SLAC-69
UC-28, Particle Accelerators
and High-Voltage Machines
TID-4500(49th Ed.)

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 April to 30 June 1966

September 1966

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 seventeenth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the eleventh 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 has as its chief instrument a two-mile-long linear electron accelerator. Construction of the Center began in June 1962. The electron beam was activated in May 1966. The present schedule calls for the first research experiment with the beam to take place before the end 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. 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.

Contract AT(04-3)-515 provides support for the various activities at SLAC that are necessary in order to prepare for the research program which will eventually be carried out with the two-mile accelerator. Among the principal activities covered in the scope of Contract AT(04-3)-515 are theoretical physics studies, experiments performed by the SLAC staff at other accelerators, research-equipment development programs (such as particle separators, specialized magnets, bubble chambers, etc.), and research into advanced accelerator technology. Contract AT(04-3)-515 went into effect on January 1, 1964.

Contract AT(04-3)-515 also provides for the initial stages of operation of the Center after construction is completed.

II. PLANT ENGINEERING

A. GENERAL

The conventional facility construction program which was begun in July 1962 is now nearly complete. The present status of a number of these facilities is shown graphically in Figs. 1 through 5. The remaining field effort will be finished early in the next period. Phasing out of the Aetron-Blume-Atkinson forces is well along.

Construction of the 220-kV feeder line to the accelerator site was continued during the quarter and is now 92% complete. This work was contracted for by the Atomic Energy Commission and is being supervised by that agency. Cable stringing was commenced on April 25. Energization of the line will take place in mid-July, 1966.

B. DESIGN AND CONSTRUCTION STATUS (ABA)

The design work for the project is complete. A minor amount of engineering remains to be done on inspection and "as-builts."

The status of the major facilities now under construction is as follows, those shown at 100% having been completed during the quarter.

Facility	Percentage of Completion
Klystron Gallery Utilities	
Electrical (600-Y-2)	100
Cooling Towers (600-Y-3)	100
End Stations "A" and "B"	100
Material Handling System (BSY)	100
Cryogenics Facility	99
BSY Site Improvements and Utilities	99
End Station Site Improvements and Utilities	96
Master Substation	96
Beam Dump East	94
Site Fencing	93
Landscaping (Increments V and VI)	85
Concrete Shielding Doors (End Stations)	85

Completion of the Master Substation (Fig. 5) will occur as soon as the installation of the 220-kV transmission line is finished in July. Electrical services to the site from this system will commence during the first week of August. Meanwhile, site services continue to be provided from the existing 60-kV transmission line.

Work on the remaining construction items is proceeding satisfactorily. With the possible exception of the concrete shielding doors, all remaining field work will be finished next month.

C. PLANT ENGINEERING SERVICES

The department continued its activities in support of SLAC's operational program and the acquisition of new facilities. Status of the major plant items is as follows:

1. General Services Building

The architect has prepared a revised layout for review by the Stanford Board of Trustees in July.

2. Fire Station

Title 1 design is underway. Both this and the preceding facility are scheduled for construction completion in 1967.

3. Research Support Laboratory

A draft of the criteria report for a 28,500-gross-sq. ft. addition to the Central Laboratory has been issued for project review. This is preliminary to the selection of an architect-engineer firm for the design effort.

4. 82-inch Hydrogen Bubble Chamber

This facility is to be installed in the Target Area on the center beam line. Title 1 design for the enclosure building and utilities has been started.

5. Data Assembly Building Extension

Bids for the construction of a 3,000-sq. ft. addition will be invited next month.

6. Two-Meter Spark Chamber Housing

Footings have been poured for this Target Area facility.

7. 40-inch Bubble Chamber Enclosure

Framework for this Target Area facility has been erected (center of Fig. 1).

The service program of alterations and minor construction work was continued throughout the quarter. An architect-engineer assistance subcontract in support of this and other engineering work items was established in June and is now active. A new time and materials subcontract in support of the Craft Shops effort was executed in April.

Of particular interest in this program was the relocation in May of Temporary Building "A" from its position near the Fabrication Building. This 10,000-sq. ft. facility was moved in sections and re-established as two buildings in the Target Area for use in support of the research effort.

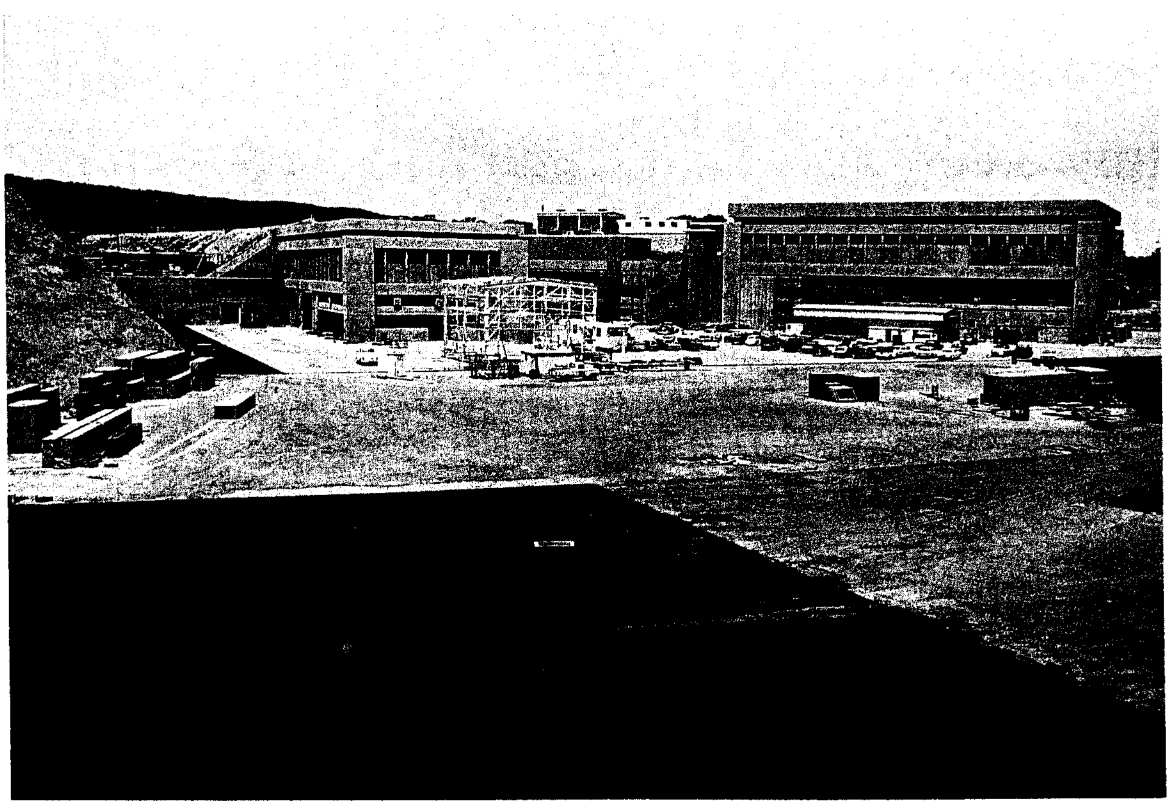

FIG. 1--Target Area and End Stations, looking northwest.

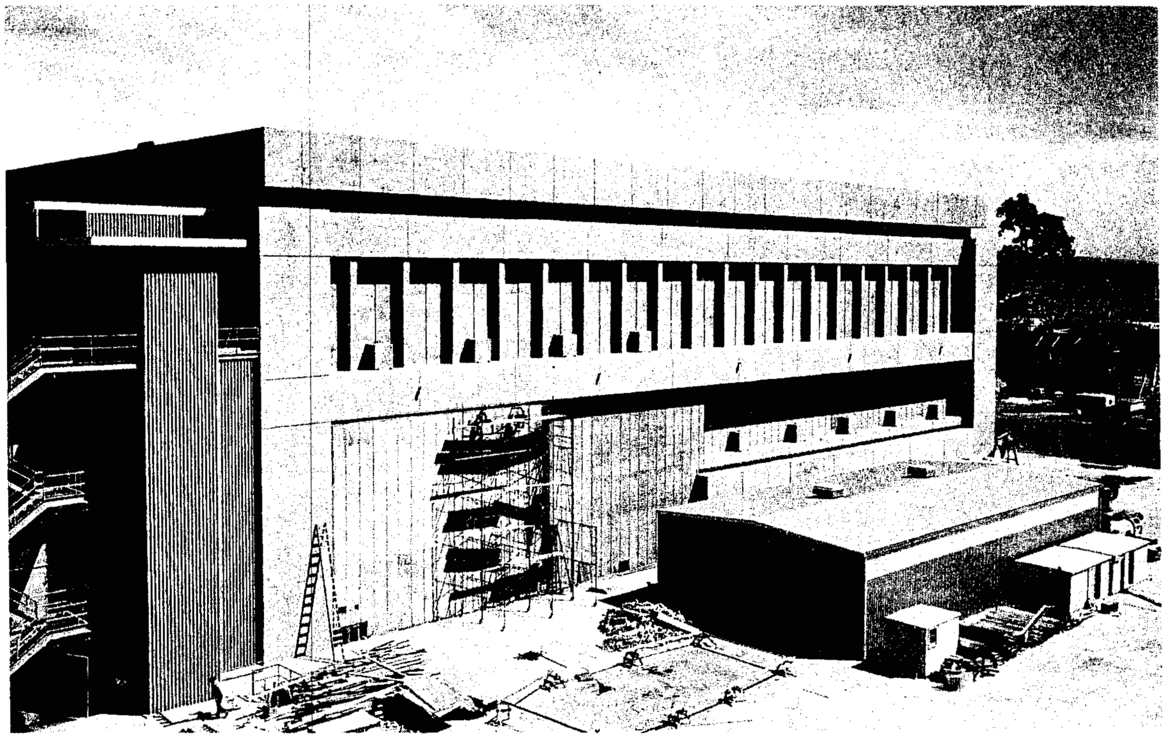

FIG. 2--End Station A; Beam Dump East at far right.

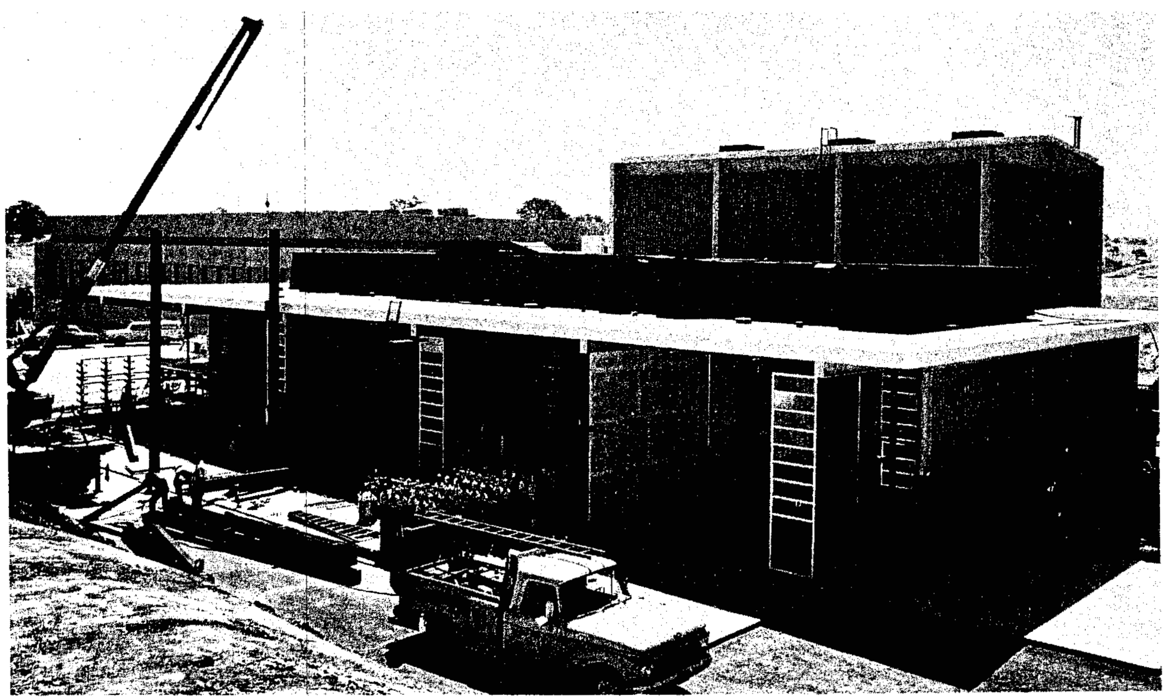

FIG. 3--Cryogenics Facility.

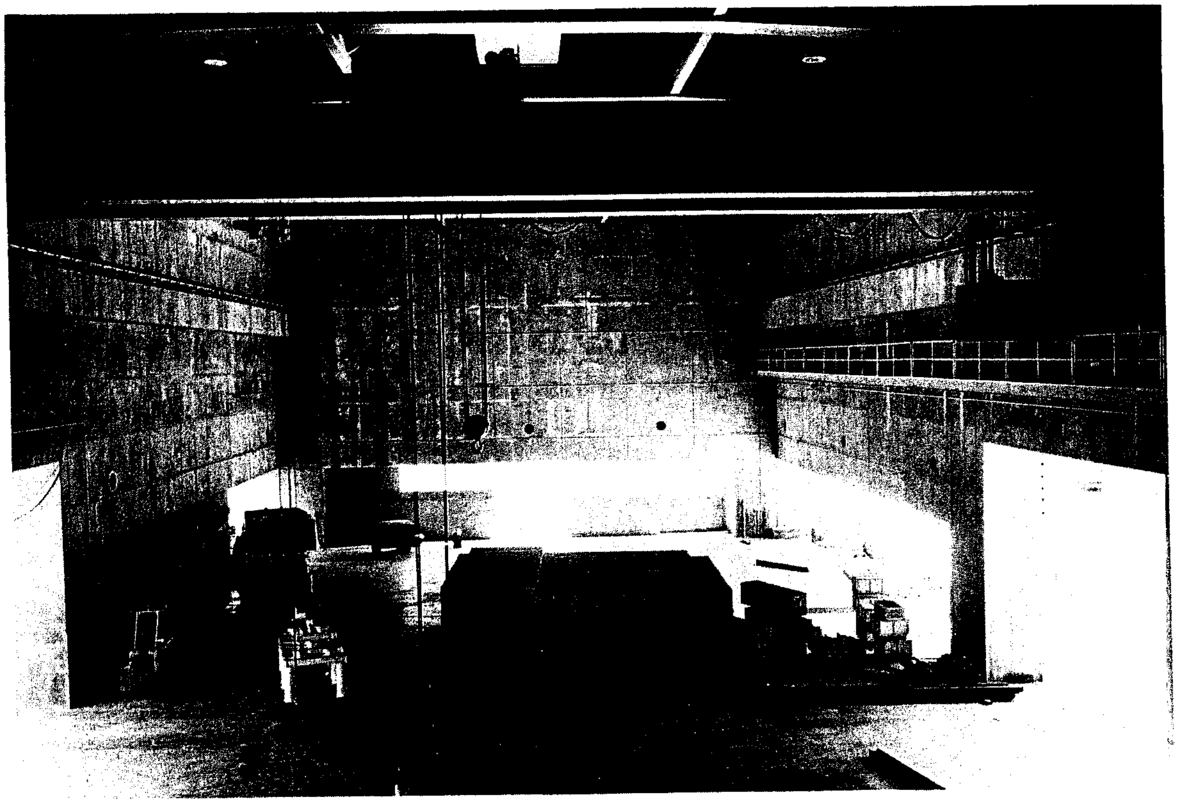

FIG. 4--Interior of End Station B.

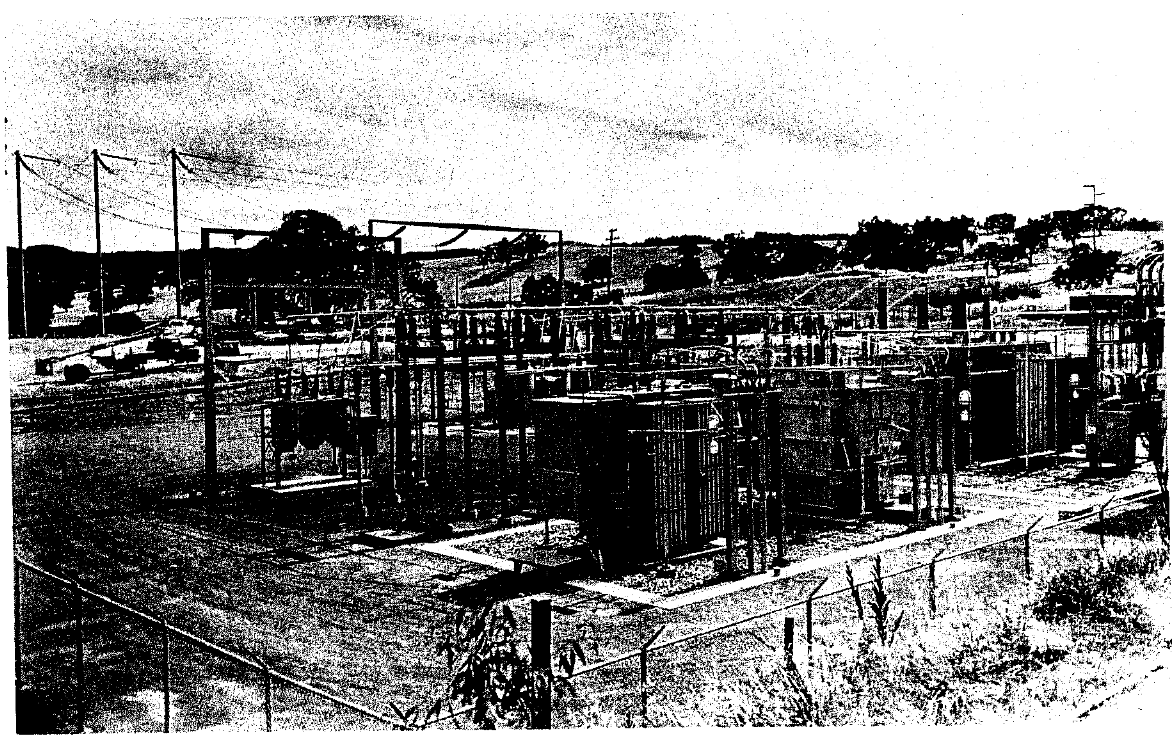

FIG. 5--Master Substation, looking southwest.

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. SUMMARY

The overall department work is 96% complete. Accelerator systems installations were essentially completed. Beam Switchyard systems design work was 96% complete and installations were 84% complete. Low power electron beam tests were conducted along the accelerator and the central leg of the Beam Switchyard.

B. ACCELERATOR

1. Design Coordination and Equipment Installation

This phase of the work was completed except for completion of as-built drawings.

2. Vacuum

All vacuum systems were complete and in operation.

3. Cooling Water

All initial work was complete except at the positron source. A program for upgrading the various systems was initiated and will provide increased capacity at the main injector. Work on improving reliability of low flow alarm interlocks continued.

4. Electrical

All initial work was complete except for temporary connections still in use pending completion of the project 220-kV tie line.

5. Electronics

The installation of the cable plant was essentially complete. Installation of electronic equipment racks was complete except for final connection of positron source control panels and power supplies. The beam analyzing station at Sector 20 was completed. First beam tests through Sector 20 were underway during April.

C. BEAM SWITCHYARD

1. Design Coordination and Equipment Installation

Equipment installation continued in all areas of the Switchyard. During April and May, priority was given to completing sufficient installation along the central beam to permit low power beam testing. Beam turn-on was effected May 21, 1966, using the two central beam low power tune-up beam dumps. During June, priority was given to the installation of equipment along the A-beam portion of the Switchyard in order to allow early beam testing through to the high power A-beam dump. All 30 bending magnets and much of the beam-line instruments for the A-beam were installed during this period.

2. Vacuum

Installation of the Beam Switchyard vacuum pumping systems was accomplished. The main divergent vacuum chamber was installed and leak-checked. The alignment light pipe was installed and leak-checked. The machining and assembly of vacuum valve parts were underway. Two refrigeration units for a differential pumping system between the accelerator vacuum and Beam Switchyard chambers were installed and tested. Beam Switchyard vacuum measured at the pumps was in the high 10^{-7} torr range. Vacuum system work is 88% complete.

3. Cooling Water

Circuits were completed for the A-Beam magnet cooling system, B-beam magnet cooling system, and magnet power supply cooling system. Connections were made to all equipment required for initial beam testing. Stainless steel piping fabrication continued at the heat exchanger pads for the main collimator, A-beam and B-beam slits, and the A-beam dump. Fabrication of hose assemblies for connecting to beam energy absorbing equipment was started. Cooling water system work is 86% complete.

4. Electrical/Electronic

Work continued on the wire lists for terminal connections to all electrical devices and distribution frames for the A-beam and B-beam paths. Electrical wire was procured for use in internal wiring of all BSY equipment. Electrical/electronic installation for the central beam path was substantially completed. A fire detection system for the Beam Switchyard was approved for installation. Installation of multipair cable trunk lines between the Beam Switchyard distribution frames and the accelerator and the end stations was underway. Electrical work was 95% complete; electronic work was 89% complete.

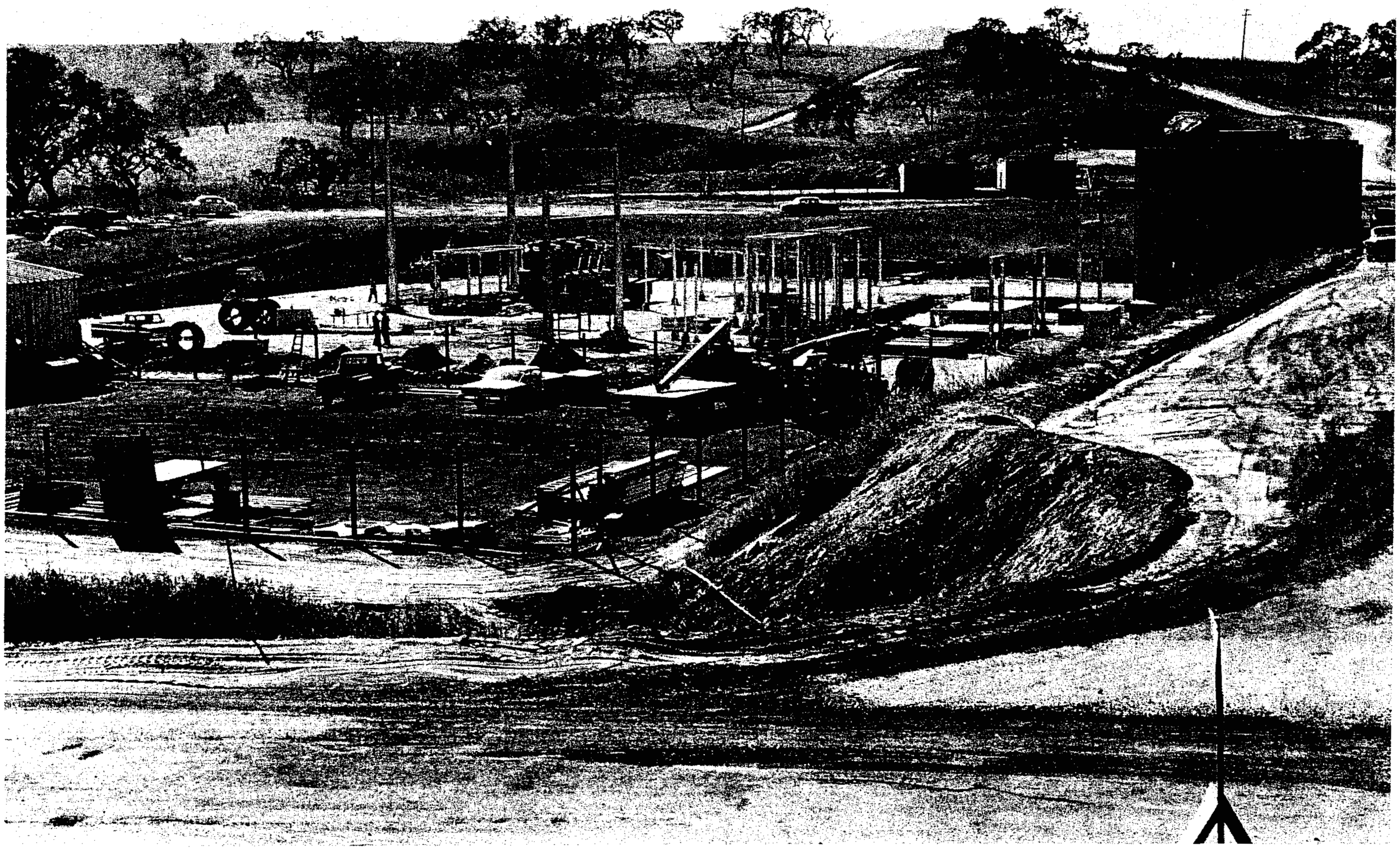

FIG. 6--220-kV master receiving substation and switch house.

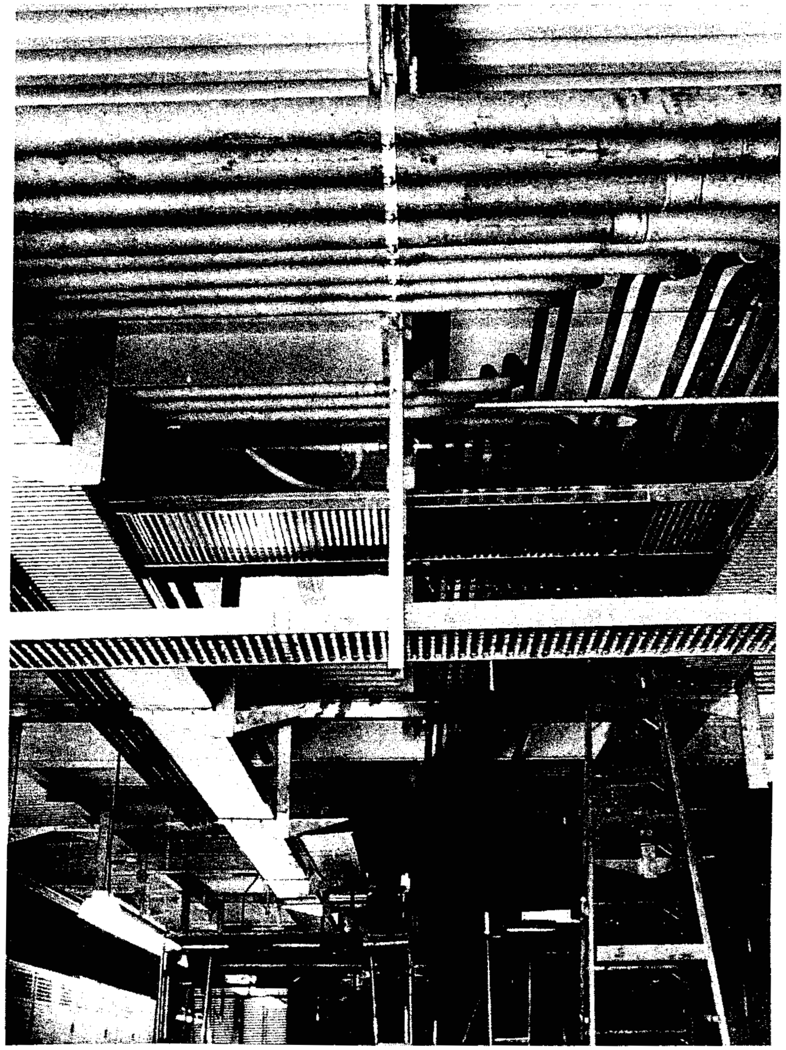

FIG. 7--BSY Data Assembly Building magnet power supply area showing conduit tray layout (looking west).

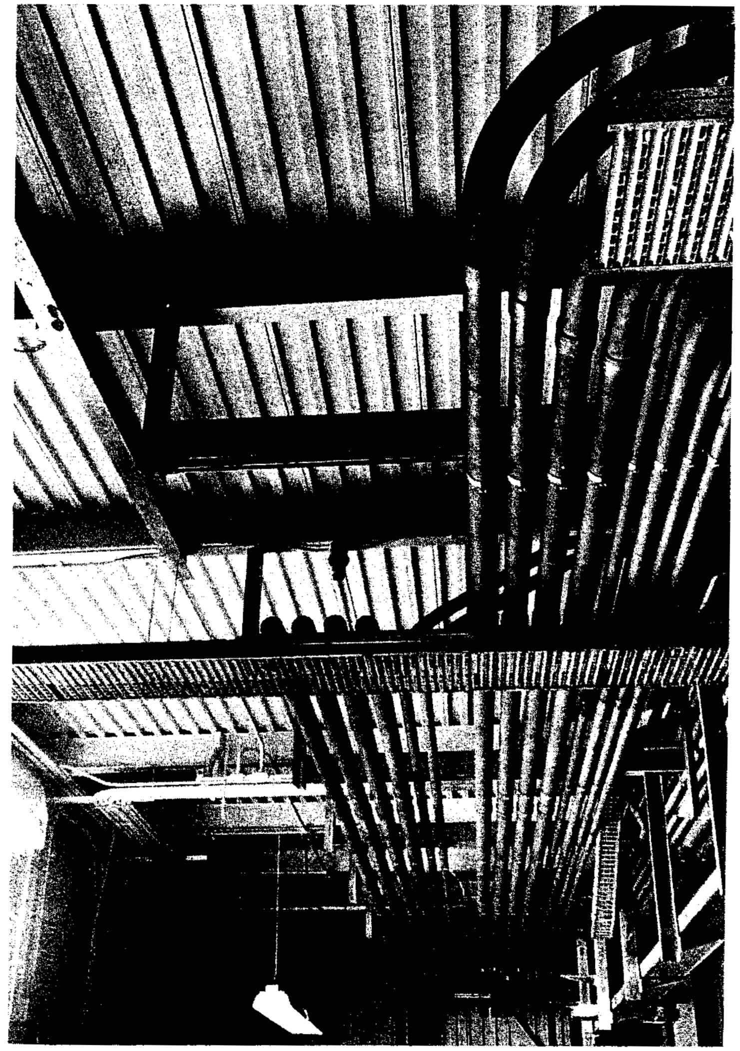

FIG. 8--BSY Data Assembly Building conduit run to distribution panel area (looking south).

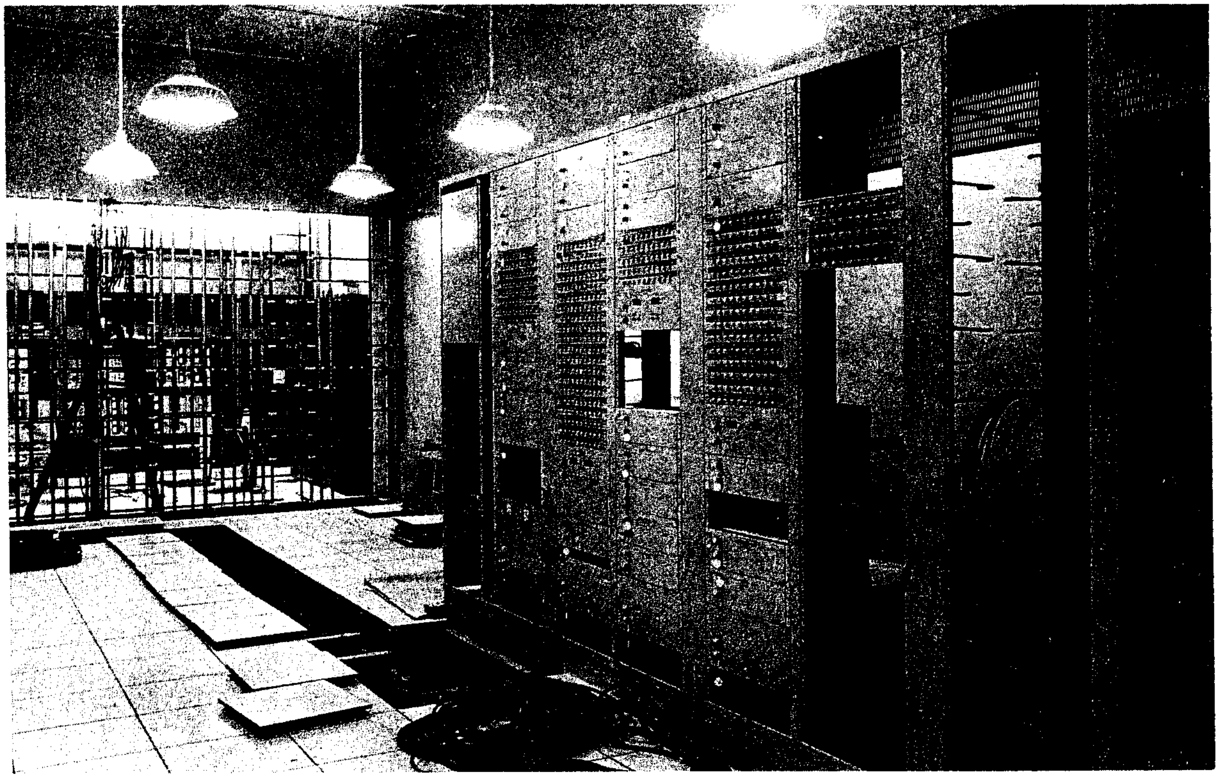

FIG. 9--BSY Data Assembly Building control room rack line-up with main distribution frame at left.

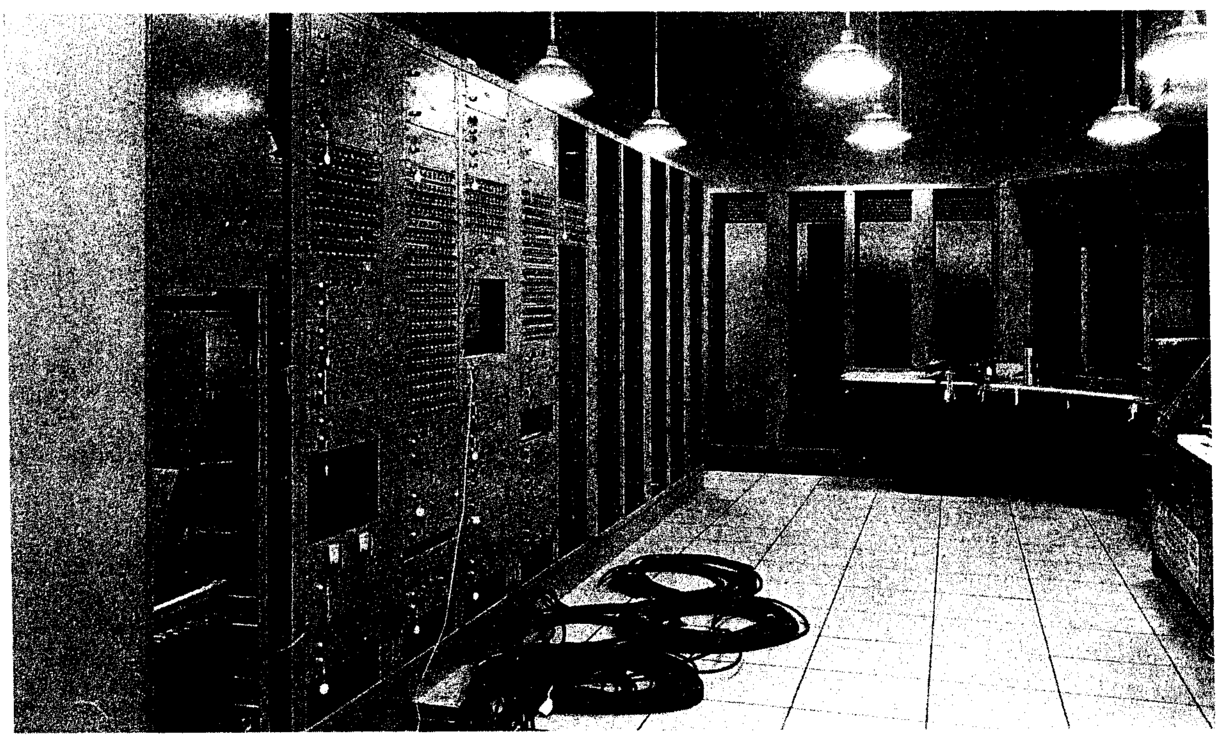

FIG. 10--BSY Data Assembly Building control room rack line-up and master console at right.

FIG. 11--BSY B-beam housing, looking west toward central beam area.

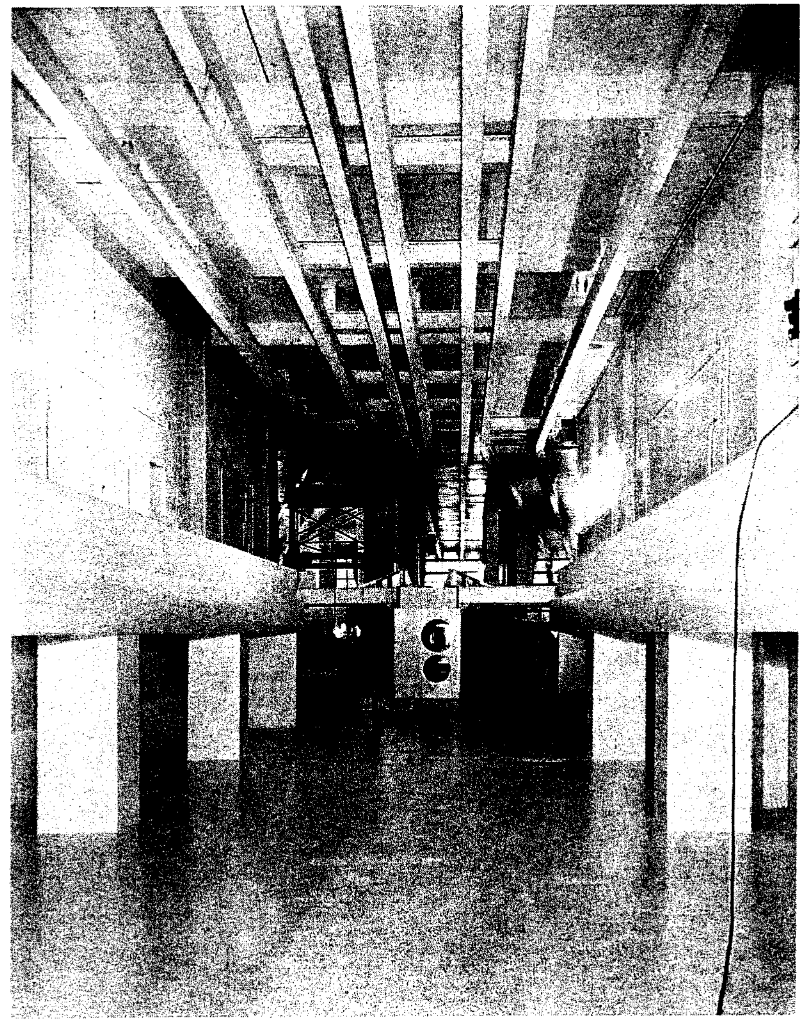

FIG. 12--BSY central beam area, looking east from main accessway at A beam, central beam, and B beam diverging housings.

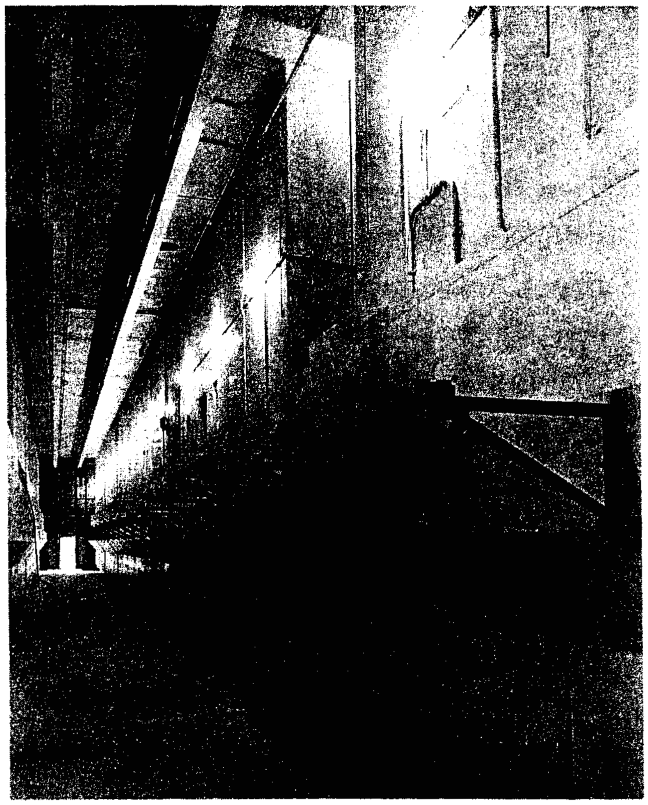

FIG. 13--BSY B-beam housing, looking east toward End Station B, showing catwalk supports.

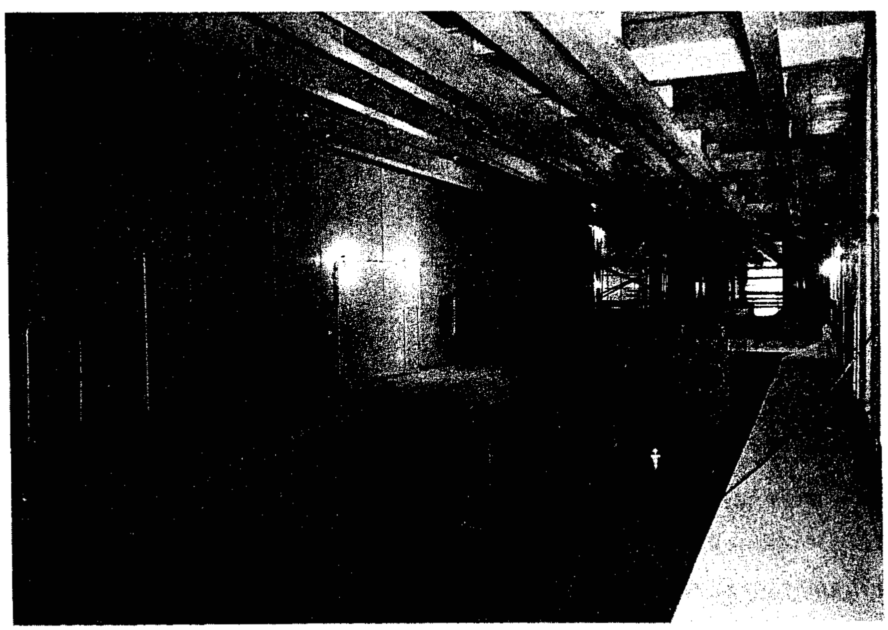

FIG. 14--BSY central beam area, looking east from main accessway at A-beam, central beam, and B-beam diverging housings.

IV. ACCELERATOR PHYSICS

The most important event of this quarter was the successful turn-on of the SLAC beam, first over two-thirds of the accelerator length (6700 feet) on April 21 and then over the full length on May 21. The results of the beam turn-on experiments which, among many others, involved the participation of the entire Accelerator Physics Department, are summarized in an article published in SCIENCE on June 3, 1966, titled "Electrons Accelerated to the 10- to 20-GeV Range." This article is reproduced in this status report as Appendix A.

Other topics on more specific subjects are reported here as usual.

A. INJECTION

1. Main Injection System

The main injector is essentially complete except for the permanent gun modulator and the beam knockout system. The temporary gun modulator is operating satisfactorily. The new gun modulator will be ready in about six months.

2. Electron Guns

By May 1, four complete SLAC guns were available: one on the main injector (4-1C), one as a backup for the main injector (4-1P), and two additional guns for laboratory use. The standby gun (4-1P) was recoated and converted on April 20. It emitted a current of more than 1 ampere (temperature limited) at 36 watts of filament power.

Also in April, the first 4-2 inner gun was mounted in a 4-1 vacuum envelope and processed to 100 kV dc. Arcing was only found on the corona ring support cylinder. A SLAC W2%Th cathode was successfully carburized by using painted colloidal carbon and a temperature cycle of 1850° C for less than one minute. Two coats were applied in this manner. Pulsed testing resulted in a 1-ampere temperature-limited current at 1620° C and 140 watts of bombarder power. This cathode was operated for 25 hours in gun 4-1Q, which was let down to air twice for at least two hours. After each operation, the emission was retested and found equal to that of the original test. The first complete SLAC model 4-2 gun (4-2A) was successfully processed at high potential and will be tested early in the next quarter with a carburized cathode.

3. Gun Modulators

The new low level pulser circuitry, which allows both remote control of pulse width and multiple beam operation of the temporary modulator, has been installed and has operated without failure for the last three months. This circuitry will also be used in the new modulator. This modulator will be built from new modules rather than by modification of the existing Manson units. Development work is well underway. The low level circuitry is transistorized on plug-in cards and the power supplies are of the quick-change type of manufacture. A new high power pulser is being designed to replace the multitube Manson distributed amplifier which has been the source of many difficulties to date. The new pulser will drive the gun cathode directly, thereby eliminating the pulse transformer, the clippers, and the clipper power supply.

Fabrication and testing of the pulser has progressed to the final amplifier and rise times of 16 nanoseconds have been achieved. The entire modulator should be ready for installation around the end of this year.

4. Beam Knockout System

The design of the modulator for the beam knockout system is being provided by the Electronics Department. Breadboards of the critical circuits have been successfully tested and fabrication of the final unit is well underway. A design study of a second modulator capable of operating between 10 and 20 MHz has also been initiated.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

The installation and insulation of the entire drive line system was completed during this quarter. Preliminary tests showed that the line, installation, and temperature control operated according to specifications. It also appears that the frequency can be changed within the range $\pm$ 0.1 MHz without the phase difference between the rf signal in the main drive line and the beam exceeding 8°. More exhaustive tests are planned for the next quarter.

The installation of the drive line extension into the Beam Switchyard and the End Stations was not begun during the quarter as planned because of more urgent contractor work.

2. Varactor Frequency Multipliers

The varactor multipliers have been in service for most of the quarter without exhibiting any operating problems. There appears to be an early aging period during which their characteristics change. Retuning of the multipliers after this aging cycle seems advisable and appears to eliminate any further noticeable changes.

3. Main Booster Amplifiers

While one of the main booster amplifiers was out of service and the high power switch was being repaired, the other unit was connected directly to the main drive line and operated satisfactorily. Meanwhile, various modifications and improvements are being made in the standby unit.

4. Positron Phase Shifters

It was found that the amplitude of the positron signal pattern available at the sub-booster racks was less than had been originally specified. Consequently, the input circuit to the phase-shifter driver had to be redesigned. All printed circuit cards have now been modified.

In one sub-booster isolator-phase shifter-attenuator unit, a relay has been added to the positron phase shifter control circuit. This relay ensures that the switching circulator continues to be energized if the driver card is removed for any reason. De-energizing the circulator removes rf drive to the sub-booster. This modification will be made to applicable units during the next quarter.

5. RF Drive System Control Unit

Control from the Central Control Room (CCR) and automatic switching of the master oscillator, main boosters, and injector sub-boosters have not progressed because of lack of manpower. The individual systems, however, are being operated locally and there appears to be no urgency in this area.

6. Sub-Booster Modulators

Sub-booster modulator operation has been improving steadily. Switch tubes have been showing improved lifetimes. The new fans have been installed and the precision power supplies have been updated. Out of 20 units, there have been of the order of one or two failures per week.

7. Sub-Booster Klystrons

The initial procurement of klystrons from Eimac is nearly complete. Four tubes are still undelivered at the end of this quarter. The second procurement cycle is underway and significant progress has been observed. Preliminary design parameters have been tentatively approved and receipt of the first tubes is scheduled around February 1967.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

The only difficulty found so far in these units during accelerator operation concerns the nylon coupling between the protection attenuator and its motor. Several instances of roll-pins shearing off or dropping out have occurred. In faulty units, the coupling has been replaced by a simple coiled spring flexible coupling. Modification of Sector 27 units for manual control from CCR has not been started. The third and final injector control phase shifter unit has been received from the subcontractor.

2. RF Detector Panels

All thermionic diode detectors have been fitted. A modification, which permits 20 dB of additional attenuation to be automatically switched into the rf circuit when a klystron signal is being phased, has been installed and successfully tested in detector panels in Sectors 2 and 15 of the machine. The additional attenuation prevents failure of the automatic phasing system due to excessive unbalance of the thermionic diodes.

3. Programmers and Electronics Units

Random and systematic faults which affect the reliable operation of the automatic phasing system are being corrected as soon as possible after diagnosis. Noise on the video input to gated voltmeters has been suppressed by increased shielding. The problem of servo loop instability, which causes oscillation about the balance point in some sectors, has been traced to crossover distortion in the gated voltmeter amplifiers. The timing generator in the programmer is being improved. Video attenuators have been inserted between the rf detector panels and the electronic units to reduce system sensitivity to thermionic diode unbalance. Sources of phase instability in the signal inputs to the phasing system are being investigated.

4. Linear Detectors

All rf detector panels and beam position monitor detector panels have been fitted with thermionic diode assemblies. A number of spare detector assemblies will be maintained for replacement purposes.

D. BEAM POSITION MONITORS

1. In-Line Beam Position Monitor System Performance

The beam position monitoring system in each sector was calibrated by injecting into the detector panel rf signals which simulated the cavity outputs over the specified ranges of beam current and position. Level and balance adjustments were made in the detector panel and the sector electronics to obtain the required $\log Q$, x and y signals for baseband transmission to CCR. When the beam was turned on, the system worked well after an interference from the steering power supplies had been suppressed by additional filtering. The "zeroing switch" in CCR, which remotely disconnects all position signal inputs to the monitor detector panels so that zero errors due to diode unbalance may be noted, was installed and found to be very useful.

2. Beam Switchyard Beam Position Monitors

All monitor cavity assemblies were delivered to the BSY Group. Two assemblies were installed and tested with a beam. Performance was satisfactory. Polystyrene semi-rigid cables with SLAC-designed quick-disconnect connectors were made up, and are being installed.

3. End Station A Beam Position Monitors

Procurement of components for the system described in the last report was completed during this quarter. The beam coupler, vacuum windows, and waveguide components were assembled and adjusted to the precise electrical symmetry required. Intermediate frequency components were tested, and preparations were made to install the equipment in the Injector Test Stand for electron beam tests.

E. BEAM ANALYZING STATIONS

The two stations operated satisfactorily during the past quarter. No changes were made.

F. GENERAL MICROWAVE INVESTIGATIONS

A large variety of microwave experiments are being started to investigate the beam break-up problem. The main frequencies at which tests are being performed are 4140 MHz and 4428 MHz. Results will be reported in the next status report.

G. OPTICAL ALIGNMENT SYSTEM

The accelerator was aligned just before the April beam tests. The position of the drift sections on June 9, 1966, is shown in Fig. 15. The largest vertical deviations correspond exactly to the areas of the broad valley fill. The indicated rate of settlement is less than 0.15 inch/year in the worst area. This rate is easily within the recording and readjustment cabability of the system.

Final focusing and positioning was completed for both the accelerator and BSY lasers. A computer program was written to analyze the results. The plot in Fig. 15 is the result of the computer run. The program allows the operator to choose any two targets as defining a straight line. Errors from this line are computed taking into account the correction factors for all the targets in the system. Finally, a table of numbers is compiled for the horizontal and vertical shift encoder position for each target. The program works equally well for either the BSY or the accelerator lines.

Some of the targets in the BSY were aligned before the second-level alignment. Recent checks indicated that in effect the BSY was set to two different lines differing by about 0.010 inch. The probability is that this discrepancy resulted from making the initial setup differently on different days. Use of the computer program should eliminate this problem. The checks also showed that on successive days the BSY alignment results were consistent to within 0.001 inch.

H. THEORETICAL AND SPECIAL PROJECTS

In view of the discovery of the multisection type of beam break-up at SLAC, much of the theoretical work which is being undertaken is geared toward understanding the effect and proposing a corrective program. Results obtained to date are still preliminary and a more comprehensive report on the whole subject of beam break-up will be given in the next status report.

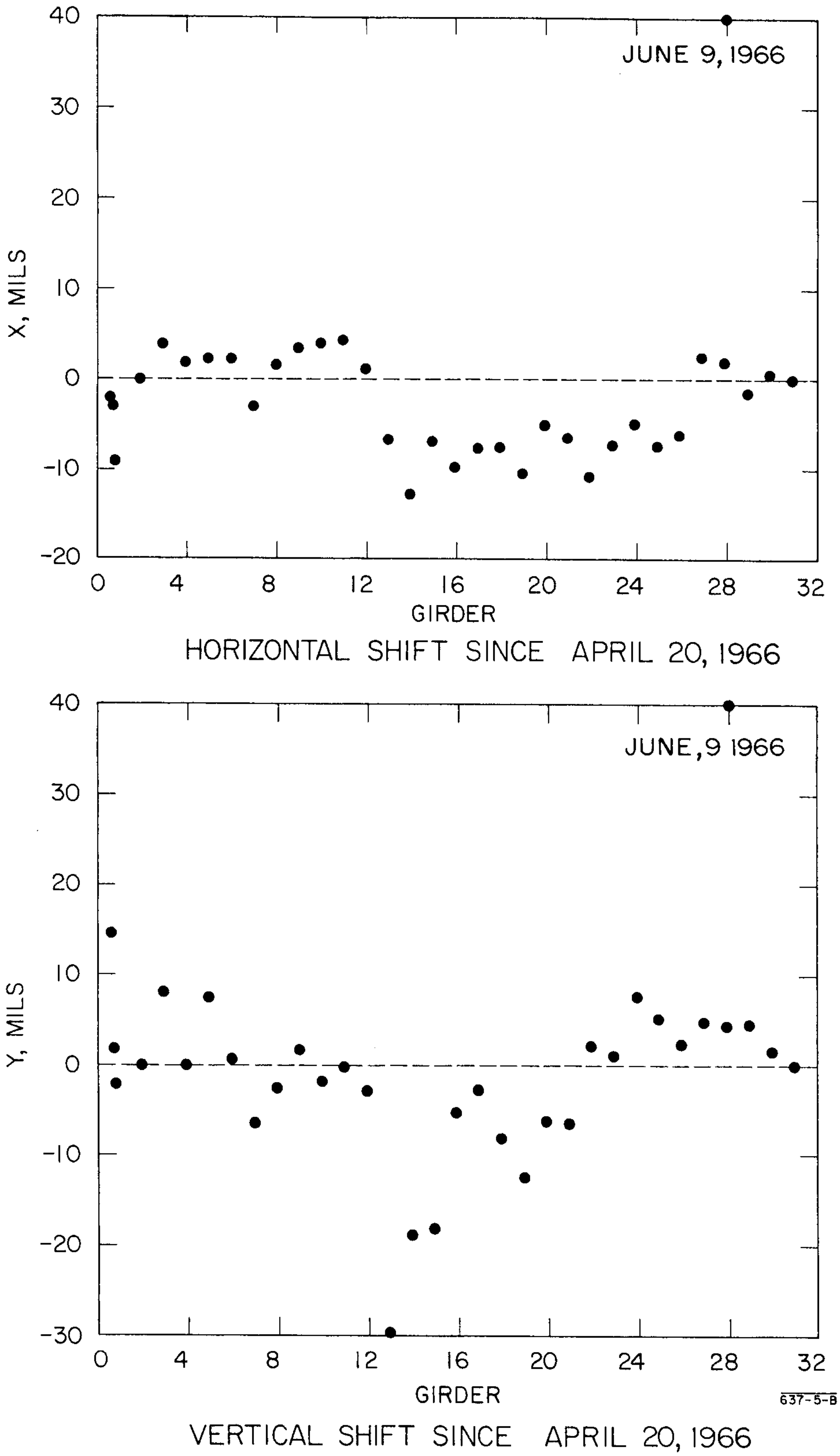

FIG. 15--Vertical and horizontal alignment deviations.

I. MAGNETIC MEASUREMENTS

During the past quarter, measurements were performed in the Accelerator Housing on all machine quadrupole triplets and steering dipoles. A degausser for the quadrupoles was built. The earth's magnetic field was sampled along the beam pipe and the degaussing power supplies were adjusted for proper field cancellation.

"In place" measurements of the first four 3° bending magnets in the A beam were completed and the data analyzed. Measurements were completed on the first five 8-cm quadrupoles, bending magnets B-28 and B-29A, and the measurements were repeated on the modified model of the 8-GeV spectrometer magnet. The data were analyzed. Work continued on the development of an NMR system for the Group A spectrometers, on the development of a rapid magnet mapper, and on preparation for the measurements of the RAO and spectrometer magnets. The first beam dump magnet was tested and the data analyzed.

V. INSTRUMENTATION AND CONTROL

A. GENERAL

Most of the control system was installed and operated satisfactorily for the tests of thirty sectors starting May 20. Operating experience dictated a need for some changes, particularly in the personnel protection system. The status monitoring and control systems, beam guidance system, and the trigger system have been shown adequate to control the accelerator. Modifications of the control console, found desirable to improve operating convenience, will be made on a time available basis.

B. CENTRAL CONTROL (CCR)

Central Control contains a number of equipment racks and three console areas: the Operations Console, the Maintenance Console, and the Backup Console.

The Backup Console contains analog displays from all thirty sectors, trigger programming equipment, radiation monitor readouts, and display and control panels for specialized equipment such as the master trigger generators, the master oscillator and main boosters, water towers, etc. The complement of equipment in this area is reasonably stable, and except for the polarity of some steering current meters, the wiring is complete and correct. The switchyard portion is not complete largely because the signals are not complete from the switchyard. Some of the injector displays and controls are lost in the interface at Sector 0.

The Operations Console is the most fluid of the three areas. The largest change during this quarter was the installation of panels to control the Beam Analyzing Station at Sector 20. The Operations Console also contains injection controls, beam monitoring displays, beam guidance controls, a panel which can be switched to display status and analog signals and to operate controls in any one sector at a time, and a summary panel to alert the operator which sector is likely to contain the source of trouble when he cannot obtain a beam.

The Maintenance Console contains two panels for monitor and control of individual sectors, a continuous display of much of the status information from all thirty sectors, and some of the injector and beam switchyard monitors and controls.

During the last quarter, equipment installation and rack wiring has been completed for the injector systems and the third switched sector-by-sector system. Most of the units for the trigger system have been installed and checked out. Rate and pattern signals are being transmitted from CCR for use along the machine.

Oscilloscopes for steering and beam charge display have been installed, checked out, and are in regular use. BSY status signals have been wired and are displaying personnel protection status. Tune-up spectrum monitor signals are transmitted over a baseband system and are being displayed on a temporary oscilloscope. Steering controls for Sector 30 pulsed steering modulators AP1A through AP4A have been installed and are operating normally.

C. DATA HANDLING

1. Status Monitoring

Binary status information from each area is transmitted to Central Control on a time-shared multiplex system. Installation is complete for the basic system, which consists of transmitting units in the injector, thirty sectors and BSY, and receiving equipment for continuous display of status and for three switched sector-by-sector display panels. A few channels at the injector and most of the BSY status channels still remain to be connected at the source information.

2. Analog System

Slowly changing analog signals are transmitted to standard panel meters in Central Control by means of individual hardwire pairs. Except for a few steering current meters, the circuits are complete from the injector and all thirty sectors. Only one analog signal is yet received from BSY (GI-O Vacuum).

3. Remote Control

The remote control system consists of a transmitter which transmits binary codes and a receiver in each sector which translates the code into a signal to actuate a relay or motor. All transmitting and receiving equipment has been installed and checked out. A few channels at the injector and most of the channels in the BSY are not connected to the equipment to be controlled.

4. Beam Monitoring

Beam operation into the BSY gave an opportunity to verify satisfactory operation of many functions in CCR. These included all the steering controls except for a few in the injector, all the beam intensity and position monitoring signals except for a few in the BSY, the tune-up spectrum monitor signals, the PLIC (Panofsky Long Ion Chamber) monitoring signal, the PLIC beam shut-off system, the slow and fast beam shut-off loops, and the looped video cable system. The video cable system was used to transmit TV signals from the Data Assembly Building (DAB). One channel was used to watch the activity of people in DAB; two channels were connected to BSY beam profile monitors.

The FM signal which represents the charge per pulse at each sector and the multiplex baseband signals which represent log Q, x, y for each beam pulse have proved quite satisfactory for guiding the beam through the accelerator. Some difficulty has been experienced with calibration of the charge-per-pulse system and with zero drift of the x, y position monitor signals. A new system was installed, making it possible to check the zero errors in the rf beam monitoring system by remote control from CCR.

5. Video Cable System

Video repeater units have now been installed in each I/C Alcove along the accelerator. Compensation for reduction of rise time of transmitted pulses due to cable effects is provided at each third sector, and video signals can be introduced at any sector. Final checkout tests on the installed system remain to be done.

Two coax cables have been installed the length of the Klystron Gallery. With repeater amplifiers in each sector, the cable may be operated at any sector to allow transmitting to Central Control. The system has been used to transmit TV signals from profile monitors, signals from the beam monitor toroid in Sector 19, and signals from the phasing system.

D. 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. All three subsystems were proved during the beam tests in May. The main portions of the PLIC system have been installed and are functioning satisfactorily. To provide additional capabilities and flexibility, additional printed circuit cards have been designed to provide a means for inhibiting machine shut-off for signals produced when the positron target is in use, a warning discriminator for operator convenience, and an isolation amplifier between the protection circuitry and the operator's display oscilloscope.

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.

Installation and testing of the pattern generator subsystem in CCR has been completed for multiple electron beams at 60, 120, 180, and 360 pps. A temporary frequency divider has been installed in CCR to provide for accelerator operation at 10, 20, and 30 pps. Subsidiary equipment for positron beams and/or operation at lower pulse rates is in process of design. Preliminary design of the pulsed steering magnet and of the End Station A, End Station B, and counting house trigger generators has been completed. A temporary pulsed steering magnet trigger generator has been installed in Sector 30, pending completion of the permanent unit.

F. BEAM GUIDANCE SUPPLIES

Difficulty with procurement of power supplies for steering, degaussing and focusing were cleared up to the extent that enough supplies are now installed to operate the machine.

TV cameras were installed in Sectors 0, 1, 10, and 19 to observe the Cerenkov light produced by the beam in quartz targets. These systems were helpful in focusing and steering the beam, and were useful in investigations of beam break-up. Some mechanical difficulties were experienced with the mechanism which inserts and withdraws the thin quartz radiators. The mechanisms were modified to improve reliability.

G. PERSONNEL PROTECTION SYSTEM

A number of modifications to the PPS have been requested since the operational tests. The main protection circuit, consisting of two tone loops, was found marginal. In the interrupted condition the loops are broken between transmitter and receiver and the receiver side of the break is shorted, but the resulting circuit is unbalanced and allows only -20 dB feedthrough. The receiver shuts off the accelerator when the tone level drops 6 dB, and a -12 dB level in the interrupted condition would provide a sure shutoff. The feedthrough signal is of variable amplitude from day to day, however. The circuit will be modified to provide a properly balanced break which will give better than 30-dB isolation.

The switchyard and end station areas now have double doors at each entrance, like those of the gallery. These had been wired in series. Separate interlocks and monitoring of each door and gate will now be provided. A new type of warning sign, keyed to accessibility of an area rather than to machine operation, will be used at each entrance of the research area. Circuits to control these signs will be added.

H. CHECKOUT

1. Gallery

During this period, the remaining equipment for the beam guidance and monitoring racks was installed and hot-checked. Toroid calibration, field direction and intensity tests, and beam monitoring sector electronics tests were completed. These tests were completed in cooperation with the Magnetic Measurements, Light Electronics and Electronics Departments.

Much of the temporary personnel protection which was used during sector testing was removed from the Klystron Gallery. The temporary control center previously installed in the Sector 2 I/C Alcove was removed and the alcove was restored to normal.

Operational checks of all systems were made previous to the May 20 beam turn-on to BSY.

2. BSY Interface

Most of the internal cross-connections between the IDF and the Control Console in CCR are installed, and ready for DAB/CCR interface check.

On the DAB side, a cross-connection wire list is being made. This wiring should be completed in August. At least 80% of the total signal wiring will have been checked out in August. If panels are not completed, simulated signals will be used for checkout.

I. CONTROL SYSTEMS

1. Positron Control and Instrumentation

The wheel position monitoring panel and wheel speed monitoring panel were completed during this time interval. The development of concepts for the control and monitoring of the operation of the positron wand has begun.

2. General Work

A memo has been prepared outlining the need and cost of changes to the fast valve control panel. The need for this modification arose when the BSY and accelerator vacuum systems were interconnected and one isolating valve was to be controlled from CCR.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

The transition from an installation-checkout phase into a maintenance phase took place during this quarter. Essentially all modulators were operated for beam tests and endurance runs, and our maintenance troubles began showing up. Most of the component failures were small parts, as was expected. There was not an unusually large number of failures because, in many cases, weak points in the life testing of these modulators had been discovered and corrected early in the procurement cycle.

Such life testing also revealed that some of the capacitors in the pulse-forming network would fail early in their life. The manufacturer was alerted to this situation and took steps to rectify the problems; however, many of these bad capacitors were installed on the accelerator. By the end of the quarter, about 115 capacitors had failed, and some 200 additional swollen capacitors were present in the modulators on the accelerator. The manufacturer is continuing to supply replacements.

About five de-Q'ing SCR assemblies were lost during the quarter. The main problem has been in the small triggering transformers, which are unable to stand the voltages involved. The manufacturer is replacing all of the transformers with higher voltage units on a routine schedule. Our spares are being used so that machine operations are not affected.

Two main rectifiers in the Klystron Gallery failed during this quarter. The type of failure of the first one appeared the same as with previous ones—two or three card assemblies (out of 100 total) burned up. The problem has been studied quite extensively here and with the manufacturer. The results of the studies indicated that additional cooling by installation of an air baffle around the rectifier to channel cooling air through it would lower the diode case temperature by 25 - 30° C, thus making it more reliable. Such a baffle has been designed and it is planned to install it in all the modulators.

Probably the most significant finding was the cause of the second rectifier failure, which occurred when the main contactor in the modulator "hung up," probably because of eroded contacts. When this happens, the circuit breaker (which has thermal and magnetic trips) will supply short-circuit current to the rectifier for many seconds unless the magnetic trips are set sensitive enough to trip the breaker rapidly. Semiconductor rectifiers generally do not have enough heat capacity to withstand this duration of short-circuit current. In order to test this theory, and to prevent future failures, all magnetic trips on the modulators in the Klystron Gallery were set on the sensitive position. Since then, no rectifier failures have been experienced. However, we are planning to investigate the problem further and possibly install shunt trip coils in the breakers to protect the rectifiers against this type of contactor failure.

A preventive maintenance program on the modulators in the Klystron Gallery was implemented. At present, one crew cleans and checks the operation of the modulators, as well as ranging switch tubes and flattening output pulses. The turn-around time is about 400 to 500 hours of high voltage operation under the present machine operating schedule.

1. Switch Tubes

Both manufacturers continued to supply satisfactory tubes within schedule this quarter. At the end of the quarter, we had about 70 spare tubes on hand.

The switch tubes in the main modulators operated satisfactorily during the quarter. The ones at the beginning of the machine had about 2000 hours of operation on them; those at the end of the machine had only a couple hundred hours. The average is about 1000 hours.

We have lost a total of 16 tubes during all operations on the accelerator. Many of these were early failures due to design defects which were corrected during the procurement cycle.

At the end of the quarter, we were preparing to procure a new set of switch tubes to replace the existing ones, which are expected to reach end-of-life during fiscal year 1967. Specifications were being brought up to date and the procurement cycle started.

2. Pulse Transformer Tank Assemblies

Thirty-six pulse transformer tank assemblies were completed during this quarter, bringing the total to 271 and thus maintaining a small margin over the Klystron Group's requirements. In addition, rework continued on tanks which were on klystrons that failed on the machine.

Five pulse transformer tank assemblies failed on the machine due to arced-over klystron socket supports. These failures resulted in three pulse transformer failures. These may have been due to manufacturing defects, but we have also taken steps to minimize such failures by eliminating sharp edges around the support bracket and increasing the creepage path by raising the socket above the Lexan support plate.

B. SUB-BOOSTER MODULATOR

These modulators operated several hundred hours this quarter. We improved their operation by upgrading weak spots: The defective blowers were replaced by new ones, nearly all the 4PR1000 tubes were replaced by PL279 tubes, and the power transformers in the small regulated power supplies were replaced by improved ones. These modulators have shown themselves to be satisfactory, reliable units.

C. CAPACITOR CHARGER POWER SUPPLY

This project consists of two power supplies, each capable of charging a 3/4-microfarad capacitor to 50 kilovolts in 80 milliseconds after allowing a 20-millisecond dead period. Planned for use on a spark chamber in the Research Division, the supplies are now in the "hardware" phase. The transformer-rectifier units and SCR gating circuits are in-house and are now undergoing test.

D. BEAM KNOCKOUT MODULATOR

This modulator, consisting of a pulsed radio frequency amplifier at 39 megacycles to be used on the front end of the accelerator to break up the beam into a series of extremely narrow pulses for certain physics experiments, is in the "hardware" phase. The final amplifier is ready for test, power supplies are in-house, and control circuits have been constructed. The driver circuits remain to be built.

E. MAGNET POWER SUPPLIES

All the remaining Beam Switchyard power supplies were received and installed this quarter. Those that had magnet loads connected to them were checked out.

End Station B beam transport power supplies continued to be checked out. At the end of the quarter, we had tested and delivered six power supplies.

The spark chamber power supply and the 20-GeV spectrometer power supplies were behind schedule at the end of the quarter, mainly because of the copper shortage.

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

The solenoid A housing and the solenoid C unit for the positron source were both completed during the reporting period. The high current connectors for the 10-foot section were also completed and installed during the quarter.

Some solenoid target drive system redesign is also in progress. It had been thought that an electrical drive system could be developed, but the apparatus initially tried proved inadequate. As a result, a pneumatic system actuator for the wand target is being developed.

Difficulty has been experienced with the internal insulation on the solenoid A housing. High voltage breakdown was occurring; new insulation material is being sought.

Work on BSY and End Station components was also done during the quarter; such work is covered elsewhere in this report.

B. MAGNET ENGINEERING

The magnet engineering group was concerned primarily with magnet designation, processing and installation during the reporting period, as well as testing of the magnets after installation.

1. Emergency Bending Magnets

All of the emergency magnets were installed and readied for operation by May 20. The magnets were used for the steering of the beam through the BSY and to the tune-up dump at the time of the first full-length beam turn-on, May 21, 1966.

2. Three-Degree Bending Magnets

All three-degree bending magnets for the A beam line were designated, their vacuum chambers were installed, and the magnets were put in place during the reporting period. The reference magnet, B-100, was also installed in the Data Assembly Building. Post-installation magnetic measurements were made for a month after this; the measurements showed that the magnetic fields could be accurately set to 1 part in 10^4.

The B-beam magnets were ready for vacuum chamber installation during the period, but designation of these magnets had not been made. The last magnet was not received until June and its magnetic measurements had not been completed to allow for designation.

3. Pulse Magnets

Two magnets were completely assembled and magnetic mearurements were made. An end plate heating problem arose, however, and disassembly and modification had to be performed. Coil cracks also caused the magnets to go back for rework. None of the magnets, therefore, were ready for installation by the end of the period, but it is anticipated that they will all be ready by the end of the next period if their vacuum chambers are acceptable.

4. Quadrupole Magnets

The first six 8-cm quadrupole magnets were received, serviced and tested, and their positions were assigned in the A-beam line. The first 18.6-cm cores and end plates were received but the coils were held up because the vendor was working on other magnets whose delivery was more critical.

5. Photon Beam Stripping and Bending Magnets

All three of these magnets were readied for installation during the period except for the installation of vacuum chambers. This work should be completed and the magnets installed by the end of the next quarter.

6. Dump Magnets

The cracks were repaired on the coils of all four magnets and four coils were used with each magnet rather than the six in the original design. It was found that the magnets still stayed within design parameters with this modification.

The coils were all installed, and water manifolding and vacuum installation is to be done during the next quarter. All precision alignment and magnetic measurements were completed on the cores.

7. BSY DC Steering and End Station A Alcove Steering Magnets

These magnets were all installed and tested during the reporting period.

8. Beam Dump East Steering Magnets

The coils for these magnets had been wound, but partial assembly and installation of personnel protection covers still remained to be completed at the end of the quarter. It was anticipated that the magnets would be completed and installed during the next reporting period.

C. PRECISION ALIGNMENT

1. Laboratory Work

The shop alignment of all bending magnets for both the A and B beam lines was completed during the reporting period. Also, 90% of the diagnostic instruments, protection collimators, position monitors, Cerenkov cells and zinc-sulfide screens for the A beam were completed during the quarter.

The A-beam dump, beam dump east, and the front half of the C-1 collimator were both installed and aligned.

2. Field Work

Procedures for establishing the vertex points were completed during the period and a points set list was evolved.

The BSY 10-inch pipe laser light was installed and the central beam transport equipment was aligned for beam startup. The alignment procedures were satisfactory and no difficulty was experienced in using second-level alignment procedures with the laser as a reference.

Vertex lines were established for the A beam using second-level alignment procedures and instruments. These points control the alignment of all components located in the A-beam line. Approximately 30% of the A-beam components had been aligned by the end of the reporting period.

Alignment control provisions, using optical means, were established into End Station A, and the position of the spectrometer pivot was measured. Similar vertical surveys were made to control the elevation of components along the A and B beam paths and into the end stations. Measurements were also made to establish the horizontal calibration constants from the grid system installed in End Station B.

The tape bench facility became fully operational during the period and was used for analysis and checking of tapes. The tapes had been scribed for use in both second-level and other alignment and, after use, calibration of the tapes was made on the bench.

VIII. KLYSTRON STUDIES

A. SUMMARY

During the quarter, the Klystron Department has gradually been shifting emphasis towards the maintenance and operation of the machine. An endurance run was initiated in an attempt to determine a relationship between klystron failure rate and operating level. Knowledge of such relationship would enable us to make recommendations of station operating levels to minimize the cost of machine operation for a given energy level. By the end of the quarter, 75,800 hours had been accumulated in the 112 stations in the endurance test, with seven failures recorded. The total number of klystron operating hours for the quarter was 118,000 with a total number of 16 failures, giving a cumulative number of klystron hours of 156,000 and a cumulative number of 39 klystron failures.*

We experienced a total of five driver amplifier klystron failures (four in the Klystron Gallery, one in the Test Laboratory), and completed negotiations for the procurement of additional driver amplifier tubes.

No major difficulties have been encountered in the vacuum system maintenance. The majority of the ion pumps operate in the low 10^{-8} torr region, and the vacuum at the klystron windows is usually 10^{-7} torr or better during rf operation.

B. KLYSTRON PROCUREMENT

During the quarter, the vendors continued deliveries both of new tubes against the contracts and of repaired or replacement tubes. Acceptances averaged seven to eight tubes per month per vendor. A review of the vendor performance follows.

1. Sperry Subcontract

The manufacturing yield at Sperry, which had been improving as reported last quarter, has again shown a decrease during the last two months of this

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*Failures reported previously had included life test tube failures. The present number includes only gallery-operating tube failures.

quarter. In addition, the acceptance rate at Stanford of Sperry tubes has been lower than desirable.

One of the difficulties at Sperry has been a rash of leaks and pinch-off failures during bake. In addition, general tube gassiness which may result either in sparking and arcing in the cathode region or in pulse breakup, amplitude droop, or similar misbehavior of the output pulse is still present.

One of the possible sources of the low acceptance rate at Stanford was the processing procedure at Sperry. Normally, the tubes operated in only one permanent magnet. It is possible that when tested in a different magnet at SLAC, subtle differences in magnetic field produce different focusing and/or steering of the beam with the result that some portions of the tube may see much higher power densities at Stanford than they had at Sperry, resulting in additional gassiness.

In general, the window problem appears to be well in hand at Sperry with only one failure.

2. RCA Subcontract

RCA has also experienced a poor manufacturing yield during the quarter. In their case, however, most of the failures were caused by window difficulties, and most of these were noticed prior to shipment of the tubes so that the acceptance rate at Stanford was satisfactory.

The best evidence at present seems to indicate that gradual improvements made in the window coating apparatus had resulted in a window coating which is highly unstable. Contrary to usual tube techniques, window coating requires impurities (probably oxygen) or else the titanium deposited on the window which oxidizes upon exposure to air can revert to a metallic deposit with high resistive losses after bake. During the quarter, RCA installed a controlled leak in the coating equipment to prevent coating at too low a pressure. The preliminary results appear promising. In addition, RCA is also conducting basic studies such as secondary emission characteristics of their coating.

RCA has very strict quality control during final tests of the tubes; they monitor window temperature and have set up limits below which the window must run in every tube that is to be shipped to Stanford. They also carefully monitor the appearance of the window during operation to eliminate those windows which show excessive multipactoring. During the quarter, RCA completed delivery of all magnets, and we have had little or no problems with magnet and tube interchangeability.

3. Litton Subcontract

Some additional work has been performed at Litton to eliminate the marginal instabilities that were reported in the last quarter. Litton's yield appears to be in general high and acceptance at Stanford satisfactory. Only a few windows may be marginal in operation as indicated by operating temperature.

4. Driver Amplifier Klystrons

Deliveries of Eimac sub-booster klystrons have continued during the quarter, and a contract for the procurement of additional tubes to permit continued operation has been signed with Litton Industries. The Litton klystron, although meeting the same electrical specifications and the same size limitations as set out by Stanford, will weigh considerably more than the Eimac tube. The main reason is that Eimac used periodic focusing, whereas Litton will use unidirectional focusing. Litton has started the design work on their tube, and we are keeping in close contact with their progress.

C. KLYSTRON RESEARCH AND DEVELOPMENT

The activity of fabrication of "standard" klystrons has been greatly reduced since the last quarter's effort, and additional emphasis has been placed on further tube improvements.

Of seven new tubes built, two incorporated new and hopefully better designs of extended interaction output cavities. Unfortunately, the results were disappointing because of heavy oscillations. It appears that these oscillations were caused by backward waves in the two-cavity output system. The result was a tearing up of the rf output; it was only possible to achieve approximately the same power output as with a standard klystron with extremely critical focusing.

In view of the poor results of extended interaction, several other approaches are being followed. First, a double output cavity with a double output waveguide is being built for test during the next quarter. In this case, there is very little interaction between cavities and we wish to study the possibility of salvaging the rf energy left in the beam after a normal output cavity.

We have also started the construction of a scaled version of a gun to be used as a beam tester. We feel that the possibility of further beam optics improvement by better beam control in permanent magnets should not be overlooked.

During the quarter, we have tested a number of "standard" tubes which have given us power output in excess of 27 MW in electromagnets (efficiency between 42 and 44%). For reasons which are not clear yet, these tubes require a magnetic focusing field different from that around which the existing permanent magnets had been designed. In spite of these high power outputs in electromagnets, these tubes do not perform better in permanent magnets than the other "standard" tubes; thus, the power output from the electromagnet to permanent magnet drops approximately 4 MW compared to approximately 2 MW for the usual tube.

Here again we will follow two different approaches for improvements in an attempt to achieve the same results in permanent magnets as we have achieved in electromagnets. The first approach is a modification of the field shaping in the gun region of the permanent magnet. Instead of using "bucking" magnets in that region, we have been able to achieve the desired (or slightly improved) field shape by using only cold-rolled steel shielding. We intend to test in such a magnet both tubes which had showed anode burning,* as well as other experimental tubes. We also expect to test in this magnet the high efficiency electromagnet tubes. In addition, we are building a few experimental tubes with increased drift tube diameters between cavities three and five. The field plots of the high efficiency tubes indicate that the magnetic field requirements in the region of these drift tubes is much higher than can be achieved in practice by permanent magnets. It is hoped that by increasing drift tube diameters the efficiency will not be substantially lowered in the electromagnet, but the focusing requirements will be reduced to a point where the operation in existing permanent magnets will be substantially the same as in electromagnets.

Minor improvements are continuing to be introduced into the standard tubes. A new rf input is now being used in the klystrons and appears to operate

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*"Two-Mile Accelerator Project, Quarterly Status Report, 1 January through 31 March 1966," SLAC Report No. 65, Stanford Linear Accelerator Center, Stanford, California (June 1966).

satisfactorily. We have also modified somewhat the bake cycle to help reduce the possibility of tube gassiness and arcing problems. We are now activating the cathode with the tube body at 200° followed by a bake at 525°. The results seem encouraging.

D. KLYSTRON TEST AND MEASUREMENTS

During the quarter, we ran a total of approximately 50 individual tests for Stanford tubes and 385 acceptance tests. The total HVRT is approximately 4800 hours for all tests. The decrease in running time from last quarter results from the discontinuance of the endurance run on some of the vendor tubes which will not be called upon to be used in the Gallery immediately.

As in the past, we have very good agreement on comparison of power output measured by vendors and SLAC, and no special difficulties have been encountered in the measurements area. Equipment malfunction or operator error may have contributed to the failure of a few tubes during tests. Corrective measures have been instituted to prevent the recurrence of such failures.

The test stand maintenance indicated that the majority of failures in the main modulators have been involved in the 5-kV driver, with the trigger generator being a close second. We are also in the process of modifying test stands to introduce de-Q'ing and to improve stability during measurements. No main thyratrons failed during the quarter. In the sub-booster modulators, 14 switch tubes (4PR1000) had to be replaced. Modifications to replace the 4PR1000 by PL279 tubes are proceeding.

E. GALLERY OPERATION

1. High Power Klystron Operating Experience

During the quarter, the number of operating hours increased considerably because of the initiation of beam tests and of an endurance run. A total of 118,000 plate hours was accumulated, bringing the total hours of operation in the Gallery to approximately 156,000.

In spite of the increase of operating hours since last quarter, the total number of klystron failures remained reasonable, with a total of 16 klystron failures. Of these, 6 had output window failure, one was a high voltage seal failure, and 9 failures were probably caused by tube gassiness evidenced by excessive arcing, pulse droop, pulse breakup and/or oscillation. On the other hand, a total of 45 klystron-pulse transformer assemblies were removed from the Gallery for various reasons. Reasons for removal included failures in the pulse transformer tank, oil leaks, water leaks, etc., in addition to the 16 tube failures.

One of the purposes of the endurance run is to obtain data which could lead to an estimate of the mean time to failure of klystrons as a function of operating level. As of now, the number of failures in the sectors run under endurance test conditions has not been sufficient to make any statistical analysis meaningful. Based on the average life of tubes at the time of failure, we would expect the mean time to failure to be greater than 250 hours. Based on the average operating hours per tube now installed, one would expect the mean time to failure to be in excess of 600 hours. Based on the total number of failures and operating hours, one would expect the mean time to failure to be approximately 6000 hours (considering the last quarter and including accidental failures in the Test Laboratory), or approximately 3500 hours considering all failures and all operating hours to date. Similarly, analysis based on a normal distribution function with a standard deviation equal to one-half the mean time to failure, indicates a probable mean time to failure of approximately 3000 hours. However, as stated above, the number of failures experienced up to now makes the validity of such analysis extremely doubtful and it is as yet impossible to make predictions of mean time to failure under different operating conditions. In Table I below, the typical operating conditions and status of the endurance run sectors as of July 1, 1966, are given. In addition, the number of faults are being counted during the endurance run to allow plans for a population control system to proceed on a better foundation. In general, the maximum number of faults (interruptions of a few seconds) takes place in the sectors operating at the highest peak and average power, as would be expected. After a large number of faults initially in those sectors, the count has stabilized to approximately 1/2 per hour per station at the maximum power output and repetition rate tested, and to less than 1/10 per hour per station at the lower operating levels.

TABLE I

2000-Hour Endurance Run Klystron Status

Sector Pair	Operating Level				Operating Hours	Klystron Replace. (All)	Cumulative Klystron Failures
	Ref. V	Kly. Beam V	Kly. P_{out} pk	PRF			
3/4	115	240-250	19-22	60	10883.9	5	1
5/6	115	240-250	19-22	360	10103.1	8	5
7/8	105	220-230	16-18	60	11384.0		
9/10	105	220-230	16-18	180	10348.6	1	
13/14	105	220-230	16-18	360	10629.3	1	
15/16	90	195-205	11-14	60	11186.7	1	
17/18	90	195-205	11-14	360	11253.5		

It is interesting to notice that of the 16 failures experienced in the Gallery during the quarter, only seven were in the endurance run sectors. It is suspected that some of the failures due to gassiness experienced in other sectors would be more appropriately attributed to shelf life failures than to operating troubles; in many cases, stations had been left unused for many months and tube troubles developed immediately upon turning them back on. The average time to failure, the total number of tube failures, and tube replacements, and the average operating hours per tube (including those which failed or were replaced) are given in Fig.16 . Figure 17 (a) gives the distribution of plate operating hours of the tubes installed in the Gallery on July 1, 1966. Note that one tube has nearly 3000 hours of operation; this tube had originally been life tested in the Test Laboratory prior to installation in the Gallery.

2. High Power Klystron Maintenance

The klystron maintenance has begun on a full-time basis and consists of two main functions: trouble shooting and preventive maintenance.

Trouble shooting consists of investigation and correction of specific trouble reports. The trouble reports have three origins: (1) formal reports from the Operations Group, (2) on-the-spot trouble reports by operations and

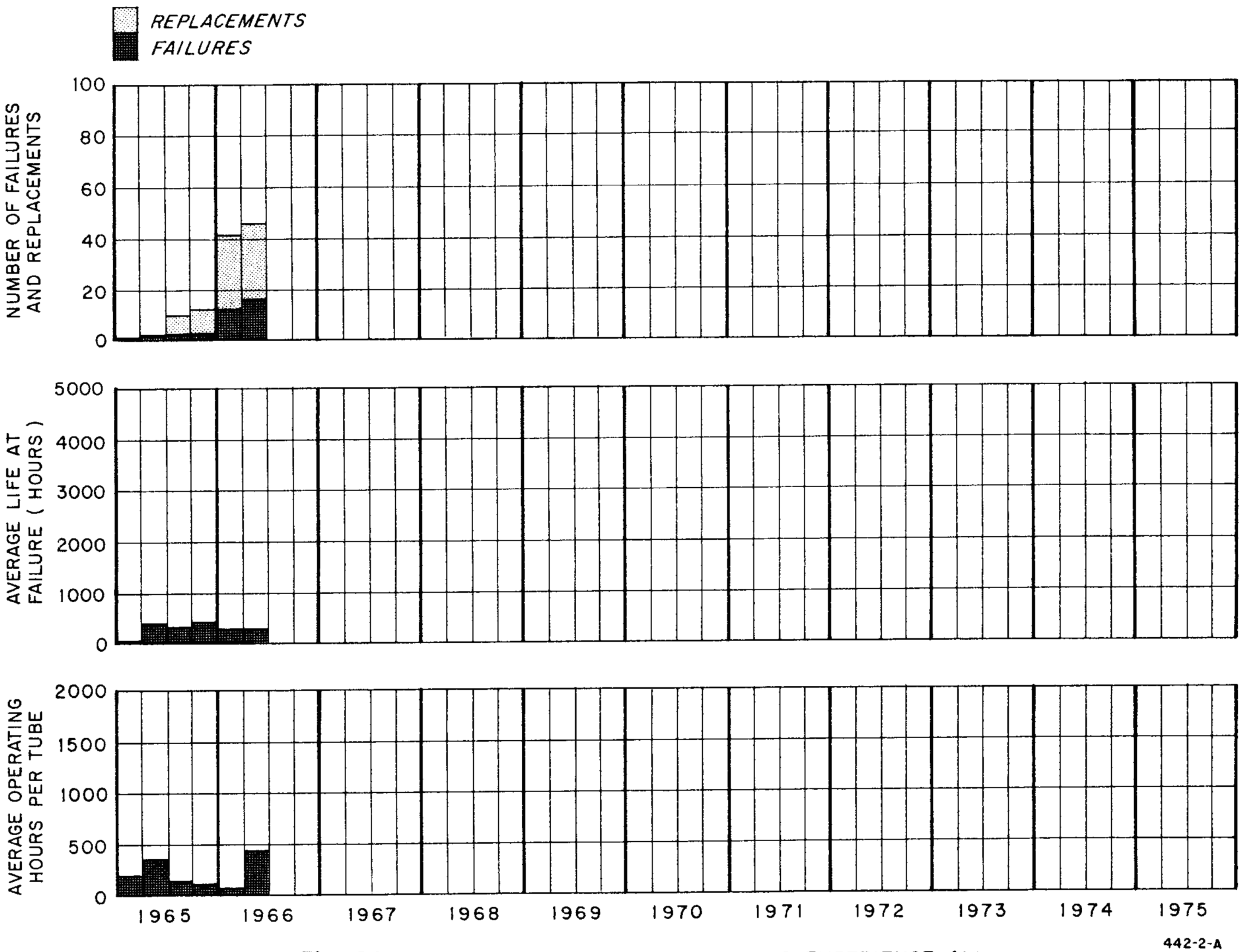
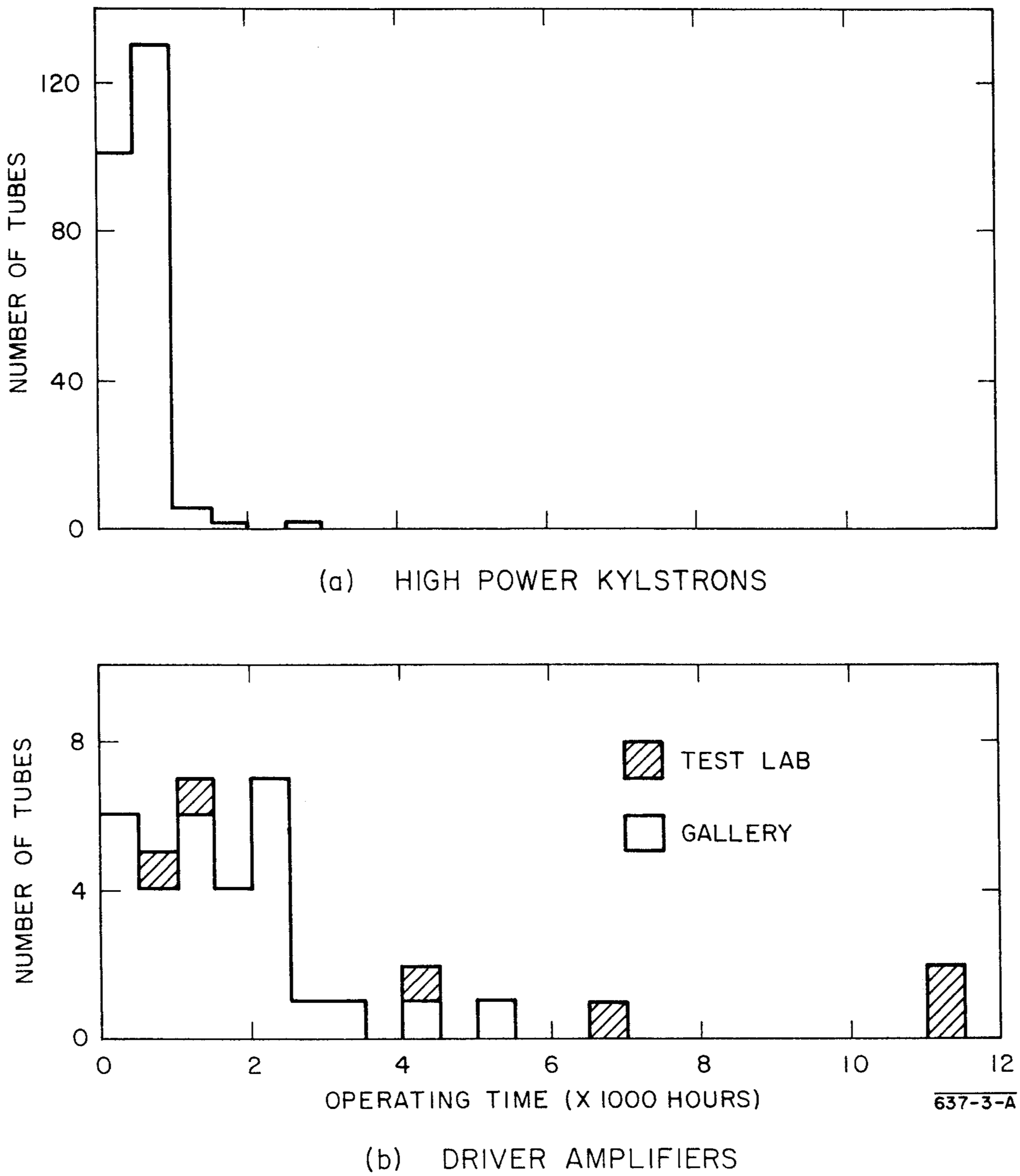


Fig. 16 -- KLYSTRON QUARTERLY OPERATING EXPERIENCE, ALL HIGH POWER KLYSTRON VENDORS



OPERATING HOURS DISTRIBUTION

Fig. 17

maintenance personnel, and (3) data processing print-out from the daily gallery data-taking.

During the quarter, the most used sources of indicated klystron problems were the formal and on-the-spot trouble reports. 243 problems were reported and checked out. An additional number of verbal reports were also checked out. The data-taking system had suffered at the beginning from lack of reliability, but has improved considerably and has pointed to some areas of trouble which would not have otherwise been noticed (for instance, low perveance, rf pulse breakup, wrong drive conditions, etc.).

The purpose of the preventive maintenance operation is to make a careful and detailed analysis of each klystron on the line approximately once every 500 hours of operation. Although the preventive maintenance has not been running as smoothly as hoped for, 36 stations have been examined during the quarter and resulted in the discovery of four tubes with serious problems; one bad pulse breakup (a failure); two temperature limited and requiring an increase in filament voltage setting; one showing increased drive requirements.

In addition to the above duties, the electrical maintenance crew is required to "run-up" the tubes which have been replaced in the Gallery prior to turning them over to operations. This run-up, done with the portable Variac and adjustable rate generator, consists of gradually increasing the voltage and power output to reprocess the tube after its storage period and outgassing the waveguide window area. The tube performance on the station is also checked carefully at that time. The time required varies from one to two hours per tube.

3. <u>Driver Amplifier Klystrons</u>

There was a total of 26,300 hours of operation in the Gallery and approximately 10,000 hours in the Test Laboratory during the quarter. Seven tubes were replaced from the Gallery for various checks and suspicion of troubles; four tubes had actually failed. Three of the failures appear to be caused by shelf life problems; that is, the tubes showed gassiness shortly following return to operation after several months of disuse. One tube failed in the Test Laboratory and was also found to be soft after having not been used for several months. Figure 17(b) gives the distribution of plate operating hours of the tubes installed on July 1, 1966. It is worthwhile to note that the mean operating time of the driver amplifiers in the Test Laboratory is approximately 6200 hours, and that the mean operating time in the Gallery is only 1600 hours.

Initial maintenance checks of driver amplifier klystrons indicated wide differences in performance in stations. In the majority of the cases, the beam voltage appeared to be responsible for variations in operating levels. After recalibrating all capacity dividers and current transformers, most of the discrepancies have been removed.

4. Main Booster Klystrons

The main booster klystron that failed at the end of the previous quarter, after almost 9000 hours of operation, was replaced, and a systematic maintenance of the klystron rf cavities has been instituted. It is hoped that by regularly cleaning the cavities, arcing in the cavities will be eliminated and the life of the main booster tubes will be further increased.

5. Vacuum System

The first cryosorption roughing vacuum pump was received. Acceptance testing was completed after the manufacturer made numerous modifications to allow the pump to meet specifications. After modifications (including the addition of a small third pump), a sector was pumped down from nitrogen to a pressure of approximately 5×10^{-4} torr in two hours with a liquid nitrogen consumption of about 200 liters. The second cryosorption pump was received at the end of the quarter and has not yet been tested.

Liquid nitrogen storage tanks were ordered and received during the quarter. They include vaporizing coils to allow gaseous nitrogen withdrawal for systems let up to nitrogen. The smaller tanks (100 liters) have been installed on trailers to make self-contained leak detection systems, including mechanical roughing pumps, cold traps, leak detectors and a helium cylinder.

During the initial start-up of the Beam Switchyard, a residual gas analyzer was connected between Sector 30 and the refrigerated baffle separating the accelerator from the Beam Switchyard vacuum system. To date we have not detected any heavy hydrocarbon molecules in Sector 30. The primary gas present is water vapor. The residual gas analyzer proved helpful in indicating an argon leak in the Cerenkov cell in the beam switchyard. The argon was causing high pressure instabilities in the ion pumps upstream of the refrigerated baffle.

About 15 drift section (beam tube between sectors) let-ups and pump-downs were made during the quarter, primarily to install or remove beam-monitoring or beam-stopping equipment. The only serious problem noticed is the lack of adequate sealing in the thin valves; in any case, the adjacent sector could not be held in vacuum by the ion pumps and it is suspected that at least 50% of the thin valves have leak rates in excess of 0.1 torr liter/second.

In general, the accelerator vacuum system performed very well, with many ion pumps running consistently in the low 10^{-8} and high 10^{-9} torr range. The vacuum at the klystron windows is also usually in the high 10^{-8} torr range with the klystrons running.

F. HIGH POWER KLYSTRON WINDOWS

1. Stanford Klystron Windows

Of the 22 tubes baked at Stanford during the quarter, only one window failed during tests, although a second one initially indicated high operating temperature. The window which failed had a relatively thick coating and had been coated at a faster than normal rate. Its coating history was similar to that of two hot windows reported during the previous quarter.

2. Resonant Ring Tests

a. Klystron Window Pretest

During the quarter, no windows were rejected on the basis of pretesting. It must be noted that the ring test is best suited to indicate insufficient coating, but not those coatings which may become lossy as a result of vacuum bake. Six windows were not allowed through bake on the tubes because of suspected overcoating on the basis of crystal monitor data or of coating history similar to windows which have failed in tube test.

b. Double Window Test

To date, the tests with double windows have confirmed the effect of the vacuum bake on window coating losses. The first vacuum bake produces significantly higher window operating temperatures than produced by unbaked windows with equivalent coating; exposure of the vacuum-baked coating to air reverses the effect, but a second bake produces much more pronounced deterioration of the coating effectiveness.

The double window test is being used to determine criteria for coating stability as a function of process (evaporation, sputtering or a combination) as well as coating material. Hopefully, it will give us a good understanding of the best coating technique for maximum stability. Some of the variables to be further studied are speed of coating, partial pressure of impurities such as oxygen, and coating material.

3. Window Life Test

During the quarter, the klystron used for window life test was replaced since its power output had decreased to approximately 15 MW. The replacement tube is capable of 27 MW output; 250 hours of operation have been logged at power levels increasing gradually to 22 MW. There have been no failures to date, although two windows have reached operating temperature of 120° C.

4. Window Tests for Klystron Vendors

As has been our practice in the past, we have attempted to help vendors who find themselves with unexpected and unexplained window problems. As stated previously in this report, RCA has had a low tube fabrication yield because of window failures. We have attempted to measure the stability of RCA evaporated coatings as affected by coating thickness, coating method, tube processing and roughness of the ceramic surface. It appears that in general, the RCA coating was so unstable that any one of the variables mentioned might influence the behavior of a particular window.

It is believed at present that the RCA coating problem can be traced to "improved" coating apparatus. A decrease in operating pressure during the coating process preceded the onset of the failure problems. We now suspect that as a result of this improvement there was insufficient oxygen during the coating to insure a reasonable stability of the coating.

IX. ACCELERATOR OPERATIONS

A. SUMMARY

Testing has been completed in all sectors, as far as has been possible, while operation from the Central Control Room has expanded as circuitry has been installed.

The beam analyzing magnet at the end of Sector 2 was moved to the end of Sector 19, making possible acceleration and analysis of beams up to 3 GeV. Operation into Beam Analyzing Station (BAS) II started April 21 and has continued throughout most of the period since.

To obtain klystron life data, a 2000-hour run was started using 14 sectors running at various power levels.

On May 21, beam was accelerated throughout the length of the machine into the Beam Switchyard. Operation into the Beam Switchyard continued for three weeks.

B. SECTOR TESTING

1. Test Program

Begun September 1, 1965, the sector test program has progressed with the goal of having all equipment and circuitry in the Klystron Gallery, Accelerator Housing, and Central Control Room checked for proper and reliable operation. The sector test program, with the exception of the Central Control Room, was completed early in this report period.

A comprehensive description of Formal Sector Test is presented in a prior Quarterly Report.* Briefly, it may be described as follows:

> Upon completion (accelerator in place and under vacuum, klystrons installed, all electronic equipment and circuitry installed and checked out) a group of sectors is turned over to the Accelerator Operations Group. Sector testing then consists of an operational check of the personnel protection system and all water interlocks, after which the modulator/klystron stations are turned on and run up to full power as rapidly as processing of the rf vacuum system permits. After all parameters have been set to their proper operating values, a 16-hour high power run completes the test.

Sector testing has moved, generally in blocks of six sectors, seemingly haphazardly through various sectors of the machine. The testing schedule was set

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* " Two-Mile Accelerator Project, Quarterly Status Report, 1 October to 31 December, 1965." SLAC Report No. 59, Stanford Linear Accelerator Center, Stanford, California (1966); p. 61.

up in this order to minimize interference with the installation of the accelerator sections and the auxiliary equipment and wiring. The following is a calendar of the testing as it has proceeded:

SECTORS	TEST PERIOD		
5 and 6	9-1-65	to	11-16-65
13 through 18	11-11-65	to	12-10-65
25 through 30	12-15-65	to	1-19-66
3, 4, 7 through 12	2-1-66	to	3-3-66
19 through 25	3-21-66	to	4-8-66

There are areas where it has not been possible to complete the formal sector test program. These include the following:

a. Sectors 1 and 2

Sectors 1 and 2 were used for prototype design checkout, and the design of Sectors 3 through 30 was based on experience gained in these two sectors. Later, Sectors 1 and 2 were rewired to conform to the rest of the accelerator; but by the time the rewiring was complete, the pressures of preparation for beam to BAS II (in Sector 20) made it impossible to fulfill a complete sector test program. Those items that were missed have largely been picked up as operation has proceeded.

b. Sector 11

In preparation for the positron source installation, there has been a large amount of work going on in the west end of Sector 11. This has made it possible for only a minimal amount of sector test work to be completed. There has been no checkout of Stations 1, 2, 3A and 3B.

c. Sector 30

Use of Sector 30 as a guard sector (for radiation protection) while work was proceeding in the Beam Switchyard, plus the fact that, while the Sector 25 through 30 block was being tested, there were insufficient full specification klystrons available, made a complete sector test of Sector 30 impossible. The testing has never been formally completed, but nearly all items have been picked up during beam operation into the Beam Switchyard.

2. Central Control Room Checkout

After a group of sectors had been turned over to Accelerator Operations as complete (i.e., the sectors had already been through installation, wiring, and both cold and "hot" checks of the wiring), the rigorous "formal sector test" procedure was begun, with the operation of each item checked off as it was tested.

It had originally been thought that a similar system would be used for Central Control Room operation; with the exception of the personnel protection system, this has not proved to be the case. Operations initially moved into the Central Control Room about December 15, 1965. Only a small portion of the equipment was completed at that time. As the components have become available, they have been pressed into use; this, essentially, has been the course of Central Control Room "checkout." The method has worked very satisfactorily.

C. NINETEEN-SECTOR BEAM

When the accelerator installation in Sector 3 was completed, BAS II (Beam Analyzing Station II; BAS I is located on Girder #1 in Sector 1) was removed from its location on Girder #1 in Sector 3, rebuilt for higher energy, and installed in place of two of the four accelerator sections on Girder #1 in Sector 20.

The redesign of BAS II allows analysis of beams of up to 3-GeV energy; this makes possible analysis of electrons accelerated by four sectors. The addition of strategically located shielding, plus the 3300-foot separation, has kept the radiation at the Beam Switchyard low enough so that beam operation into BAS II is possible while work is going on in the Beam Switchyard. This has been true even with unanalyzed beams of up to 12 GeV.

On April 20, beam was achieved to Sector 10; April 21 saw beam to BAS II. Since that time, beam operation to BAS II has been almost continuous, for three shifts a day, five days a week, except for the three weeks the beam was sent into the Beam Switchyard. There were also two shifts a week of down time for maintenance and positron source installation.

Nineteen-sector beam operation has become so useful for accelerator physics research that BAS II has become a permanent installation. Easily insertable beam dumps have been installed and the personnel protection system redesigned so that it is a relatively simple matter to switch over from full accelerator to BAS II operation.

D. ENDURANCE RUN

The high cost of klystrons has made it desirable to obtain statistics on klystron life as a function of power level, both peak and average. On April 25, a run was started with the goal of achieving 2000 hours of operating time on the klystrons in 12 sectors. Each pair of sectors in the run was assigned an operating level as follows:

Sectors	VVS Ref. (volts)	Pulse Rate (pps)
3 & 4	114	60
5 & 6	114	360
7 & 8	104	60
13 & 14	104	360
15 & 16	90	60
17 & 18	90	360

Variable voltage system reference voltage was chosen as a parameter because it is easily and quickly readable. The voltages chosen corresponded closely to peak voltages on the klystrons, as follows:

VVS Ref. (volts)	Klystron Peak Pulse Voltage (kilovolts)
114	245
104	228
90	200

Sectors 9 and 10 were added to the run on April 29. These sectors are operating at 104 volts reference and 180 pps.

To achieve the 2000 hours in a reasonable period of time, the accelerator is now being operated three shifts a day, five days a week. By the end of the report period, June 30, 1966, a total average run time (for the original 12 sectors) of 680 hours had been accumulated. This operation, of course, proceeds in parallel with beam operation, either into BAS II, or into the Beam Switchyard. A concerted attempt has been made to hold the endurance run sectors to the specified levels; this has sometimes reduced the flexibility of planned beam experiments.

E. BEAM TO BEAM SWITCHYARD

While the endurance run and beam to BAS II (Sector 20) were proceeding, generally on a five-day, three-shift basis, the Beam Switchyard was being prepared for the acceleration of a 30-sector, high energy beam. Early in the evening, May 20, 1966, turn-on was attempted. Many last minute problems, due largely to the pressures of achieving an almost impossible schedule, delayed operations for several hours; but in the early morning hours of May 21, beam was turned on. By the end of the shift a 9.5-GeV beam had been delivered to the Beam Switchyard and analyzed with the Beam Switchyard spectrum analyzer.

Beam operation to the Beam Switchyard continued until June 11 on a two-shift basis. Between the hours of 0800 to 1700, the Beam Switchyard was open for construction; during the evening and morning shifts beam experiments continued.

On June 11, 30-sector beam operation was terminated and will not resume until the latter half of August. The period will be used for completion of the Beam Switchyard and the End Stations. In the meantime, beam operation to BAS II at the end of Sector 19 has resumed.

X. BEAM SWITCHYARD

A. GENERAL

By the end of the reporting period, the Beam Switchyard housing was completed, the cranes were installed, and all equipment necessary to get the beam to the tune-up dump had been installed. The beam was run to this distance on May 21, 1966, and for several weeks following. Then, after shutdown, work was continued on the completion of the water system for both A- and B-beam lines and on installation of equipment in the lines. Approximately 75% of the work had been done on the B-beam line and approximately 25% on the A line.

B. INSTRUMENTATION AND CONTROL

1. Instruments

During this period all instruments (see review in the Status Report, SLAC 59, March 1966) were completed. They have all been tested and calibrated in the laboratory before installation in the Switchyard housing.

The beam monitors installed on the two instrument stands in the straight-ahead beam functioned successfully during the May 20 to June 10 accelerator-switchyard testing. The monitors involved were the Cerenkov light profile monitor, the current intensity transformer, and the microwave position monitor.

The beam spot definition on the Cerenkov cell was better than 1 millimeter, and the sensitivity about 3×10^{-10} amp. The current transformer sensitivity was 2 volts/ampere and the noise level about 100 μV, so that current pulses down to 5×10^{8} electrons per pulse could be observed easily. The video output from the position monitor has a sensitivity of about 10 millivolts/milliamp-mm with a minimum readable value of approximately 0.3 milliamp-mm.

The energy spectrum monitor located in front of the tune-up dump was used during the run to measure beam energy; its performance was entirely satisfactory. Some initial difficulties were experienced with surface contamination of the ceramic insulators.

The installation of beam monitors on instrument stands in the A- and B-beams is now 80% complete.

2. <u>Magnetic Measurements</u>

With the exception of the probe units, the equipment for measurement of remanent field in critical magnets in the BSY has been completed and installed. Production difficulties have delayed installation of the probe units and only 75% of the probes have been installed.

The variable frequency NMR units have been completed and are installed along the A-beam line; modifications to the control room electronics have proved necessary to solve noise problems. These modifications are still in progress.

The testing of the pulsed magnet field measuring equipment has been delayed until the magnets and power supplies are installed in the Switchyard.

3. <u>Electronics and Controls</u>

a. Beam Current Monitoring System

The control room electronics and local pre-amplifiers associated with the beam current monitoring system were installed and tested. During the accelerator-switchyard test period, the system performance was quite satisfactory. The difference between the monitor in Sector 30 and I-1 was about 10% because no compensation was applied to differences in cable length. The tests also showed that the long video cables must be equalized for frequency response. Design of a compensation network has been started.

Design for the differential current interlock system has been started. The first unit will be completed in September 1966.

b. Beam Position Monitoring System

Position monitors P-1 and P-2 and associated microwave detectors were installed and have been tested. The control room electronics for all Switchyard position monitors is complete.

During the accelerator test period, this system was thoroughly tested. The results were very close to predicted values. The normalized output from the "sector electronics" is useful above 1 mA.

c. Spectrum Instrumentation

The 1% resolution Tune-Up Dump Spectrum Monitor was successfully tested during the initial beam turn-on. Beam spectrum measurements were made for currents as low as 100 μA peak at 10 pps (1.5 mA average current).

The baseband transmission link to send spectrum information to CCR was tested. Some modifications are required to improve the frequency responses of this link.

A modification was made to the spectrum monitor to plot the spectrum on a chart recorder from a single foil by a beam sweeping technique. A final design has been completed for controls in the Data Assembly Building that allow the selection of a sweeping foil from any of the spectrum systems.

The construction of the 0.1% resolution spectrum analyzer electronics is about 90% complete. System checkout is underway.

d. Secondary Emission Monitor Foil Circuits

A one-channel SEM interlock system was installed and checked out. An additional 18 channels are being checked out. During the initial beam tests, reliable linear interlock and beam steering signals were obtained for a current range of 100-μA to 5-mA peak current.

e. Switchyard Control Computer

All interfaces to the Switchyard control computer have been completed, installed and tested, with the exception of that for the pulsed magnets. The latter is being delayed pending delivery of a multiplexer and an analog-to-digital converter.

Magnet Control: Eighteen digital-to-analog converters have been fabricated, tested, and installed in the power supplies to be controlled by the computer. The cross-connects between the cables of these units and the BSY control computer were not completed, but tests have been done to insure that the system will operate properly after the cables are installed.

At the end of June, the computer entered a "shake-down" period, during which minor problems could be corrected and reliability tested.

Slits and Collimator Control: All the necessary (25) chassis required to operate the slits and collimators have been completed and have been individually checked. They were tested as a system on the bench. This system test showed that by either manual or computer operation the slits/collimators motor gear boxes can be controlled to close tolerances on both slow and fast speeds. The slits/collimators control system was used to help adjust the limit-switch settings, and to align the mechanical position counters and the shaft encoders in the motor gear boxes. At the present time the entire system is being installed in the control room. A final test will be given to the system after the installation of the electronics and the motor gear boxes. The final test will involve the computer in real-time closed-loop control.

Interlock and Status Signal Scanner: The interlock-status scanner has been tested. Under program control the computer scans the 1008 signals in 330.75 μsec. Because the interlock-status scanner is interfaced to other systems, in addition to the computer itself, noise problems cause the scanner to print status changes incorrectly. At present, the scanner is being modified slightly to improve noise rejection at the inputs. More tests will be made on the scanner in the immediate future in order to make it a fully reliable system.

f. Interlocks and Status Signals

The Switchyard interlock system has been tested and performed well after only a few minor modifications. The interlock and status signal wiring system has been checked thoroughly.

During the May/June test runs, both the ion chamber and thermometer interlock circuits were tested. The ion chambers were found to be more sensitive than had been anticipated and frequently tripped the beam off. In order to reduce their sensitivity, the input to the detector circuit will be modified and the gas filling of the ion chambers changed from argon to helium.

C. SLITS, COLLIMATORS, DUMPS AND ASSOCIATED HARDWARE

The status of these components will be reported in the Research Area Section of the third period QSR.

XI. RESEARCH AREA OPERATIONS

A nine-month progress report of Research Area Operations work will appear in the next Quarterly Status Report.

XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. EXPERIMENTAL GROUP A

As of June 30, installation of the structures for the three spectrometers was proceeding in End Station A. Considerable schedule difficulties were encountered during the last quarter due to vendor problems with power supplies and magnets, and slippage in the completion of End Station A. Completion of all three spectrometers will now extend into the late fall, but it is still hoped that the delays will not prevent use of the accelerator beam in End Station A.

1. Installation

A time and materials subcontract has been established for the installation of all the spectrometer equipment. Work began immediately on receipt of beneficial occupancy in End Station A. Considerable effort has been expended in the preparation of the rail system to the close tolerances required. This work was almost complete at the end of the quarter. Installation of the structures was just beginning, and electrical installation was about to commence. Approximately 40 time and materials men are involved in this work.

2. Magnets

Magnet-coil procurements continued to slip during this quarter, and to the end of the quarter only one set of coils (for the smallest quadrupole) had been delivered. Steel for the magnets is in better shape, with some problems due to unsatisfactory plates. Magnet assembly and magnetic measurements have not yet begun.

3. Power Supplies

The power supplies have non-standard transformers which have given considerable problems to the vendor, due to excessive corona. Some delays in delivery are anticipated on both the large and small supplies required for the spectrometers. Testing of the larger magnets will be delayed until the large supplies are operational.

4. Structures and Shielding

Much of the 8-GeV structure has been delivered and assembly is underway. The 1.6-GeV structure is complete, except for wheels which are now available. The 20-GeV side girders have encountered some delays in fabrication and are expected near August 1. Shielding block configurations are being designed, and block casting will commence within a couple of weeks.

5. Utilities

Installation is delayed because of the lateness of End Station A. All special materials are on hand and all possible prefabrication is being undertaken to speed assembly.

6. Detectors

The MIT subcontract for producing counters continued through the quarter. The manufacture of the 8-GeV hodoscope is well advanced, and final procurements for the 20-GeV hodoscope and the particle discriminator are being made. It is hoped that workable counter systems can be delivered by September.

7. Electronics, Monitors, etc.

Design is complete on the electronics for reading data into the computer and on the various readout devices. Fabrication has begun on much of the work. The fast electronics (under the MIT subcontract) is under construction and scheduled for delivery in July. Beam monitors are under construction at SLAC and should be ready for beam turn-on.

8. Computer

A real-time tape system, under design for some time, has begun to operate on the 9300 system. Two new tape units were delivered during the quarter, and only the disc remains to be delivered out of the original subcontract. The real-time tape system will be replaced when the disc is delivered, but this is a relatively small change. Software programs for data accumulation and display are being written.

9. Physics

Several experiments have been investigated by the various members of the collaboration. An experiment on the production of asymmetric μ-pairs will be submitted in the near future. An experiment proposed by Christ and Lee on charge conjugation in electromagnetic interactions has been investigated and work will continue on this and other experiments.

B. EXPERIMENTAL GROUP B

1. Analysis

Approximately 4000 measurements of four-prong π^-p interactions at 16 GeV/c have been made, and ionization checks are being made to remove ambiguous fits. A strong signal is seen in the "A" region (mass of $\pi^+\pi^-\pi^-$ between

1.0 - 1.4 GeV) which seems freer of background than previous experiments at lower energy, and so we may be able to determine how much of the enhancement is due to resonances. The measurements represent about 20% of the available data.

Measurement and interpretation on the K^- D interactions at 2.65 GeV/c continue, but the short tracks in Σ events cannot be measured precisely enough to provide unique interpretations. E. Pickup has joined the group for a year and will work on this experiment.

Implementation of the LRL program "MATCH" in our system has encountered a number of bugs owing to details of the chamber coordinate systems. It should be completed this quarter. The rest of the system can now be considered in production.

2. Annihilation Beam

Traversing tables for the detectors are complete, and the special collimators nearly so. Sweeping magnets and stands will be ready by November 1. Lithium Corporation has accepted a contract for the lithium hydride hardener, which should be delivered in September.

The detectors are nearly completed. It is expected to test the "sandwich" counter this month at Mark III.

3. On-Line Computer for Measuring Machines

Design of the interfaces and preparation of wiring lists is complete and wiring should be done this month. The program modifications for our configuration are essentially complete, and come modification of measurement checking routines has been made.

C. EXPERIMENTAL GROUP C

1. Storage Ring Work

a. Magnet Lattice

The Stanford 3-GeV storage ring design has been revised to incorporate long straight sections having very small values of the vertical β-function at their centers. The beam reaches a minimum in vertical dimension in the center of a five-meter-long free space for high-energy detectors. The displacement of the equilibrium orbit for off-momentum particles is zero throughout the experimental regions and is unaffected by adjustments of the interaction-region quadrupoles. The luminosity ranges from 3.7×10^{32} cm^{-2} sec^{-1} at 3 GeV up to 0.9×10^{34} at 1 GeV.

b. Vacuum

(1) Electron Desorption Studies. Electron desorption measurements on pure aluminum continued. The quadrupole mass spectrometer has been incorporated and now makes possible detailed analysis of the gases produced or desorbed during electron bombardment. Recent measurements show that aluminum is similar to the other metals examined in that the principal gases produced during electron bombardment are H_2, CO and CH_4. One difference, however, is that electrons penetrating the surface of aluminum can activate subsurface diffusion of hydrogen with consequent reduced surface desorption rates for this gas. This effect has been measured for electron energies up to 6 kV and will be extended to higher energies.

(2) Aluminum Outgassing Measurements. Outgassing measurements were made with aluminum (1100) sheet stock (≈ 3.5 m^2) with the following results:

Treatment	Outgassing Rate (pico-torr liters/sec/cm^2)
Degreased only and baked at 250° C for 72 hours.	0.36
Exposed to N_2 for 4 hours and pumped for 24 hours.	2.4
Exposed to air for 4 hours and pumped for 24 hours.	3.6

These measurements are being continued with 6061 aluminum alloy sheet stock.

(3) Aluminum to Stainless Steel Transitions. Some of the advantages of aluminum or aluminum alloys as vacuum chamber materials are offset by the problems associated with joining and flanging. Of special interest is the problem of the transition from aluminum to stainless steel.

A number of solutions or transition techniques have been developed commercially, such as roll bonding and co-extrusion. These aluminum to stainless steel "transitions" and flanging techniques are being evaluated, and some of them show promise of having the prerequisite strength and tightness.

(4) Stainless Steel Prototype Vacuum Chamber. Ion-pump speed measurements made seven months apart show little change in pumping speed for the gases N_2, H_2 and CO.

The new large-celled ion pump has been installed and speed measurements will be made to compare the two pumps.

(5) Aluminum Prototype Vacuum Chamber. A 14-foot ext ruded aluminum alloy tube has been received and will be set up to permit measurements of outgassing rates (specie analyzed) and electron desorption rates from large-scale representative surfaces.

c. RF Design

With the revised lattice, the minimum frequency of operation required is now the 34th harmonic of the rotation frequency. We have chosen to design our rf system for this minimum frequency, which is 50 megacycles. The radiation loss is now 563 keV per turn at 3 GeV, requiring 1.13 megawatts to store one ampere each of e^+ and e^-. Allowing 10% for cavity and other losses, there is a requirement of 1.24 megawatts of rf power. For adequate quantum life time, 880-keV peak rf voltage is required at this higher harmonic; this is close to the requirements of the previous lattice. The rf system has been redesigned at 50 megacycles employing a system with six instead of eight accelerating stations. The rf transmitters will each be capable of delivering 210 kilowatts and each cavity of achieving a peak voltage of 210 kilovolts, which is above the 150 kilovolts necessary to store the 3-GeV beams. The new frequency of 50 megacycles makes the cavity proposed in the Berkeley 200-GeV design study attractive to us. The Berkeley cavity consists of two folded quarter-wave cavities with two ceramic sleeves which isolate part of the cavity volume from the vacuum system. The cavity design is in progress with consultations with the Berkeley rf design group.

Two Collins 205G-1 transmitters have been installed and operated at 50 megacycles. By combining the output powers in a diplexer, continuous wave operation at 40 kilowatts has been obtained. This power will be adequate to test prototype cavities at full voltage and power dissipation levels. The quarter-wave test cavity has been modified to operate at the new frequency of 50 megacycles to test the ceramic pieces at high rf voltages.

d. Princeton-Stanford 500-MeV Ring

The installation of the liquid-hydrogen cryogenic pump system has been completed. The system was tested with liquid hydrogen and performed satisfactorily with a hydrogen-loss rate of about three liters per hour.

2. Streamer Chamber Development

One half of a two-compartment chamber that had been designed previously was completed. The compartment size is 100 × 125 × 30 cm. The compartment was tested with our 600-kV (max) pulser. The chamber worked when driven with 500-525 kV pulses between 10 - 15 nsec wide. The tracks were not as good as our smaller chambers, partly because the chamber was still dirty. We have found that clean gas is necessary for good-quality tracks. There should be no leaks in the chamber. Pick-up from the pulsed chamber is severe. Such large chambers should be electrically shielded as completely as possible. The large chamber was driven as a terminated transmission line. We were able to mismatch the chamber by 50% without noticing any difference in the chamber operation. For pulsing systems of the type we use, there seems to be a dividing line at 450 kV above which surface breakdown and operation of gaps in the pulse-shaping section become more difficult to handle. Above 500 kV, very careful design of surfaces and gaps is necessary. For good photography we still need 18 - 20 kV/cm and pulse width ≈ 6 - 8 nsec. In this range streamers can be photographed with an f/1.5 lens and fast film like Kodak 2475 or 340. The brightness of the tracks increases very nearly linearly with pulse length and $\propto V^2$. Unless much higher voltage and very narrow pulse (1 - 2 nsec) is obtained, there is no hope of increasing the brightness any further.

The above indicates that two-compartment chambers with total gap 40 - 50 cm should be easy to handle. Increasing the gap significantly above that is difficult.

3. Photoproduction Experiments

Programming has continued on analysis and display programs for the SDS 9300 computer connected to the spectrometer detection equipment. Most of the analysis subroutine programs involve building histograms for various variables such as momentum, angle, counter number, etc. Some variables may be sorted only if other conditions are met, e.g., sort the momentum variable if a Cerenkov counter pulse height is larger than some threshold cut.

A method has been worked out which allows for any of the histograms stored in memory to be displayed on the oscilloscope, line printer, or calcomp plotter by selecting appropriate codes on thumbwheels. In addition, the histograms may be cleared, scale factors may be changed, and new cuts may be read via typewriter. Automatic scaling factors are also possible and statistical error bars may be displayed. Both one-dimensional and two-dimensional (rotating isometric) displays have been programmed.

The differential freon-13 Cerenkov counter which will be used in the 20-GeV/c spectrometer has been partially assembled. The steel pressure cell has been static tested to 600 psi and is now being fitted out with heaters, mirror mounts, etc. The freon storage tanks have been fabricated and the gas system will be assembled in the next few weeks.

The ϕ and x hodoscope mount has been completed. This mount houses 15 counters for the ϕ hodoscope, 10 counters for the x hodoscope, and 1 master counter. The counter mount is capable of vertical adjustment. Horizontal adjustment will be obtained by moving the whole frame.

Philips XP 1110 (10-stage, 3/4-inch diameter) tubes were tested and found adequate for use in the hodoscope, and more elaborate tests for selection are in progress. Special bases were designed and are under construction. All components for the hodoscope have been procured.

D. EXPERIMENTAL GROUP D

1. Large Streamer Chamber

The $2 \times 1.5 \times 0.6$-meter chamber is being assembled for testing in a shielded room. A Marx-generator-powered Blumlein will be used to drive the chamber.

2. Two-Meter Magnet

The magnet iron has been delivered. The delivery of the coils has been delayed until the end of September.

3. 5.8-Megawatt Power Supply

The power supply should be delivered early in September.

4. Mark III Program

a. Using the small streamer chamber and a tagged photon beam, about 40,000 pictures have been taken of pair and triplet production to study the cross section for the triplet production interaction.

b. Preliminary work has been done using the small streamer chamber and the parasitic electron beam to study the peak end of the bremsstrahlung spectrum.

c. An investigation has been started of the operation of a small streamer chamber with a cylindrical Mylar bag of hydrogen used as the target for a pencil electron or photon beam. Backgrounds seem as predicted at the 200 Q per pulse level postulated for the large chamber.

5. Experiment on Trident Production (at Orsay)

An experiment has been performed investigating the cross section for trident production. This experiment was done at the Orsay linear electron accelerator at 500 MeV using the triple-focusing spectrometer. This experiment explores a calculable (but incompletely calculated) electrodynamic process at low momentum transfer. Preliminary analysis indicates an absolute precision of 2 - 3%, roughly one order of magnitude better than previous experiments on the trident process.

E. EXPERIMENTAL GROUP E

1. Experiments Being Analyzed

(1) The first part of the 1- to 6-GeV neutron-proton elastic scattering experiment has been completed. Results based on 15% of the pictures were published in Physical Review Letters 16, 1217 (1966). The remaining 85% of the pictures are now being analyzed so that more detailed information, particularly on the large-angle scattering, can be obtained (M. Kreisler, F. Martin, M. Perl).

(2) The measurements of strange-particle events in the 6-GeV/c proton-proton exposure in the 72-inch Lawrence Radiation Laboratory chamber have been concluded. Theoretical studies of the results are now being made. The scanning and measurement of non-strange particle events has begun (J. Brown, F. Martin, M. Perl, T. H. Tan).

(3) Analysis of K^--deuterium interactions in the 72-inch Lawrence Radiation Laboratory chamber is continuing.

(4) Analysis of proton-antiproton annihilation events obtained in spark chambers at Brookhaven AGS is continuing (T. Zipf).

(5) Analysis of the 16-GeV/c π^- + p interactions in the 80-inch Brookhaven National Laboratory hydrogen bubble chamber is continuing (T. H. Tan, F. Martin, M. Perl).

2. Experiments Under Design and Construction

(1) A muon + proton elastic and inelastic experiment at SLAC (J. Brown, J. Cox, M. Perl, W. T. Toner, T. Zipf).

(2) An experiment to search for new particles at SLAC (A. Barna, J. Cox, F. Martin, M. Perl, W. T. Toner, T. Zipf).

(3) A large spark-chamber magnet (L. Cooper, T. Zipf).

(4) A neutron-proton elastic scattering experiment at 8- to 25-GeV/c to be carried out at the AGS of the Brookhaven National Laboratory. Spark chambers will be used. (M. Kreisler, J. Cox, W. T. Toner, T. Zipf, M. Perl).

3. Publications

A. Barna, M. Kreisler and M. Longo (U. of Michigan), "Electroluminescent Panels as Pulsed Fiducial Marks in Spark-Chamber Experiment," Rev. Sci. Instr. 37, 4 (1966).

F. EXPERIMENTAL GROUP F

Coils for the 1.6-GeV/c spectrometer are being wound and the iron is being machined. The support structure has been erected and is ready to receive the spectrometer. The design of the shielding is completed.

The design for the hodoscope and scintillation counters is complete and the counters are being fabricated. Design of a high-pressure Cerenkov counter is near completion. A large thin mirror for this counter is being built.

A time-of-flight system to be used with the 1.6-GeV/c spectrometer is being designed.

A hydrogen target to be used in End Station A is being fabricated. Tests on the effects of high beam currents on thin windows are being made.

G. 40-INCH HYDROGEN BUBBLE CHAMBER

A six-month review of this group's work will appear in the next Quarterly Status Report.

H. PHYSICAL ELECTRONICS

1. Relativistic Rise Detector Study (SLAC)

Pulsed gain measurements have been continued on low density CsI and KCl. As reported in the previous report, KCl was observed to break down at low values of collector potential as with a dc bombarding current, whereas CsI did not exhibit breakdown to much higher collector potentials. Initially this was believed to be an inherent difference between KCl and CsI, but additional data has revealed that it is related to the thickness of the dynode. That is, thin dynodes seem to be able to acquire an equilibrium exit surface charge below that causing breakdown but sufficient to yield enhanced pulsed gain. Results for KCl and CsI have been very similar, but CsI has shown consistently higher gains.

More data has been taken on the energy distribution of the secondary electrons to delineate those parameters which determine the limiting exit surface potential, V_m. [As discussed in the previous report, V_m is the collector potential above which the most probable secondary electron energy increases linearly (with a slope of one) with the collector potential.] V_m has been found to be dependent on dynode thickness, primary energy, and dynode-to-collector spacing. At present it is believed that this reflects a dependence of V_m on the state of ionization near the exit surface (that is, on the gain), but why there should be a V_m is not understood at this time.

Some difficulties have been encountered in the construction of an electron multiplier tube with four or five transmission-type dynode stages. Recently we have been unable to transfer thin, low-density CsI dynodes with a gain greater than that of the bulk material to small bakeable vacuum systems. This difficulty is believed to be associated with the slightly higher bakeout temperatures being employed (225° C as opposed to ≈150° C); this possibility will be checked early next quarter. Considerable difficulty has been experienced in obtaining a suitable substrate for a multiplier tube. It is believed that the standard 1000 Å of Al_2O_3 overlayed with 500 Å of Al substrates employed thus far would necessitate too high an overall tube voltage, $\gtrsim$ 8 keV/stage; thus time is being devoted to fabricating a 500-Å Al_2O_3 substrate which will be overlayed with ≈300 Å of Al .

As a "first generation" of direct particle detectors, we have supplied a low-density CsI dynode (≈ 5% of the bulk density) to La Radiotechnique of France, which is fabricating a multiplier tube to be tested by Dr. L. Yuan at Brookhaven, in a SLAC-BNL collaboration. The dynode supplied by SLAC is to be used to convert relativistic particles to low energy secondary electrons at the input to a standard multiplier structure (56 AVP). The operation and statistics of this tube will be of interest to SLAC and measurements on it are planned here using the single electron pulses available at the Mark III accelerator.

An investigation has been started to see if other alkali halides can be easily fabricated in low-density form. NaBr, CsCl and CsBr are being studied since they have the highest secondary yield in bulk-density form of the alkali halides. Low-density NaBr and CsCl have been prepared which exhibit field enhanced gain, but the gain has been found to be lower than for the KCl and CsI dynodes already in use.

The tube to measure the statistics of secondary emission is still under construction. If all goes well, data should be available next quarter.

2. Development of a "Gridless" Multiplier Structure (DBM)

In addition to the pulsed gain measurements and the multiplier tube reported above, the overlayer study discussed in the previous report was continued. $\begin{Bmatrix} Al \\ Au \end{Bmatrix}$-KCl (bulk density)-$\begin{Bmatrix} Al \\ Au \end{Bmatrix}$ "sandwiches" were successfully fabricated on pyrex, as well as on 1000-Å Al_2O_3 substrates. The gain in transmission of the overlayed bulk-density dynode was found to be ≈ 1 (that is, characteristic of the metal overlayer). Work on fabricating low-density dynodes with overlayers has begun.

I. MAGNET RESEARCH

1. Water-Cooled Magnets

a. Positron Source Magnets

After considerable difficulties with the casing's ground insulation, a method was successfully used to spray epoxy on the inner surfaces of the coil casings in contact with water. All parts are at SLAC and the uniform-field section is installed. The high-field edge-cooled section will be installed in the near future.

b. The SLAC Computer Program, NUTCRACKER

Further work on the program, code modification, and language translation from ALGOL to FORTRAN is in progress. No work on three-dimensional iron configuration has yet been started.

2. Superconducting Magnet Research

a. 12-Inch Bore, 70-kG Superconducting Magnet

The 40-inch-diameter, 12-foot dewar is in the procurement stage. The vacuum tank, the helium jacket, and the flanges have been built. It is expected that the dewar will be ready for testing in August 1966. The winding form for the magnet is completed. The winding machine, the impregnation materials, and the wrapping tools are in the procurement stage. The wire and cable testing have been performed up to fields of 93 kG using the water-cooled magnets of the MIT National Magnet Laboratory. No size effect in the usual sense could be measured. However, the current-carrying capacity of the AI cables dropped considerably at fields above 80 kG. Part of this deficiency has been corrected in the meantime.

b. Change of Location from Stanford Campus to Site

Beginning in June 1966, the Cryogenics Building at SLAC was near enough completion so that the move from the Stanford campus to the Cryogenics Building was possible. It is anticipated that by the end of August full operation can be started.

3. Publications

(1) H. Brechna, L. R. Anderson, E. A. Burfine, "A Computer Code for Variable Permeability Magnetostatic Field Problems," SLAC Report No. 56, Stanford Linear Accelerator Center, Stanford, California.

(2) H. Brechna, "A High Field 1.3m Superconducting Split Coil Magnet with Forced Liquid Helium Cooling," presented at Superconductivity Conference, Zurich, May 17-18, 1966, sponsored by the Swiss Electrical Engineering Society, SEV (SLAC-PUB-182).

J. THEORETICAL PHYSICS

1. M. Nauenberg and M. A. Ruderman, "Antimatter in the Earth's Atmosphere," Phys. Letters 22 (No. 4), 512 (1966).

2. S. D. Drell and J. D. Sullivan, "Polarizability Contribution to the Hydrogen Hyperfine Structure," SLAC-PUB-204 (submitted to the Physical Review).

3. T. Osborn and H. P. Noyes, "Reduction of the Finite-Range Three-Body Problem to Two Variables," Phys. Rev. Letters 17, 215 (1966) (SLAC-PUB-189).

4. M. Bander, "Solution of the Beam Break-Up Equation," SLAC Internal Report, TN-66-28.

5. J. S. Trefil, "Random Phase K-Matrix Approach to Absorption in Peripheral Interactions," SLAC-PUB-169 (to be published in the Physical Review).

6. Y. S. Tsai, "Estimates of Secondary Beam Yields at SLAC," Section D.3 of the SLAC User's Handbook.

The subject matter of Items 1 and 2 has been reported previously. Reduction of the Faddeev equations to two continuous variables has been verified.[3] This yields coupled integral equations with 3 [for the Faddeev channels] × (L + 1) [for the number of orbital states included in the two-particle subchannels] × min (2J + 1, 2L + 1) [for the magnetic quantum number coming from the projection of one angular momentum on the other] functions. It has further been shown that all the singularities (bound states and resonances) of the three-body system are confined to the energy variable E, while those of the two-body subsystems occur only in the individual particle energies e_i. This should allow a much more detailed understanding of the analytical structure of the amplitudes than was possible prior to the reduction. It is believed that the equations can be further simplified to allow the calculation of real amplitudes in terms of principal-value integrals, and that the principal-value singularities can be completely removed. If this is true, exact numerical solutions for simple three-body models should soon be achieved.

The equation governing the break-up of the beam at SLAC has been solved in terms of a rapidly convergent series.[4]

Electromagnetic form factors $F(q^2)$ of bound systems of two or three particles have been examined in the limit of high q^2. For repulsive core forces in the form $V \propto r^{-2(1+p)}$ it is found that

$$F \approx P(q) \exp\left[-q\, p/(1+p)\right] \sin\left[q\, p/(1+P)\right]$$

where P is a polynomial. For p = 1 reasonable agreement with unpublished data on the deuteron form factors is obtained.

Work is nearing completion of the calculation of the muon g-2 to order $\approx (5\text{-}10) \times (\alpha/\pi)^3$. It has been found that the electrodynamic terms do not contribute to this order, but that both strong and weak interaction effects can be seen.

A small-angle, high-energy approximation to the positron-electron bremsstrahlung cross section has been successfully carried out, beginning with Swanson's exact integration of the principal diagrams. The result yields improvement of better than 10% over the two previously published expressions. Increased accuracy is due to the including of neglected logarithmic dependences, and of further non-logarithmic terms of significance.

An improved absorption model for intermediate and high energy processes has been developed and applied to various two-particle scattering processes.[5]

The best currently available estimates, with due qualifications as to their reliability, of secondary beam yields to be expected at SLAC have been completed and published in the User's Handbook.[6]

K. COMPUTATION GROUP

1. Control Programming Projects

The main effort in the past quarter has been directed toward assimilating and debugging SDS-provided systems software for the SDS 9300 computer for the spectrometer facility. In particular the Real-Time Tape Monitor system (RTTM) which has been provided as an interim system until the SDS disc and Disc Monitor system are delivered. The inevitable difficulties with any new system have been encountered and most overcome.

As of July 1, a minimal SPECTRE system is operational, using magnetic tape for the system library program. A number of the program library segments have been written, including some physics analysis and display routines.

Work is continuing on the development of the SLAC system for the control of manual film measuring machines. An ASI 6020 computer is scheduled for delivery in August 1966. The programming system will be an adaption of the BUCAPS system of the University of Chicago, modified to the SLAC equipment configuration and operation requirements.

The Beam Switchyard computer (SDS 925) was used to check out various parts of the BSY instrumentation last quarter (the interlocks and magnet controls). Also it was used almost exclusively to compute and set the magnet current for beam experiments performed in May-June. The program is now able to read in and log data (magnet currents, slit positions, and $\int B d\ell$ from a flip coil in the reference 3° bending magnet located in the Data Assembly Building). Work is continuing (on both the programs and computer interface hardware) to provide (1) automatic degaussing of magnets, (2) a computer link with the spectrometer computer (SDS 9300), (3) crash-proof operation for long periods of time.

A primitive system has been developed for the digitizing of film on-line to the Model 50, putting the raw digitizings on FORTRAN-compatible tape and also allowing for their display on the 2250 display unit. Elementary I/O subroutines were written to drive the display unit and also the 2701 control unit through which data is passed and accepted to and from the scanner.

Automatic scanning of spark chamber film has been continued, and the programming support is nearing completion, the debugging phase having already been started.

2. Programming Systems

Work continues on the SLAC Computer Program Library which is being expanded to include programs for the IBM System/360 Model 50 and SDS 9300.

A system to handle arithmetic error conditions arising from both hardware and software on the Model 50 has been proposed and programmed for FORTRAN IV.

A project to study the floating-point feature of the IBM System/360 machines and to recommend possible changes has been started. A preliminary report has been written.

The study of numerical integration techniques continues with attention centered on adaptive methods and gaussian quadrature.

Several machine-language subroutines have been coded for FORTRAN users which will perform a variety of logical shifts and arithmetic operations. A study of the distribution of divisors of Mersenne numbers over a large range is in progress.

3. Application Programs

The beam transport system for the proposed 3-GeV storage ring has been updated. The magnet cell structure was redesigned. Further modifications in the design are currently being studied with the help of the TRANSPORT program.

The results of beam calculations done chiefly in the first quarter of 1966 have been published in the SLAC User's Handbook.

Three new programs for the reduction and analysis of electron-electron scattering data have been started. The first program reduces data from the Princeton scanning table to a form which is input to the analysis programs. The second computes the expected angular distribution, and the third computes maximum likelihood.

4. Central Computing Facility Planning

During this quarter considerable progress has been made in planning for the SLAC central computing facility, as a joint effort of the Stanford Computation

Center and SLAC. Progress has been made in the following areas:

(1) Analysis of SLAC computational needs and evaluation of proposals from computer manufacturers for the large computer system. A number of alternate proposals for initial configurations of equipment from each manufacturer were carefully considered, their technical feasibility being weighed against the availability of funds for the procurement. The magnitude of the initial outlay for the central computer and significant price increases by the manufacturers hindered the definition of configurations to satisfy conflicting budgetary, operational, and computational requirements. It is anticipated that the acquisition will take place in several phases. The configurations for the equipment to be installed after the first phase represent our best current guess, but are likely to undergo further modification as the SLAC computation needs develop over the next year.

(2) Physical planning for computer site. The space, air conditioning, and power requirements for the central computer were investigated. Considerable planning in this area will be required after the computer selection has been made.

(3) Design of software system. Briefly, three modes of operation of the central facility are envisaged: batch processing, real-time processing, and on-line consoles for program development and for direct man-machine interaction. Initial planning has been done for a remote programming console system to be available as soon as possible after the initial configuration arrives at SLAC. Considerable time has been devoted to studying the manufacturer's system and attempting to match it to the general needs of SLAC. This study has been hampered by inadequacies in the documentation of their programming systems and by continued uncertainty of delivery dates for important software items. It is to be hoped that once a contract has been signed for a particular computer, the manufacturer involved will give SLAC more aid and support in the area of documentation and explanation of their programming systems.

(4) Preliminary study of the restructuring of application programs to utilize new computer systems. Consideration has been given to the restructuring of bubble chamber and spark chamber data reduction codes to use direct access storage devices and on-line access techniques. The aim is to speed up the processing of events, to reduce the personnel overhead for computer operations, and to keep the experimental physicists in more immediate contact with the processing of their data.

(5) The design of tools for program development. Consideration is being given to the development of a higher level language suitable for systems programming. It is anticipated that this development will require a year or more and that considerable systems programming will have to be done before the language is developed and implemented. Therefore, investigation is proceeding on the suitability of FORTRAN and/or PL/I as an interim higher level language for systems programming. An effort will be made to do all systems programming from the beginning in one of these higher level languages.

As a first step toward the development of the ultimate system programming language an experimental top-down syntax-directed compiler has been produced. The resulting model, written in FORTRAN, runs on an IBM 360/50.

5. Agreement with Stanford Computation Center

An agreement has been negotiated between SLAC and the Stanford University Computation Center under which the latter organization will operate the central SLAC computing facility. The agreement has been approved by the AEC and became effective July 1, 1966. The result is to create an organization known as the SLAC Computing Facility of the Stanford Computation Center. Mr. Robert T. Braden, Associate Director of the Stanford Computation Center, has been appointed the manager of the SLAC Computing Facility. Mr. Braden's group will be responsible for the operation, system maintenance, and system programming for the central SLAC facility. It is expected that his group will work in close collaboration with the SLAC Computation Group, and that the two groups will be housed in the same building. The Computation Group will continue to be responsible for general applications programming, including such topics as numerical analysis and control programming for on-line devices and peripheral computers. There is every indication that the resulting collaboration will be exceedingly productive for the effective utilization of SLAC's computer resources, and for development of new modes of computer operation—for example, real-time and time-sharing.

6. Publications

Brown, Richard M., "Characteristics of Small Computer Systems for On-Line Applications," to be published in Proceedings of Conference on Use of Computers in Analysis of Experimental Data and Control of Nuclear Facilities, Argonne National Laboratory, May 1966 (SLAC-PUB-191).

Brown, Richard M., "Desirable Characteristics and Features of On-Line Computers," TN-66-25, May 1966.

Burfine, Edward A., "LINGO, A Dynamic Syntax Directed Compiler," submitted to Communications of the ACM (SLAC-PUB-198).

Miller, William F., "Data Analysis Now and Thence," to be published in Proceedings of the Conference on Use of Computers in Analysis of Experimental Data and Control of Nuclear Facilities, Argonne National Laboratory, May 1966.

Whitis, Van S. (with Y.S. Tsai), "Thick Target Brensstrahlung and Target Considerations for Secondary Particle Production by Electrons," to be published in Physical Review (SLAC-PUB-184).

L. AUTOMATIC DATA ANALYSIS

During this quarter the Hummingbird CRT film digitizer was connected on-line to the IBM 360/50 computer. Transmission of data and commands was checked out on a bit-by-bit basis; no insoluble problems were encountered.

Due to the different limitations of the two available systems on the 360/50 (the Basic Programming System, or BPS, and the Operating System, or OS), the decision has been made to split the software package into two pieces temporarily. One, which controls the scanner and can output the returned data on tape, printer, or display scope, will run under BPS. Much of this program has been completed. The second piece, which performs the actual analysis of the digitizings from the colliding beam experiment film, will run under OS. Most of this analysis program has been written. Integration and debugging of the subroutine components is expected in the next quarter. This debugging will be considerably simplified by the use of a simulation program which has been written. This program produces fairly realistic data in precisely the format that will be obtained when we digitize real film (which is not yet available) on the scanner.

M. HEALTH PHYSICS

The Research Area monitoring system has been completed and tested with a prototype tissue-equivalent chamber. The remaining chambers are being built. Installation of the complete system will probably be limited by cable procurement, but several stations will be in operation by beam turn-on.

The portable gamma monitors have been delayed by procurement problems. Most of the remainder (45) will not be ready for testing and calibration before September 1. Arrangements have been made to borrow survey meters, if necessary, and some antique but operable units have been obtained from surplus.

Air monitors have been received and installation is proceeding. Meteorological studies are being carried out and some atmospheric diffusion studies have been made. We have been operating a borrowed meterology station on the East survey tower. These studies will be completed in July and sufficient meteorology equipment purchased and installed in Central Control to permit venting decisions by the operator.

We are studying several commercial systems for measuring tritium in air (both HTO and HT) and in water. Some ion chambers are on hand for making measurements on a sample basis, and arrangements have been made to use equipment on campus for water measurements. Better and faster equipment is needed, however, to handle our range of problems.

Quarterly reports to the Water Pollution Board will start as of July 1, with the first report covering sampling techniques and all data up to then. The normal activity in our wells has been found to cover a range of two orders of magnitude with the highest activity being of the order of 10% of the MPC (Maximum Permissible Concentration).

A set of muon flux calculations was made and used in designing the central beam shielding. Some measurements were made which verified the calculations. Assistance was given to other groups on shielding problems in the End Stations also.

At the request of Group C, we measured the fast neutron attenuation in lead and obtained an attenuation length of 48 cm. Investigation has been started to provide high dose measurement capabilities. This is primarily for use in radiation damage studies, prediction of accelerator component life, etc.

In conjunction with Batelle Northwest Laboratory, an experiment was performed at Mark III to determine the activation of an irradiated man. A chemically correct phantom man with a skeleton was irradiated near a collimator and spectral measurements were made in a whole body counter. The spectrum and half life observed indicated almost entirely C^{11} production. This will enable a rough but fast dose estimation on a person caught in the accelerator housing during operation.

SLAC-PUB-197
May 1966

Electrons Accelerated to 10-20 GeV Range

The first full-length operation of the
Stanford two-mile linear electron
accelerator is reported.

by the Technical Staff of the Stanford Linear Accelerator Center

(Submitted to "Science.")

Introduction

On May 21, 1966, electrons were accelerated for the first time through the full length of the Stanford Two-Mile Linear Electron Accelerator. Construction of this machine had begun in April, 1962. Beam operation with the first two sectors (each sector 333 feet long) had initially taken place on January 3, 1965 and operation with 2/3 of the machine (6700 feet) started on April 21, 1966. The design objective of this machine is to accelerate a maximum electron current of 30 microamperes average to an energy of 20 GeV. Detailed design characteristics of the accelerator can be found elsewhere.[1]

During the first full length operation, an energy of about 10 GeV was obtained with 24 out of the 30 sectors contributing energy but operating at reduced power levels. Subsequently, during the two runs scheduled since that date, the energy has been increased to 16.4 GeV by activating 208 out of the total of 245 klystrons, by improving the phasing adjustments, and by increasing the peak power of the klystrons. Higher energy operation will be approached cautiously until more experience with component life has been obtained.

Overall Accelerator Performance

Overall accelerator performance to date has been good. Energy measurements have shown that the design goal of 20 GeV should easily be met. The attainable intensity is at present limited to about one half the design value of 30 microamperes by the "beam break-up" limit discussed below. Corrective measures are under investigation. Below the beam break-up threshold, at least 90% of the beam measured at a monitor 30 feet from the injector is transmitted through the entire length of the machine. At a pulse repetition rate of 360 pulses per second and a pulse length of 1.5 microseconds, a peak current of 10 ma corresponds to an average current of 5.4 microamperes. When operating klystrons at a conservative output power of 15 Mw peak, the stability of the machine has been very good. In the absence of any major changes in operating conditions, it has been possible to turn off the beam and re-establish it several hours later without retuning. The automatic phasing system which uses the electron beam as a phase reference has functioned well. Typical energy spectra with and without beam loading such as shown in Fig. 1 have exhibited spectrum widths at half maximum of less than 1%. Microwave beam position monitors located at the end of each sector have indicated the transverse beam location with respect to the accelerator axis within $\pm$ 0.5 mm. Their use has greatly facilitated the functions of steering and focusing the beam along the machine. These functions have been further aided by the use of a two-mile long, argon filled, coaxial line installed along the accelerator. This line works as a continuous ionization chamber and enables the operator to detect beam losses and from the times of arrival of the ionization signals to resolve their location within one to two hundred feet. The capability of the laser alignment system to read out remotely the accelerator transverse coordinates to an accuracy of $\pm$ 0.010 inch has been demonstrated. Preliminary experiments with inter-laced beams such as that illustrated in Fig. 2 have demonstrated the feasibility of transmitting beams of different energies, intensities, and pulse lengths through the accelerator. These beams can then be separated in the beam switchyard for experimental purposes.

Life tests on accelerator components including klystrons are in progress. In accordance with design, such tests and the associated maintenance and repairs are being carried out without interrupting beam operations.

Beam Dynamics and Beam Break-Up

Considerable testing time has gone into beam dynamics studies. The bunch length at the 30-foot point has been measured to be $\approx 5^{\circ}$ of the operating frequency (2856 MHz). The transverse phase space at the injector has been calculated by measuring the beam diameter at two positions, for one of which the beam has been focused to minimum spot size. The phase space is given approximately by the product of the beam diameter at the beam minimum times the angular divergence of the beam. This divergence can be inferred from the beam diameter at the second position. Eighty percent of the injected current was found in a phase space of 1.2×10^{-2} (MeV/c · cm) (expressed as a product integral of the transverse momentum in units of MeV/c and the beam displacement in centimeters). This transverse phase space should be conserved along the whole machine up to currents where the phenomenon of beam break-up sets in. Below beam break-up threshold, the beam diameter was observed visually at a final energy of 16 GeV to be less than 1/8 inch and showed a negligible spread in 480 feet, the distance between two viewing points using argon-filled Cerenkov cells after the end of the accelerator.

Beam break-up (BBU) manifests itself through a progressive shortening of the transmitted beam pulse when a certain combination of peak beam current and accelerator length is exceeded. Among other extensive measurements, data have been taken with the beam accelerated to 600 MeV through the first 333 foot sector and then permitted to coast through the remainder of the accelerator; these are shown in Fig. 3. As the number of activated sectors increases, the current which can be accelerated without BBU also increases; the measurements indicate that about 25 ma can be accelerated at full gradient to the end of the accelerator, corresponding to an average current of 14 microamperes at the full 360 pulse-per-second repetition rate. Focusing adjustments have only small effects on the BBU threshold.

The observed phenomenon of beam break-up, while undoubtedly related to the excitation of the higher order TM_{11}-like deflecting mode, appears to be somewhat different from similar effects reported earlier[2] in other linear accelerators. In short machines with similar design parameters, BBU occurs typically over a 10-foot length for peak currents of $\approx$ 300 mA in uniform structures and $\approx$ 600 mA in constant gradient tapered structures. In a multiple section machine, it appears that the transmitted beam can successively interact with this higher order transverse mode in each of the 960 accelerator sections. Subsequent bunches in the beam undergo transverse modulation while passing through the sections. This modulation is carried to the following sections resulting in progressively higher excitation. The next portion of the beam entering the accelerator finds each section already pre-excited in this transverse mode and the progressive build-up from section to section therefore proceeds from a higher value. For these reasons, the transverse modulation of the beam will in general increase exponentially both in time and with distance along the accelerator and the onset of BBU will occur at much lower current than in short machines. It had been expected that the non-uniform accelerator structure arising from the constant-gradient design adopted for the two-mile accelerator would prevent this difficulty. It now appears that the use of this structure has served to reduce but not to eliminate the break-up problem. The action described is the transverse analogy to the amplification of longtudinal bunching in a multi-cavity klystron.

RF measurements performed by means of a variety of coaxial and waveguide probes reveal that the onset of break-up is associated with the presence of transverse beam modulation at 4140 MHz. This frequency corresponds to the π-mode of the input end of each constant gradient accelerator section in the TM_{11} mode. A second frequency of 4428 MHz is also observed; it is simply a "beat note" of 4140 MHz with the third harmonic of the accelerator frequency, 2856 MHz. Self-excited break-up invariably seems to occur in the vertical direction, at 90^o with the waveguide couplers. It has also been possible to lower the threshold current for BBU artificially by injecting a few milliwatts of 4140 MHz or 4428 MHz rf power into an early 10-foot section of the accelerator. Experimental and analytic work is underway, aimed at gaining an understanding of the mechanism of transverse modulation build-up from noise and to test alternate corrective measures.

Detailed Energy Measurements

Both cumulative and incremental energy measurements have been made over two-thirds of the length and over the full length of the machine to verify the relation between energy gain and radiofrequency power input to the accelerator.

For a constant gradient structure with negligible beam loading, the energy gain V in a length ℓ having a shunt impedance r per unit length is given by

$$V = (1 - e^{-2\tau})^{\frac{1}{2}} (P\ell r)^{\frac{1}{2}}$$

where P is the rf peak power input and τ is the net attenuation of the structure in nepers. In the SLAC accelerator, $\tau = 0.57$, $\ell = 305$ cm, and r = 53 megohms per meter. Using these values and correcting for the power loss of 0.54 ± 0.1 dB in the waveguide system between the klystrons and the accelerator, one obtains the energy gain per klystron, each feeding a power P into four ten-foot accelerator sections, of

$$V_{MeV} = 19.9 \sqrt{P_{MW}} .$$

For the highest energy run to date (16.4 GeV), the sum of the square roots of all the power inputs from the 208 contributing klystrons was 840 $(MW)^{\frac{1}{2}}$. Thus, the measured constant in the above equation of 19.5 is in reasonable agreement with the theoretical value.

Further Plans

Accelerator test runs will continue for about three months while construction of the beam switchyard and the experimental areas is progressing. After survey experiments on secondary beam production, a scheduled program in elementary particle physics will begin by late fall 1966.

Footnotes

1. See e.g., R. Borghi, A. Eldredge, G. Loew, and R. Neal, "Design and Fabrication of the Accelerating Structure for the Stanford Two-Mile Accelerator," Stanford Linear Accelerator Center, Stanford, California, SLAC-PUB-71, (January 1965) (to be published in Advances In Microwaves, Academic Press, Inc., New York, N.Y.); or J. Ballam, G. Loew, and R. Neal, Proceedings of the Fifth International Conference on High Energy Accelerators, Frascati, Italy, September 9-16, 1965.
2. See e.g., T. R. Jarvis, G. Saxon, and M. C. Crowley-Milling, Proc. IEE 112, 1795 (1965).

FIGURE LIST FOR SLAC ARTICLE FOR JUNE 3rd ISSUE OF "SCIENCE"

Fig. 1--Typical energy spectra measured at end of accelerator with and without beam loading. Width at half maximum was measured at 1.33% with 0.9% attributable to experimental resolution.

Fig. 2--Energy spectra of two interlaced beams displaced in time by 1/120 second, each beam operating at 60 pulses per second with 8 ma peak current. (Measured with beam through two-thirds of the accelerator.)

Fig. 3--Fore-shortened pulse length, t_B, after beam break-up as a function of peak current, I_p. The sector number where break-up is observed is shown as a parameter; the distance from the injector is 333 feet times the sector number. Low energy beam used to permit extended range of parameters.

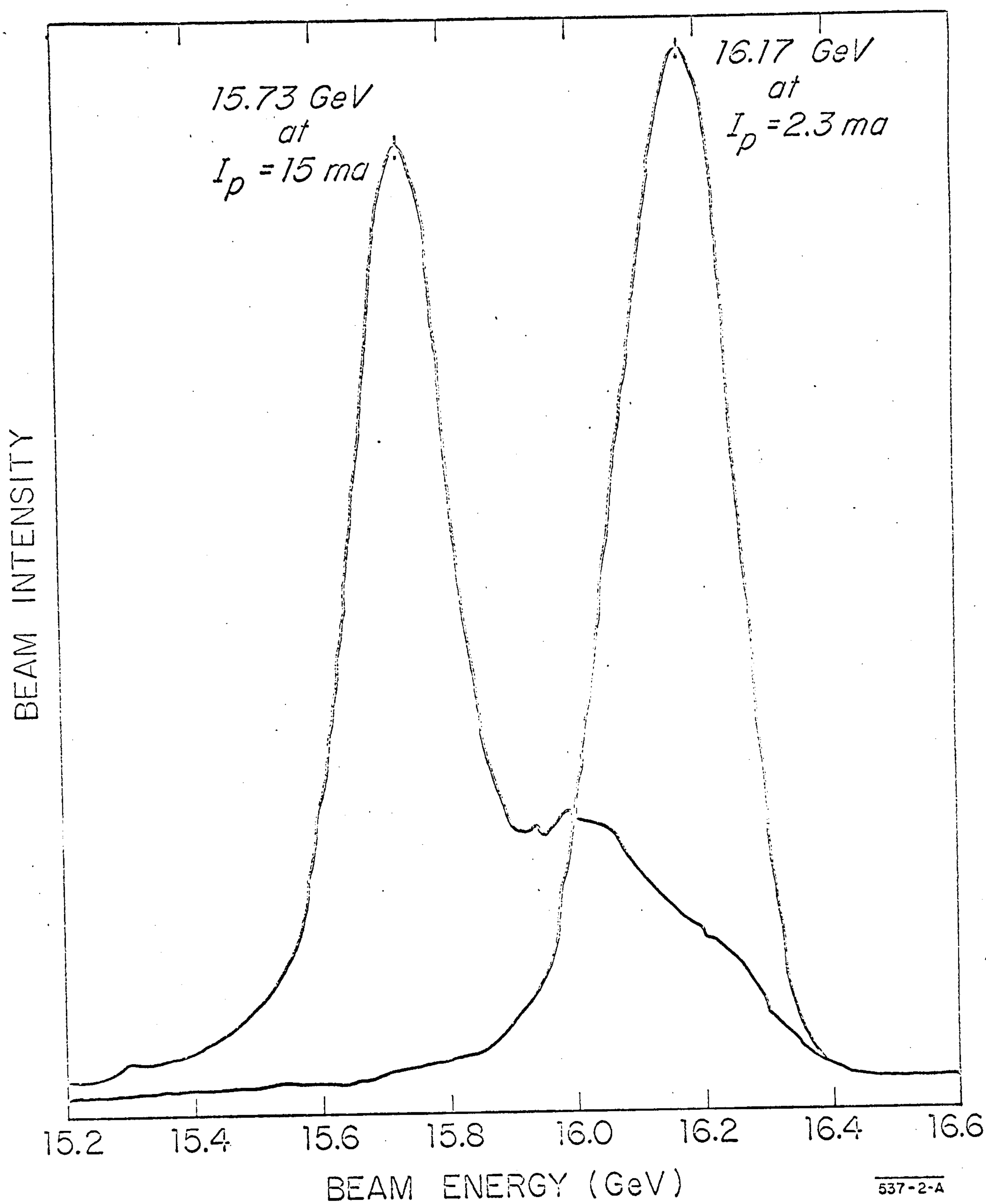

15.73 GeV
at
I_p = 15 ma
16.17 GeV
at
I_p = 2.3 ma
BEAM INTENSITY
15.2
15.4
15.6
15.8
16.0
16.2
16.4
16.6
BEAM ENERGY (GeV)
537-2-A

Figure 1

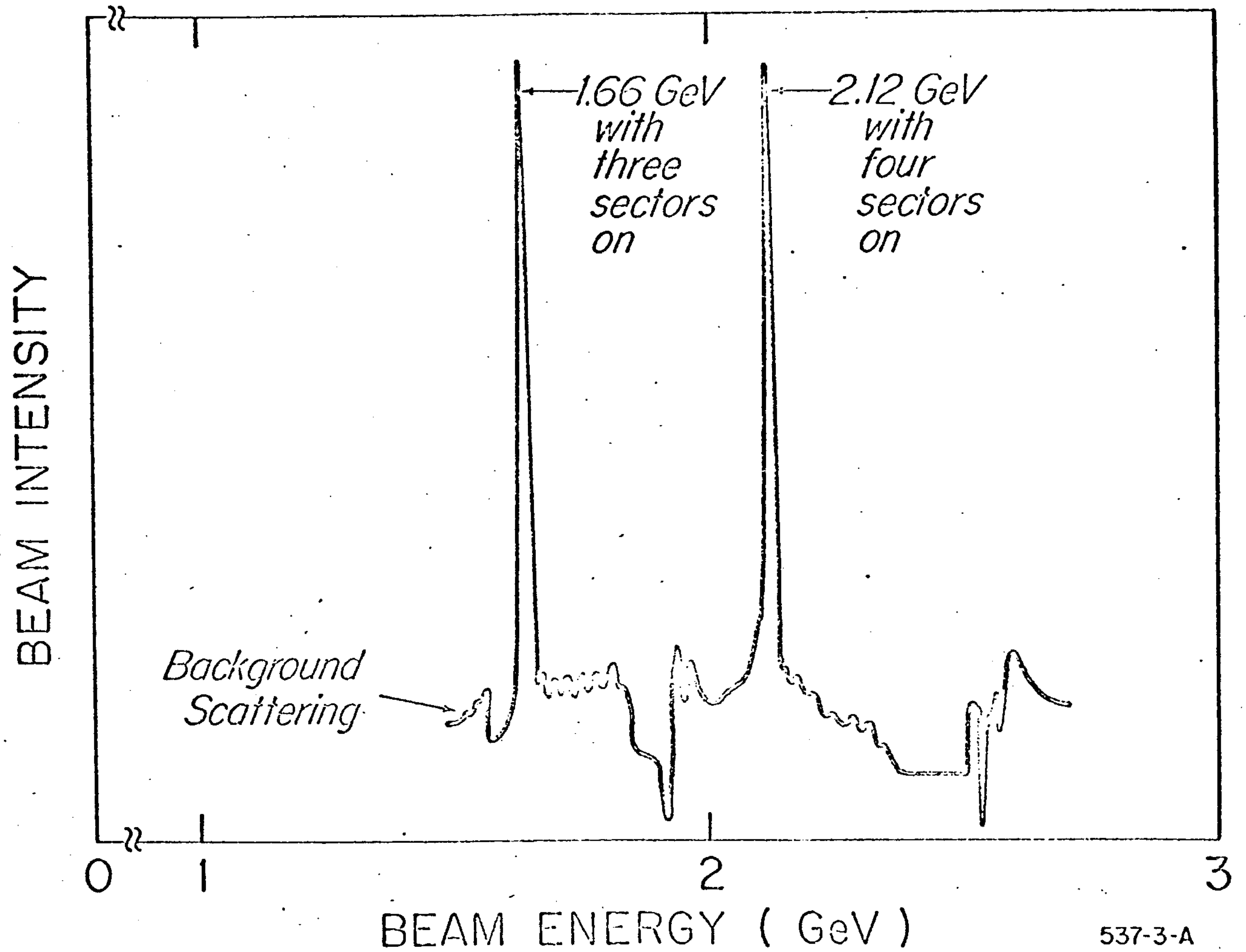
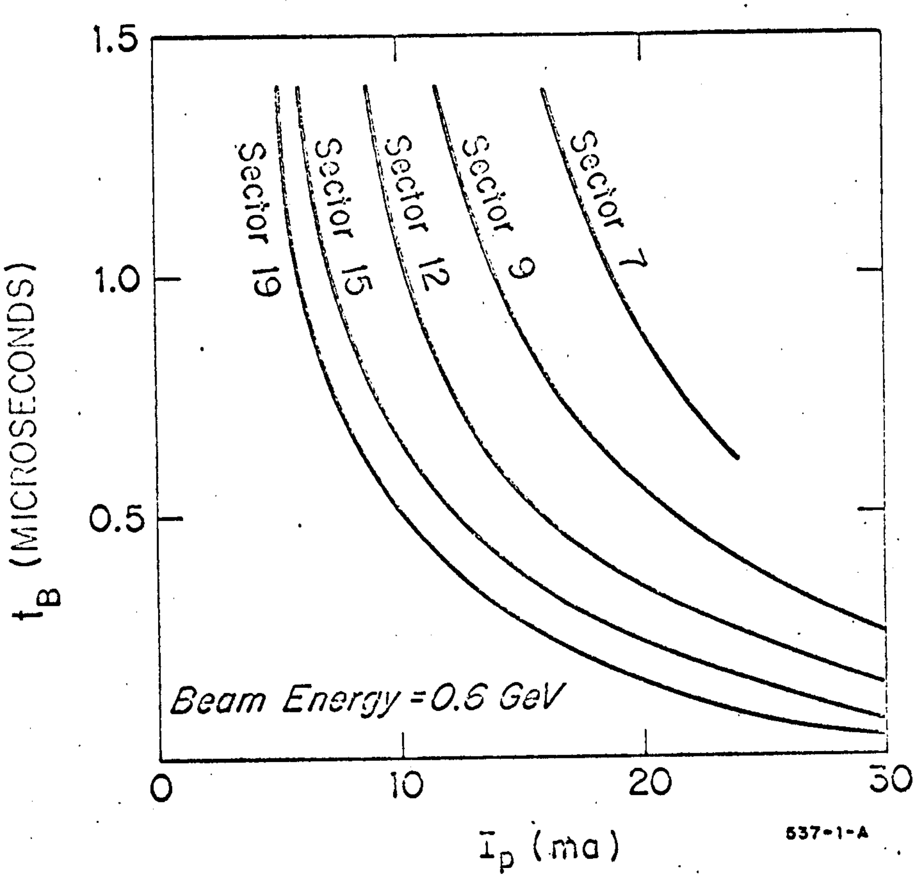

1.66 GeV with three sectors on
2.12 GeV with four sectors on
Background Scattering
BEAM INTENSITY
0
1
2
3
BEAM ENERGY (GeV)
537-3-A

Figure 2



1.5
1.0
0.5
t_B (MICROSECONDS)
Sector 19
Sector 15
Sector 12
Sector 9
Sector 7
Beam Energy = 0.6 GeV
0
10
20
30
I_p (ma)
537-1-A

Figure 3