CEAL-3063-01

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SEMI-ANNUAL REPORT

For the Period

July 1 through December 31, 1971

K. Strauch, Director

W. A. Shurcliff

May 15, 1972

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE, MASSACHUSETTS 02138

MASTER

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SUMMARY

Part I indicates the purpose of the contract: to operate and improve the Cambridge Electron Accelerator. It indicates that essentially all effort is now being concentrated on the colliding beam project (Bypass) and the two detection systems (BOLD and MAGNOLIA) being built to analyze the results of the colliding beam events. Advisory Boards and Review Boards are described.

Part II indicates the number of 8-hour shifts devoted to (a) studies of beam accumulation and storage, and (b) maintenance, installation of new equipment, and unscheduled downtime.

Part III describes the advances made in the development of the colliding beam facility, including (a) control of beam resonances, instabilities and beta-function-at-interaction-region with the object of increasing the limits on peak currents and peak luminosity, and (b) increasing the reliability of control

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and the speed of accumulating beams and switching them into the bypass, with the object of increasing the long-term average luminosity attainable. Regarding (a): instabilities were controlled to the extent that a weak (~ 1 mA ave) e^+ beam could be maintained in the ring in the presence of a 50-mA-peak, 8-mA-ave e^- beam; a single e^- beam current as large as 19 mA ave was established in ring-plus-bypass. Luminosity was observed with 2-GeV beams and also 3-GeV beams. With 2-GeV beams, a luminosity of $0.4 \times 10^{28} \text{ cm}^{-2} \text{ sec}^{-1}$ was obtained with a 3-mA-ave e^+ beam and a 4-mA-ave e^- beam. Regarding (b): the process of beam accumulation, ramp-up, and switching into the bypass was automated to such an extent that the efficiency of particle retention exceeded 80% and the entire process took ~ 5 minutes.

Part IV describes the bypass on-line detector (BOLD) which was ready for use on short notice.

Part V describes the magnetic on-line detector (MAGNOLIA), designed to be effective in the analysis of hadron events.

Part VI deals with repairs and improvements to the accelerator proper.

Part VII discusses other programs.

Part VIII lists the major publications.

PART I - INTRODUCTION

A. The Contract

This report summarizes work done under the Harvard-AEC Contract AT(30-1)-2076* during the six-month period from July 1 through December 31, 1971. The contract calls for the operation and maintenance of the CEA electron synchrotron and for designing, procuring, installing and operating various essential facilities.

B. Committees and Boards

The general policies of the Laboratory are determined by a joint M.I.T.-Harvard "Executive Committee of the CEA". In December 1971 this Committee included the following:

From M.I.T.: Prof. Albert G. Hill

**Prof. Francis E. Low

**Prof. Louis S. Osborne

Prof. Walter A. Rosenblith

**Prof. Victor F. Weisskopf

From Harvard: Mr. Hale Champion

Dean John T. Dunlop

**Prof. Francis M. Pipkin

**Prof. J. Curry Street

**Prof. Richard Wilson

The Cambridge Electron Program Advisory Committee (CEPAC) reviews the status of experiments in progress and examines proposals for future experiments. CEPAC serves in an advisory capacity

*Now Contract AT(11-1)-3063

**Denotes member of Scientific Subcommittee

to the Director. During the half-year in question this committee included, in addition to the Director:

Prof. Stanley Brodsky, SLAC

Prof. Martin Deutsch, M.I.T.

Prof. Clemens Heusch, U. of California, Santa Cruz

Prof. Wolfhard Kern, Southeastern Mass. U.

Prof. Francis E. Low, M.I.T.

Prof. Francis M. Pipkin, Harvard

Prof. Burton Richter, SLAC

Prof. Albert Silverman, Cornell

Dr. Gustav-Adolf Voss, CEA

Dr. James M. Paterson, CEA, secretary

The CEA Visiting Board reports to the Presidents of M.I.T. and Harvard. Its membership in late 1971 was:

Dr. James B. Fisk, Chairman
President, Bell Telephone Laboratories

Prof. James W. Cronin
Dept. of Physics, University of Chicago

Prof. Maurice Goldhaber
Director, Brookhaven National Laboratory

Prof. J. David Jackson
Dept. of Physics, Univ. of California, Berkeley

Prof. Boyce D. McDaniel
Director, Lab. of Nuclear Science, Cornell

Prof. W. K. H. Panofsky
Director, Stanford Linear Accelerator Center

PART II - ACCELERATOR UTILIZATION

As explained in the previous semi-annual report (CEAL-1056), since June 1, 1970, all work at CEA has been concentrated on the colliding beam facility - a facility designed for

- (1) Producing head-on collisions of electrons and positrons with energies up to 3.5 GeV in each beam, and
- (2) investigating the results of such collisions by means of large-solid-angle detection systems.

During the period July 1 - December 31, 1971, the distribution of accelerator time was as shown in Table 1.

Table 1
Accelerator Use in Second Half of 1971
(Number of 8-hour shifts)

Month	Studies of Beam Accumulation, Storage and Collision	Installation of New Equipment, Maintenance, Repair and Unscheduled Downtime	Total
July	40	30	70
August	30	40	70
September	32	36	68
October	31	27	58
November	26*	40	66
December	25	32	57
	<hr/> 184	<hr/> 205	<hr/> 389

* Includes 3 shifts allocated to tests made by Rubbia et al of Harvard on lead glass counters to be used at NAL.

PART III - COLLIDING BEAM FACILITY

A. Principle of Operation of Colliding Beam Facility

The procedure is to fill the orbit of the synchrotron with countertraveling, high-intensity electron and positron beams by means of multicycle injection. Positrons and electrons are injected by means of two linacs arranged in tandem in the (nearly radial) Linac Tunnel. When positrons are to be injected, the upstream linac produces 120-MeV electrons which strike a tungsten converter from which gamma radiation and electron-positron pairs emerge; positrons of ~ 10 -MeV energy are collected and guided into the downstream linac whence they emerge with an energy of 120 MeV; they are then deflected to the right so as to enter the circular orbit in clockwise sense. When electrons are to be injected, the converter is removed (in a few seconds, by remote control), the phase of the second linac is shifted suitably, and the two linacs are operated in series to accelerate electrons to 240 MeV; these are deflected to the left and are inflected into the orbit in counterclockwise sense.

When the beam intensities have been built up as high as instability limits and beam-beam interaction permit, synchrotron operation is converted to dc mode and the particle energies are increased to the desired value. The stored beams are then switched into a 150-ft-long detour or bypass (see Figs. 1 and 2) and remain in orbit with a $1/e$ lifetime of the order of one half hour. In most of the ring and bypass, the two beams are kept vertically separated by means of electrostatic fields so as to minimize beam-beam interactions; but they are guided so as to collide at the interaction region, at the

Fig. 1. Relationship of the bypass to the synchrotron ring of 48 magnets. The terminations of the bypass, and likewise the septum magnets used in switching, are at straight sections 10 and 19.

Fig. 2. Main components of the CEA Bypass. The symbols Q, BM, ABM, LM, IR stand for quadrupole magnet, bending magnet, auxiliary bending magnet, luminosity monitor and interaction region

center of the bypass. Focusing magnets reduce the beam cross section here (the typical cross section is 0.1-mm high by 0.2-mm wide) and accordingly increase the interaction rate (number of collisions per second).

The interaction region will be surrounded by a detector array that includes spark chambers, absorbers and scintillation counters. Initially a non-magnetic "bypass on-line detector" (BOLD) will be used. The spark chambers are of wire type, digitized; all signals from spark chambers and scintillation counters are read out and analyzed by an IBM computer. A magnetic on-line detector (MAGNOLIA) also has been under construction; it was designed to provide a more detailed analysis of complex events.

By the start of the half-year in question, most of the equipment known to be necessary for beam storage was in place, many studies of multicycle injection, ac turn-off, and switching into the bypass had been made, many preliminary problems had been identified and some had been solved. The progress made in the half-year period in question is summarized below.

B. Efforts to Increase Beam Currents and Peak Luminosity

A continuous program to increase the intensity of stored beams and to increase the peak luminosity produced the following results:

October 1971: Established, in ring, at fixed 2.5 GeV energy, a

50-mA-peak (8-mA-ave) e^- beam together with a much weaker e^+ beam which was not disturbed by the high-current e^- beam.

Established, in ring-plus-bypass, a single e^- beam of 19-mA-ave.

November 1971: Measured luminosity by double bremsstrahlung method for the first time. Obtained a luminosity of $4 \times 10^{27} \text{ cm}^{-2} \text{ sec}^{-1}$ with 3-mA-avg and 4-mA-avg e^+ and e^- beams at 2.5 GeV.

December 1971: Achieved, in the ring, a single e^- current of 150 mA peak (at 2 GeV). On a different occasion we achieved a single e^+ current of 25 mA peak.

These results were obtained as a consequence of many improvements, the major ones being described below.

1. Increasing the Intensity of the Positron Beam

In October, in an effort to increase the intensity of the stored e^+ beam, we increased the useful horizontal aperture of the ring. This was accomplished by reducing the frequency of the main rf system by 50 KHz (0.01%) and thus increasing the orbit radius by 0.01% (0.14 inch). The horizontal aperture was found to be 0.28 inch larger, and increases were observed in the rate of accumulation of e^+ and in the ceilings on peak and average e^+ currents.

2. Minimizing Single-Bunch Transverse Instability

Having found earlier that the ceiling imposed on single-beam intensity by single-bunch transverse instability could be raised by overcoming the machine's negative chromaticity by means of distributed sextupole windings, we improved the sextupole system further in August. We revised the choices of locations of the ac-powered sextupole magnets so that the 10-pole components of field of these magnets would largely cancel and thus would not reduce useful aperture during multicycle e^+ injection. In addition, we improved the powering of the sextupoles.

Using the new arrangements we were able to accumulate e^+ currents of 12 mA peak, 4 mA avg, without onset of betatron instabilities or other difficulties.

3. Minimizing Single-Bunch Longitudinal Instability

Earlier, we had built and installed a 1427-MHz Landau cavity, intended to increase the degree of non-linearity in the relationship between accelerating force on a particle and its longitudinal position relative to the center of gravity of the bunch in question (without need to increase the bunch length and thus minimize single-bunch longitudinal instability). Initially, the Landau cavity was self-powered, i.e., powered by the induced emf from the bunches passing through. In August we for the first time applied 1427-MHz power to the cavity, and although the power source used was a very preliminary one, delivering only 150 watts to the cavity, the threshold for coherent synchrotron oscillation was found to be increased by approximately the predicted amount ($\sim 40\%$). However the peak current that could be accumulated was not increased significantly. Plans were made for increasing the power.

We also increased the number of normally powered rf cavities from 2 to 4 in order to provide enough voltage per turn to maintain beams at energies as great as 2.5 or 3.0 GeV. The number of such cavities (four) was still low enough so that bunch length was appreciable and the resulting non-linearity (of the type mentioned in the previous paragraph) contributed significantly to the damping of single-bunch coherent longitudinal oscillations.

4. Minimizing Bunch-Bunch Longitudinal Instability

As explained in earlier reports, under some circumstances the ceiling on current in a single beam was sometimes limited by bunch-bunch interactions resulting in longitudinal instability. It was recognized (see Monthly Report for May 1971) that such interaction could be reduced by operating one of the rf cavities at a slightly different harmonic of orbital frequency - such as the 361, 362, 363, or 364 harmonic, compared to the 360th harmonic used in normally powered rf cavities. Accordingly, we modified Cavity 3 so that it could be tuned to any of the above-mentioned harmonics. Preliminary tests with passive powering showed promise, and preparations for supplying 10 kW of special harmonic power were made; the power was to be supplied by a 200-ft-long, 3.1-inch-diameter coaxial Styroflex cable.

5. Minimizing Beam-Beam Interaction

To reduce interaction between the two beams, we increased the vertical separation of the beams at all locations where they passed by simultaneously (except the interaction region itself). The increase was accomplished by increasing the potential across the electrostatic separation plates. But before increasing the potential we had to modify some of the plates and their mounting in order to reduce arcing. At the same time, the cabling and power supplies were improved. As a result, beam-beam interaction in the ring was reduced sufficiently that a 50-mA-peak (6-mA-avg) e^- beam had no harmful effect on a coexistent several-times-smaller e^+ beam.

6. Development of Superior Tune

Much effort was devoted to the development and appraisal of new tunes; the goal was to reduce beta function at the interaction region (without making beta overly large at certain bypass quadrupole magnets where high-order multipole components of field tended to be harmfully large for particles far from the equilibrium orbit) and also to reduce the momentum vector at the interaction region to zero. In December, for example, we developed a Tune 7 which, according to computer calculations, might be expected to produce an order of magnitude reduction in horizontal beta function and reduce momentum vector to zero - and thus increase luminosity by a factor of 5. Trial use of the new tune was started early in 1972.

C. Efforts to Increase Long-Term-Average Luminosity

To make it possible to maintain satisfactory luminosity over periods of hours or days, we devoted much effort to (1) reducing the time required for filling the ring with positrons and electrons, (2) increasing the lifetime of the stored beams, and (3) increasing the reliability of operation.

1. Reducing Time Required for Filling the Ring

Many adjustments - to linac, injection trains, and ring - are required during the steps of (a) changing from e^+ injection to e^- injection, (b) changing from ac-mode storage to dc-mode storage, (c) ramping up the energy, and (d) switching the beams into the bypass. During the previous year we had made a beginning at automating many of the changeovers involved, and in the present half-year period most of the automation was completed. By the end of October changeovers (a), (b), (c) were almost entirely automated, the total elapsed

time in making these changes was only 30 seconds, and the loss of e^+ current in this interval was only $\sim 15\%$. By the end of November all of the steps were sufficiently fast and accurate that the overall efficiency of beam retention was often as high as 90%. The system was sufficiently stable that two technicians, working without advice of any senior member of the Bypass Group, could carry through the entire process again and again, at approximately 15-minute intervals, throughout an 8-hour shift, without encountering any significant difficulty.

2. Increasing Beam Lifetime

As a result of the improvements made in the vacuum system (see Part VI), we obtained, in the synchrotron ring during cycling-mode operation (after an 8-hour bakeout, and with no beam in orbit) pressures in the 10^{-9} to 10^{-10} Torr range, giving a beam $1/e$ lifetime of 400 seconds, to be compared with the 100 to 200 second lifetime attained in earlier months. In high-energy (2.5-GeV) dc mode, the lifetime of a 1-mA-avg beam was 3.5 hours and the lifetime of a 20-mA-avg beam was 1/2 to 1 hour.

Beam lifetime in ring-plus-bypass was greatly improved also. The $1/e$ lifetime of a single, 2-GeV beam was about 1 hour when beam current was small (<1 mA avg) and $\sim 1/2$ hour when the current was 10 mA avg.

3. Increasing Reliability of Operation

Reliability of operation was improved in many ways, discussed in Part VI. In addition, the training of operators continued. (Reliability of operation was stressed to even greater extent in the subsequent half-year: January 1 - June 30, 1972.)

D. Increased Versatility of Measuring Luminosity

Under certain circumstances of machine adjustment, the single bremsstrahlung method of measuring luminosity (see Monthly Report for May 1971) gave erratic results because of unpredictable variations in background rate. Therefore in November 1971, we successfully tried out the double-bremsstrahlung method employing the two on-axis monitors (at the ends of the central straight portion of the bypass) each with a discriminator setting of, for example, $1/5$ of the energy of an individual beam. When both monitors give above-threshold responses, a pulse representative of the time difference between the two shower signals is sent to a pulse height analyzer. When there are two beams in orbit, colliding at the interaction region, the zero-time-difference bin shows several times the count of any other bin, and permits easy calculation of the luminosity. See Figs. 3 and 4.

In subsequent months, both methods of luminosity measurement were used. The single-bremsstrahlung method is quicker, and the double-bremsstrahlung more reliable.

E. Storage Trials and Luminosity Measurements

In the six-month period in question we made many beam accumulation and storage trials and many measurements of luminosity, with the general goal of understanding and controlling the factors that were limiting luminosity. Some of the trials were made with a fixed energy of 2 GeV, and some with 2.5 GeV. Detailed results are presented in the individual monthly reports for the last half of 1971.

Fig. 3. Scope display of time-difference histogram from luminosity-measurement run using double bremsstrahlung method. Channel width of PHA: 2 nsec. Points at left and right, from channels associated with large (>4 nsec) time difference between signals from two symmetrically placed monitors, represent background. The two (high) points at the center show the number of events in which the two signals were simultaneous within ~ 4 nsec. The excess of this count over the typical background count indicates a luminosity of $4 \times 10^{27} \text{ cm}^{-2} \text{ sec}^{-1}$.

Fig. 4. Luminosity in double bremsstrahlung runs of 11/22/71 as a function of amplitude of beam bump. With zero beam bump, the beampaths cross at the desired location and the luminosity is large. With increasing beam bump, the location of beampath intersection shifts along the orbit, fewer collisions occur, and the luminosity is smaller. The width of the pattern implies that the full $1/e$ height of cross section of a beam was 0.0035 inch.

In summary, we found that nearly all of the control schemes provided in recent months were effective. The threshold current for the existence of coherent transverse oscillations could be increased by control of machine chromaticity through use of sextupole magnets - although the need for further improving the sextupole system was clearly evident. The threshold current for onset of coherent longitudinal oscillations could be increased by providing greater non-linearity of main rf fields, use of an off-harmonic cavity, and use of the Landau cavity. Beam-beam interactions could be reduced by use of well-adjusted electrostatic separation plates; but the need for further improving this system was evident.

Control of high-order multipole components of field of bypass quadrupole magnets (by means of pole-face windings, or by employing quadrupoles of larger bore) was very helpful, and plans were made for installing additional numbers of large-bore (4-inch) quadrupoles in place of the remaining 3-inch-bore devices.

Greater stability of power in bending magnets, septum magnets, etc., was found necessary, and likewise the control of certain fringeing fields.

Many such improvements were made or were scheduled for completion early in 1972.

The importance of the interaction-region flick-through fiber for reliable and accurate measurement of height of beam cross section was further demonstrated, and plans were made for providing more accurate beam-height monitors in the synchrotron ring also.

PART IV - BYPASS ON-LINE DETECTOR (BOLD)A. General Design

Figures 5 and 6 show the general design of the bypass on-line detector (BOLD), designed primarily to detect photons, electrons, muons, and hadrons. The detector consists essentially of four core-quadrants and two flanking assemblies called hadron converters. Each quadrant contains six spark chambers, five scintillators, and five radiators (with thicknesses of 1.25, 1.25, 1.25, 1.25, and 1.5 radiation lengths). The outermost scintillators are used in distinguishing (by time-of-flight method) cosmic-ray particles from particles originating at the interaction region (bypass midpoint).

Each spark chamber includes two gaps, defined by four planar arrays of wires at angles of 0, 75, 105, and 180 degrees. Each array is served by one magnetostrictive pick-up wand, and the arrival times of sonic pulses reaching the transducer at the output end of the wand correlate with the positions of the wires participating in spark production.

Each scintillator is viewed by one or two photomultipliers, the signals from which pass to discriminators and thence to pulse-area digitizers and a logic system. When pulses received simultaneously satisfy the criteria for trigger, the spark chamber high-voltage supply, and other key components, are gated on. Also, the areas of pulses from the scintillators that serve as shower counters (i.e., scintillators preceded by radiators) are measured and expressed in digital form.

Fig. 5. Vertical section through bypass (and adjacent portion of synchrotron ring) at the bypass midpoint.

Fig. 6. Cross section of north quadrant of detector core, showing the six wire spark chambers (w), five scintillation counters (Sc), and five radiators (R). The e^- and e^+ beams are at the center of the beampipe.

Figure 7 shows the flow of information from spark chambers and scintillators to the main computer, where the useful data are recorded in compact form on magtape. Also, a Fortran IV program causes this same computer to make an on-line, preliminary determination of event-type, and on command, to present the operator with a quick visual reconstruction of the tracks of any given event.

An off-line Fortran IV program, employing the CERN SUMX program, processes the magtape data in more sophisticated manner. The interpretation of data from a given event is determined and recorded. Totals by class are maintained. The efficiencies of individual spark chambers and scintillators are compiled.

B. Progress and Status

As in earlier months, the four quadrants of the core were essentially complete and ready for use on short notice.

Construction of the two hadron converters, each of which includes ten 72" x 72" x 1" iron plates and four spark-chamber gaps, was nearly completed. The sequence of components of a hadron converter is: one iron plate, two gaps, eight iron plates, two gaps, one iron plate. Each plane of wires includes twenty 5-mil copper wires per inch, and in the four planes of a set, the wire directions are 0, 75, -75, and 0 degrees. The applied potential, applied with a delay of ~ 100 nsec, is 5 kV.

We modified the on-line program so that it can identify electron pairs, muon pairs, and gamma-ray pairs, as well as identify hadronic events. A list of other important capabilities is presented in the Monthly Report for August 1971.

Fig. 7. Flow of BOLD data from primary sensors to on-line computer

We nearly completed the task of modifying the on-line and off-line programs so that they can be used with the Harvard Computation Center's IBM 370/145 computer, which in November 1971 replaced the IBM 360/65. We succeeded in reducing the memory requirement from 150K to 100K bytes.

We purchased a Textronix Type T-4002A scope with interactive graphics capability. It will be used to display the geometry of those events that cannot be identified unambiguously by our off-line program, so that a physicist can use his judgment in appraising the events.

An opposite pair of core quadrants has been used in several preliminary measurements of background events that occur (a) with no beams in the bypass, and (b) with few-mA-avg, 2-GeV or $2\frac{1}{2}$ -GeV countertraveling beams. Using a trigger consisting of signals from any three scintillators of one quadrant in coincidence with signals from any three scintillators of the opposite quadrant, we obtained a satisfactorily low background rate of ~ 0.03 counts per mA-second. The rate could be halved by use of a scraper situated 100 feet from the interaction region. Several other methods of reducing background, as by use of shielding or reducing gas pressure in the bypass, were explored.

It was hoped that the BOLD detector would be fully assembled and put into preliminary use before the summer of 1972.

PART V - MAGNETIC ON-LINE DETECTOR (MAGNOLIA)

A. General Design

The magnetic on-line detector (MAGNOLIA), developed by a group of physicists and engineers from CEA, MIT, Northeastern University, and Southeastern Massachusetts University, is the CEA's second-generation on-line detector.

Figure 8 shows the general design of MAGNOLIA. It includes a rectangular solenoidal coil the axis of which is coincident with the e^+ and e^- beampaths, and includes also ~80 tons of 1-inch-thick iron plates that almost entirely enclose the coil on all six sides. When powered at 2 MW the coil provides a 5-kilogauss field throughout a volume of 94" x 62" x 78". At each end of the assembly there is a compact 17-inch-diameter correction coil (Collins coil); these coils produce local fields that cancel the defocusing effects of the main magnet field on the orbiting e^+ and e^- particles.

Included within the region of magnetic field are proportional chambers for providing trigger signals, momentum spark chambers for use in determining direction and curvature of paths of charged particles, and shower chambers for detecting photons and for distinguishing e^+ and e^- from other kinds of charged particles. Additional chambers are installed in the assembly ends (to deal with gamma-gamma events) and at locations external to the solenoidal coil and the enclosing iron.

A versatile trigger system will give the operator wide range of choice of trigger tightness. An on-line computer program employing the Harvard IBM 370/145 computer interfaced by an SDS-92 computer will record the data on magtape and make preliminary

5/8/72

Figure 8.

Simplified diagram of the main features of the MAGNOLIA detector.

Above: Vertical cross section, looking toward west.

Below: Horizontal cross section.

analyses. An off-line program will provide more sophisticated analyses and compilations.

B. Progress and Status

By December 31, 1971, all main components of the magnet proper were on hand, and a partial assembly of the magnet iron had been completed. The solenoidal coil has been assembled. The overhead bridge structure required in making final assembly was on hand.

Construction of the 40 outermost proportional chambers was more than 50% complete. Each chamber is 36" x 21" in area and includes one plane of gold-plated-tungsten 0.8-mil wires (twelve wires per inch) parallel to the 21-inch sides of the frames and midway between the two metallized face-plates, as indicated in Figs. 9 and 10. The face plates are held at 7 kV and the plane of wires is grounded. The time resolution is ~ 30 nsec.

Each of the shower chambers includes six gaps defined by wire planes consisting of twenty 12-mil-diameter copper wires per inch, at angles of $+4$ and -4 degrees from the beam axis. Between gaps there are $0.5 X_0$ lead plates. The wires extend outside the chambers and outside the magnet, in the form of 12-foot-long tail assemblies, and the magnetostrictive pick-up wands are clamped to these tails (in field-free region). See Fig. 11. By December 31, construction of the four shower chambers was 60% complete.

The outermost momentum chambers are similar in size and construction to the pairs of gaps of the shower chamber. The spatial resolution of a pair of gaps is ~ 22 mils. Construction was 60% complete.

Designs of the inner proportional chambers and momentum chambers were nearly complete and construction was getting underway.

Preparation of the necessary computer programs was about 25% complete.

Fig. 9. General design of outermost proportional chamber of the MAGNOLIA detector.

Fig. 10. Cross-section of region AA of outermost proportional chamber. Not to scale.

Fig. 11. Forming the tail system of a wire spark chamber for the MAGNOLIA detector. (a) Array of 1400 parallel wires on 4 x 24 ft. sheet of plastic. (b) Nine cuts are made along the parallel lines indicated --without cutting any of the wires. (c)Folds are made along the short lines at 45° . (d) Final form of tail assembly. Later, a pick-up wire (magwand MM) is attached to the tail sheet, as indicated.

PART VI - ACCELERATOR MAINTENANCE AND MINOR IMPROVEMENTS

A. Linac and Injection System

In general the 260-MeV linac and the injection system performed well. Minor difficulties (tube failures, capacitor failures, leaks) are described in the individual monthly reports.

Improvements included:

A circuit for de-Q'ing the linac modulator pulse-forming voltage network and improving uniformity of output energy.

A faster and more reliable post-acceleration chopper which permits accurate phasing of the e^+ and e^- sausages and can produce bunches so short as to include only one (2-inch-long) bunch - helpful in studies of single-bunch instabilities.

A "fill standard" CRO display giving quick, simple verification of the phasing of the e^+ and e^- sausages.

Installation of three 10-ton air-cooling refrigerators for the Linac Power Area.

Installation of shutters of more reliable and more easily repaired type.

B. Synchrotron Ring

The components of the synchrotron ring performed well. No noteworthy difficulties were encountered.

We connected the ring of 48 magnets to a superior dc supply, free of troublesome low-frequency (2 to 5 Hz) variations such as were present in the output of the earlier supply.

The electrical interlock system governing operability of magnet power supply, beam bumps, etc., was much improved.

We installed additional back-leg windings for control of the radial positions of the beams before they are switched into the bypass. Also, improved vertical steering coils were installed.

Ripple in the power supplies of septum magnets was reduced.

Major improvements are discussed in Part III.

C. Rf System

The system performed well, aside from failure of a choke in Power Supply 4 in August, failure of the magnet of one of the four 953-C klystrons in September, failure of a 100-kW load in October, and failure of a 250-kW load in November.

We installed automatic switching to readjust the rf-power level to accommodate, successively, e^+ injection mode, e^- injection mode, ramp-up mode, and dc-storage mode.

We built and installed a system for maintaining correct phase of rf power in the rf cavities as beam accumulation and cavity loading increase. Details are presented in the Monthly Report for August 1971.

Installation and use of the Landau cavity and of a 361st harmonic cavity are discussed in Part III.

D. Vacuum System

Failures of vacuum system components were infrequent, and the system was improved in several respects. Failures included: leaks in several vacuum chambers, segmenting valves, bellows, and rf cavities. In every instance, the faulty part was promptly repaired or replaced.

The bakeout system for the vacuum ring was greatly improved, so that bakeout temperatures were more uniform and a higher average

bakeout temperature could be used. Even when the coolest portion of the vacuum ring is at 120°C , the hottest portion does not become excessively hot, i.e., does not become hotter than 200°C .

The ion-gage system, and the ion-gage read-out system, were greatly improved.

E. Other Components

We made much progress towards preparing the machine controls and sensors for automatic computer monitoring.

Schemes for reducing usage of electrical power were worked out and put into effect.

Installation of a Freon 1301 fire-suppression system for the Control Room and other vulnerable areas was $\sim 50\%$ complete.

Many major improvements are described in Part III.

F. Hardware in the Ring and Bypass

Figure 12 is a tabulation of all major pieces of hardware in the synchrotron ring early in 1972, and Fig. 13 shows the equipment in the bypass.

Fig. 12. LOCATIONS OF DEVICES IN THE 48 STRAIGHT SECTIONS ON JAN. 10, 1972

Str. Sect. No.	Elec. Sep'n Plate	Valve Fl or segm.	Ion Gage	Monitor		v-sep. Quad.	Sext. Wind- ings	Injec. or Inflec.	Preswitch Steering Coils		Other Device
				Loop or Coil	Syn. Li. Mir'n						
1rf			H				**				RF-cav. intens. monitor
2		T	H	FD			**				
3rf			H				**				
4		T	UI				**				Target DI RF quad., inside Vertical caliper T
5			H		DO		**				
6			H			UI, DI	**				
7	UI	T, U	MO		DI		**Z				Ultraflector, inside
8	EB7D		UO								
9rf 361 harmonic			H								
10	EB, 9D	T	H								Septum OUTSD; {multi-tgt DI caliper UI Horiz. scraper, UI
11	DI		MO	T					H _m , V _D		
12			H								
13	EI	T	MO						H _m , V _U		
14	UI		MO			DI			H _m , V _U		
15rf			H						H _m , V _U		
16	UI	T, U	MO			DI					
17	DI		MO	UIz					H _m , V _D		
18	EB17D		H								
19	EB19U		H								Septum OUTSD; caliper DI Horiz. scraper DI
20	UI	T	MO	D							
21rf			H								
22	EB21D	T	H				**				Ultraflector, inside Kicker DI
23			H	FU		UI, MO	**				
24rf			H				**				
25		T, D	H	FU			**	MI&DO			Kicker DO
26			UO				**	Inside			
27rf			H				**				
28		T	DO				**Z	Inside			Fluoresc. screen UI.
29			UO	FD			**	DI			
30rf			H				**Z				
31	UI		H	U, MO			**Z				Kicker DI Octupole, inside
32	EB31U		MO				**Z				
33rf			H				**				
34	UI	T, U	H		DI		**				
35	UI		MO	D	DI		**				
36rf			H				**				
37	UI	T	H		DI		**				Betatron osc. exciter DI
38	UI		MO				**				
39 Landau			H				**Z				
40	UI	T	DI				**				Electrost. quad., outside
41	DI	U	MO				**				
42			H				**				
43	DI	T	H								Electrost. quad. Variable leak in header
44	UI	T	MO		DI		**				
45			H								
46	EB45D		H								Damping magnet Damping magnet
47		B	H								
48			H				**				

Key: B: bottom. D: downstream, i.e., counterclockwise. EB: end box. f: ferrite.
F: in flange and bellows. Fl: foreline. H: in pump header. H_m: horiz., in magnet.
I: inside, i.e., toward accel. centerpt. Li: light. M: middle. O: outside.
rf: non-powered rf cav. (rf): rf cav. powered at 360 harmonic. Segm: segmenting.
(Sp): special design. T: top. U: Upstream. V: vertical. z: not connected.
*: at junction of magnet bearing this number there is a sextupole winding pulsed or pow'd
by d.c. ***: same, but powered in series with magnet ring.

FIG. 13. LOCATIONS OF DEVICES IN THE CEA BYPASS ON MARCH 30, 1972

Key: ABM: auxil. bending magnet. B: bottom. BM: bending magnet. Lum: luminosity. 0: outside. Q: quadrupole magnet. T: top. TMP: turbomolecular pump. TwQ: twisted quadrupole. z: not connected.

PART VII - OTHER ACTIVITIES AND PROGRAMS

A. Safety

In the six-month period in question there were no disabling injuries.

No one received a radiation dose as large as the permissible dose (2500 mrem). The two highest doses recorded by film badges were 1785 and 805 mrem.

B. Training of Disadvantaged Persons

We continued to participate in training programs (arranged by the Cambridge Neighborhood Youth Corps, the Cambridge Work Study Program, and the Harvard Summer Program) designed to introduce disadvantaged young persons to a variety of technical jobs. Eleven persons participated in training programs in four of the CEA departments.

PART VIII - PUBLICATIONS RESULTING FROM WORK DONE AT CEA

A. Papers submitted to the 1971 International Symposium on Electron and Photon Interactions at High Energies, August 23-27, 1971, Cornell University, Ithaca, N.Y.

"Elastic Scattering and Resonant Electroproduction", R. Wilson.

"Electroproduction of $\pi^{\pm} \Delta(1236)$ from Hydrogen and Deuterium", C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, F. M. Pipkin.

"Coincidence Measurement of Backward π^0 Electroproduction", C. N. Brown et al (as above).

"Coincidence Measurements of Single K^+ Electroproduction", C. N. Brown et al (as above).

"Coincidence Electroproduction of Single Charged Pions from Deuterium", C. N. Brown et al (as above).

"Coincidence Measurements of Backward Inelastic Electroproduction", C. N. Brown et al (as above).

"Coincidence Measurements of Backward Vector Meson Electroproduction", C. N. Brown et al (as above).

"Measurement of π -Meson Photoproduction Asymmetry with Polarized Photons in the Resonance Region", J. Alspector, D. Fox, C. Nelson, D. Luckey, L. Osborne, Z. Bar-Yam, J. De Pagter, J. Dowd, W. Kern, G. Tarnopolsky, S. Martin.

"Photoproduction of Rho and Omega Mesons at 3.0 - 4.7 GeV", G. E. Gladding, J. J. Russell, M. J. Tannenbaum, G. B. Thomson, J. M. Weiss.

"A Search for Photoproduction of Bosons by the Missing Mass Technique and a Measurement of the s and t Distribution of Photoproduction of the Hadronic Continuum", G. E. Gladding et al (as above).

" $\pi^{\pm} \Delta$ Electroproduction in the Electric Born Model", F. A. Berends and R. Gastmans.

"Large Angle Quasi-Elastic Electron-Deuteron Scattering", K. Hanson, J. R. Dunning, Jr., M. Goitein, T. Kirk, L. E. Price, R. Wilson.

B. Papers presented at the VIII International Conference on High Energy Accelerators, September 1971, Geneva, Switzerland

"Colliding Electron and Positron Beams in the CEA Bypass", R. Averill, A. Hofmann, R. Little, H. Mieras, J. Paterson, K. Robinson, K. Strauch, G.-A. Voss, H. Winick.

"Observation of the Head-Tail Instability at the Cambridge Electron Accelerator", A. Hofmann.

"Performance of the CEA Low-Beta Bypass", R. Averill, A. Hofmann, R. Little, H. Mieras, J. Paterson, K. Strauch, G.-A. Voss, H. Winick.

"Synchrotron and Betatron Instabilities of Stored Beams in the CEA", R. Averill, A. Hofmann, R. Little, H. Mieras, J. Paterson, K. Strauch, G.-A. Voss, H. Winick.

C. Theses

"Coincidence Measurement of Inelastic Electroproduction in the Backward Direction", William Lockeretz (Harvard), August 1971.

"A Measurement of Charged Pion Electroproduction from Hydrogen and Deuterium", C. R. Canizares (Harvard), August 1971.

"Production of π^- Mesons Using .7 to 2.3 GeV Linearly Polarized Photons", C. A. Nelson, Jr. (M.I.T.), August 1971.

"Production of Single π^0 's Using Polarized Photons in the Resonance Region", J. L. Alspector (M.I.T.), September 1971.

"A Measurement of the Asymmetry from Linearly Polarized Photons for the Reaction $\gamma + p \rightarrow \pi^+ + n$ in the Resonance Region", D. J. Fox (M.I.T.), September 1971.

"A Coincidence Measurement of Backward π^0 Electroproduction", V. B. Montana (Harvard), September 1971.

"Proton Compton Scattering near the Forward Direction at 2.5 - 4.3 GeV", R. B. Wearn, Jr. (Harvard), October 1971.

"A Search for Neutral Mesons Using a Tagged Photon Beam and the Missing Mass Technique", G. E. Gladding (Harvard), November 1971.

D. Other High Energy Physics Publications

"Single π^+ Electroproduction and the Vector-Meson Dominance Model", F. A. Berends and R. Gastmans, Phys. Rev. Letters 27, 124 (1971).

"Backward-Angle Electron-Proton Elastic Scattering and Proton Electromagnetic Form Factors", L. E. Price, J. R. Dunning, Jr., M. Goitein, K. Hanson, T. Kirk, Richard Wilson, Phys. Rev. D4, 45 (1971).

"Recoil Effects in High-Energy Hadron-Deuteron Collisions", G. Fäldt, Nuclear Phys. B29, 16 (1971).

"An Energy-Independent Multipole Analysis of Pion Photoproduction on Protons below 450 MeV", F. A. Berends and D. L. Weaver, Nuclear Phys. B30, 575 (1971).

"Coincidence Electroproduction of Single Charged Pions from Deuterium", C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, and F. M. Pipkin, Phys. Rev. Letters 27, 536 (1971).

"Theorem on the Vanishing of Z_2 : Evidence from Electron Scattering that the Proton Really is a Composite Particle", G. B. West, Phys. Rev. Letters 27, 762 (1971).

"Photoproduction of π^0 's from Neutrons at 4 GeV", G. C. Bolon, D. Bellenger, W. Lobar, D. Luckey, L. S. Osborne, and R. Schwitters, Phys. Rev. Letters 27, 964 (1971).

"Coincidence Measurement of Backward π^0 Electroproduction", C. N. Brown, C. R. Canizares, W. E. Cooper, A. M. Eisner, G. J. Feldman, C. A. Lichtenstein, L. Litt, W. Lockeretz, V. B. Montana, and F. M. Pipkin, Phys. Rev. Letters 27, 1611 (1971).

"Yields of Radionuclides in Thin Iron Targets Bombarded with 40-MeV to 16-GeV Electrons", C. B. Fulmer, K. S. Toth, I. R. Williams, G. F. Dell, T. M. Jenkins, Phys. Rev. C3, 1955 (1971).

"Discussion of Isotensor Terms and T-Violation in Pion Photoproduction Near the First Resonance", F. A. Berends, D. L. Weaver, Phys. Rev. D4, 1997 (1971).

E. Other Publications

CEAL-1056 "Semi-Annual Report for the Period January 1 through June 30, 1971, K. Strauch and W. A. Shurcliff, July 21, 1971.

CEAL-TM-196 "Some Key Definitions Relating to the CEA Colliding Beam Facility", W. A. Shurcliff, June 30, 1971.

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