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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 January to 31 March 1965

July 1965

Technical Report

Prepared Under

Contract AT(04-3)-400 and

Contract AT(04-3)-515

for the USAEC

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I. INTRODUCTION

This is the tenth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the fourth Quarterly Status Report of work under AEC Contract AT(04-3)-515, both held by Stanford University. Contract AT(04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that will have as its chief instrument a two-mile-long linear electron accelerator. Construction of the Center began in June 1962, and the present schedule calls for first turn-on of the electron beam in the summer of 1966. The principal beam parameters of the accelerator in its initial operating phase are a maximum beam energy of 20 BeV, and an average beam current of 30 microamperes (at 10% beam loading). The estimated construction cost of SLAC is $114,000,000.

The work of construction is divided into two chief parts: (1) the accelerator itself and its related technical environment; and (2) the more conventional work associated with site preparation, buildings, utilities, etc. To assist with these latter activities, Stanford has retained the services, under subcontract, of the firm Aetron-Blume-Atkinson, a joint venture consisting of Aetron, a division of Aerojet-General Corporation; John A. Blume and Associates, Engineers; and the Guy F. Atkinson Company. In these reports this architect-engineer-management firm is often referred to as "ABA."

The terms of Contract AT(04-3)-400 provide for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision is made for an initial complement of general-use research equipment with which it will be possible to perform certain exploratory studies, such as measurement of the intensity and energy distribution of various secondary-particle beams.

II. PLANT ENGINEERING

A. GENERAL

Highlights of the conventional facilities program during the quarter were: occupancy of the Central Laboratory and Control Building, commencement of construction of the End Stations and Cafeteria-Auditorium, and award of contract for the Target Area substations.

The remaining project design effort relates principally to the Cryogenics Building, Beam Dump East, and utilities associated with the End Stations. Overall field construction for the project is well along and is now scheduled for completion in March 1966. The present status of a number of facilities in the construction phase is shown in Figs. 1 through 5.

The design of the overhead 220 kV power feeder line to the Sand Hill site was completed under contract to the AEC. Construction bids on this line have been invited by the AEC and will be opened in April 1965. The Master Substation, to be located on the project site, is already contracted for and scheduled for completion late this year. The latter contract, awarded through Aetron-Blume-Atkinson, is being modified to include an oil circuit breaker at the substation.

Discharges from all cooling towers and drainage from the accelerator structure housing and end stations are to be periodically monitored and reported to the Regional Water Pollution Control Board. Data from sampling stations in the vicinity of San Francisquito Creek and within the project area will be submitted. Information for the initial report is now being assembled. This program will be a continuing operational requirement of the Laboratory.

A committee of SLAC and ABA personnel, appointed in February, meets weekly to consider the interaction of Target Area construction and the installation of SLAC equipment. Problems of joint occupancy, reconciliation of schedules, and the effects of construction changes are being studied. The overall purpose is to facilitate operational use of the area and to resolve any conflicts which may arise in this critical phase of the project effort.

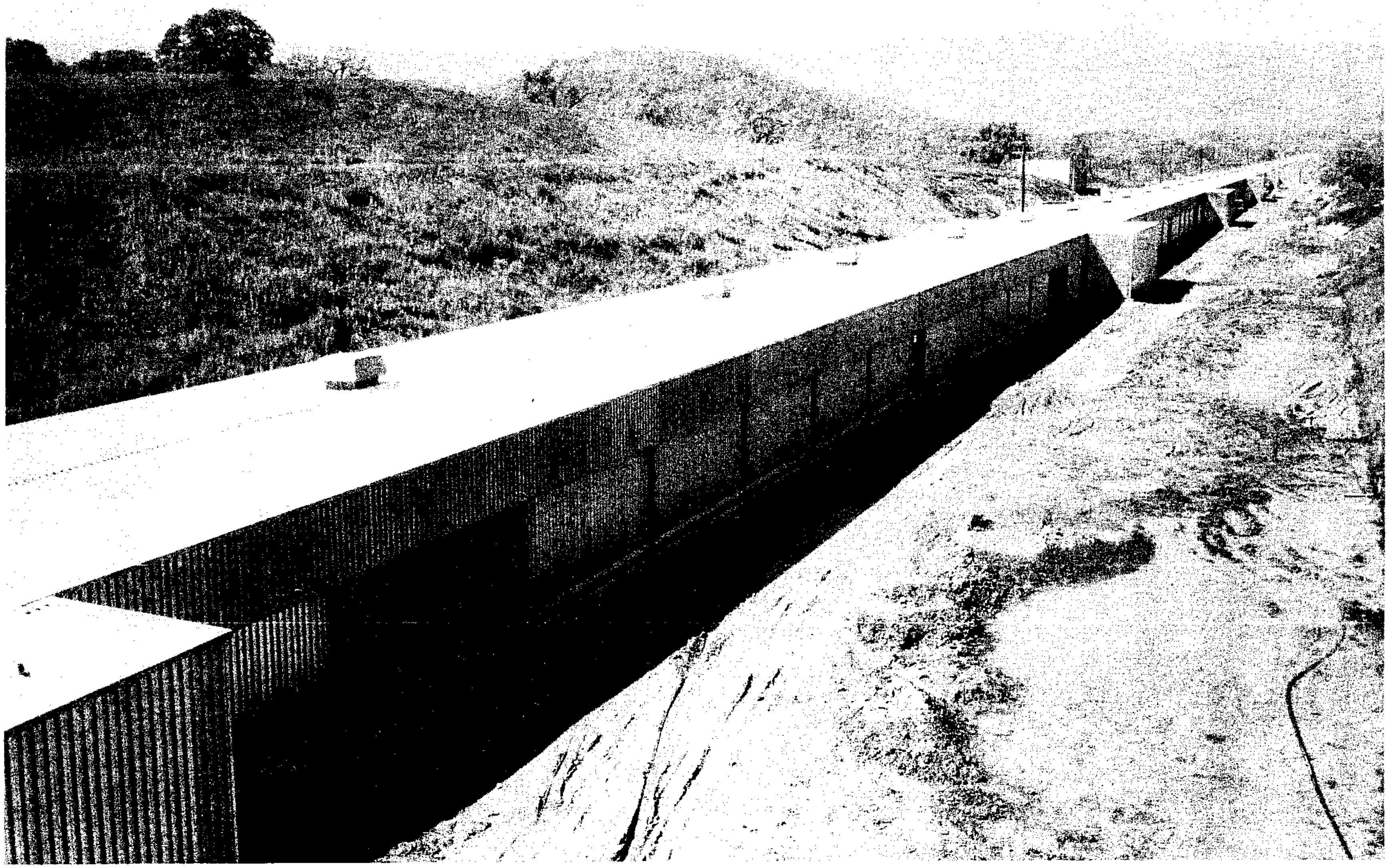

FIG. 1--Klystron Gallery from freeway overpass; looking west.

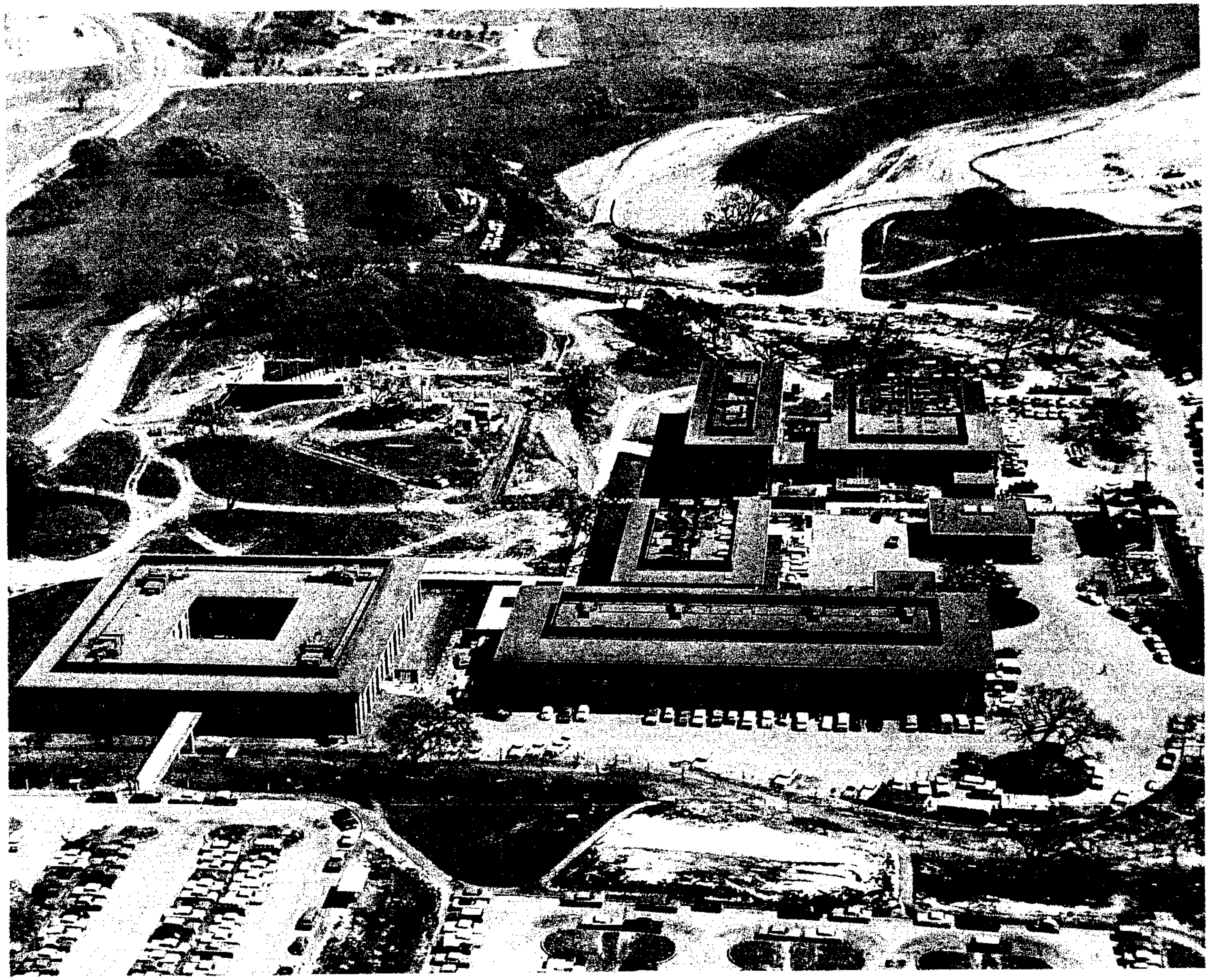

FIG. 2--Aerial view of "campus" area.

FIG. 3--Construction status of Auditorium-Cafeteria.

FIG. 4--Control Building.

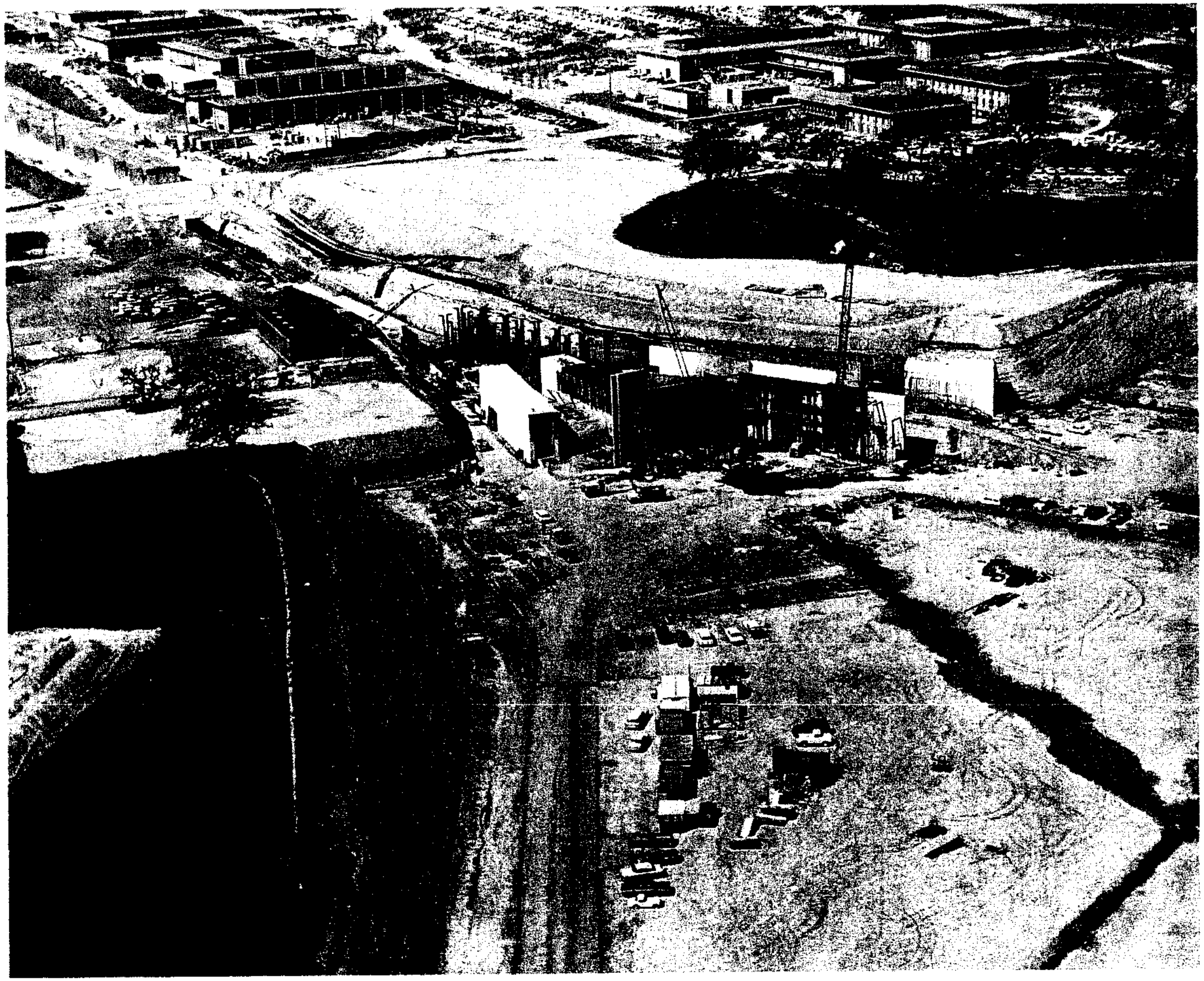

FIG. 5--Beam Switchyard under construction, with laboratory and shops complex in background.

B. DESIGN STATUS

The project design effort is concentrated on completing the Cryogenics Building, Beam Dump East, certain utilities in the Target Area, and any necessary changes to facilities under construction. The status of major items at the end of the quarter is as follows:

Master Substation Equipment: Shop drawing submittals are being received and reviewed.

Central Laboratory: Bids were invited for the remaining work on the second-story addition and will be opened in early April 1965.

Beam Switchyard Materials Handling System: Component testing has been performed by the contractor. Work is on schedule.

Beam Switchyard Site Improvements and Utilities: Bids opened on March 26, 1965 are being evaluated.

End Station Site Improvements and Utilities: The Title II design is 80% complete.

Target Area Substations: A contract was awarded for these two substations, and a notice to proceed was given on March 11, 1965.

Target Area Cranes: Proposals received from three firms for the four cranes in this package are being evaluated.

Cryogenics Building: The Title II work is 25% complete.

Heavy Assembly Building Cranes: Shop drawing submittals are being received and reviewed. The two 20-ton cranes will be operational in June 1965; the 50-ton crane one month later.

Beam Dump East: Title I work is essentially complete. This facility forms a functional part of End Station A, although located downstream in the large hill east of the research yard for shielding purposes. Its basic components are a beam transport vacuum pipe, water-cooled dump tank, a cooling system whose water coolant will become radioactive, a heat-exchanger and pumping complex, and instrumentation and control systems.

Concrete Shielding Doors: The 100% procurement package, "Request for Proposals," was mailed out early in May. The installation will consist of one power-operated door for End Station A, one power-operated door for End Station B, and one manually-operated door for the BSY entrance structure.

End Station Modifications: Designs were completed on the modifications for the 20 BeV/c spectrometer foundations and the spark chamber pit in End Station A, and for miscellaneous changes in both A and B.

Landscaping: This program is proceeding in incremental packages, bids having been received for Increments II and III in March. These provide most of the remaining landscaping associated with the "campus" area. Landscaping for the Cafeteria-Auditorium is provided in Increment IV, for which Title II work is 70% complete.

C. CONSTRUCTION STATUS

The status of major conventional facilities now under construction is as follows:

Facility	Percentage of Completion
Central Laboratory	99
Landscaping (Increment No. 1)	98
Control Building	98
Klystron Gallery	96
Klystron Gallery Utilities	
Piping and Site Improvements (600-Y-1)	72
Electrical (600-Y-2)	13
Cooling Towers (600-Y-3)	96
Switch House (for Master Substation)	65
Data Assembly Building	84
Beam Switchyard	34
Cafeteria-Auditorium	26
End Stations "A" and "B"	*

*Field work commenced on March 17, 1965.

All items of work associated with Sectors 1 through 14 of the Klystron Gallery contract have been officially accepted from the contractor and turned over to SLAC. Beneficial occupancy has been taken on all sectors through No. 24 in order that equipment installation and testing may proceed. A "broom raising" ceremony on February 16th at the end of Sector No. 30 symbolized the final placement of structural steel in the gallery.

In addition to the above, beneficial occupancy was taken of the Central Laboratory and the Control Building during the quarter. These facilities are now occupied by SLAC personnel, many of whom had previously been housed in Buildings M1 and M2 on the campus.

A BSY contract modification is in process to revise increments and schedule for coordination with the end station work. This provides a more realistic work arrangement since the same contractor is handling both projects.

The Control Building contractor employed the services of a consulting engineer to conduct electrical resistance tests in the facility. They are to determine if any direct or approximately 1-ohm short circuits exist between any one column of the rack area steel floor structure and the reinforcing bar in the lower concrete floor. The results of the tests are being reviewed.

D. PLANT ENGINEERING SERVICES

The department continued its activities relating to facility planning, alterations, and provision of craft support for all SLAC groups.

The preliminary design of a proposed electron-positron storage ring to be located on the project site requires an investigation of soil and foundation problems. Arrangements are being made to perform this work during the next quarter. The tentatively proposed center of the storage ring facility is approximately 280 feet north of the accelerator centerline, opposite Station 66. The ring itself will have a diameter of approximately 250 feet.

Preliminary scoping and cost estimating of a proposed computer building for SLAC were completed in March. This effort is in support of a policy decision on funding for the project. The selected site is southeast of the Central Laboratory on a knoll located between that facility and the Cryogenics Building.

Plant Engineering designed a 25-ton air conditioning system for use in rooms 2F10 and 2G10 of the Central Laboratory. This modification was required for the ultra-high vacuum testing which will be performed in that area. The installation was contracted for in March and the work is now underway. Completion is scheduled for mid-April.

Beginning in January, the Craft Shops initiated a plant surveillance service on the night and week-end shifts to provide fast detection and repair of equipment malfunctions. Critical electrical and mechanical equipment throughout the site is checked periodically for proper operation.

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. General Accelerator Design

The design report on the alignment system vacuum components was issued for comments prior to making final installation drawings. Late in the quarter, it was decided that the laser installation used to align the accelerator will be located at the east end of the accelerator rather than the west end. This decision will affect the vacuum system arrangements; the vacuum station must now be located at the east end of the accelerator in the former alignment station at the end of Sector 30.

Positron source system drawings are being revised to reflect the latest changes in the system requirements.

The design of shielding for the waveguide penetrations was finalized; plywood discs will be used in lieu of silastic membranes. A beam through Sectors 1 and 2 was achieved.

2. Model Shop

A model of the Data Assembly Building was begun and the positron source alcove model was completed. A model of the main injector, in which actual cables are being located in accordance with the subcontract drawings, is almost complete. Periscopes, scope mounts, and level vial reflector housings to be used for visual experiments on accelerator level control were fabricated.

Studies preparatory to making a model of the B-beam target area housing were initiated, and a model of the pivot pit for the mass spectrometer utility routings at End Station A was made.

3. Installation Drawings

Modifications to the electrical system drawings are approaching completion. Revisions of the cooling water system drawings for the positron source continue. It was decided to water-trace the main and sub-drive lines for improved temperature stabilization, and drawing changes started.

Work to finalize the electronics systems installation bid drawings for Sectors 3-30 is in process, and changes to the positron vacuum system are underway.

4. Vacuum

The drift section connection procurement award was made and deliveries were on schedule.

Tests on the getter-ion pump power supplies disclosed a transformer problem. Power supplies with reworked transformers were resubmitted and passed performance tests at 55°C and 60% relative humidity.

Despite changes made in cold cathode gauge control units, problems continue to exist. A back-up program was initiated for an in-house gauge control design, and a prototype and ten production units will be built. Design is proceeding satisfactorily.

5. Cooling Water

Installation work on the cooling water system is 67% complete. The corrosion test unit was shut down after completion of a third test run of 180 days. Quotations on pumps and heat exchangers were received. Tests on the main and sub-drive line water tracing to improve temperature stabilization were started.

6. Electrical Services

Installation work is now 64% complete. Results of acceptance tests to check the performance of substations and systems were satisfactory. The drive line temperature stabilization problem will require new support and anchor designs, and studies are in progress.

7. Electronics

Sectors 1 and 2 electronics installation work was essentially completed with the establishment of the beam. Final completion and verification of as-built drawings will continue.

The first delivery of fiat racks under the first assembly subcontract for Sectors 3-30 was made on schedule. The second rack assembly subcontract package for the control alcove and central control racks is undergoing 90% review.

The multi-pair cable subcontract was awarded, in-plant tests were witnessed, and 133,000 feet of 25-pair, 22-gauge cable was accepted for shipment. A subcontract award was made to procure 9000 feet of main trigger cable. Negotiations to procure the long ion chamber are in process.

Bids for a time and materials subcontract for miscellaneous electrical/electronic installation and connection work were received and are being evaluated. This work will effectively accomplish final cross connections in these racks where design information will be received too late for incorporation into lump sum subcontracts.

A definitive list of the audio-visual equipment for the auditorium received project approval and procurement was started.

B. BEAM SWITCHYARD

Concentrated effort was placed on the development of drawings for an equipment installation subcontract. This package will consist of the installation of all major beam switchyard components, such as the magnets, power supplies, instrument stands, and vacuum system piping chambers.

1. Vacuum

Vacuum pumping system bids were received and the subcontract awarded. Preliminary parts lists and shop drawings were received for approval.

Drawings and specifications for the vacuum chambers were completed.

Detail design of the fast valves is nearing completion. A new lead-indium seal has been designed to allow the valve to meet the closure criterion of five hundred repeated cycles.

Fabrication of a prototype 10-inch isolation valve has begun.

2. Electrical/Electronics

Specifications and drawings for the electrical/electronics system installation work are being approved.

The proposed remotely-operable power connectors have been tested with one bending magnet unit. Cable connections to the connectors will be modified to minimize the temperature rise noticed during the test.

Specifications for special instrumentation and control cables were reviewed and are being modified to optimize economy and function.

Recommendations for the purchase of the high and moderate radiation resistant cables have been made.

The drive line package redesign is still under review.

3. Cooling Water

Work on flow diagrams and layout drawings for the cooling water system continued, and progress drawings were issued for review. Three addenda to the heat exchanger specifications were submitted, and bids will be requested early in the next quarter.

IV. ACCELERATOR PHYSICS

A. INJECTION

1. Main Injection System

a. Wiring and Electronic Assembly

Assembly and wiring of the injector electrical systems are progressing on schedule. The internal rack wiring program has been completed and all racks have been delivered to the site. The electrical contractor has started his interconnecting wiring.

The control console is in place and its internal wiring is complete. The interconnecting wiring is being installed by the electrical contractor. Individual panels are being installed as they become available.

Testing of the high current power supply control systems is in progress with no major problems encountered to date. Final testing awaits receipt of the high current power supplies which are to be delivered in May. The medium current power supplies are to be delivered as part of the overall steering power supply subcontract for the machine. The remote control system for these supplies is nearing completion and an available prototype power supply will be used for checkout.

The design of the injector vacuum system is complete and about 70% of the components have been either purchased or fabricated. Special control units have been designed to provide automatic vacuum readout at the console as well as interlock circuitry for injector protection. The injector phasing system concepts have been established and hardware design has begun. Most components of this system are similar or identical to other units on the machine.

Other related instrumentation and control systems being worked on include power monitoring, video monitoring, phase and power level controls and control of the momentum spectrometer.

b. Waveguide Components

The injector disk-loaded waveguide with the .75c buncher has been brazed with its water cooling pipes and is ready to be assembled in the concentric strongback. The 10-foot stainless steel concentric strongback was delivered and found straight to 0.003 inch. The contract for winding the focus coils was awarded with delivery scheduled for May 7, 1965. All waveguide components are in the Machine Shop and have reached 90% completion. A few straight sections of waveguide will not be brazed until the scheduled installation date in order to alleviate the clean room storage problem.

Engineering design for all drift section components is complete and drafting is 50% completed. Fabrication of these components is about 25% completed. A thin valve employing the basic Mark III valve design will be used in the injector gun end.

During the next quarter, the gun lenses and prebuncher will be dynamically tested in the Injection Test Stand. Other in-line components will be tested as they are completed prior to installation in the Accelerator Housing. Installation in the housing is scheduled to begin in June.

2. Electron Guns

The initial design of SLAC gun 4-1 has been tested in the bell-jar vacuum station. The original pancake-shaped filaments were found unsatisfactory. Operation at temperatures above 1500°C resulted in mechanical growth which caused shorts between adjacent turns. These mechanical growths also resulted in a deviation from flatness of as much as three wire diameters. New winding jigs were made and a stress relieving cycle developed so that filaments made from 2% Th-W 0.010-inch spacing between turns can be operated above 1800°C with very little distortion. Development of the carburization process began near the end of this quarter.

Several other defects in the design were corrected. All heat shields required additional strut supports because they tended to collapse on adjacent surfaces when tested. A cracked ceramic post, apparently due to different thermal expansions of the two connected decks, indicated the necessity for redesigning to permit deflection.

Difficulty was encountered with the filament, which began to poison at about 1400°C. After a systematic spectroscopic examination, it was found that the heat shields contained molybdenum and platinum rather than molybdenum and tantalum. The accidental substitution of platinum is believed to be responsible for the poisoning effect and new heat shields using only molybdenum and tantalum are being fabricated.

Despite these emission difficulties, the cathode was operated at temperatures as high as 1600°C. At 1540°C cathode temperature, the filament temperature was 1620°C, the filament power was 40 watts and the bombarder power 80 watts, i.e., 120 watts total input power. When the emission problems are solved, the contribution of the filament will decrease.

The vacuum envelope was completed this quarter and is awaiting static load, high potential and operating gun tests. It has been leak-checked and is pumped down on the bake-station but has not yet been baked-out.

3. Gun Modulator

The Manson modulator, Model 4-2, is to be modified for use on the machine. Studies are now underway to determine what modifications are required. The bombarder supply will be added. Control and pulse forming circuitry will be repackaged to fit the requirements of the machine. The temporary gun modulator presently installed on the machine will be used for initial injector turn-on.

4. Injection Test Stand

The Injection Test Stand operated throughout the quarter and continued to be utilized for a large variety of experiments including measurements of bunching, rf sweeper efficiency, beam position monitors and radiation studies.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

Installation of the main and sub-drive lines has been completed through Sector 2. All remaining sectors have been delivered and acceptance testing is expected to be completed next quarter. Extensive tests have been performed to determine the minimal additional requirements to remedy the difficulties encountered during the last quarter regarding temperature-phase stabilization. The following modifications will be implemented:

(a) Both the main and sub-drive lines will be temperature controlled individually by means of water tracing lines.

(b) Rigid A-frames, constructed of 4-inch steel pipe, will be used to anchor the main drive line at the beginning of each sector. The sub-drive line will continue to be anchored to the fiat rack by means of a reinforced structure.

(c) In order to decrease the friction of the main drive line, teflon supports will be replaced by rollers.

(d) The expansion sections of the main drive line will be improved to reduce the friction load.

(e) The thermal insulation will remain of the same size and type but extra care will be used during installation to insure free motion of the drive lines.

(f) The main and sub-drive lines will be purged and filled with dry air at a nominal maximum pressure of 1 atmosphere. At that pressure, the lines will be sealed so that the dielectric constant of the medium is independent of temperature.

2. Varactor Frequency Multipliers

One manufacturer has been testing diodes for the production run of the multiplier units and, at the end of the quarter, had 23 acceptable and eight unacceptable diodes with regard to output power. Final testing of the production run will begin on April 13.

Two other manufacturers have made diodes which would be satisfactory substitutes for those of a fourth manufacturer, should the latter be unable to continue to meet our needs.

3. Main Booster Amplifiers

The main high voltage circuit breakers were replaced and fewer trip-outs were experienced during the quarter. Overall operation has been very satisfactory. The units now have 4500 and 3500 hours of klystron operating time respectively.

4. Master Oscillators

The master oscillators and synchronizer have been permanently installed in the master oscillator rack, together with individual frequency counters for each master oscillator, and frequency multipliers to permit a direct readout of the frequency at 2856 Mc/sec. Minor difficulties with meter relays have been resolved.

5. Sub-Booster Modulators

Following checkout of the pre-production units, a formal production go-ahead has been given to the manufacturer. Receipt of the first units is expected in the middle of the next quarter.

6. Drop-Out Cables

Drop-out cables have been received, tested and accepted. All specifications were met. Installation will proceed as terminal equipment arrives and is installed.

7. "Positron" Phase-Shifters

A "π" phase-shifter for positron acceleration with its driver was installed in a I$\varphi\alpha$ unit. An assembly drawing was prepared to reflect this change. Eleven additional I$\varphi\alpha$ units will be modified in this manner. The conversion will be completed by the time the I$\varphi\alpha$ units are installed in sub-boosters 1 to 10. Printed circuit boards for the phase shifter driver have been ordered.

8. RF Drive System Control Circuits

Design work on the master oscillator switching unit is almost complete and construction of the unit is beginning. After completion, the design of the main booster switching unit will be reviewed and, if appropriate, these units will be substantially simplified and incorporated into the master oscillator switching unit. Design of the sub-booster switching unit will proceed on a higher priority basis as soon as the second sub-booster modulator and the sub-booster transfer switch have been installed.

9. Sub-Booster Klystrons

Delivery of the first part of the sub-booster klystron contract is nearing completion. The problem of shelf life still remains unsolved. Three special klystrons were given a shelf life test during the past three months. All three failed and were returned to the manufacturer.

C. PHASING SYSTEM

1. Isolator, Phase-Shifter, Attenuator Units

Delivery and testing of the 249 standard units, 31 sub-booster units and 33 control phase-shifters are nearly completed. No major problems have arisen. The units installed in Sectors 1 and 2 have performed very satisfactorily during machine tests.

Work remaining includes modification of the 25 pre-production units to conform with the production run, for which the sub-contractor is supplying components. In addition, modifications to meet the special remote-control requirements for Sector 27 will be made at SLAC. The sub-contractor will supply three special control phase-shifters for use in the injector phasing system.

2. RF Detector Panels

Three pre-production units were delivered at the end of January. They were tested, both in the laboratory and in service on the machine, and found to be satisfactory. Minor changes have been made, and the first five production units are expected early in April. Operation of the rf detector panels in Sector 1 and 2 tests has shown the design to be entirely satisfactory. The only problem relates to the thermionic diodes which will be discussed below.

3. Programmers and Electronics Units

Three pre-production programmers and three pre-production electronics units were received, tested and found to meet the requirements of the procurement specification. However, experience with the phasing system in Sector 1 and 2 tests indicated that some re-design of the 90° delay and servo amplifiers was required. In addition, it was necessary to improve the sensitivity of the remote manual control system for the klystron phase-shifters. New designs have been tested, and negotiations are proceeding so that the changes may be incorporated in the production run.

4. Linear Detectors

Six prototype housings were tested. The input VSWR was satisfactory after a few small changes were made. All drawings have been completed, and the procurement of 280 housings has begun.

The thermionic diodes themselves have proved to be a source of difficulties in the automatic phasing system. Rapid drift of the diode balance position occurs when the peak power level of the applied klystron signal exceeds 500 watts. The problem was solved by reducing the power levels of all signals at the diodes. It was found that the system worked very satisfactorily with a 0.5 MW CW reference signal at each diode, and with beam-induced signals as low as 1 MW (peak) at each diode.

5. Overall Performance of the Automatic Phasing System

Operation of the automatic phasing system in Sectors 1 and 2 has shown that, because of time delay problems, a pulsed reference signal obtained from the sub-drive line is unsatisfactory. Accordingly, the system has been changed so that part of the CW output from the varactor multiplier in each sector is used as a phasing reference. This signal is obtained from a 10dB coupler inserted in the input of each sub-booster $I\varphi\alpha$ unit. Couplers for Sectors 1 through 30 will be procured. With this modification and the other modifications of the diodes and the servo amplifiers, this system worked satisfactorily, completing the phasing of one sector within one minute. The phasing error is estimated to be less than 3°. This system works reliably, but slow diode drift necessitates occasional rebalancing.

6. Permanent Beam Analyzing Station

The station was installed in the accelerator housing in early January. All power supplies, slow interlocks and monitors were connected and tested. The station has been used at the beginning of each evening's test run in Sectors 1 and 2, to optimize the injector beam spectrum. The secondary-emission foil scanner unit has proved invaluable for this purpose. Numerous changes and improvements have been made as a result of experimental use during this quarter.

7. Temporary Beam Analyzing Station

The station was installed in the accelerator housing at the end of Sector 2 during January. A floating-wire check on the energy-calibration was performed prior to installation. All power supplies, interlocks and monitors were connected. The station has been used to measure the energy and spectrum width of the beam produced by the Sector 1 and 2 machine. All controls and readouts have recently been made remotely controllable from the Sector 2 alcove.

8. <u>Beam Position Monitors for Drift Sections</u>

Three beam position monitors have been in operation in Sectors 1 and 2 during this quarter, and are performing satisfactorily.

In the light of experience gained so far, three changes are being made in the cavity assembly design for the rest of the machine. These are:

(i) Elimination of a stainless-steel/copper interface in a water jacket, to avoid corrosion.

(ii) Incorporation of a "two-way" dimpling mechanism to increase the range of resonant frequency adjustment.

(iii) Increasing the loaded "Q" of the position cavities to increase the available power.

Detailed drawings of the cavity assembly are complete, and the procurement of machined components for the rest of the machine has been initiated.

Sector 1 and 2 tests have shown that the beam position detector panel design is satisfactory. A procurement specification is being prepared.

9. <u>Beam Position Monitors for the Beam Switchyard</u>

Cold-testing of pre-prototype cavities has been completed, and a set of drawings for the final cavity assembly has been prepared. The first assembly to be made from these drawings is nearing completion. This assembly will be tested on the injector test stand before initiating the procurement of further parts.

All components for six associated beam position monitor detector panels have been ordered. A prototype unit is nearly completed.

D. GENERAL MICROWAVE STUDIES

1. RF Separators

As a result of experiments done on the injector test stand, the deflecting efficiencies of the LOLA II and LOLA III rf deflectors were remeasured. All rf couplers used in these measurements were carefully recalibrated in order to reduce the uncertainty in the microwave peak power measurements. The new results are tabulated in Table I. This table also allows comparison with the original results obtained on the Mark IV accelerator and gives the efficiencies to be expected with a 3-meter long structure.

An attempt was made to measure the beam induced signal as a function of beam current and beam position. This measurement is of interest because it is important to know whether such a signal could become large enough to appreciably deflect the electron beam. The measurements showed that for a 55 mA beam off-centered by 7 mm, the induced signal was 6 watts peak, which is entirely negligible.

Work is also in progress on a TM_{01} structure with an offset disk hole. Early measurements of transverse impedance have suggested that it has a higher shunt impedance than the TM_{11} structure and that it is also aberration free.

E. OPTICAL ALIGNMENT SYSTEM

Targets are being installed in the completed girder segments during girder assembly in the Mechanical Design and Fabrication shops. Design work has continued for the hinges, hinge actuators and the calibration fixture to determine the position of the target relative to the accelerator. The hinge design has been tested and is in production.

In the process of establishing the design parameters for the mirror system to bring the laser beam up to the klystron gallery, it was realized that the required tolerances were overly restrictive. The mirror system would have been the limiting factor to the entire accelerator alignment program. To avoid the need for the mirror system, the direction of the laser beam has been reversed. The detector will be installed in the west portal of the accelerator housing. With suitable shielding,

Table I

Name of Structure	2a cm	2b cm	Relative Group Velocity v_g/c	Transverse Shunt Impedance r_{oT} MΩ/m		$E_o/\sqrt{P_o}$ MeV/m $\sqrt{MW}$	$I\ell$ for 3-meter structure	$\sqrt{2I\ell}\,\frac{1-e^{-I\ell}}{I\ell}$	$V/\sqrt{P_o}$ for 3-meter structure MeV / $\sqrt{MW}$
				Mark IV	Injection Test Stand				
LOLA II	4.064	11.789	-0.0296	8.90	14.66	1.76	0.331	0.670	4.44
LOLA III	4.732	11.571	-0.00766	5.56	10.26	2.66	1.038	0.900	4.99

it is expected that a man will be able to work safely in this area even while the accelerator is operating.

The laser will be placed at a right angle to the accelerator housing in a special cubicle under the road which crosses the housing behind the east end of the klystron gallery. The radiation in the cubicle is expected to be low enough to prevent damage to the laser. The single small mirror which is required for the laser is relatively easy to make and support. The Beam Switchyard will have a second laser similarly located which will form target images on the same detector used by the accelerator system. A set of actuated baffles will permit the alignment operator to choose either the accelerator or the Beam Switchyard system.

F. MAGNETIC SHIELDING AND DEGAUSSING

There was no technical effort in this program during this report period. Shielding is being received, tested and installed routinely.

V. INSTRUMENTATION

A. GENERAL

The work reported in this section was performed by the Instrumentation and Control and Light Electronics groups.

B. BEAM TESTS

The first two sectors of the accelerator have been under test for three months. Results of these tests are reported throughout this report.

In general, all equipment has worked properly once correctly installed. The beam proved very useful both to demonstrate the general adequacy of the subsystem and to uncover minor design errors.

1. Physical Arrangements

A temporary injector from the Mark IV accelerator was installed at the beginning of Sector 1.

The beam was analyzed at two points. One was at the beam analyzing station (BAS) at the end of the first 30 feet of the accelerator, which is part of the final injector tune-up system. The other was a similar set-up beyond the end of Sector 2 occupying the space where the first 40 ft. section of Sector 3 will eventually be installed. The temporary analyzing station is sketched in Fig. 6. The spectrometer magnet is identical to that used at the BAS. By increasing nominal water flow and maximum current and by using a deflection angle of 7.5° instead of 30°, it has been used to about 1.5 BeV even though it was originally designed for use to 250 MeV.

The deflected beam strikes a copper dump within a lead shield. The undeflected beam also strikes a shielded copper block. A 3-foot concrete wall was placed behind the dumps to reduce radiation downstream in the housing. A gate was installed at the drift section downstream of Sector 3, and it was found that the radiation at this point was less than one mr/hr when the beam was striking one of the dumps; however, even the addition of lead shielding around the 8-inch pipe between the magnet and the foil assembly could not bring the radiation at this gate below 5 mr/hr when the beam was deflected to miss the dumps. An additional gate was installed at the foot of Sector 5. Radiation

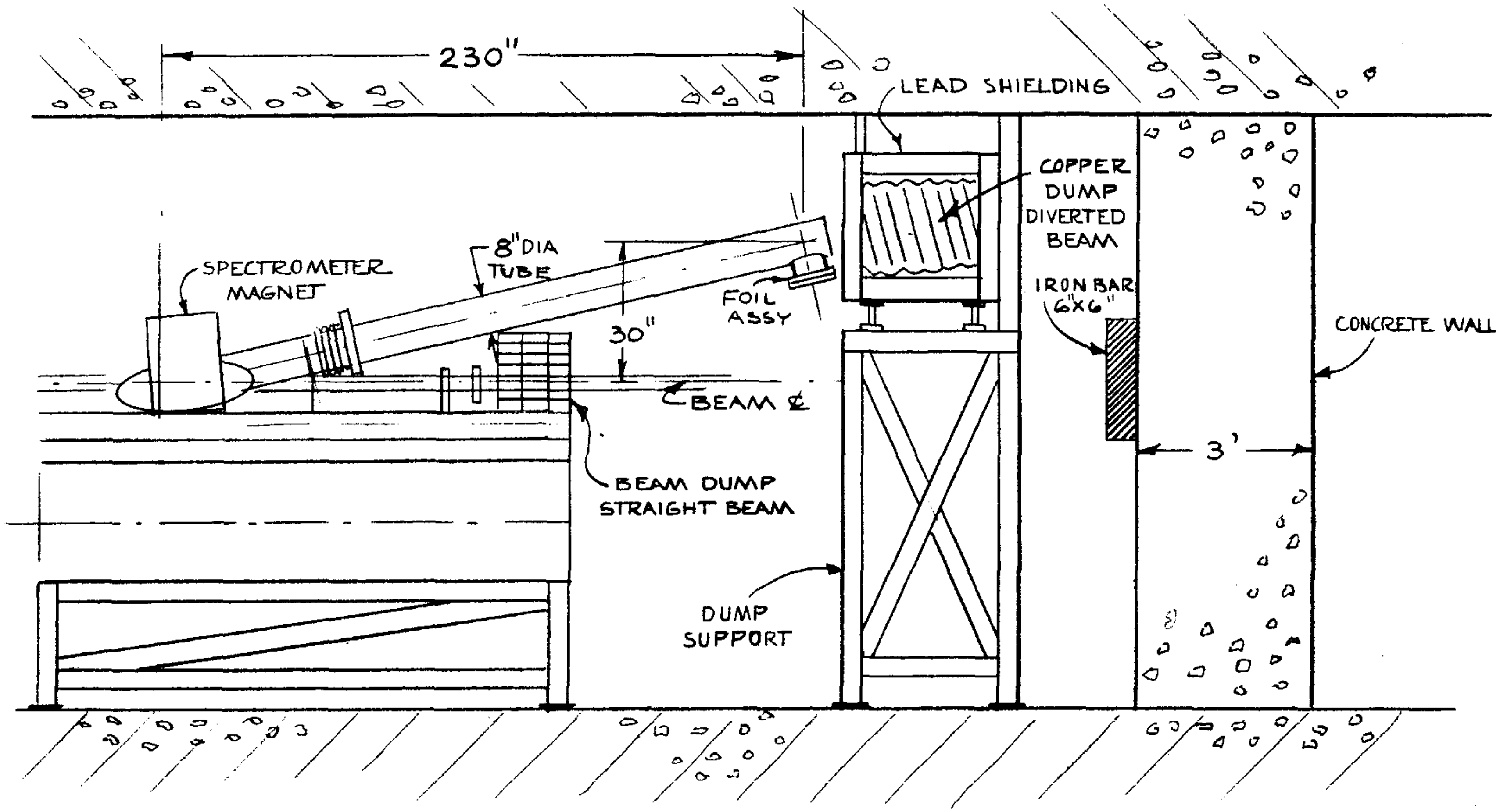

FIG. 6-- SKETCH OF TEMPORARY BEAM ANALYZER

BEAM DIRECTION

there is below 3/4 mr/hr under all conditions of operation. The entire area upstream of the latter gate is searched, cleared and locked before operation can begin.

2. Foils

An array of secondary emitter foils at the focal point of the magnet is used as slits to examine the energy spectrum. In one mode of operation the foil outputs are sequentially sampled and presented on an oscilloscope giving a continuous visual plot of the spectrum. In another method of operation a single foil output is recorded on a chart recorder as the magnet current is varied. The latter method has provided the most convenient hard copy for experiments with the beam. The former, however, is the only mode which will be usable in the switchyard.

Typical spectra obtained when the beam was swept across individual foils are shown in Fig. 7. They all represent the same beam. The solid curve is the normal scanning foil located at the focus of the beam. The other two foils are located lower in the foil assembly so that less magnet current is required to deflect a given beam to that foil. It is clear that they are acting like identical slits.

The anomalous response at about 175 amps appears for the same beam deflection angle on all three traces. It can therefore be explained as follows:

a) scattered electrons from the 8-inch drift pipe, causing a hump below 175 amps, and

b) secondary emission from the "collector" assembly before the beam has been deflected enough to strike an "emitter" foil, causing a negative signal just above 175 amps.

A similar anomalous response is observed in Fig. 8-D at the upper end of the trace.

A typical experiment was to observe the change of energy versus the position of the protection attenuator at the input to a klystron. This attenuator is inserted whenever the klystron is off for more than two seconds. The attenuator is then withdrawn slowly so that the power gradually returns to a high level. A klystron is normally left on "standby" (triggered 25 μsec after the beam) until the attenuator is fully withdrawn.

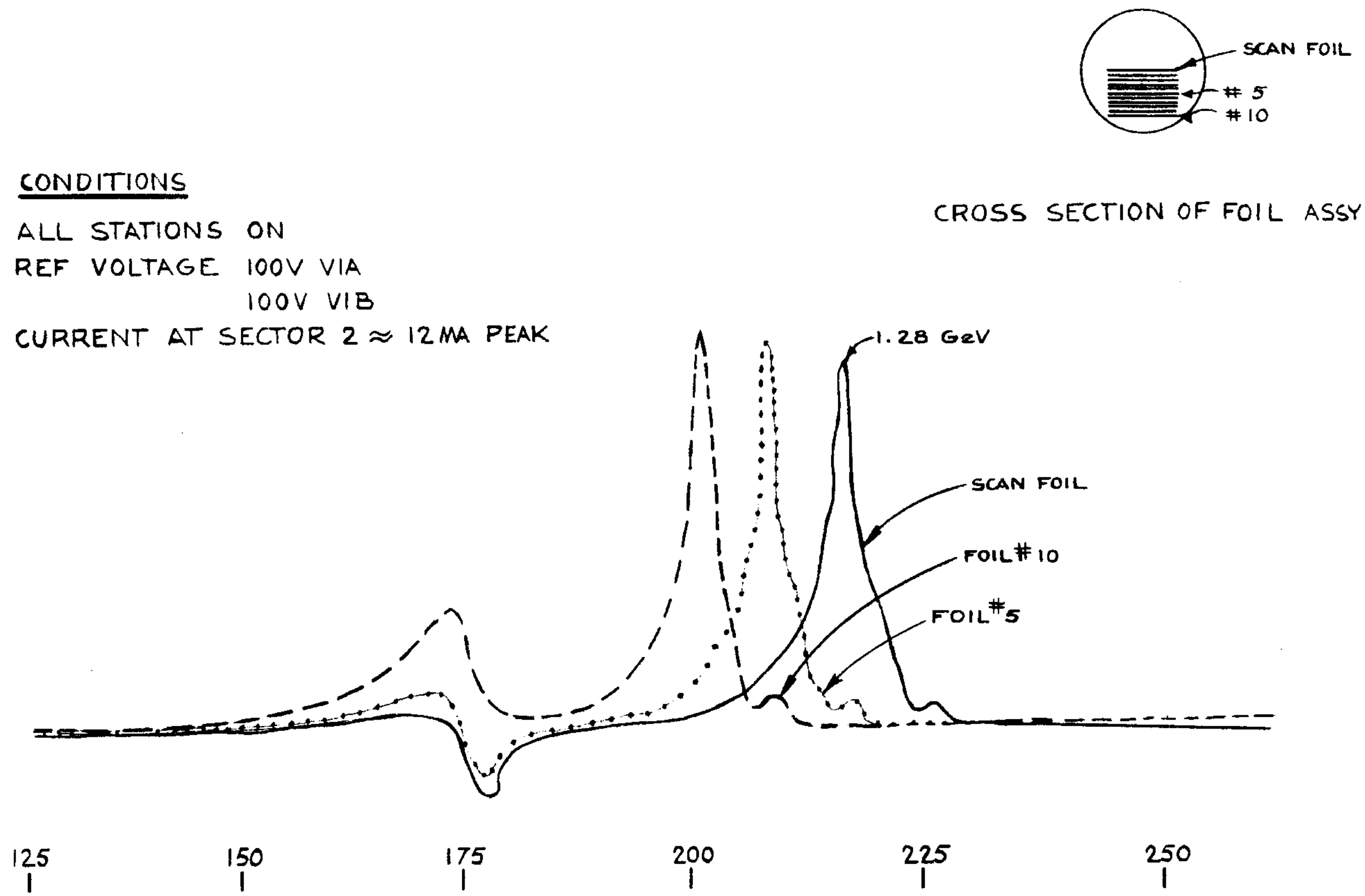

FIG. 7 -- ENERGY VS FOIL NUMBER

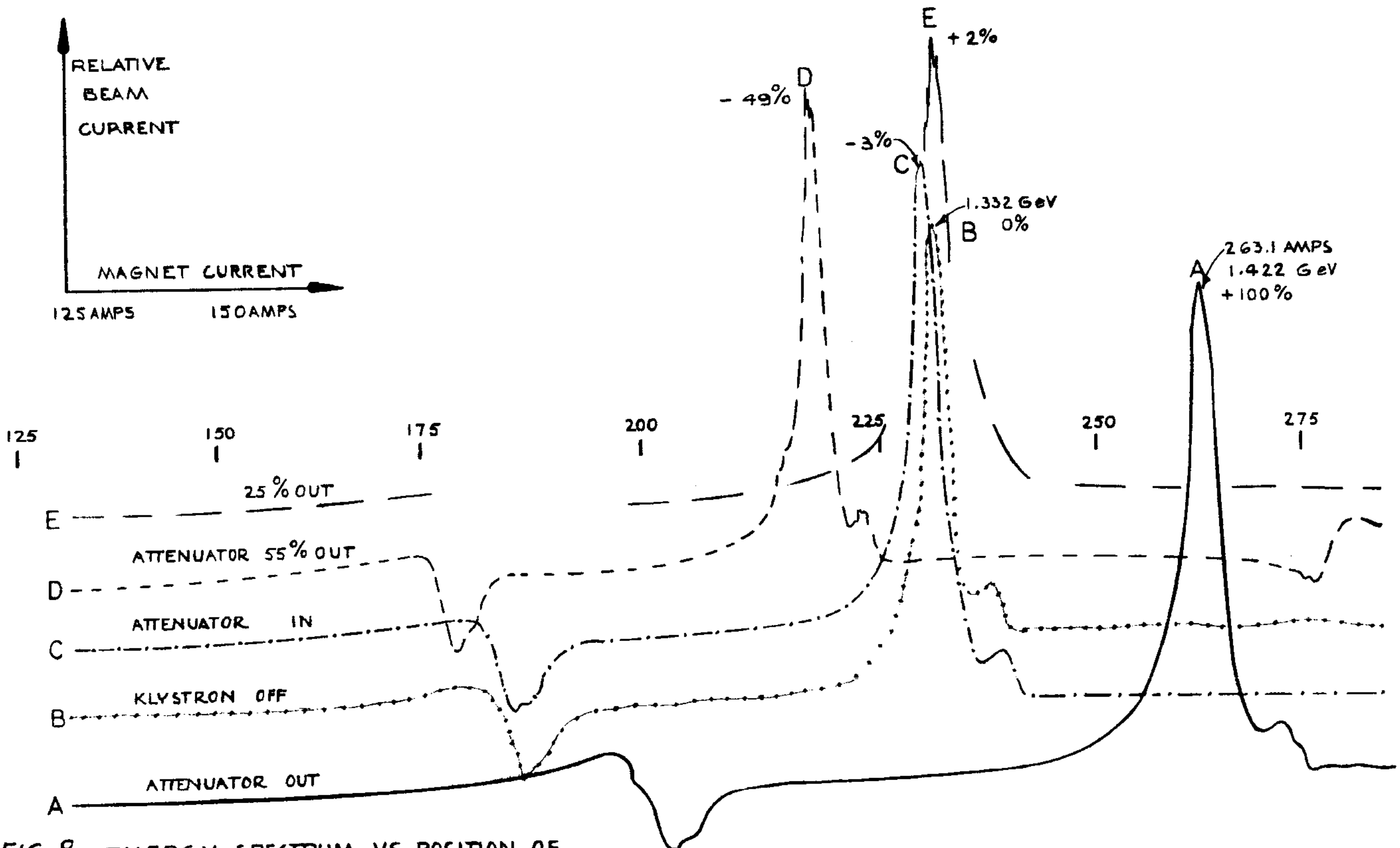

FIG. 8--ENERGY SPECTRUM VS POSITION OF PROTECTION ATTENUATOR AT KLYSTRON 2-1.

For this experiment the klystron was allowed to accelerate the beam; the attenuator was stopped at various significant points on its motion. Data for a typical klystron is shown in Fig. 8. These tests were performed on several klystrons. In general they all indicated that the attenuator introduced more than 360° phase shift. The range of variation of energy during the motion of the attenuator is shown in Fig. 9.

It can be concluded that it would be very difficult to control the beam energy unless the klystron is triggered at the standby time during this attenuator cycle. The energy contribution can then easily be compensated for by switching on another standby klystron.

3. Control System Tests

The testing of Sectors 1-2 has been primarily devoted to tests of components and subsystem operation as in the example above. The operation has also provided information about the control system as a whole.

A number of basic requirements of the control system are listed below. Each point is followed by discussion based on results of operating experience.

a) The accelerator operates 24 hours per day so that routine maintenance must be accomplished during normal operation.

The accelerator is shut down every day. In this mode of operation some of the arrangements for turning on and off proved cumbersome.

The personnel protection system is designed for continuous surveillance by an operator. Once the housing is cleared he can be sure that no one will enter without his knowledge and that the rf can therefore be turned on whenever he is ready. Since an operator is not present 24 hours a day, there is no way to always be sure that the housing is empty, and particularly rigid control must therefore be exerted over the high voltage supply for the klystrons. Currently this involves collecting 22 keys at the end of an operating period. For all sectors of the accelerator this number would approach 300. These keys would have to be inserted in the appropriate points throughout the gallery before one could turn on again. The entire housing would also have to be searched.

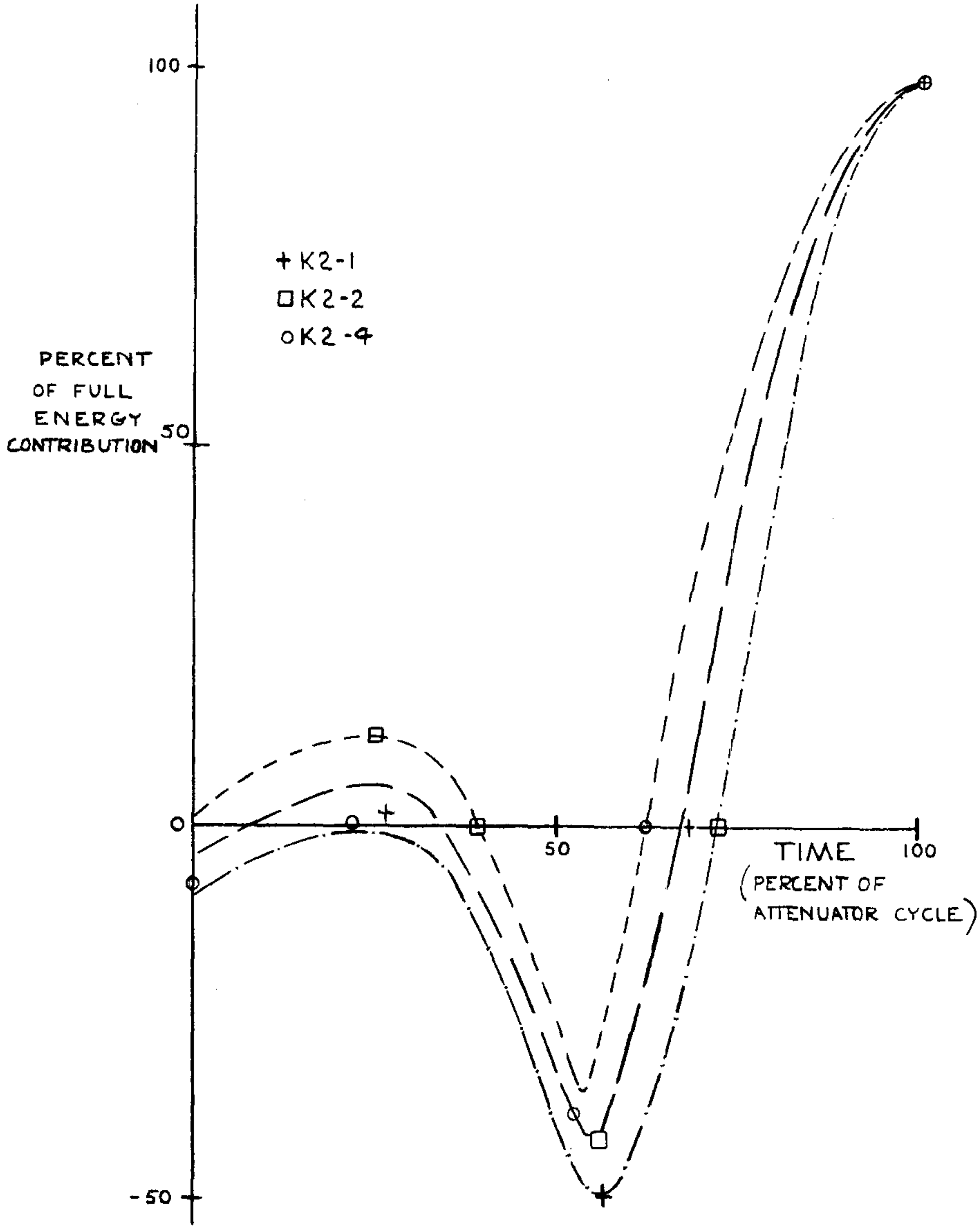

FIG. 9--ENERGY VARIATION DURING CYCLE OF PROTECTION ATTENUATOR

b) The subsystems are designed for unattended operation. The data system transmits just enough information to identify the location of faults. Faults are identified locally by instrumentation at the equipment itself.

In general, operation has proved remarkably stable. We have not had maintenance crews running back and forth in the gallery making continuous repairs. However, some subsystems are still not adequately self-protecting. Modulators have been found to be not self-protecting when condensers in the pulse forming networks blew up. The quadrupole supplies could not handle intermittent open circuits. Electrical substations and certain rf drive components were found not self-protecting against overheating if cooling water failed.

c) As many signals as possible are handled as binary signals. The remaining analog signals are handled in a system which is stable and can be calibrated to the required precision.

Confusion has arisen from the assumption that detailed troubles could be identified from the information gathered for Central Control. During the interval when individual subsystems were being tested and adjusted, no signal calibrations have remained constant.

d) Multiple beams are to be interlaced, with arbitrary patterns. The beam monitoring signals for each pulse are transmitted to Central Control and the signals for each beam are separated at the console display.

The trigger system has shown that it is capable of handling multiple beams. Beam rates as low as 10 pps have been produced by the trigger programming equipment. The beam position monitors have adequate sensitivity for steering but the zero setting is not yet stable. The beam has been operated at 60 pps on each of the six possible phases. During this test it was shown that the magnetic shielding eliminates detectable 60 cycle steering of the beam. One spectrum monitor using a set of foils for scanning the spectrum has proved usable. It has not yet been tested on a pulse-to-pulse basis.

e) The sector is the unit trigger pattern control. The number of klystrons in the sector determines the energy contribution of that sector. When a klystron fails, permanently or temporarily, it is replaced automatically by a standby klystron.

It was found that replacing one klystron by another indeed had little effect on beam energy. The automatic replacement circuit is not yet operational. A distinct beam energy loss is observed during the recovery cycle after a klystron fault, if the klystron is allowed to accelerate the beam during completion of the cycle.

f) Monitoring of klystrons and of beam parameters is based on a magnitude per pulse (peak sampled or integrated) rather than a time-average value. The klystrons are turned off by a circuit which measures peak reflected power. This appears to offer adequate protection for the klystron windows. The pulse-by-pulse beam position monitors have not yet indicated stability. A pulse-by-pulse sampling circuit for the spectrum monitor has been tested but is not yet ready for regular service.

g) The injector is shut off automatically by signals from a long ionization chamber parallel to the machine when the beam strikes the accelerator or the walls of the vacuum chamber in the switchyard. The injector is also shut off by faults which are likely to cause such a condition.

The long ion chamber gives a good indication of where the beam hits the accelerator. No automatic shut off circuits have yet been installed.

h) Steering controls are continuously available on a console panel adjacent to the beam position monitor displays.

A routine to determine the relative displacement of position monitor and electrical axis of quadrupoles was found using the position monitors and steering controls.

The adjustment of speed of the steering controls appears to be critical to operator satisfaction. An automatic method to produce higher control speed in the high energy downstream sectors would be desirable.

C. DATA HANDLING

1. Status Monitoring

Binary status information at each sector will be transmitted to Central Control on a time-shared multiplex system. The preproduction model was tested and has met all electrical specifications.

Approval for production was given in March, subject to incorporation of a number of packaging improvements. Delivery of the first production unit is scheduled for June 1965.

2. Analog System

Slowly changing analog signals will be transmitted to Central Control by means of individual hardwire pairs and will be read on standard panel meters.

The Engineering Design report has been approved and work has commenced on the packaging for the Central Control switching relays. A prototype relay chassis will be built and is due for completion in June 1965.

3. Beam Monitoring

Beam monitoring signals are transmitted to Central Control in two forms:

a) An FM signal which gives an accurate representation of the charge per pulse (Q) at each sector, and

b) A multiplexed baseband signal which transmits pulses representing Log Q, x, y for each beam pulse.

Preproduction units, consisting of two FM transmitters and FM receivers, have been received; evaluation testing will start March 31 and will be completed in April 1965.

Prototype transmitter and receivers for the position signals have performed well in Sector 1 and 2 tests.

4. Remote Control

The remote control system consists of a transmitter which transmits binary codes and a receiver in each sector which translates the codes into a signal to actuate a relay or motor.

Remote control signals are sent to each sector as binary coded signals which may operate one control relay or motor at a time. A few controls are transmitted directly on hardwire transmission line-pairs.

Two remote control receivers and one thirty channel transmitter have been installed in Sectors 1 and 2.

The bid package for production receivers and transmitters was issued March 25. All receivers will have a 64 channel capability instead of 32 channels as previously planned.

D. BEAM GUIDANCE

Beam guidance equipment consists of the electronics for intensity and position monitors, and power supplies and controllers for degaussing, quadrupoles and steering dipoles.

Three beam monitor sector electronics units were installed in the Klystron Gallery during the last quarter. These are fed from microwave cavities located at the 30-foot beam analyzer station and at the first and second drift sections. The sequential outputs, ℓn Q (beam charge) and x and y position information have been fed by the baseband telemetry system to the temporary control room in the Sector 2 alcove and there displayed. The displays have been satisfactory and have aided greatly in handling the beam.

One unit of the electronic circuitry to give an output linearly related to the charge in each beam pulse has been installed in the Klystron Gallery above the first drift section. Final development work is being conducted, preliminary observations indicating that the unit works satisfactorily. The procurement package for the beam monitor sector electronics, comprising ℓn Q, x and y and accurate Q circuitry, is nearing completion.

E. TRIGGER SYSTEM

The trigger system consists of a master clock near the injector, a distribution system for master clock signals, multiple trigger generators near the equipment to be controlled, and trigger programming equipment in Central Control.

All trigger system components used in Sector 1 and 2 tests are installed and operating staisfactorily. A temporary injector trigger generator will be replaced with a prototype of the final injector generator in June 1965.

The sector trigger generator design has been completed and is out for bid.

The comparator, pattern generator and Beam Switchyard trigger generators are scheduled for completion during the last half of 1965. All other subsystems have been prototyped and tested.

F. KLYSTRON INSTRUMENTATION

Several external monitoring and protection circuits are provided adjacent to each klystron and modulator. These monitors include vacuum, water, input and output power, de Q'ing, reference voltage, maintenance operate switch, trigger delay, IΦA package and reflected energy.

1. Modulator-Klystron Protection System

Experience gained in testing of Sectors 1 and 2 indicated generally satisfactory performance of the M-K protection unit. However, minor design modifications were required to improve reliability. For example, it was found that the plug-in receptacles for the relays were unreliable, requiring that the relays be wired in. In addition, a minor circuit change was found to be desirable to increase the bandwidth of the amplifier circuit in the detected reflected energy analog fault sensing instrumentation.

2. Reference Voltage System

During this period, operational experience was gained using two interim systems in the Sector 2 alcove. A decision was made to employ a commercially available power supply, the Trygon Model RS160-1AX, as the reference voltage power supply. A similar power supply, the Trygon Model RS160-1A, has performed satisfactorily in Sector 2. As a result of test operations, minor design modifications have been made in the monitor-rectifier.

G. PERSONNEL PROTECTION SYSTEM

The personnel protection system has a machine shut-off circuit, which turns off high voltage to all modulators when the housing is entered, an access control circuit which prevents entry to a radiation area while the machine is on, and radiation monitors and warning devices.

A temporary circuit containing the basic elements of the final system has been installed in Sectors 0 - 5. Pressure for operation has delayed installation of the final circuits and will probably continue to do so for the next quarter. The operation of the temporary circuit does not indicate any need for changes in the final system.

A portable radiation monitor with a sensitivity of 3 mr/hr full scale and a response time of three seconds has been developed and tested. A second design is also under development. One of these will become the standard portable monitor.

A fixed gamma monitor (manway monitor) will be installed at each normal accessway to the radiation areas. The primary purpose of the manway monitor is to determine levels of residual radioactivity in the vicinity of the base of each manway penetration to determine the hazard that will be posed to personnel who wish to enter. A secondary purpose will be to determine radiation levels while the machine is in operation for purposes of shielding evaluation, etc.

To eliminate a servicing problem in the two-mile gallery, high stability and accuracy will be demanded of the electronics. Also, the detector chamber will be located in a radiation environment that is of a higher energy than is normal for the usual commercial detector. The detector must be capable of reading correctly in pulsed radiation fields with the requirement that the detector will not saturate in a field that is 10^4 greater than the highest meter indication (10 R).

The first requirement, stability, precludes conventional floating-grid electrometer circuitry. The second requirement eliminates detector chambers constructed of iron, because the residual activity of an iron chamber is too high. To be more specific, we have tested chambers in the high energy gamma fields of the Mark III and find that only an aluminum chamber will be satisfactory. The third requirement, pulsed radiation, precludes Geiger tube detectors and narrows the detector essentially to an ionization chamber.

An ionization chamber satisfying these requirements has been found and procurement has been initiated.

H. MACHINE PROTECTION

The machine protection system provides three gun interlock circuits: a one-millisecond network using a carrier tone, a 50-microsecond network using permissive-pulses, and a long ion chamber interlock.

1. One-Millisecond Network

The one-millisecond network consists of a tone generator and tone receiver, and a set of tone interrupt units, one at each sector. Preproduction units of the tone generator and receiver were received. Tests were completed and production was authorized on March 10, subject to incorporation of several minor mechanical changes. Delivery of the production equipment is scheduled for June 1965. A final engineering model of the tone interrupt unit has been produced by Light Electronics. Evaluation testing started March 30 and will be completed by April 15, 1965.

2. 50 μsec Network

A pulse train, generated in the switchyard, allows the gun to be turned on once for each pulse. Interlock circuits, acting on a pulse-to-pulse basis, interrupt the pulse train when it is determined that the switchyard cannot accept the beam for the next pulse.

3. Long Ion Chamber

The long ion chamber proved an invaluable aid in initial steering of the accelerator. Because of the transient time of the beam down the accelerator and the induced signal back through the cable to the injector end, it has been found possible to determine where the beam is striking the walls of the accelerator. The steering was adjusted to make the return echo as late as possible and, eventually, as small as possible.

It has been determined that the long ion chamber will be installed throughout the length of the accelerator housing. A similar ion chamber will be installed in the switchyard.

I. CENTRAL CONTROL

The control console has been moved into the control building. Installation of the remainder of the equipment is scheduled to start during the next quarter.

It is desired to operate Sectors 1 - 2 with beam from the Central Control building as soon as the long haul cables to Sectors 1 - 2 are installed and can be hooked up.

Rack profiles, wiring diagrams and wire tables were prepared for the 30 identical racks containing status monitoring equipment in Central Control. This information is being incorporated by Systems Engineering and Installations in a bid package due for release in April 1965.

Work on the Central Control room oscilloscope display modules has progressed further and a design report is in preparation.

J. CONTROL SYSTEM

The documentation of the control and monitor signals for Sectors 3 - 30 has been completed. The wiring diagrams for inter-connections for Central Control will be made up from this documentation.

Documentation has been started on the instrumentation for the positron area and the integration of the injector area, Sectors 0, 1, 2 and with Central Control.

K. COMPUTER CONTROL

Serious study is again being given to controlling various accelerator functions by a computer. The present control system is designed entirely for manual operation. Various pieces of interface equipment are now being studied so that when the control characteristics of the machine are known experimentally, some of them may be profitably assigned to control by the computer.

It is obvious that more efficient operation will be achieved through such functions as automation of steering and spectrum control. Such control will be both more rapid and more reliable than straight operator control of these functions. It will also reduce the tedium of the operator's job and reduce the number of operators necessary to run the accelerator. Another advantage of a computer which contributes to improved efficiency is that emphasis on areas which need control can be shifted through the simple expedient of programming changes. This fact opens up the possibility of continually improving machine efficiency by trial and error refinements on operating programs.

Improved monitoring and record keeping will be achieved through automation of status and analog monitoring functions within the computer. Although these functions have been designed for surveillance by the operator, it is felt that a computer may be needed to help process the information during times of large changes. Furthermore, a computer will simplify the recording of all log type information, and in the case of large numbers of changes will continue to log information where an operator might fail. The presence of detailed machine recorded information will aid greatly any statistical studies of component failure. Such studies could be performed by the computer off line and lead to preventive maintenance procedures which maintain the accelerator at much higher performance potential.

In the present study, it is proposed that the computer be associated with status monitoring, analog monitoring, beam monitoring and steering, spectrum control, as well as certain off-line functions such as beam programming, performance data and compiling. It would take a very powerful computer to perform simultaneously all of the functions that are being considered. Fortunately there does not seem to be a requirement that all of the functions be performed simultaneously, but rather a large number of them will be performed serially. There are a few tasks which will be performed more or less continuously, and there are others which may later be performed continuously after first being developed in a serial fashion. As experience is gained, more and more of these serial tasks can be made automatic and be put on a time sharing basis with other tasks.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

1. Modulator Procurement

Production modulators began arriving this quarter. In February the first shipment of seven was received and shipments of seven arrived about every ten days thereafter. By the end of the quarter, fifty-five had been received (including the first twenty pre-production modulators).

Two production modulators (Serial Nos. 21 and 22), were installed in the Test Laboratory for life testing of the modulators themselves and pulse transformer tank components. The rest of the production units were installed in the Klystron Gallery as they arrived. By the end of the quarter modulators were being installed in Sector 6.

The first 20 pre-production units continued to be tested. Eighteen units in Sectors 1 and 2 were run a few hours each working day for sector tests. By the end of the quarter, they each had about 300 hours of high voltage operating time. Two other pre-production units continued to be tested in the Test Laboratory. By the end of the quarter serial number 2 had 6230 hours and serial number 3 had 5560 hours of high voltage operation time.

Life testing has indicated that these modulators are, indeed, very good units. There have been failures on some of the small parts, but this was to be expected. None of the major parts had failed except for a few pulse capacitors. A total of 12 has failed of about 500 in operation on the project.

Another defect in the modulators is in the step-start system. In two of the pre-production modulators the start-up contactor held in too long, resulting in overheating of the start-up resistors with subsequent burning of an adjacent wiring harness. This situation was partially rectified by eliminating step-stop operation on the contactors. Other measures are being taken to eliminate the trouble.

In two of the pre-production modulators the end-of-line clipper fast shut-down circuit proved to be slightly too sensitive. These modulators would not run up to full output voltage before this circuit would shut them down. The circuit was made less sensitive by means of a simple modification.

The fan airflow switches on the overhead fans have been a source of trouble. Their operation has been improved but they still cause occasional trouble; work on the problem is continuing.

2. De-Q'ing

Qualification sample de-Q'ing switch assemblies from each of two bidders were tested, as provided for in our Request for Proposal.

The rest of the de-Q'ing components, with the exception of the voltage divider, were being replaced in the modulator contract by the end of the quarter. The voltage divider has caused problems because of noise pulses appearing on its output. These small pulses occasionally trigger the de-Q'ing circuit early on the charging waveform, causing about a 0.5% drop in output pulse voltage from the modulator. Although this is not a serious problem, it should be eliminated if possible. It may be due to corona or various sharp points along the voltage divider or it may be a result of noise in the deposited carbon resistors which make up the divider. We have tried various ways of eliminating the trouble but have yet to do so.

In the meantime, the pre-production modulators in the Klystron Gallery continued to operate with de-Q'ing, with the exception of a failure of one switch assembly. This unit was subsequently replaced.

3. Switch Tubes

The switch tube picture brightened considerably during this quarter. One manufacturer finished delivering its GL-7890 order, giving us 50 pairs of these tubes. A second company had a problem with element spacing varying during production. Our X-rays revealed the problem and the company corrected it. By the end of the quarter, we had about 50 of their large KU 275A tubes. We exercised our option with them for 150 additional tubes. A third manufacturer continued to deliver acceptable tubes. By the end of the quarter 41 were on hand.

Life testing of switch tubes has yielded the following information: Two tubes have 2600 and 1200 high voltage hours each, and are still operating satisfactorily. We lost one tube after about two hundred hours; it appeared to be a leaker. About ten other tubes are in operation but with only a few hundred hours. Of the second company's KU 275A tubes, we have 5800, 2400, 1800, and 1800 high voltage hours each. The two 1800 hour tubes failed. The 2400 and 5800 hour ones are still in operation. Evidence indicates that by operating these tubes with "keep alive" current their lives are lengthened considerably. The 5000 hour tube has had "keep alive" operation for 4600 hours of its life. The 2400 hour tube has had "keep alive" for 700 hours. The 1800 hour tubes had no "keep alive" operation. Another ten KU 275A tubes are in operation in Sectors 1 and 2 and test stand modulators with two hundred hours operating time.

4. Pulse Transformer Tank Assembly

During this quarter, production pulse transformers arrived on schedule. The cores seem to change shape slightly with operating life, thus degrading pulse characteristics. The manufacturer has been trying to solve this problem. We are continuing to life test transformers and feed back to them our findings. By the end of the quarter the manufacturer was still getting a few good cores from one source and was looking into a second source as a backup measure.

A new set of specifications for another pulse cable contract was drawn up and a new source was selected. A contract for the remaining cable assemblies was signed toward the end of the quarter.

The oil expansion chamber continued to be a problem during this quarter. The initial metal bellows type chambers were much too rigid. Although they were within specifications, the large pressure differential between a cold tank (18 inches of mercury) and a hot tank (12 psi gauge) was undesirable. Such a pressure differential would place an undue burden on the oil seal around the klystron body and increase the possibility of an oil or air leak. The company was asked to look into other materials and wall thicknesses in order to reduce the pressure differential. They found that they could roll a bellows out of 0.010-inch phosphor-bronze. This will result in reducing the pressure differential by a factor of nine, which should be satisfactory.

In the meantime, in order to continue production on pulse transformer tank assemblies, a small quantity of rubber tubing which has been used in the past as an oil expansion chamber was ordered.

B. SUB-BOOSTER MODULATOR

The first two sub-booster modulators have been operating practically continuously since their arrival near the beginning of the quarter. Initially, we had trouble with the auxiliary high voltage power supplies, but these units have been improved and appear to be operating satisfactorily. One sub-booster is installed in the Klystron Gallery for sector tests. The other is on life test in the Test Laboratory. In February, the manufacturer was given production go-ahead on the remaining 29 units. At the end of the quarter it was gathering parts to begin building in mid-April.

C. GUN MODULATOR

This group became involved in the gun modulator for the two-mile accelerator during this quarter.

We are modifying one of the two gun modulators received from the manufacturer so that it will operate on a SLAC gun located in the tunnel. We are striving to keep as much of the electronics of the system in the Klystron Gallery as possible to minimize maintenance on components in the Accelerator Housing.

D. STORAGE RING INFLECTOR MODULATOR

As a part of the storage ring study program, a full scale model of an inflector modulator for pulsing an inflector magnet is being manufactured. The design is finished and parts are being ordered.

E. MAGNET POWER SUPPLIES

During the quarter this group has become responsible for procurement of magnet power supplies.

The pulsed magnet power supplies, A and B beam quadrupole power supplies, and $\frac{1}{4}\%$ regulation A beam dump power supply were all contracted for during the quarter.

The A and B beam unregulated power supplies were close to being contracted, and the A and B beam regulator is nearly through the specification writing stage.

The power supplies for the positron source solenoids were out for bid.

Specifications for a 5.8 megawatt power supply for the spark chamber magnet were nearly complete by the end of the quarter.

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

A total of 52 forty-foot support girders had been assembled by the end of the reporting period and 51 of these were installed in the Accelerator Housing. This meant that 36 of the assemblies were completed during the quarter and 35 had been installed. By the end of March the assemblies were being completed and installed at a rate that approached one per day and it was felt that this rate could be met and maintained throughout the balance of the year. For the most part, associated hardware such as rectangular waveguide penetrations and crossbars, waveguide vacuum valves, rf loads and like equipment fabricated by MDF was being assembled and installed at a rate in keeping with accelerator structure installation.

B. ACCELERATOR STRUCTURES

A total of 200 ten-foot sections of disk-loaded waveguide was completed during the reporting period, with completion meaning all testing and tuning required to make the sections ready for installation on support girders. Two additional sections were fabricated but rejected during testing for a shrinkage loss rate of 1%. By the end of March, a total of 4,190 feet of disk-loaded waveguide had been fabricated and readied for installation. The previously reported average of 17 sections per week was maintained throughout the quarter.

Eighteen of the special seven-foot sections of disk-loaded waveguide were being fabricated during the reporting period. These sections, which will be used with the quadrupole triplets in Sectors 11, 12, 13 and 14, should be tuned, tested and ready for installation during the first part of the next period.

C. RECTANGULAR WAVEGUIDE

A total of 30 crossbars and 59 thirty-eight-foot penetration waveguides were fabricated, tested, installed and tuned during the reporting period. This brings the total production of these components to 50 crossbars and 105 penetration waveguides.

1. Phase Measurements, General

During the quarter, phase adjustment was completed from girder station 2-6 through 6-2. Operating tests on Sectors 1 and 2 gave no evidence from a beam energy standpoint that the waveguide system is mis-phased. Effort was also concentrated on fabricating the remaining reflection-modulator flanges required for phase measurement and on assembling the new phase adjustment console. The improved equipment and techniques made it possible to perform phase adjustment at a rate of better than five girder stations per week. Waveguide production, however, temporarily fell behind girder production so that phase adjustment was performed on only four girder stations per week.

Phase adjustment data were examined for systematic phase asymmetry built into the crossbars, penetration waveguides, and S-assembly waveguides. The alternating coupler arrangement or "flip-flop" geometry required two models of S-assemblies, with one for odd-numbered girders and one for even-numbered girders. On odd-numbered girders, the injector end branch of the S-assembly crosses over the accelerator structure and has two mitre bends and several feet of waveguide which are not contained in the target end branch S-assembly. The geometry on the even-numbered girders is the reverse of this. Therefore, odd and even-numbered models of the S-assemblies were considered separately in examining phase adjustment data. The before-tuning phase data had an approximately Gaussian distribution, with mean and standard deviations as follows:

Component	Mean Phase	σ
Crossbar plus penetration waveguides	Injector end 3° longer	25°
Odd S-assembly	Injector end 14° longer	11°
Even S-assembly	Injector end 11° longer	13°

The phase density function of the crossbar-penetration waveguide complex is a combination of the individual density functions of three large waveguide components; therefore, its σ is larger than that of the

S-assemblies. The S-assembly data indicated that the design of the cross-over arm of both odd and even-numbered assemblies is correct and that the average phase asymmetry is in the power dividers. The asymmetry is small enough so that no corrective action is being taken.

Reflection modulators serial numbers 23 through 42 were built and put into use during the reporting period. Sixty-six of these units have been built with two being reserved for testing and calibration. The remaining 64 units, or 16 sets, mean that the phase tuning schedule would never be more than 16 girders behind the girder production schedule. The modulators have been working well and all are still in use. The first three sets, which have been used in more than a dozen girders, however, are to be reworked because of recent design improvements and because of wear at the vacuum sealing edges. Recalibration of the modulators after each use has shown that a repetition rate in the modulator phase length of better than $\pm$ 0.2$^{\circ}\varphi$ is common and variations greater than $\pm$ 0.5$^{\circ}\varphi$ are rare. The sixteen sets thus should be sufficient for tuning the entire machine.

The new phase adjustment console was built and put into operation, greatly improving efficiency and reliability of adjustment. The various waveguide components of the console were matched and waveguide switches and flexible waveguide were used in parts of the circuit. Design was also started on a transmission phase measurement circuit which will also be incorporated into the new console. This will eliminate the need for the present 180° ambiguity test. The transmission method will require additional circuitry and a more involved calibration procedure. However, it will make the tuning procedure more efficient and reliable, particularly during any retuning and troubleshooting of individual girders in the completed machine.

2. <u>Model A Directional Coupler</u>

A total of 42 Model A couplers was completed during the reporting period. A tabulation of the forward coupling ratio at low and high rf power is given in Table I. Closer agreement between the forward coupling ratio as measured at milliwatt and 10 kilowatt power levels has been achieved by improving the insulation of the calorimeter load and the thermometers. An improved supporting system for the load and the units under test also increases the reliability of the test setup.

3. RF Waveguide Vacuum Valves

Thirty-five vacuum valves were completed during the period to bring the total to 52 valves produced to date. Because of the consistency of the data obtained on these units, the amount of low rf power testing has been reduced. Presently, a VSWR versus frequency plot is being made for one valve in six and on those units having an initial VSWR greater than 1.12 at 2856 Mc/sec.

4. RF Loads

Of the three types of rf loads being produced, 105 of the Type A were fabricated during the reporting period; 36 of the Type B loads and their associated Model B directional couplers were made; and 94 of the Type C were produced. The corrosion rate evaluations on the 304 stainless steel being used for the loads revealed that a sufficient problem existed so that redesign of the loads was necessary. Copper plating was added to the loads, and the water jacket about the load was replaced with a water pipe brazed to the load.

A summary of the initial VSWR for all Model C loads produced to date is given in Fig. 10. These loads are being tuned to have an input VSWR on the order 1.02 at 2856 Mc.

5. Power Dividers

A total of 340 power dividers had been produced by the end of the reporting period, with the average production rate having reached three units per day. Of the three types of dividers being made, power dividers PDC and PDE are now being brazed in the retort-type pit hydrogen furnace. The type PDA dividers are still being brazed in a horizontal hydrogen-oxygen, open air flame furnace used for other rectangular waveguide components because they are too large for the pit furnace.

As of the reporting date, approximately 10% of the power dividers fabricated had to be repaired because of vacuum leaks at the flanges or in the mitre joints. However, none of the power dividers made to date have been off very far electrically and all of them could be tuned within the limits of the specifications. Typical values within the power

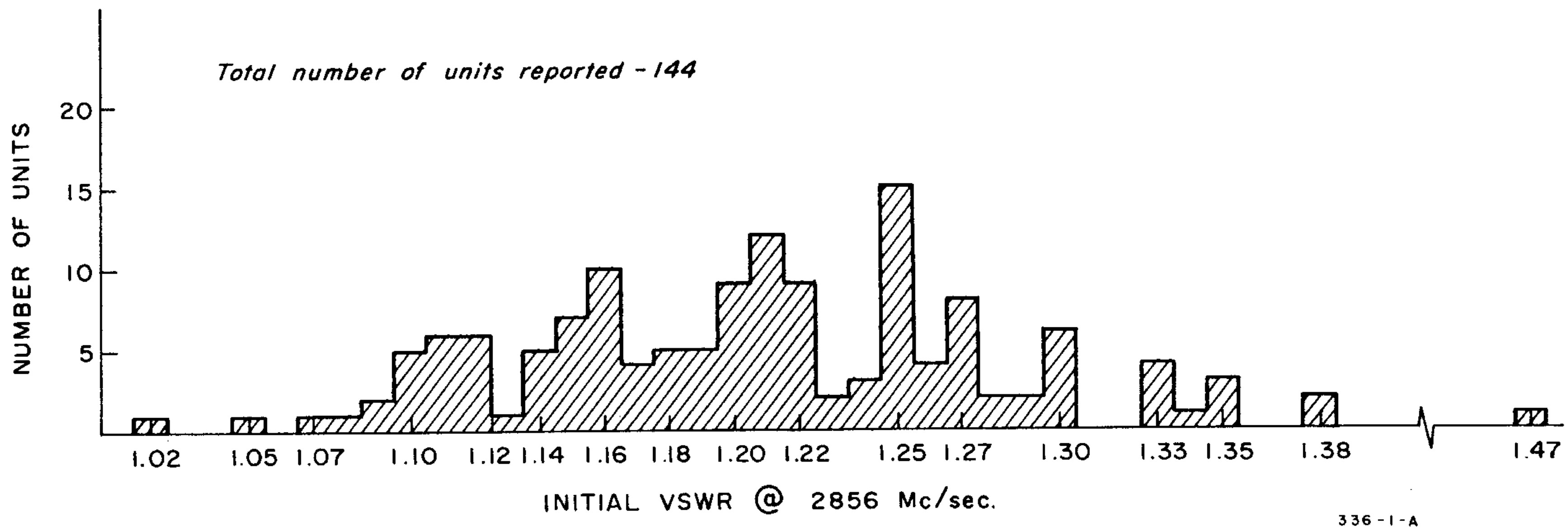

FIG. 10--INITIAL VSWR OF MODEL C LOADS, SUMMARY

dividers after tuning are as follows:

Isolation - 35 dB lowest, 43 dB average, and 55 dB highest

Difference in power split between ports 2 and 3 - 0.1 dB average

VSWR - < 1.02 in all ports after tuning

Transmission loss - 0.05 dB $\pm$ 0.02 dB

D. MAGNET ENGINEERING

The Magnet Engineering Group of MDF was organized in the last quarter of 1964. During the reporting period, they prepared drawings and specifications for a large number of the magnets to be procured for the Beam Switchyard and End Stations together with a number of the components associated with these magnets. The most significant items in work were the pulse steering magnets, the 0.25-degree emergency bending magnets, the three-degree bending magnets, the 0.1-degree pulse magnets, eight-centimeter and 18.6-cm quadrupole magnets, dump magnets, stripping magnets, and a photon beam bending magnet. The status of these magnets and their designations are given below. The location of the magnets and their associated components are shown in Figs. 13 and 14 of Section IX, The Beam Switchyard.

1. Pulse Steering Magnets, AP-1 through AP-5

The design of the pulse steering magnets, AP-1 through AP-5, was nearing completion by the end of the quarter. It was estimated that the magnets would be put out for bid early in the next period. Magnets AP-1 and AP-2 are mounted in the Accelerator Housing and AP-3 and AP-4 are mounted just ahead of the high Z collimator at the entrance to the BSY. The first four of these magnets provide for both horizontal and vertical steering of the beam while AP-5, which is mounted immediately ahead of the emergency bending magnet, B-1, provides for vertical steering only.

Each of these magnets, which are used to make fine corrections in the position of the beam on a pulse-to-pulse basis, can also be run on dc if steering is not required on a pulse-to-pulse basis.

Magnets AP-1, 2, 3 and 4 can deflect the beam a maximum of 3×10^{-4} radians. They have a gap of 1-1/2 inches and an effective length of 15-1/2 inches each. Their pulse rate is 360 pps and each pulse is a

600 cps sine wave. For deflection, the magnets each require 23 amps peak and up to 1550 volts peak with a required gap flux of 640 gauss to provide bending over their full length. Each of the magnets has a 48-turn coil and has free-convection, air cooling.

Magnet AP-5, which provides for vertical steering only, has a gap of two inches and an effective length of 16 inches. It requires a pole tip length of 520 gauss with a peak current of 24.4 amps and a peak voltage of 1620 volts.

2. Emergency Bending Magnets, B-1 and B-2

The drawings and specifications for the two 0.25° emergency bending magnets, B-1 and B-2, were in full production during the quarter and it is estimated that these will be ready to be put out for bid early in the next period. These magnets, which are essentially backup units for the PM-1 through PM-5, 0.1° pulse magnets, are located in the BSY on either side of the five 0.1° magnets. They are dc magnets but have a laminated core that allows for on-off switching with a minimum rise time of one second.

Each of the emergency magnets has a 2-3/4-inch gap and a gap flux of 5600 gauss. Each requires 410 amps for this flux in a 96-turn coil and each has a terminal voltage of approximately 18-volts dc. Each of the magnets is capable of bending the beam $1/4^{\circ}$ right or left. They are mounted on a single frame with the five pulse magnets and are equipped with remotely operated, quick-disconnects for vacuum, water and power connections. A protection collimator is mounted immediately upstream from these magnets to protect them and their vacuum chambers from direct bombardment by a misaligned beam.

3. Three-Degree Bending Magnets, B-10 through B-17, B-30 through B-36, and Reference Magnets B-100 and B-300

The coil and assembly packaging contract for 13 three-degree bending magnets was awarded during the reporting period. The contract for the cores for these magnets had been awarded at the end of the previous reporting period. Reference magnets, B-100 and B-300, which will be installed in the Data Assembly Building, were also included in this award.

4. Pulse Magnets, PM-1 through PM-5

The design of and specifications for the 0.1-degree pulse magnets, PM-1 through PM-5, were completed during the quarter and both the cores and the coils and packaging assemblies will be out for bid in the first weeks of the next quarter. These magnets are capable of bending the beam 0.1 degree each on a pulse-to-pulse basis and either to the left or to the right.

The magnets have a gap flux of 1700 gauss and an effective length of 85 cm. They require a peak current of approximately 300 amps in their two coils of 24 turns each in parallel for 1700 gauss gap flux. They require a voltage of 2500 V and have a pulse repetition rate of 360 pps with each pulse a full sine wave of 600 cps. As indicated regarding the emergency bending magnets, B-1 and B-2, these pulse magnets are mounted on a single frame with the emergency magnets which provide back-up should the pulse magnets fail.

5. Quadrupole Magnets, Q-10 through Q-14, Q-20, 21, 23, and 24, and Q-30 through Q-34

The contracts for steel cores and the coil and assembly package for two 18.6-cm quadrupole magnets, Q-12 and Q-32, were let during the quarter. Contracts for the coil and packaging assemblies for eleven 8-cm quadrupole magnets, Q-10, 11, 13, 14, 20, 21, 23, 24, 30, 31, 33, and 34, and for their cores were let during the last month of the quarter. (Twelve magnets are listed; however, one is an on-hand prototype that is being reworked for future installation.)

Magnets Q-10 through Q-14 are located in the A-branch of the BSY, while Q-30 through Q-34 are located in the B-branch as shown in Figs. 13 and 14 in Section IX. Magnets Q-20 and Q-21 are provided for use with the photon beam in End Station A and Q-23 and Q-24 are to provide control over the optics of the electron beam in End Station A.

6. Stripping Magnets B-29 and B-29A and Bending Magnet, B-28

The preliminary design of photon beam stripping magnet B-29 was completed by the end of the reporting period while the design for photon beam stripping magnet B-29A and photon beam bending magnet B-28 was in criteria review. It was estimated that the design of all three magnets would be completed during the next quarter and that project review would also be complete and the magnets let out for bid.

7. Dump Magnets, B-23 through B-26

Contracts for the complete package for the four "A" system beam dump magnets, B-23 through B-26, were let during the reporting period. These four magnets direct the beam to the beam dump in End Station A.

8. Associated Magnet Hardware

The specification package for a Request for Proposal for ceramic water tubes and bellows connectors for BSY magnets was prepared and let out during the last part of the reporting period.

Quick-disconnect vacuum couplings associated with the magnets and other BSY equipment were tested during the period. More testing is to be performed in the next quarter, but it is estimated that the design is 95% resolved.

E. PRECISION ALIGNMENT

Precision alignment personnel were concerned with two principal areas during the reporting period: the first sectors of installed accelerator and the Beam Switchyard.

Concentration with the accelerator sections initially was on the precise alignment of Sectors 1 and 2 for the beam tests. The optical tooling and techniques used for shop alignment and at initial installation were found to be inadequate when temperature control water at 113°F was introduced to the accelerator sections in the housing. (This was due to heat wave problems encountered in using optical equipment.) Therefore, a special stretched-wire technique of alignment was developed for the 660-feet of accelerator in the first two sectors. A second development for aligning individual 40-foot segments under housing conditions using the stretched wire technique was also undertaken and proved successful. These techniques and procedures will be described in the next Quarterly Report.

In the BSY area, techniques were developed for positioning mirrors on magnets and other switchyard components. Conceptual design of second level alignment in the BSY was also completed during the period and will be described in the next QSR.

TABLE I

Model A Coupler - Tabulation of Data

Summary Review of Data on Production Units.

Serial No.	Forward Coupling Level		△ Coupling[1]	Reverse Coupling at ~ MW	VSWR (input)
	at ~ MW	at ~ 10 kW			
11	51.83 dB	51.47 dB	- 0.36 dB	51.61 dB	1.035[2]
12	52.11 dB	52.16 dB	+ 0.05	52.16 dB	1.06[2]
13	51.82 dB	51.51 dB	- 0.31	51.71 dB	1.055[2]
14	51.95 dB	51.60 dB	- 0.35	51.88 dB	1.075[2]
15	51.60 dB	51.65 dB	+ 0.05	51.67 dB	1.04
16	52.65 dB	52.54 dB	- 0.11	52.60 dB	1.035[2]
17	52.35 dB	52.19 dB	- 0.16	52.34 dB	1.06[2]
18	51.71 dB	51.36 dB	- 0.35	51.74 dB	1.07[2]
19	52.0 dB	51.99 dB	- 0.01	52.0 dB	1.07[2]
20	51.81 dB	51.88 dB	+ 0.07	51.76 dB	1.08[2]
21	51.99 dB	52.04 dB	+ 0.05	51.92 dB	1.04
22	51.21 dB	not calibrated	- 0.00	51.21 dB	1.04
23	51.76 dB	51.72 dB	- 0.04	51.77 dB	1.06
24	51.19 dB	50.97 dB	- 0.22	51.14 dB	1.04
25	52.06 dB	51.96 dB	- 0.10	52.02 dB	1.04
26	51.54 dB	not calibrated	- 0.00	51.57 dB	1.03
27	51.34 dB	51.13 dB	- 0.21	51.31 dB	1.04
28	52.07 dB	51.88 dB	- 0.19	52.04 dB	1.04
29	51.36 dB	51.11 dB	- 0.25	51.34 dB	1.04
30	51.05 dB	50.86 dB	- 0.19	51.05 dB	1.04
31	51.41 dB	51.26 dB	- 0.15	51.41 dB	1.04
32	51.37 dB	51.16 dB	- 0.21	51.18 dB	1.04
33	51.42 dB	51.32 dB	- 0.10	51.43 dB	1.03
34	51.37 dB	51.29 dB	- 0.08	51.38 dB	1.04
35	51.08 dB	50.96 dB	- 0.12	51.12 dB	1.04
36	51.40 dB	51.18 dB	- 0.22	51.33 dB	1.02
37	51.12 dB	50.96 dB	- 0.16	51.12 dB	1.03
38	51.02 dB	50.78 dB	- 0.24	51.01 dB	1.04

[1]Using low power value as reference.
[2]Includes VSWR of rf valve.

Serial No.	Forward Coupling Level		△ Coupling[1]	Reverse Coupling at ~ MW	VSWR (input)
	at ~ MW	at ~ 10 kW			
39	51.08 dB	51.00 dB	- 0.08 dB	51.14 dB	1.03
40	51.13 dB	51.07 dB	- 0.06	51.14 dB	1.03
41	51.40 dB	51.18 dB	- 0.22	51.27 dB	1.04
42	51.55 dB	51.33 dB	- 0.22	51.53 dB	1.04
43	51.23 dB	51.04 dB	- 0.19	51.18 dB	1.03
44	51.37 dB	51.1 dB	- 0.27	51.41 dB	1.02
45	51.28 dB	51.04 16kW	- 0.24	51.27 dB	1.03
46	51.54 dB	51.34 "	- 0.20	51.53 dB	1.04
47	51.40 dB	51.20 "	- 0.20	51.32 dB	1.04
48	51.21 dB	51.0 "	- 0.21	51.17 dB	1.03
49	50.93 dB	50.64 15kW	- 0.29	50.89 dB	1.04
50	50.65 dB	50.4 "	- 0.25	50.63 dB	1.04
51	51.57 dB	51.37 9.3kW	- 0.20	51.51 dB	1.04
52	51.55 dB	51.28 16kW	- 0.27	51.55 dB	1.03
53	50.92 dB	50.71 "	- 0.21	50.90 dB	1.02
54	51.28 dB	51.09 9.3kW	- 0.19	51.32 dB	1.02
55	50.70 dB	51.51 "	+ 0.81	50.62 dB	1.04
56	51.43 dB			51.36 dB	1.04
57	51.41 dB	51.20 "	- 0.21	51.37 dB	1.04
58	51.09 dB	50.89 "	- 0.20	51.07 dB	1.04
59	50.75 dB	50.59 "	- 0.16	50.70 dB	1.03
60	51.30 dB	51.10 "	- 0.20	51.30 dB	1.04
61	50.88 dB	50.89 10kW	+ 0.01	50.86 dB	1.03
62	51.61 dB	51.63 "	+ 0.02	51.65 dB	1.03
63	50.82 dB	50.76 9kW	- 0.06	50.93 dB	1.03
64	51.52 dB	51.45 "	- 0.07	51.55 dB	1.03
65	50.98 dB	50.92 "	- 0.06	51.05 dB	1.02
66	51.90 dB	51.83 "	- 0.07	51.90 dB	1.03
67	51.48 dB	51.30 "	- 0.18	51.50 dB	1.03
68	51.05 dB	50.97 "	- 0.08	51.05 dB	1.01
69	51.42 dB	51.41 "	- 0.01	51.40 dB	1.04
70	50.83 dB	50.78 "	- 0.05	50.80 dB	1.04

VIII. KLYSTRON STUDIES

A. SUMMARY

During the quarter, the two main klystron suppliers have continued deliveries so that by the end of the quarter a total of 43 tubes had been received from RCA, of which 22 were accepted under end-of-life specifications, ten under full specifications, and five were still being tested. Sperry had delivered a total of 28 tubes, of which ten were accepted under end-of-life specifications, two as full specification tubes, and four were still being tested.

The backup program with Eimac and Litton has resulted in the delivery of one tube from Eimac, accepted as a full specification tube, and three from Litton, one accepted as end-of-life specification, one as full specification, and one still in test.

Most of the SLAC klystron work has been directed toward further improvement of the design by introducing minor changes in drift distances and other characteristics of the tube body. At the same time, a number of starts have been made to enable the fabrication of tubes to operate on permanent magnets which are due to be received the following quarter, but all tests this quarter have been run on electromagnets only.

Some life testing of vendor klystrons has been resumed, and the klystron installation has been completed in the first two sectors of the machine. In general, the klystron operation in the first two sectors has been highly satisfactory. Twenty-three klystrons were in storage at the end of the quarter, and ready for installation in the Klystron Gallery; some were lacking PT tanks.

The total delivery to date of sub-booster klystrons is 76, including tubes replacing those which failed within warranty periods of either plate or shelf life. A total of 37 sub-boosters has been accepted, 13 of which are now in use.

Window work has been continuing both in pre-testing windows for SLAC klystrons and in evaluation of coating techniques and further window improvements. Six windows have been undergoing life test for a total time of 4700 hours each with no failures to date.

B. KLYSTRON PROCUREMENT

A considerable amount of effort has been spent in the analysis of the contractor's capabilities and of the klystron requirements during the installation period and the first few years of operation. As a result of these studies, recommendations have been made to the AEC concerning the total number of klystrons to be purchased, total number of magnets to be purchased, and the companies with which the purchases should be negotiated. Specifically, an option has now been exercised with RCA for the delivery of an additional 36 tubes and magnets to fulfill initial installation requirements.

As a result of the negotiated repair contract which involves a turnaround time of 90 days, and considering probable failure rates of klystrons during the first years of operation and the need for a number of tubes always available at SLAC, it turns out that the number of spare tubes needed to fill up the pipeline is almost equal to the number of tubes in operation. Hence, the option with RCA was also exercised to increase the total number of tubes purchased without magnets to satisfy the spare requirements during the first few years of operation.

However, to insure the full utilization of the tubes purchased without magnets, the contract has been amended to provide for tube and magnet interchangeability and a shelf life guarantee. Under these conditions, should a spare tube not be operable when it is needed for replacement of a tube having failed on the machine, it shall be replaced by a new tube at no cost to SLAC.

The overall study also indicated the desirability of negotiating a contract with a third vendor. Proposals were received from Litton and Eimac, and negotiations with Litton have begun.

Similarly, the repair contract with Sperry has been negotiated, and exercise of option quantities with Sperry will be negotiated during the next quarter in accordance with our analysis of tube requirements.

1. <u>RCA Subcontract</u>

RCA is continuing a parallel engineering and production effort for gradual improvement of their tube performance and tube yield. Their engineering program is directed toward evaluating design changes covering the following:

Modification of drift distances.

Investigation of cathode-anode spacing in relation to both perveance increase and gun oscillations.

Construction of a tunable cavity tube to investigate optimum cavity frequency.

Duplication of the Stanford design for evaluation.

Freezing of design parameters for full scale production.

Evaluation of optimum magnetic field and final specification thereon.

The major accomplishments of this period were a final specification on the magnetic field and some testing on tubes with modified drift distances. No conclusive data was obtained on gun oscillations versus cathode spacing; however, this part of the program did give information required to increase the perveance up to a nominal 2.0 microperveance. The Stanford duplicate and the tunable tube both have suffered constructional delays and have not yet been tested. In spite of numerous accidents to the engineering model tubes, progress has been made in power output to the point where almost all the tubes finishing final test are giving full specification output. This progress has been attributed partially to some slight changes in drift distances and partially to an improvement in the permanent magnet fields.

It has been reasonably well demonstrated that the criteria for good tube performance is not necessarily a high axial magnetic field; rather, good performance generally occurs when the transverse field component is minimal. Thus, with axial fields of about 1000 gauss and transverse fields less than 10 gauss, full specification performance may be obtained with magnets currently being delivered. Transverse field compensation with magnetic shunts has not been completely resolved; however, it appears that with no field reversal, present magnetic shunts may be effective. RCA expects that its present specification to the magnet vendors will insure optimum performance for a particular tube design.

RCA tubes generally require a careful balance between maintaining 12 MW output at 200 kV and over 21 MW at 250 kV. This balance is usually obtained by adjustment of the output waveguide tuners. It is expected that completion of the engineering program will provide a design that gives well over the minimum values noted above. Although a few tubes have shown ample power margin at the above voltage levels, it has not been clearly understood just why such performance was obtained.

The problem of pulse ripple and "glitches" is yet to be resolved. These phenomena occur frequently and are a major cause for tube rejection at final (RCA) test. It is expected that a better choice of cavity frequency may mitigate this problem.

2. Sperry Subcontract

During the quarter Sperry was able to complete the fabrication and shipment of tubes corresponding to their initial design (end-of-life specifications), and to conclude satisfactorily an engineering program to demonstrate the design of a full specification tube. As a result of this program, which covered the construction and test of nine engineering model tubes, a tube body design comparable in dimensions to the Stanford design has been utilized by Sperry as a production design, and firm magnetic field requirements have been established.

Although Stanford's electrical specifications are met by the Sperry tubes, we have observed a relatively large number of tubes which are either sparking or gassy; the acceptance rate of Sperry tubes by Stanford has not been as high as anticipated because of these problems. Sperry has been informed of the problems and is working in the fabrication techniques area to improve their product.

3. Eimac Subcontract

A series of constructional problems and failures of both tubes and test equipment consumed the major part of the quarter, with the result that only one tube was delivered to Stanford. The tube showed very good performance with power output comparable to the Stanford tubes. This is to be expected since Eimac's design is a copy of Stanford's. Work on the extended interaction structure for a high efficiency tube has been terminated.

4. Litton Subcontract

Litton has delivered three tubes during the quarter which are essentially copies of the Stanford design. The main difficulty encountered with these tubes is that the performance measured at Stanford is usually substantially lower than that measured at Litton. In the last tube, we remeasured the magnet and found that the field had been degraded approximately 100 gauss, which would explain the poor tube performance.

Litton built and tested a tube with extended interaction output cavity. However, the results were extremely poor, including oscillations and output power lower than in standard tubes. It is expected that Litton will do no further work on extended interaction cavities under this program.

5. Stanford Built Klystrons

The emphasis at Stanford during the quarter has been on further engineering improvements to our tubes, and these will be reviewed in the section on Klystron Fabrication and Development. Some of the experimental tubes which have performed satisfactorily in electromagnets will be tested in permanent magnets when these become available and should then be ready for installation in the Klystron Gallery. Sufficient material has been ordered to allow for a reasonable fabrication schedule during the rest of the year.

6. Magnets

A contract has been signed for the procurement of 36 magnets for use with the Stanford-built tubes. In general, the manufacturers appear to be able to meet our specifications or our tube vendor's specifications, and there seems to be an improvement in the delivery rate. Hence, at the present time we do not anticipate that magnets will cause any major problems in achieving klystron installation on schedule. However, we are still retaining the possibility of switching to electromagnets for a portion of the accelerator if needed to meet installation schedules.

C. FACILITIES

The high temperature ceramic metalizing furnace mentioned in the last report* is now in full operation. It has performed extremely well, giving high quality metalizing for our own requirements as well as for the requirements of other groups within the project.

The window coating equipment is still being improved, particularly with respect to methods for measuring the thickness of the titanium deposited on the windows. Several techniques have been evaluated, including a commercially available coating monitor based on photometer measurements. However, the results were not as good as the quartz crystal resonance shift technique tested previously. Hence, 8.5 Mc crystals, a crystal impedance meter, and counters have been obtained and are being installed to enable us to monitor the coating and to make in-process measurements of the crystal resonance shift and the corresponding coating thickness.

The X-ray facilities continue to be used extensively, both by the Klystron Group and other SLAC groups, including Mechanical Design and Fabrication, Heavy Electronics, Health Physics, and other users interested in effects of radiation on materials.

The trailers, carrying equipment for klystron installation and tests, have been completed and tested satisfactorily, both in the mock-up test stand and in the gallery. Other klystron handling equipment such as a special truck, storage dollies, etc., have been received and have proven satisfactory in operation.

D. KLYSTRON OPERATION IN THE GALLERY

Eighteen klystrons (13 RCA, three Sperry, two Stanford) were in operation in the gallery at the end of the quarter. As an aid in testing the first two sectors, as well as in training our personnel to maintain proper klystron operation, the Klystron Group has supplied one technician and one supervisor during each night's operation. In general, the klystron operation appears satisfactory, with detailed comments below.

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* "Two-Mile Accelerator Project, Quarterly Status Report, 1 October to 31 December, 1964," SLAC Report No. 42, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965), p. 58.

1. <u>General Performance</u>

The performance of the klystrons operating on the machine in the first two sectors has been monitored regularly during the past quarter. Data has been recorded virtually every evening that the accelerator has been running. Recently, some measurements were made in the daytime with no accelerator beam. In general, the performance has been consistent, with no indications of klystron deterioration. There are, however, systematic differences between the gallery data and the klystron acceptance test data. The klystron beam current measurement is made on the primary side of the pulse transformer in the gallery, and a firm ratio for transferring this current measurement to the secondary side has not yet been established. Tests are now being conducted to resolve this problem. The measured power outputs using calibrated directional couplers and a temperature compensated thermistor bridge average about $5\frac{1}{2}\%$ higher than the calorimetric measurements made during the acceptance tests would indicate.

There were some stations which repeatedly responded to reflected energy faults when the trip level in the modulator-klystron protection unit was set in the 0.5 MW range. It was decided that if the trip level was relaxed to 2 MW there would be adequate protection for the klystron output window and the outages due to lower level, harmless reflected power occurrences would be eliminated. This also reduced the output waveguide clean-up time considerably.

The vacuum protection in the output window region works moderately well, although there are still some reservations on the reliability of one of the cold-cathode, discharge-gauge control units used. The protective circuitry is now adjusted to disable the modulator if the pressure in the output waveguide exceeds 10^{-6} torr. The vacuum pumping system works well except for the ion pump outage in the middle of Sector 1.

2. <u>Harmonic and Phase Measurements</u>

The investigation of possible adverse klystron performance due to the presence of the waveguide valve has been completed. Of concern was the possible interaction between harmonic reflections from the valve and the output phase at the operating frequency. Using a two-video signal phase bridge, the phase shift through the klystron was displayed on the oscilloscope face with a sensitivity of approximately one electrical degree per centimeter. This allowed easily discernible phase instabilities as small as 0.1 electrical degree if present. These measurements were made on all 18 klystrons at approximately 230 kV. Photographs were taken of the beam voltage pulse top, the detected rf pulse and the video phase display for each klystron. Close inspection of the pictures revealed no phase variations in excess of 0.4 electrical degrees which were not directly related to the deviation from flatness of the beam voltage pulse top or the beam voltage amplitude jitter. At present, the phase variation across the rf pulses due to the non-flatness of the beam voltage pulses averages about two electrical degrees.

Harmonic power measurements were made on three klystrons in the gallery and on one klystron on the mock-up test station. These measurements were made using a series of filters on the reflected power arm of the Type A directional coupler in the output waveguide. Since the Type A coupler has not been calibrated for the various modes of propagation at the harmonic frequencies, the reduced data determines only the harmonic content measured by the power meter and not the content of the klystron output.

Measurements on the mock-up klystron showed that the measured relationship between frequency components in the harmonic spectrum is altered considerably when the waveguide valve is removed. Shifts in the harmonic standing wave patterns with respect to the coupler may be the cause of this measured change in harmonic spectrum.

The larger amount of phase jitter with the valve in the circuit which was reported previously* appears to have been due to FM in the driver which appeared as jitter in the phase display.

3. Modulator-Klystron Protection

The reflected energy portion of the M-K protection unit appears to work satisfactorily since many klystron interruptions have been observed as a result of its operation. However, an attempt has been made to determine the actual operation on a single pulse basis by initiating an

*Ibid. p. 60.

arc in the waveguide in which the system is installed. Several combinations of matched tungsten electrodes mounted in the waveguide were tested to achieve repeatable arcing at given levels. However, no electrical breakdown has been obtained yet below 30 MW. The unit is being redesigned to hopefully bring the arc-over level at about 10 MW.

E. KLYSTRON FABRICATION AND DEVELOPMENT

A dozen experimental tubes were built and tested during the quarter. The following modifications were introduced: (1) change in output cavity gap spacing to improve the energy transfer, (2) minor variations in drift distances to determine the effect of bunching parameters, (3) adjustable cathode position to determine effect of gun alignment, and (4) extended interaction output cavity.

At present it appears that the greatest improvement has been obtained by a slight change in drift distances or bunching parameters. Two tubes built with the modifications have given an efficiency of approximately 41% at 250 kV with good stability and gain. Figure 11 gives the results obtained with one of these tubes with optimum focusing at each voltage level. The change in output gap had little or no effect in operation, and no significant improvement in transmission could be found by adjusting the cathode-anode spacing in the adjustable tubes.

The first of several planned extended interaction output klystrons has been tested. The tube is stable but unfortunately the power output is no better than for a standard output. In fact, the efficiency barely reaches 35% compared to better than 40% in some of our standard tubes and 41% for the modified bunching parameter tube.

As a result of the tests with the adjustable cathode tubes, the cause of heater hum which is observed occasionally remains unknown since small changes in cathode alignment did not appear to have any significant effect on heater hum in the experimental tube.

Continuing improvements are being attempted in the fabrication and exhaust techniques to give as high a yield and as easy a processing as possible. To date, no significant correlation has been observed between various modifications in baking and fabrication techniques attempted and the gassiness or lack thereof as the tube is being processed.

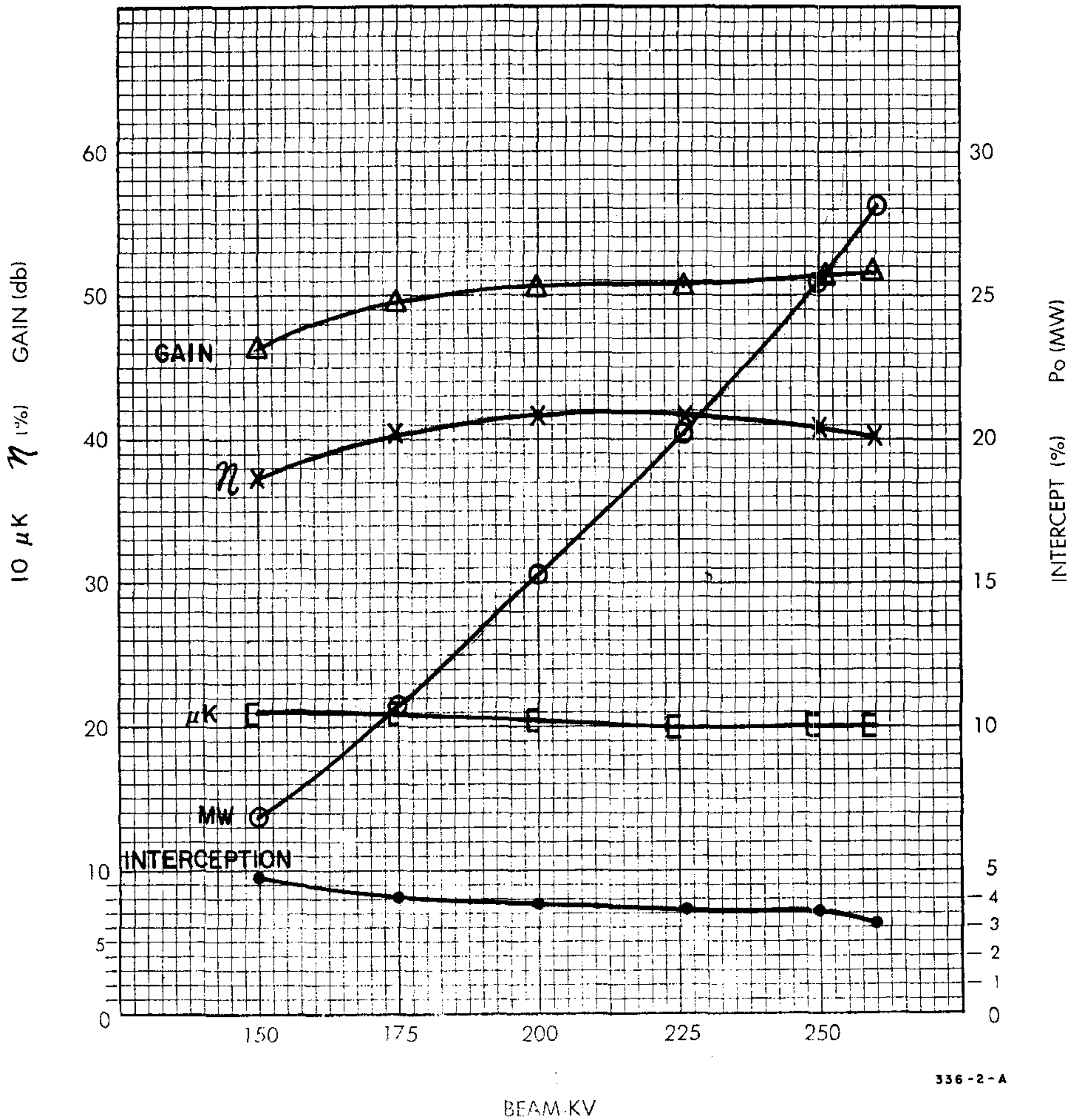

Fig.11 --SATURATION CURVES, 180 PPS, TUBE #H-80-A XM-7, TEST STAND #01

In the area of tube rework, however, a significant improvement appears to have been achieved by using a 3% formic acid rinse of the tube body before it is reassembled on a new gun. However, in two cases a window which had been running cool previous to reworking ran hot after rework, and it is suspected that the formic acid,combined with the high temperature bakeout, has an effect on deteriorating the window coating.

Facilities for remagnetizing permanent magnets have been completed and tested. Until now, we have been able to achieve in several magnets an axial field which is equal to or better than that measured when the magnet was initially delivered. However, the transverse fields were higher than acceptable and additional work needs to be done to resolve the transverse field problems.

Stanford-built tubes and diodes are still being operated regularly by various SLAC groups. As of now, one diode in use by the Modulator Group is still in satisfactory condition after 4200 hours of operating time, and the SLAC-built klystron used on window life test equipment has over 1900 hours of full power operation. No klystron failures were reported during the quarter, but one diode failed on the mock-up test stand.

F. KLYSTRON INSTALLATION AND MAINTENANCE

As stated above, 18 tubes are installed in the klystron gallery. In addition, 23 spare tubes are available for installation in the gallery. Two tubes are undergoing life test in the Test Laboratory and, although from a power output and stability standpoint these tubes are still satisfactory, the X-radiation from the tubes has gradually increased and exceeded the specified limits in approximately 200 and 400 hours respectively. This phenomenum had not been observed in tubes which were previously life tested in the test stands. Radiation protection has been provided by adding lead shielding as needed around the tube transformer tank and magnet, but the situation will have to be followed closely in the gallery to insure that safe radiation levels are not exceeded.

During the first three months of gallery operation, one tube failed by cathode seal puncture near the heater seal end of the bushing. This is very unusual and the reason for this early failure has not yet been ascertained.

G. HIGH POWER KLYSTRON WINDOWS

1. Resonant Ring Tests

a. Klystron Window Pre-Testing

A total of twelve klystron windows were pre-tested in the all-metal ring (up to 42 MW at 36 kW) during the quarter. All windows were judged suitable for tube service on the basis of satisfactory performance during ring test. The ring duty factor was changed to 8.6×10^{-4} at the first of the year when the magnetron ring driver failed and was replaced by the in-house fixed frequency drive line. The house drive has been in use since and ring tuning is now being done by means of waveguide tuning rather than by frequency variation as had been the case when the tunable magnetron was being used.

b. Window Coating Tests

Several short test sequences were used in investigating various aspects of the sputtered titanium coating. Coating stability is being studied in connection with signs of window deterioration associated with tube reprocessing. Experiments have been and are being made with the intention of identifying reasons for the effectiveness of the coating and relationships to variations in the coating procedure.

Window overheating was observed during operation of two reprocessed SLAC klystrons. Reprocessing includes rinsing of the tube interior with a 3% formic acid cleaning solution. A series of resonant ring tests is now being performed to determine whether or not the acid rinse is responsible for apparent deterioration of the window coatings in the reprocessed tubes. Tests completed to date seem to indicate that the cleaning rinse followed by a bake cycle does reduce the effectiveness of the window coating. A previous test of the effect of formic acid rinse was included in the test program on RCA window coatings. No ill effect was detected in that test, but the rinsed sample used had not been baked.

An attempt was made to determine whether secondary electron suppression is indeed the dominant reason for the effectiveness of titanium coating. A suggested alternative beneficial effect would be the ability of the coating to provide a lower resistive path for removal of charge accumulated on window surface which might otherwise contribute to dielectric failure. An experiment was devised in order to discriminate between these effects. This test involved application of coating to all of the window surface except for a narrow circumferential band. This technique provided an interruption of the conductive path without significantly reducing coating coverage. This test seemed to indicate dominance of the secondary electron suppression function of the coating as no symptoms of charge accumulation were observed. In a subsequent test the width of the uncoated perimeter band was increased with a noticeable increase of multipactor heating resulting.

Further attempts to explain the absence of multipactor on several of the uncoated alumina windows tested in the original ring have led to the suspicion that films of impurities, oil vapor in particular, may be capable of suppressing secondary electrons. A window which had operated free of multipactor in the old ring was mounted in the high-vacuum ring and tested to high power (36 MW, 31 kW) without multipactor. The window surfaces were then wet-blasted and a second test performed during which multipactor occurred and eventually resulted in thermal failure at 25 MW (21 kW). This result tends to support the suspected impurity film theory and further tests are planned, using a variety of surface treatments on multipactor-proof "dirty" windows.

c. Material Study Tests

Another specimen of AL-300L ceramic, a finer grained variation of AL-300 composition with increased mechanical strength, was tested to maximum peak power (71 MW, 60 pps) and average power (45 kW, 360 pps) without multipactor overheating, or damage of any kind. By contrast, the first AL-300L sample had failed thermally following multipactor. There seems to be no indication that this ceramic differs substantially from AL-300 in any properties affecting high power window service, except for the increased mechanical strength.

Window material study has been extended to include evaluation of glass windows. Excluding consideration of quartz, which has already been tested, pyroceram was chosen for testing on the basis of published data on physical properties which indicate its superiority to other available glasses. Six 1/8-inch × 3-inch discs of pyroceram were obtained, two of which have been tested in model A geometry in the original ring. Both windows failed thermally while being operated at a relatively low power level (13 MW peak, 2 kW average). The two "failures" were identical, both characterized by excessive loss in the dielectric, high temperature gradient (> 400° center-to-edge) and extreme variations in dielectric constant and irreversible reduction in electrical resistivity, both obviously caused by high temperature operation. Neither window was physically damaged, but the excessive dielectric/resistive losses clearly represent failure in themselves. Multipactor was not involved in the behavior of this material. No visual symptoms of multipactor were observed and titanium coatings had no effect on window performance whether applied before or after initial operation of the window. As pyroceram is clearly not suited for use as a window material, the high vacuum ring tests scheduled for the remaining samples have been cancelled.

2. Window Life Test

The window life test stand resumed operation in February after a six-week interruption for necessary repair and renovation of the test stand modulator. Approximately 1000 hours of operation at 20 to 23 MW peak and 18 to 20 kW average power were accumulated during the remainder of the quarter. Total operating time is now 4700 hours, 1600 hours at powers above 20 MW. No window replacements were necessary during the quarter. Window temperature acquisition has been facilitated by improved mounting of the thermocouple used to monitor edge temperature.

During several hundred hours of tests, the system was run at full power for 55 minutes, turned off for five minutes, and turned back on full power without gradual attenuation variation in the drive. These are the conditions under which Mark III reports a significant decrease in window life. No evidence has been found that under the vacuum conditions of the tests run here there is any tendency for window failures under sudden application of power.

H. SUB-BOOSTER KLYSTRONS

Eimac delivered only three sub-booster klystrons during the quarter, bringing the total number of accepted new tubes to 37. The shelf life problems continue to plague the sub-booster klystron in spite of engineering and fabrication effort at the company. For instance, of three tubes delivered during the fourth quarter of 1964 and retested during this quarter, two had failed under the shelf life warranty.

On the other hand, the operation of the Eimac sub-booster in service continues to be extremely good. Of 13 sockets in use, a total of four tubes failed during the quarter, one within plate life warranty at approximately 900 hours, two at approximately 6000 hours, and one at approximately 12,000 hours.

The low delivery rate during the quarter would give cause for alarm were it not for the fact that we still have 12 spare tubes with operating life averages of approximately 6000 hours.

IX. BEAM SWITCHYARD

A. GENERAL

Beam Switchyard housing construction is progressing. Figure 5 shows a view of the construction.

The BSY site and utilities construction contract has been awarded. The cooling water systems bid package and the electrical distribution system bid package passed the 90% mark and reviews were begun. The Beam Switchyard equipment installation bid package approached 90% completion.

Figures 1 and 4 show overall views of the Switchyard and related structures. Figure 2 shows the principal items of the beam transport systems and the beams which may be delivered to the target areas. Only the A-beam, the photon beam, and the B-beam are to be developed initially. Figure 3 shows all major items of equipment which will be initially installed in the Beam Switchyard.

B. INSTRUMENTATION AND CONTROL

1. Beam Monitoring Instruments

a. Beam Current Monitors

A production prototype of a double 3-inch i.d. current transformer has been assembled and tested. (Double current transformers are used at locations where an extra signal is needed for beam current integration, or for beam interlock purposes.) A single current transformer has the same housing as a double one. A few modifications have to be made on the prototype before production can be started.

The 6-inch i.d. transformers to be used in front of each beam dump have yet to be designed. They will use two or three ferrite rings, each one of which is built up from four sections.

A prototype beam current integrator has been tested, but requires more work. The tests indicate an absolute precision of $\approx 1\%$ and a reproducibility better than 0.3%.

Circuits to display average beam current are not yet designed. Some of the circuits developed for the accelerator will be used. For beam

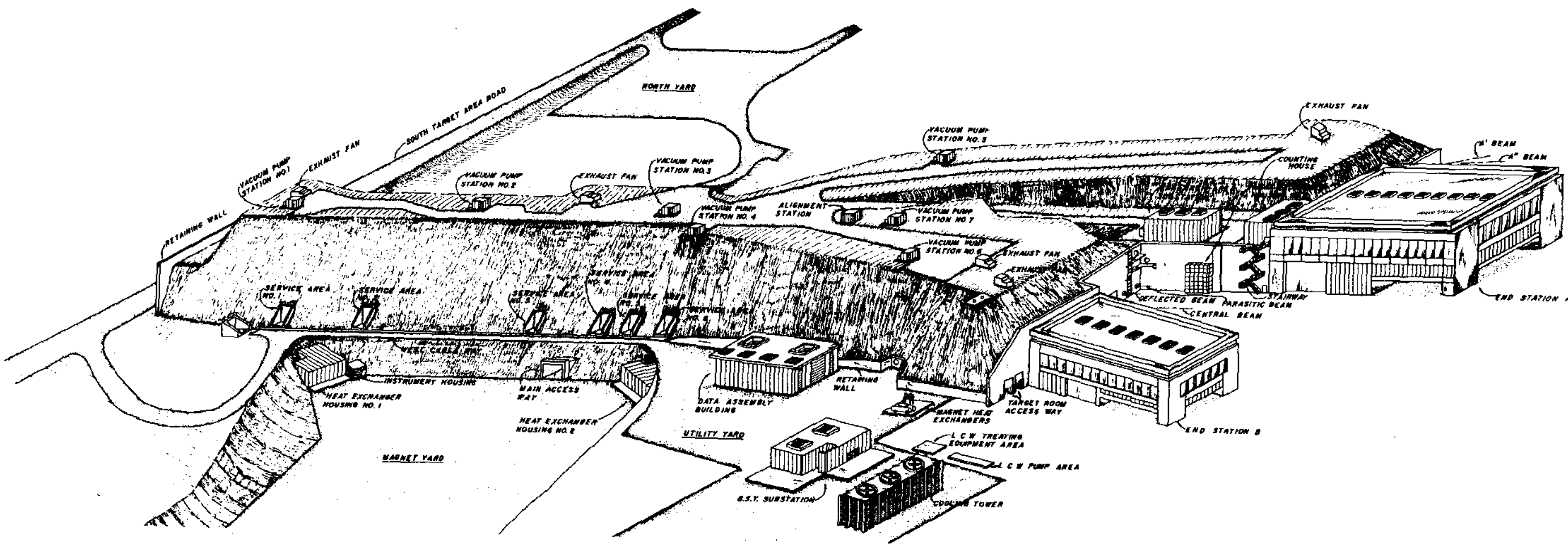

FIG. 12--Beam Switchyard and target areas.

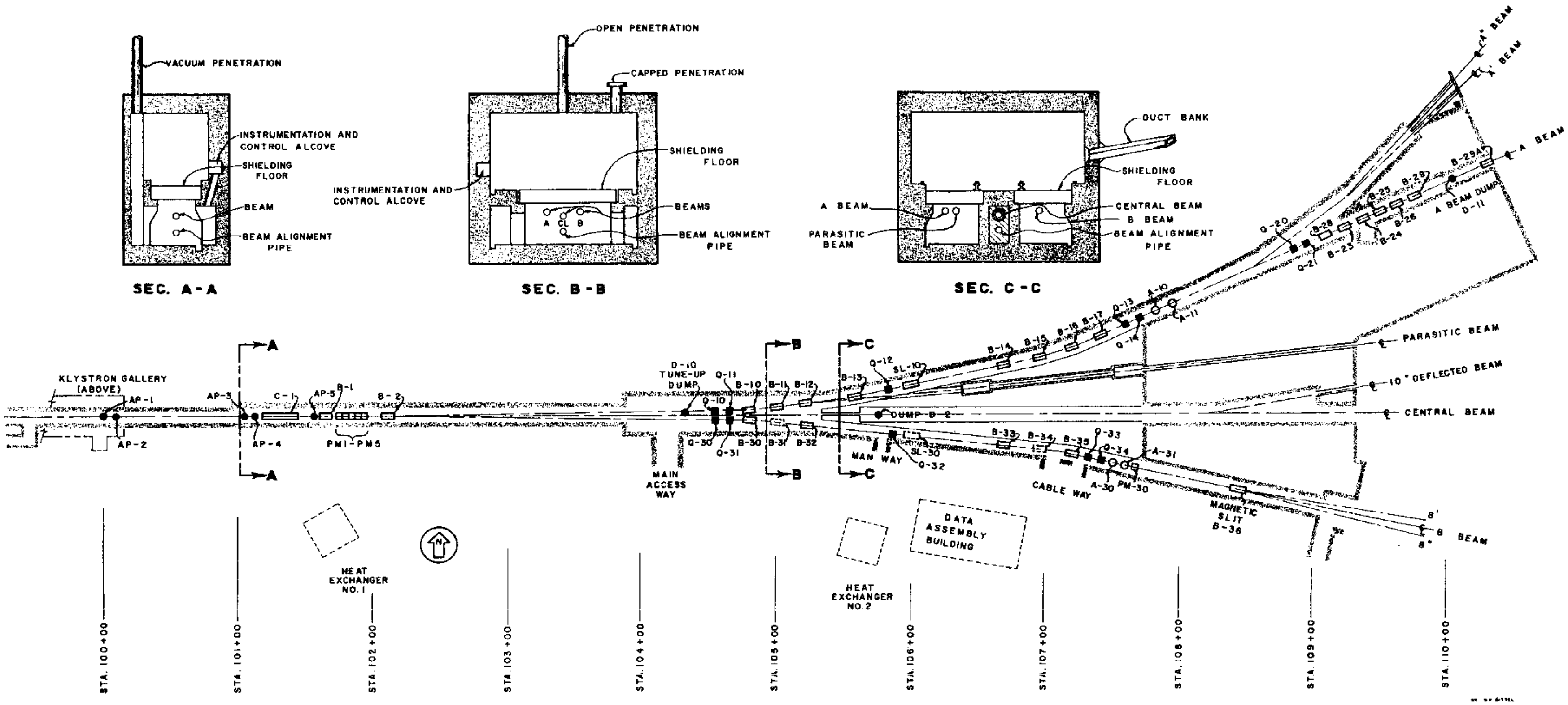

FIG. 13--Principal components of BSY beam transport systems.

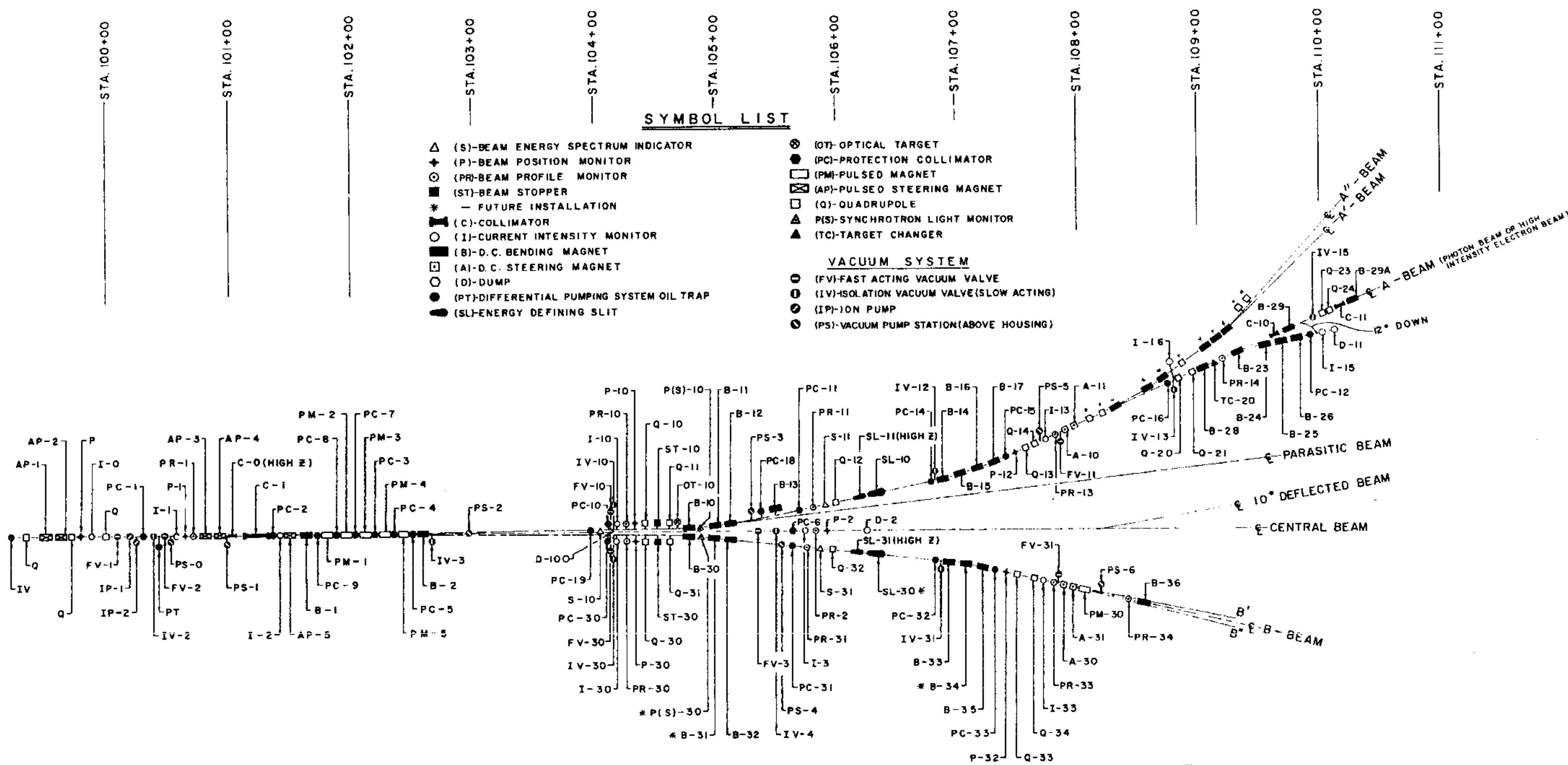

FIG. 14--Beam Switchyard transport system component diagram.

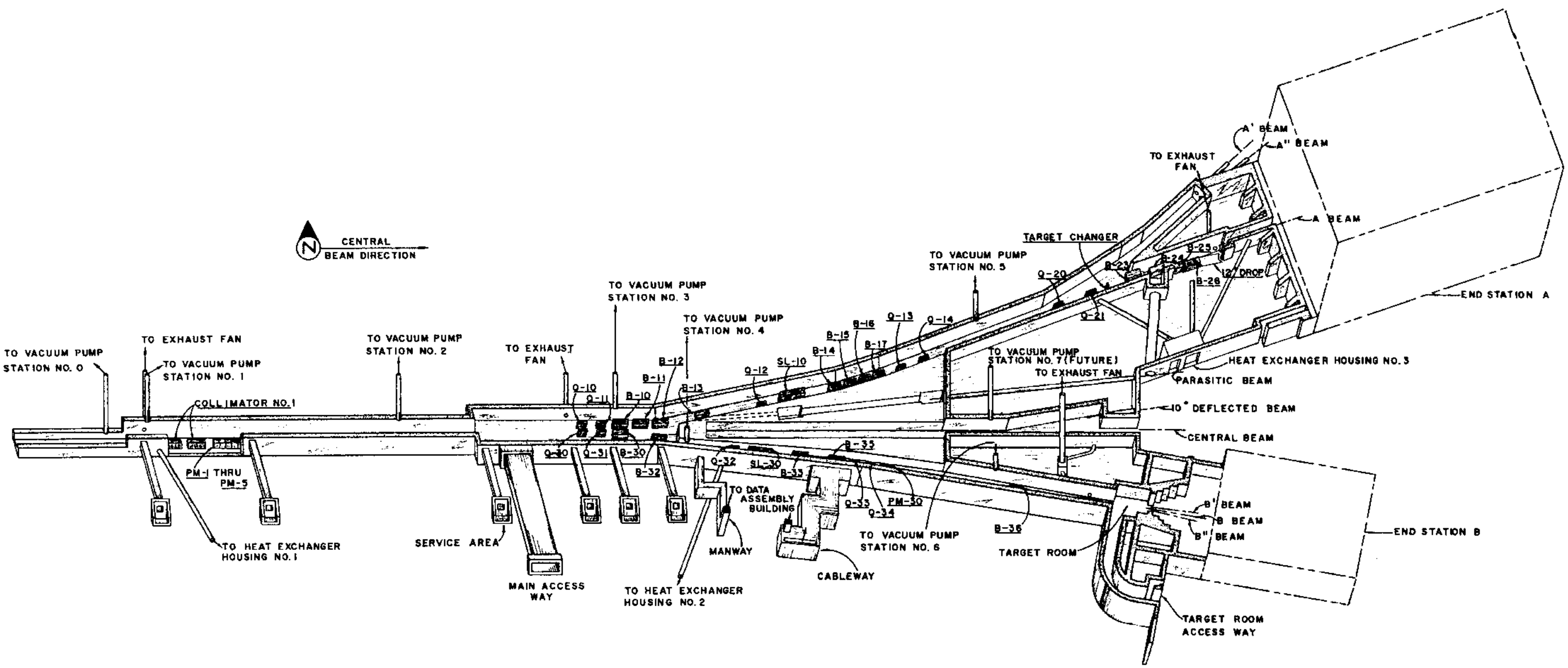

FIG. 15--Beam Switchyard structure.

set up in the Switchyard the dynamic transformer pulses will be used; the pulse height can be measured accurately with a pulse height comparator circuit. The latter circuit is almost completed. Selector panels to select any two current transformer signals on the scope are not yet designed.

It has been decided that balanced signal transformers will not be used to match twinax cable to single input amplifiers. Balanced input pre-amplifiers, which will be located within 50 feet of each transformer, are being developed instead.

b. Beam Position Monitors

A production prototype of the $\approx$ 2-inch i.d. microwave cavity position monitor has been tested satisfactorily. The Q for the x, y cavities is 500, and for the reference cavity approximately 1200. After a few modifications are made on the prototype, production will be started. The microwave electronics and the detection diodes will be located close to the monitors, in the alcoves in the Switchyard housing. A special box has been built that will protect these components from the nitric acid atmosphere in the Switchyard.

Most of the electronics for dynamic position display and normalized position display has been designed, but construction of the circuits has not begun.

c. Zinc Sulfide Screen Beam Profile Monitors

The drawings for a production prototype are nearly completed. Many design changes are included as a result of mechanical tests on an existing prototype.

There are two types of monitors, one with 6-inch wide screens and one with 10-inch wide screens. The 6-inch screens are placed in the beam at an angle of 65°; the optics looks at the screen at an angle of 45°. The 10-inch screens are placed in the beam at an angle of 90°; the optics looks at the screen at an angle of 30°.

Fixed reference marks close to the screens, but not interfering with the beam path, are illuminated from the outside. A 45° front surface mirror located inside the vacuum reflects the light in the vertical direction.

The viewing window protrudes enough to be shielded by the two-foot shielding floor. The drive motors for the two motions involved with the screens are standard non-radiation-resistant components. The motors also protrude into the shielding floor, and will be made easily replaceable.

Work still has to be done on a reproducible technique for applying the zinc sulfide to the foils.

d. Cerenkov Cell Beam Profile Monitor

A final model of the Cerenkov cell beam profile monitor is expected by the end of the quarter. The instrument is moved into the beam by an air-driven cylinder thatis dry-lubricated by dicronite. It is moved out of the beam by a weight attached at the outside. The window will not be shielded by the shielding floor, which is acceptable in view of the moderate radiation exposure in the locations where the monitor is used. The monitor has to be removed if the window must be changed.

An external illumination system for the internal reference marks will be made for this monitor. In addition, the existing internal reference glow points may remain in the system.

Work has to be done on simplifying the task of putting the monitor into the vacuum chamber and in removing it.

e. Synchrotron Light Observation Stations

Present plans call for modified vacuum chambers for synchrotron light observation to be placed after the first bending magnet in each analyzing system. The drawings for these components are being checked. Small modifications have to be made to the reference wires.

The synchrotron light vacuum chambers and the chambers of preceding magnets will be sandblasted to reduce reflections. The frame of the metal mirror has to be sandblasted and blackened in order to radiate the heat which it absorbs from intercepting the synchrotron radiation.

f. Optical Equipment and Closed Loop Television Systems

The light from the profile monitors is reflected into television cameras by independently supported mirrors. These mirrors can be adjusted manually between 45° and 65° and are remotely adjustable in the x, y direction over about 5°. A prototype of the mirror exists. Modifications as a result of tests on this prototype are being included in the final drawings. Mirror optics will be used with the television cameras to avoid the cost of non-browning lenses.

A prototype telescope using a 4.25-inch i.d. spherical mirror has been tested and is very satisfactory from an optics point of view. However, the remote focusing adjustment mechanism is not working properly. Remote focusing of the telescope could be eliminated if a television camera in which the vidicon tube position can be controlled remotely by a motor were used. This feature is available in some cameras. The effect of nitric acid on the front surface mirrors used in the adjustable mirror and in the telescope remains problematical; recent test results have been discouraging. The television requirements have been thoroughly studied and specifications are being written.

g. Beam Spectrum Instruments

The final spectrum analyzer is expected to be ready early in the next quarter. A very attractive foil support was made at the Mark III accelerator and drawings are being modified to include this feature.

The spectrum monitor located in front of the tune-up dump is constructed in two parts, each connected into the vacuum chamber by a 12-inch fast-disconnect flange. One of the parts is being constructed and is 50% complete. The other part will not be made until the first has been tested.

A prototype rack with spectrum analyzer electronics has been made and tested, using the spectrum monitor foils used in the first sector of the accelerator. Noise problems were encountered. Here, as in the case of the pre-amplifiers for the current monitors, balanced signal transformers will be replaced with balanced amplifiers.

A new universal scanner has been developed and is working properly. It will be used to scan signals from the spectrum analyzers and the spectrum monitor, as well as in the CRT display of average beam current monitor signals.

h. Secondary Emission Foil Beam Centering Devices

There are two different foil centering devices: the foils fixed to the front end of the slits, called "spectrum drift indicators," and the foils in front of the underground beam dump and beam dump east. Design work on the foils for the slits is approximately 20% complete. The foil stacks in front of the dumps will consist of four foil quadrants. Design on these devices has just begun.

2. Equipment Protection Instruments

a. Ionization Chambers

Two 1.3-liter ionization chambers have been constructed and tested. Eighty more are being ordered. A proper design for the various ionization chamber supports is not yet finished. Two pieces of "long ionization chamber" (LIC) needed in the Switchyard will be obtained from the accelerator procurement. Details remaining to be settled are the proper location of ionization chambers around the main collimator, the slits, and the dumps, and individual calibration procedures for each ionization chamber in the Switchyard.

The signal integrating and comparator circuits are in production. A circuit which will periodically test all ionization chamber interlock circuits for proper functioning is being constructed.

b. Thermometers

One-hundred-ohm platinum wire thermometers will be used throughout the Switchyard. The design of the various fixtures for the thermometers is about 40% complete.

All thermometer alarm circuits have been constructed. Routine tests have to be done on the completed chassis. The thermometer circuits give alarm above a certain temperature limit. A patch panel allowing the measurement of temperatures at each location will be designed. The circuit which will periodically test all ionization chamber interlock circuits will test at the same time the thermometer alarm circuits.

c. Secondary Emission Protection Foils

The foils which protect the side walls of the tune-up dump are being fabricated; they are actually part of the spectrum monitor. The foils at the front end of the collimator, the foils at the back end, and the foils on the slit are all fixed. Design work on this group of protection foils is not yet complete.

d. Differential Beam Current Monitors

The current monitors for this purpose have been reviewed in Section B.1. Design of the electronics for the differential measurements is being postponed. The differential current measurements act as backup to the ionization chamber interlock circuits.

3. Magnetic Measurements

a. Pulsed Magnets

A prototype integrator for the pulsed magnets is being tested. The integrator output provides, at every beam pulse, an "OK" signal to the injector gun if the magnetic field is correct.

The magnetic field readout from this integrator is designed; a fast analog-to-digital converter has to be ordered.

b. Nuclear Magnetic Resonance Devices

A commercial NMR will be ordered to calibrate the reference magnets.

The electronics associated with the fixed frequency NMR are ready for production. A few small CRT's have to be ordered. A satisfactory construction for the radiation resistant probe is being worked on.

c. Flux Loop Integrator

The integrator for this purpose has been tested and is in final fabrication. The selector panel to connect the flux loops of any of the dc magnets to the integrator has to be made.

d. Remanent Field Measurements

A laboratory circuit of a second-harmonic detector is working. A suitable radiation-resistant second-harmonic remanent field probe has to be made.

4. Control and General Interlock Status Circuitry

a. Control Room Layout

The rack assignment is completed and the layout of panels in each rack is being worked out. Racks and the operation console are being ordered. The installation of racks and equipment is scheduled to begin in August 1965.

b. Magnet Control

A panel is designed that provides remote on-off switching for any two power supplies. The panel contains, in addition, status lamps for the supplies and the magnets connected with it. The panel is ready for production.

If the computer is not operational for any reason, all magnet currents can be adjusted manually. For the 3° energy-defining bending magnets a manual dial box is designed that will set the programmable voltage reference unit in the regulator for this supply.

All other magnet supplies can be adjusted manually with a dc motor connected to the helipot in each supply. The steering magnet supplies use SLO-syn motors for this purpose. The current in each magnet is read back during the adjustment on a digital voltmeter connected to the shunt or transductor. All circuits mentioned above are in the design stage. The automatic adjustment is reviewed in Section B.5.

c. Slit/Collimator Control

Present plans suggest that a fast and slow conventional motor be used for positioning rather than a stepping motor, because available stepping motors do not have enough torque.

The position of the jaws is read back via shaft encoders. The circuits associated with the encoders and the digital display are basically designed. The beam interaction area with the edges of each jaw and some alignment tolerances are detected by an LVDT (linear voltage dependent transformer). The LVDT electronic circuits will be purchased.

d. Vacuum

Vacuum valve control circuits and display panels are ready for fabrication.

The circuits associated with the fast vacuum switches (McClure gauges) are handled by the Light Electronics Group. The amplifiers for the vacuum gauges are not designed yet.

e. Cooling Water

All status and interlock circuits associated with cooling water for the magnets and dumps are ready for fabrication.

f. Summary Interlock Circuit

This is a complicated circuit where pre-grouped fast and slow interlock signals from all over the Switchyard join together. The circuit diagram is in the shop for fabrication.

g. Summary Status Display Board

A summary status display reflecting the actual Switchyard layout is being worked out.

5. Computer System

An order was placed for an IBM 1800 computer, and delivery is scheduled for October 1965. All electronic circuits peripheral to the computer have been designed, and orders have been placed for the commercially available circuit components. Very little has been done on programming.

a. Analog Signal Handling

The 3^{o} energy-defining magnets will be computer controlled by a commercial programmable voltage reference unit in the regulator of the supply. A special circuit has to be developed to interface this unit with the IBM 1800.

All other magnets will be adjusted via digital-to-analog converters. A prototype converter exists, but it was built for the PDP-7 computer and has to be modified slightly.

The readback of analog signals into the computer is being worked out.

b. Interlock Signal Scanner

The circuits for the scanner have been designed with the DEC logic modules. The approximately 4000 wire connections in the scanner will be done by a computer-instructed wiring machine.

C. MAGNETS AND POWER SUPPLIES

Most of the magnets and power supplies are in the process of procurement. The magnets are discussed in Section VII of this report. The power supplies are discussed in Section VI of this report.

D. VACUUM CHAMBERS AND EQUIPMENT

1. Ceramic Chambers for Pulsed Magnets

The 0.1° pulsed magnet internal vacuum chambers will be exposed to intense radiation, about 10^{13} ergs/gram maximum in ten years, and to a pulsating magnetic field of 600 cps frequency with the field varying from 0 to 1730 gauss and a repetition rate of 360 cps. The radiation levels preclude the use of organic materials, and the heating due to the pulsating field precludes using metals in thicknesses exceeding about 0.001 inch. Ceramics seem a logical choice, but it appears that their electrical resistivities are so high that internal charge build-up due to irradiation will cause breakdown. It was decided to issue requests for proposals to ceramic manufacturers to supply ceramic chambers with resistivities in the range from 10^4 to 10^{11} ohm-cm.

2. Remote-Disconnect Vacuum Couplings

The bids for manufacture of the SLAC-designed remote-disconnect vacuum couplings were received. These couplings have a stepped stainless steel knife edge seating in an indium gasket. They are to be made in 6-inch, 10-inch, and 12-inch pipe sizes.

3. DC Magnet Vacuum Chambers

Bids were requested on the first group of dc magnet vacuum chambers. These are long (up to 3 meters), welded stainless steel (316-L) chambers which must closely fit the magnet gaps, and several of them have special provisions for NMR probes and the like.

E. BEAM DUMP

The beam dump bid package was completed and approval to initiate bidding was received.

Tests continued on the dump window seal which is a stainless steel knife edge seating in a copper gasket. It was determined that a vacuum tight seal could be obtained using an impact wrench to tighten one nut only. The depth of penetration of the knife edge was roughly proportional to the air pressure supplied to the wrench.

F. SLITS AND COLLIMATORS

1. High-Z Slit

The design of the high-Z slit units was settled. Detail drawings are being made, and materials for fabrication are being ordered. The high-Z collimator, which is basically two high-Z slits mounted at right angles in the same vacuum tank, is shown in Fig. 16. The jaws are 34.7 radiation lengths, minimum,* of copper, with water cooling. They will open to a width of 12 cm and can be positioned with an accuracy of ± 0.001 inch.

One difficult design problem is that of the water leads to the jaws. These leads must be flexible to accommodate the wide range of jaw travel. Stainless steel bellows are available, but in these sizes (1/2 inch) the wall thickness is in the range from 0.007 to 0.012 inch; failure of the wall for any reason would allow water leakage into the vacuum system, necessitating shutdown and repair of the equipment, which will very likely be radioactive.

2. Protection Collimators

Figure 17 shows PC-10, one of the magnet equipment protection collimators in the Switchyard. Basically, these collimators are water-cooled copper blocks with apertures of a size and shape to allow maximum beam transmission while protecting the equipment behind.

3. High Power Slits and Collimator

Proposals were requested for fabrication of the aluminum power-absorbing modules, and several proposals were received. Negotiations and design modifications to reduce costs are proceeding. The design of the tanks, jaw-positioning mechanisms, and supports is continuing. A test of a small model of a slit module on the Astron Accelerator at the Lawrence Radiation Laboratory, Livermore, California, is being prepared, which will determine the effect of shock heating on the slit module.

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*21.5 cm minimum for slits.

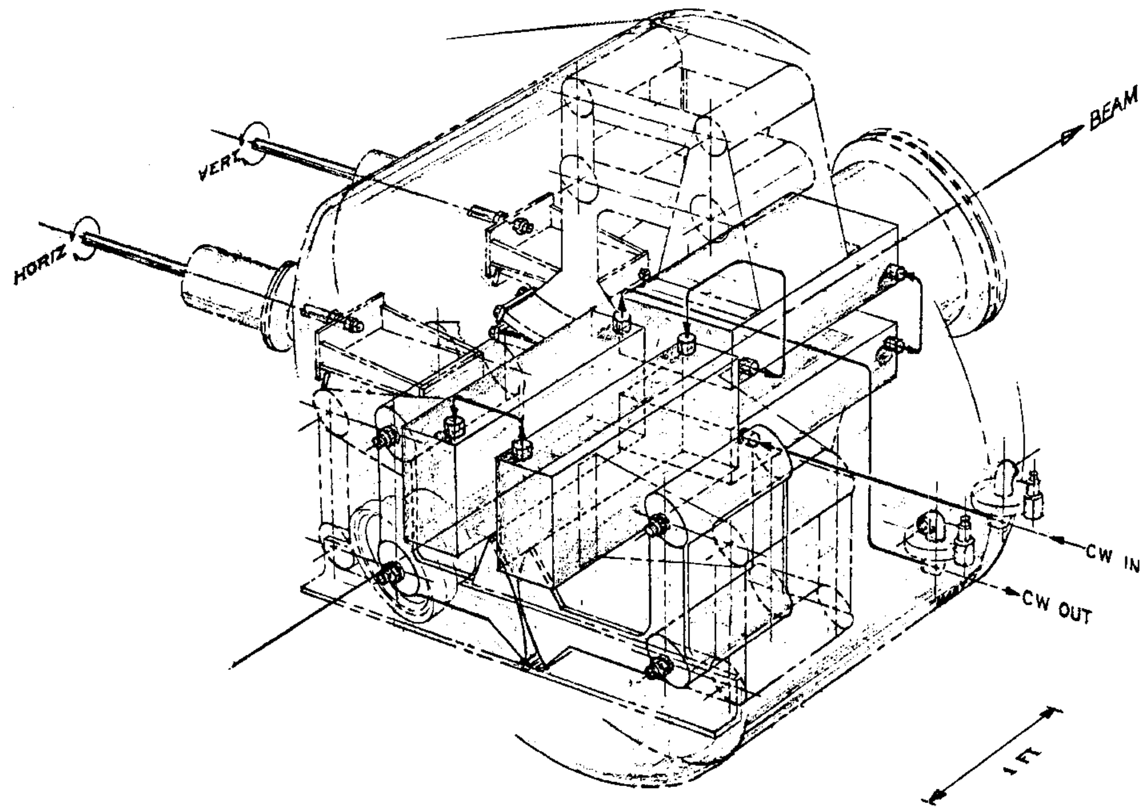
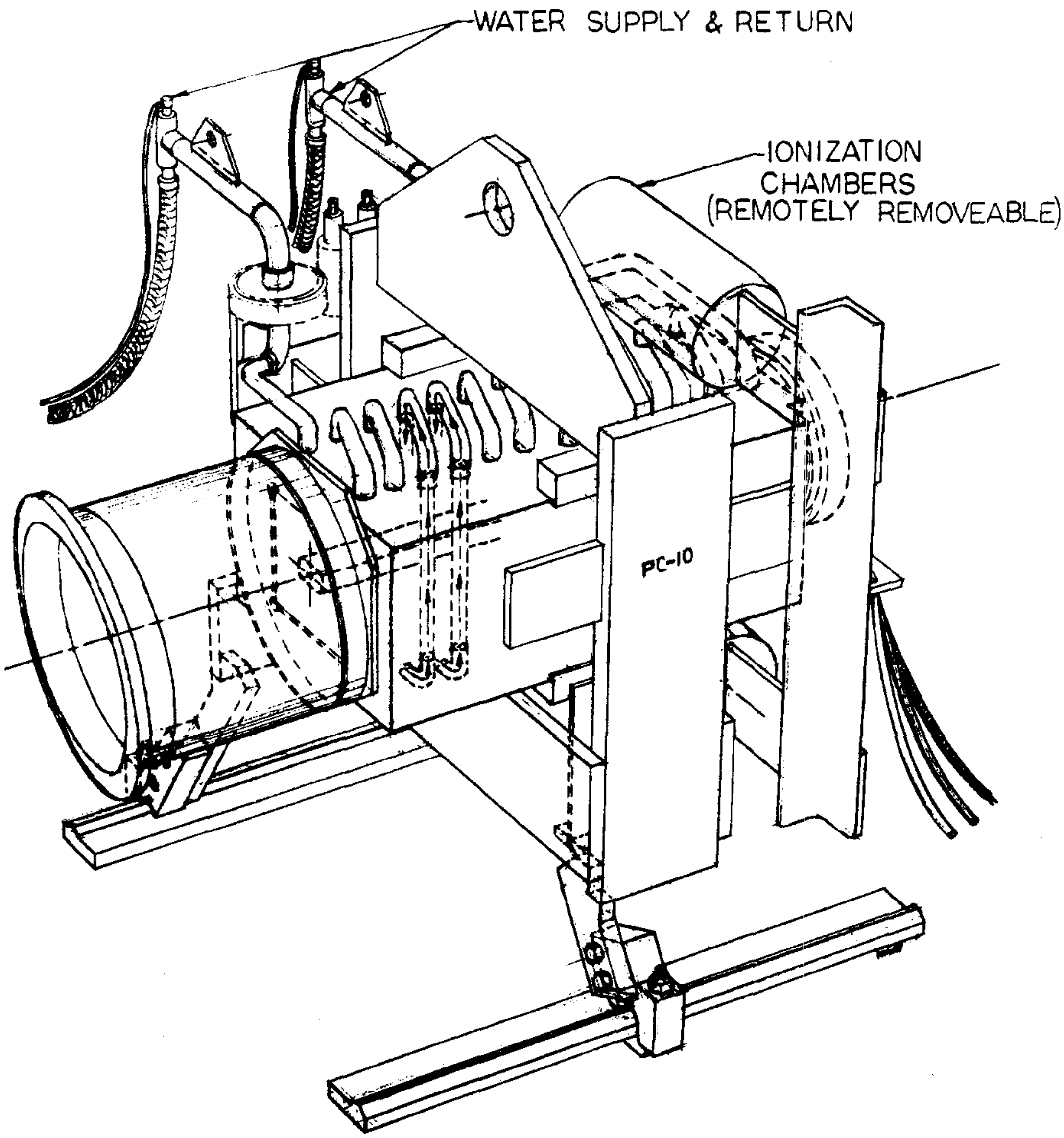


FIG. 16--High-Z collimator; mechanical schematic (C-0).



PROTECTION COLLIMATOR
(TYPICAL INSTALLATION)

FIG. 17--Protection collimator (typical installation).

G. ALIGNMENT

As a result of the decision to reverse the direction of the accelerator alignment system (see Section IV), the Beam Switchyard will now have a laser at about Station 107 + 50 and will use the accelerator alignment system detection station at the injector end.

Bids were received for the manufacture of mirror targets to be used in the alignment of magnets from the upper level of the housing, and the contract was awarded. The mirrors are of stainless steel, are 2.5 inches in diameter, and have a special engraved line pattern. The bid packages for the specially designed stages for the mirrors were sent out. The stages enable the mirror to be positioned precisely in all directions and in every rotation.

X. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. PHYSICAL ELECTRONICS

In association with development work on low density KCl dynodes, a quartz crystal thickness monitor was constructed and calibrated. The calibration was carried out for Al, Au and bulk density KCl, with the result $\tau'/\Delta f = 1.95 \times 10^{-2} \frac{\mu g/cm^2}{cps}$, where τ' is the film thickness in $\mu g/cm^2$ and Δf is the change in resonant frequency of the monitor crystal in cps. The density of Al and Au films was also determined, making possible thickness measurements with the monitor for these materials.

Gain (δ_t) and lifetime measurement were carried out on low density KCl dynodes in a recently constructed diffusion-pumped freon refrigerator baffled vacuum system (base pressure $\approx 2 \times 10^{-7}$ torr). The lifetime measurements in this system are much different from the results presented in the previous report. Generally, δ_t decays exponentially with a time constant of $\approx 200 - 500$ minutes at an incident current density of $\sim 10^{-8}$ A/cm^2 for the first ~ 150 minutes after preparation. Then δ_t is constant with time for many hours at a value of 15-25.

It has been found that δ_t can be revived to a value characteristic of that present a few minutes after preparation by evaporation of bulk density KCl (≈ 200 Å thickness) over the exit surface of the dynode. Increases in δ_t by a factor of two have been observed. Typical time constants of the exponential decay of δ_t after bulk density KCl evaporation are ≈ 1500 minutes. It is interesting to note that 20% deterioration was observed for an incident charge of 4×10^{-4} C/cm^2 in one bulk density coated low density KCl sample — about the same deterioration reported for bulk density KCl dynodes in the previous report (15% for $\approx 5 \times 10^{-4}$ C/cm^2).

That δ_t can be revived by bulk density KCl evaporation indicates that the deterioration is a result of electron beam-residual gas interaction, e.g., polymerization at the surfaces of the dynode. This is in contrast to change in the structure of the film or a change in the KCl, e.g., decomposition. These results seem to indicate that most of the secondary emission in the low density dynodes takes place at the surface of the many small particles (≈ 1000 Å in diameter) which make up the low density deposit.

In an attempt to look more closely at the secondary emission process of the low density dynodes, δ_t vs collector voltage (V_c) characteristics were measured. Changes in slope at voltage approximately equal to $Eg + \chi$ and $2(Eg + \chi)$ for KCl were observed. (Eg = band gap; χ = electron affinity.) These results indicate that internal multiplication is taking place within the dynode in disagreement with reported results.[1] δ_t vs V_c characteristics for a dynode before and after bulk density KCl evaporation are identical for $V_c < 2(Eg + \chi)$; for V_c $V_c > 2(Eg + \chi)$, δ_t for the coated film rises much more rapidly with V_c. More work in this area is planned to see if internal multiplication is characteristic of field enhanced secondary emission from the alkali halides.

Limited measurements have been carried out in an ion-pumped system free of hydrocarbons. An ultraviolet light source is used to generate the primary current via an Au photocathode (maximum current density $\approx 7 \times 10^{-8}$ A/cm^2). The sample presently in this system has had a constant $\delta_t \approx 23$ for ten days. Plans are now being made to measure δ_t vs primary energy for minimum ionizing electrons at the Mark III.

B. THEORETICAL PHYSICS

Work done during the quarter has been reported or will appear in the following publications:

1. M. Bander and G. Shaw, "Absorptive Corrections and Form Factors in the Peripheral Model," submitted to Phys. Rev. (SLAC PUB-97).
2. S. D. Drell and A. C. Hearn, "Peripheral Processes," (to be published).
3. A. C. Hearn and Y. S. Tsai, "The Differential Cross Section for $e^+e^- \rightarrow W^+ + W^- \rightarrow e^- + \overline{\nu}_e + \mu^+ + \nu_\mu{}^*$," to be presented at the International Symposium on Electron and Photon Interactions at High Energies, DESY, June 1965 (SLAC PUB-109).
4. Y. S. Tsai, "Radiative Corrections to Colliding Beam Experiments," to be presented at the International Symposium on Electron and Photon Interactions at High Energies, DESY, June 1965 (SLAC PUB-117).

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[1] G.W. Goetze, A.H. Boerio, and M. Green, J. Appl. Phys. 35, 482 (1964), E.J. Sternglass and G.W. Goetze, I.R.E. Trans. Nuc. Sci. NS-9, (1962).

5. Y. S. Tsai, S. M. Swanson, and C. K. Iddings, "High-Energy γ-Ray Source From Electron-Positron Pair Annihilation," to be presented at the International Symposium on Electron and Photon Interactions at High Energies, DESY, June 1965 (SLAC PUB-112).

6. C. Itzykson and M. Nauenberg, "Unitary Groups: Representations and Decompositions," submitted to Rev. Mod. Phys. (SLAC PUB-106).

7. J. S. Bell, Physics 1, 195 (1965).

8. J. D. Bjorken, "Experimental Tests of Quantum Electrodynamics," submitted to Acta Physica Austrica.

9. H. P. Noyes, D. S. Bailey, R. A. Arndt, and M. H. MacGregor, "Determination of the Nucleon-Nucleon Elastic Scattering Matrix III," submitted to Phys. Rev. (UCRL - 12398, University of California Radiation Laboratory, Berkeley, California).

1. High Energy Particle Production and Interaction Studies

A study has been made on the effects of different types of absorption corrections to the peripheral model. It has been found that the experimental data available on the process $\pi^{\pm} + p \rightarrow \rho^{\pm} + p$ rules out all models except one.[1] This correct prescription will be applied to other processes. A review chapter on peripheral processes for a book on high energy physics is in preparation.[2] A detailed report on the γ-ρ-π exchange current contribution to elastic electron-deuteron scattering has been prepared,[*] and the analysis extended with good success to large momentum transfer form factor observations ($q = 3F^{-1}$). A detailed analysis of radiative and recoil corrections to asymmetric μ-pairs is in progress.[**] Nucleon exchange in backward π-N scattering processes is being studied in an attempt to provide better calculations of anti-nucleon beams at SLAC. The effect of competing resonances distorting one another in final three-body states is being studied by means of the Faddeev equation. The method of spin and parity analysis in two-step decay processes previously reported has been applied to experiments originating here on $A_{1,2}$ and B_1 decays. An investigation of the process $e + p \rightarrow e + (J)$, where (J) is a state of discrete angular momentum, has been started. An analytic expression for the process $e^+ + e^- \rightarrow W^+ + W^- \rightarrow e^- + \bar{\nu} + \mu^+ + \nu$ has been obtained

[*] R. J. Adler and S. D. Drell, Phys. Rev. Letters 13, 349 (1964). (SLAC-PUB-33).

[**] S. D. Drell, Phys. Rev. Letters 13, 257 (1964). (SLAC-PUB-35).

by use of the computer, and numerical values of interest in colliding beam experiments computed.[3] Radiative corrections in colliding beam experiments[4] and spectral and angular distributions of the bremsstrahlung from electron-electron collisions[5] have also been obtained. Experimentally it has been observed that in the process $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ there is a great enhancement of the 2π $T=0$ modes near the ω-mass in addition to the usual ρ peak. A dynamical calculation of ω-ρ mixing has been undertaken with an eye to explaining this process. If successful, this could readily be applied to 2π and 3π production modes in colliding beam experiments.

2. Elementary Particle Physics

Dispersion theory is being used to calculate the contribution of low mass intermediate states to the axial vector vertex in β-decay. Keeping states beyond the usual one-pole approximation in the dispersion relation for $\partial_\mu j_\mu^A(x)$ leads to corrections to the Goldberger-Trieman relation in both strangeness-conserving and strangeness-changing processes. Work is in progress on the calculation of G_A/G_V in β-decay with sum rules derived from the equal-time commutation relations for the vector and axial vector currents of the hadrons proposed by Gell-Mann. A survey of useful formulas and methods for dealing with unitary groups has been written.[6] A renormalization study in a φ^4 theory using methods or iteration in the scattering kernel to handle the overlapping divergences question* is being pursued. It has been shown by explicit construction that any "hidden variable" theory which reproduces exactly the statistical predictions of quantum mechanics has a grossly non-local structure.[7] A review of the current experimental status of tests of quantum electrodynamics has been presented.[8] The contribution of the elastic photoproduction cross section to the neutron-proton mass difference has been calculated. It is numerically too small by a factor of ten to cancel the wrong sign obtained from the nucleon pole term contribution. The orders of magnitude of subtraction term contributions are being estimated. A simple derivation of the relation between the high energy behavior of the real part and the imaginary part of the scattering amplitude has been obtained.

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*S. D. Drell and J. D. Bjorken, Relativistic Quantum Mechanics, Vol. II (McGraw-Hill, New York, 1964)

3. Two- and Three-Nucleon Problems

It has been shown that recent triple scattering experiments at 25 and 50 MeV allow unique phase shift analyses of both n-p and p-p scattering to be carried through, thus closing the gap between the low energy region and the unique results at higher energy.[9] Further investigation of the effect of the pion mass and possible coupling constant splittings of the nucleon-nucleon $^1S_0$ state shows that the effect on both the scattering lengths and the effective ranges can be unambiguously predicted. These effects readily account for the observed splitting between the n-n, n-p and p-p scattering lengths, but the predicted n-p effective range differs by more than two standard deviations from observation. If the two n-p cross sections at 0.5 and 3.2 MeV which lead to this conclusion are confirmed, there must be some gross violation of charge-independence of unknown origin. It has been shown that the three-body problem can be separated into two parts, one of which is readily soluble and dependent only on the behavior of the component two-body systems at infinite separation. Whether this forms an adequate first approximation in interesting cases, or whether knowledge of the short-range behavior of the two-body interaction (which cannot be obtained from two-body scattering data) is always required, is now under study.

C. HEALTH PHYSICS

The peripheral monitoring station prototype is completed and has been put in a temporary location near the guard house. The gamma monitor is working very well but the neutron monitor suffers from occasional periods of high count rate. It is suspected that this is an artifact due to environmental conditions but it has not yet been specifically determined.

Light Electronics has undertaken some development work on a standard survey meter for SLAC's peculiar requirements. At present their design is usable but not perfected. A second design will be studied by Health Physics. Eventually a construction contract will be let for approximately 50 instruments of the final SLAC design.

A 1600-channel analyzer was received and accepted. After some initial problems it seems to work well.

A contract has been let to perform a study on scil and water activation and a desirable drainage water sampling system. Simultaneously, Health Physics is studying other aspects of the ground water and drainage water problem.

A set of three wells has been completed to house large γ-ray sources and form a calibration facility. Two of them will be put into use in the next few months; the other will be kept as a spare for the moment.

The final design for the manway monitors was completed and an order for fifty has been placed. Three designs for air monitors are being tested. A radioactive gas calibration system has been built for checking the air monitors. A prototype of an ozone monitor has been constructed and it is being tested. A water monitor prototype has been designed and is on order.

Additional shielding for the 660 feet of installed accelerator was designed and put in place, bringing the radiation levels within acceptable limits. The work necessary before the sector test team can start daytime operation is underway.