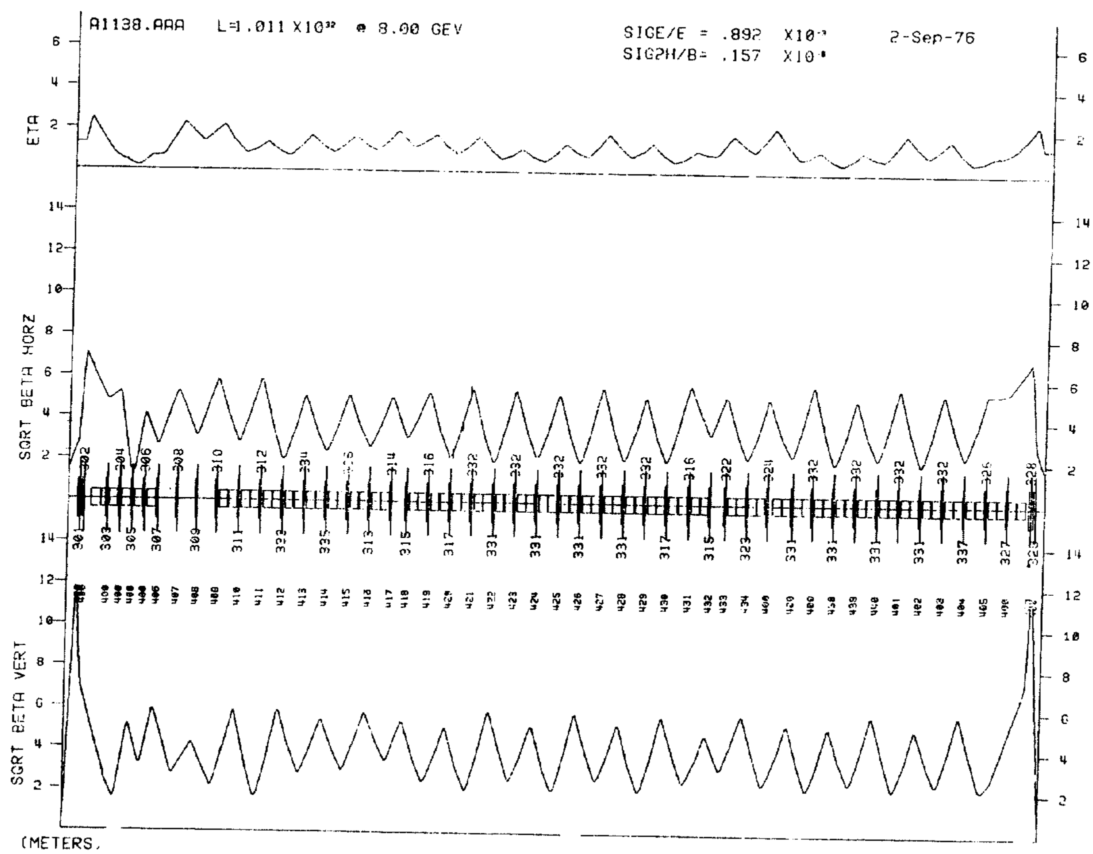

Fig. 2. 8 GeV Envelope Functions

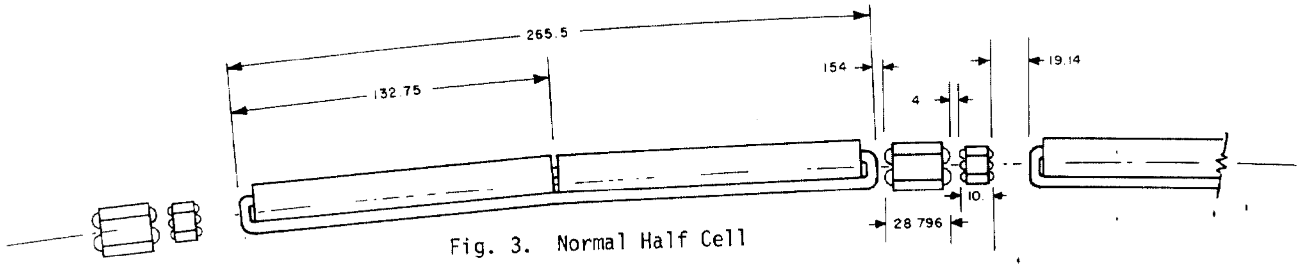

Fig. 3. Normal Half Cell

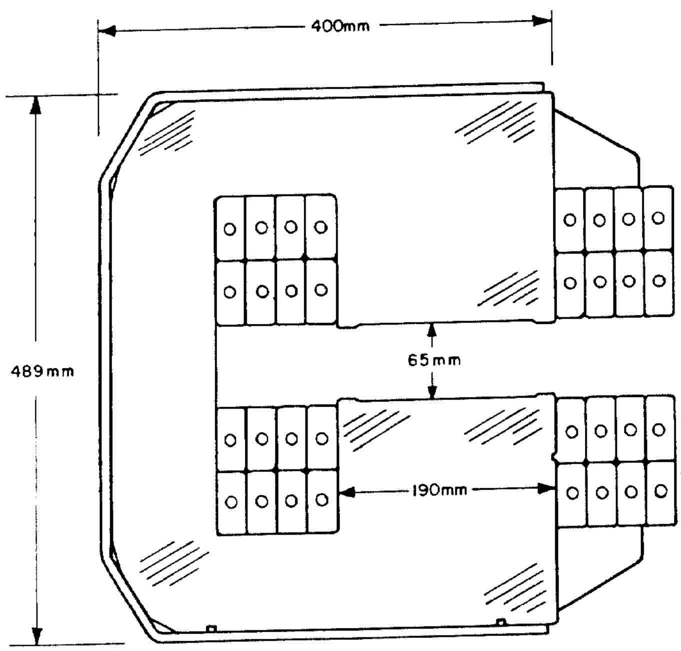

Fig. 4. Dipole Cross-section

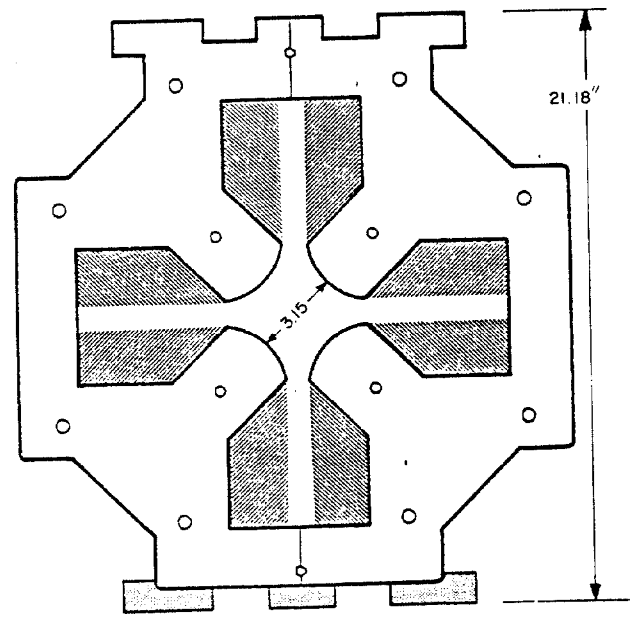

Fig. 6. Normal Quadrupole Cross-section

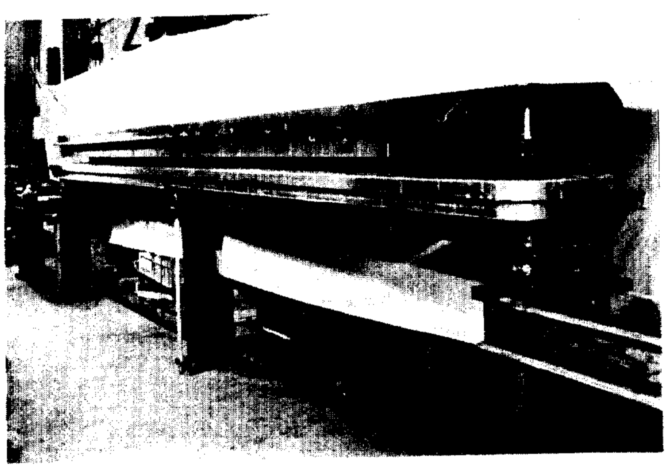

Fig. 5. Dipole with Lower Coils in Place

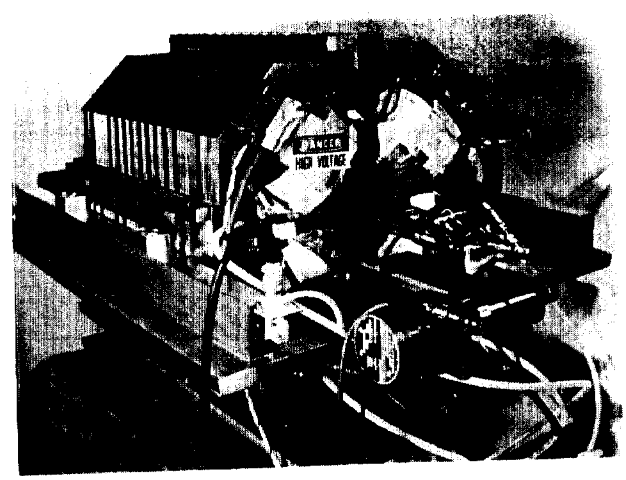

Fig. 7. Four Piece Quadrupole, Measuring Coil

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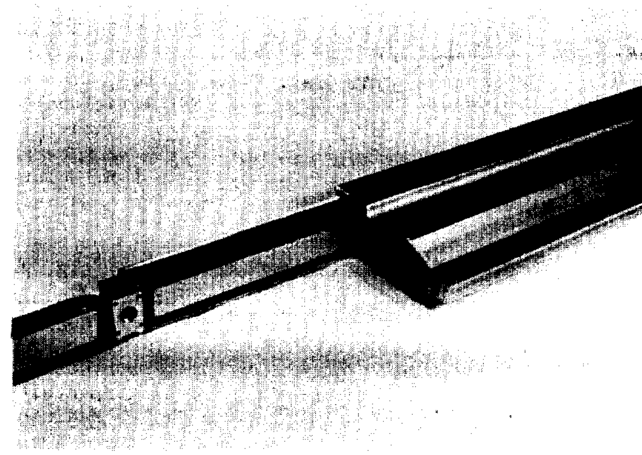

Fig. 9. Vacuum Chamber with Pump Segment

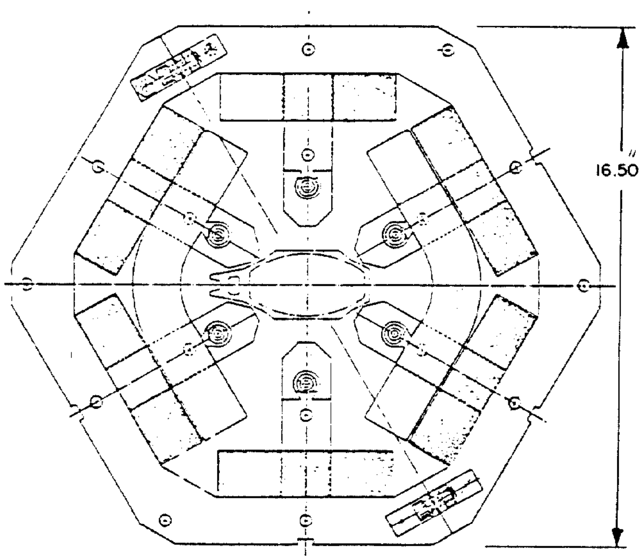

Fig. 8. Sextupole Cross-section

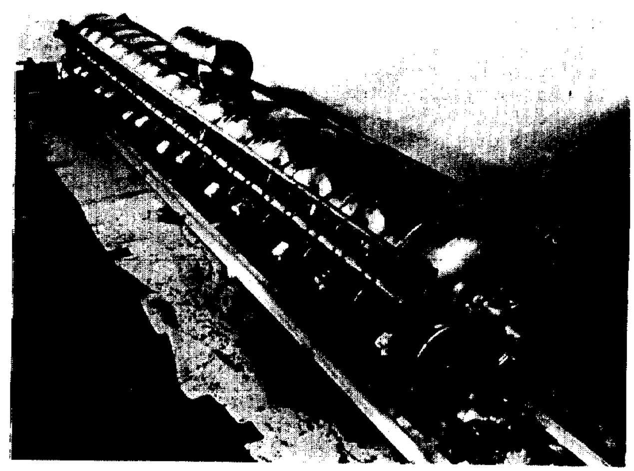

Fig. 10. Partially Assembled 14 Cell Cavity

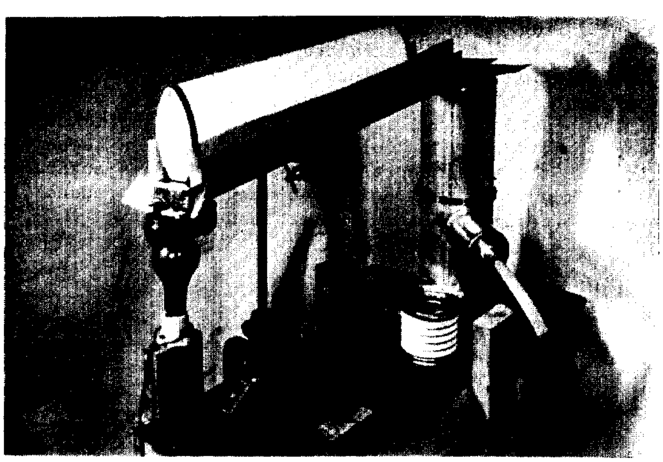

Fig. 11. Fast Kicker Magnet Prototype

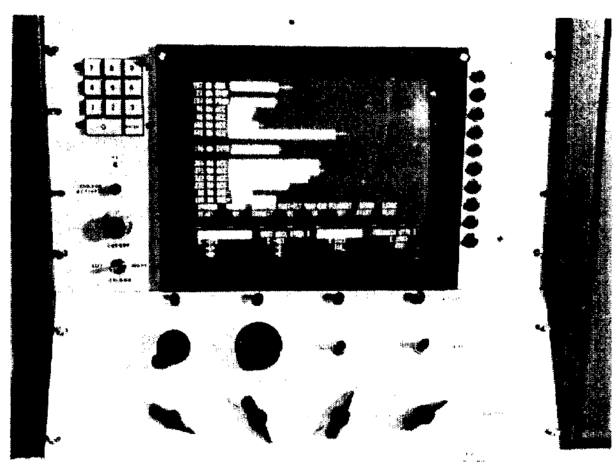

Fig. 12. Linac Computer Control Panel