

REFERENCE USE

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and High-Voltage Machines  
TID-4500 (47th Ed.)

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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Contract AT(04-3)-515

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## I. INTRODUCTION

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

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

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

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, so that this development work is presently in an early stage.

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

Construction of the conventional facilities was continued throughout the quarter, with most of the work effort expended in or near the Target Area. The present status of a number of these facilities is shown graphically in Figs. 1 through 4. Generally speaking, the "campus" area, the accelerator facilities, and the Beam Switchyard are already available or in use.

The overhead 220-kV power feeder line to the accelerator site has been contracted for by the Atomic Energy Commission and construction started during the past quarter. The work is now 45% complete. This facility, together with the existing 60-kV service to the site, will tie in to the SLAC Master Substation to provide the necessary electric power for the laboratory.

### B. DESIGN STATUS

The major design effort by Aetron-Blume-Atkinson has been completed, although some engineering remains to be done on field changes, "as-builts," and miscellaneous contract matters. The current status of the significant items is discussed below.

#### 1. BSY Materials Handling System

All units have been delivered to the site and installed. Take-over by SLAC is awaiting correction of operating deficiencies by the contractor. Change orders were initiated to extend the tracks into the "A" beam alcove and to modify the cab control boxes.

#### 2. Concrete Shielding Doors

This package consists of one power-operated rolling door each for End Stations A and B and a pair of manually-operated swing doors for the Beam Switchyard entrance. The contract was let and the contractor's shop drawing submittals are being reviewed.

#### 3. Data Assembly Building Extension

The Title II design on the 3000 gross-square-foot extension of the building is nearly complete.



Fig. 1--Construction status of target area; looking west





Fig. 2--220/12.47 kV transformer at master substation

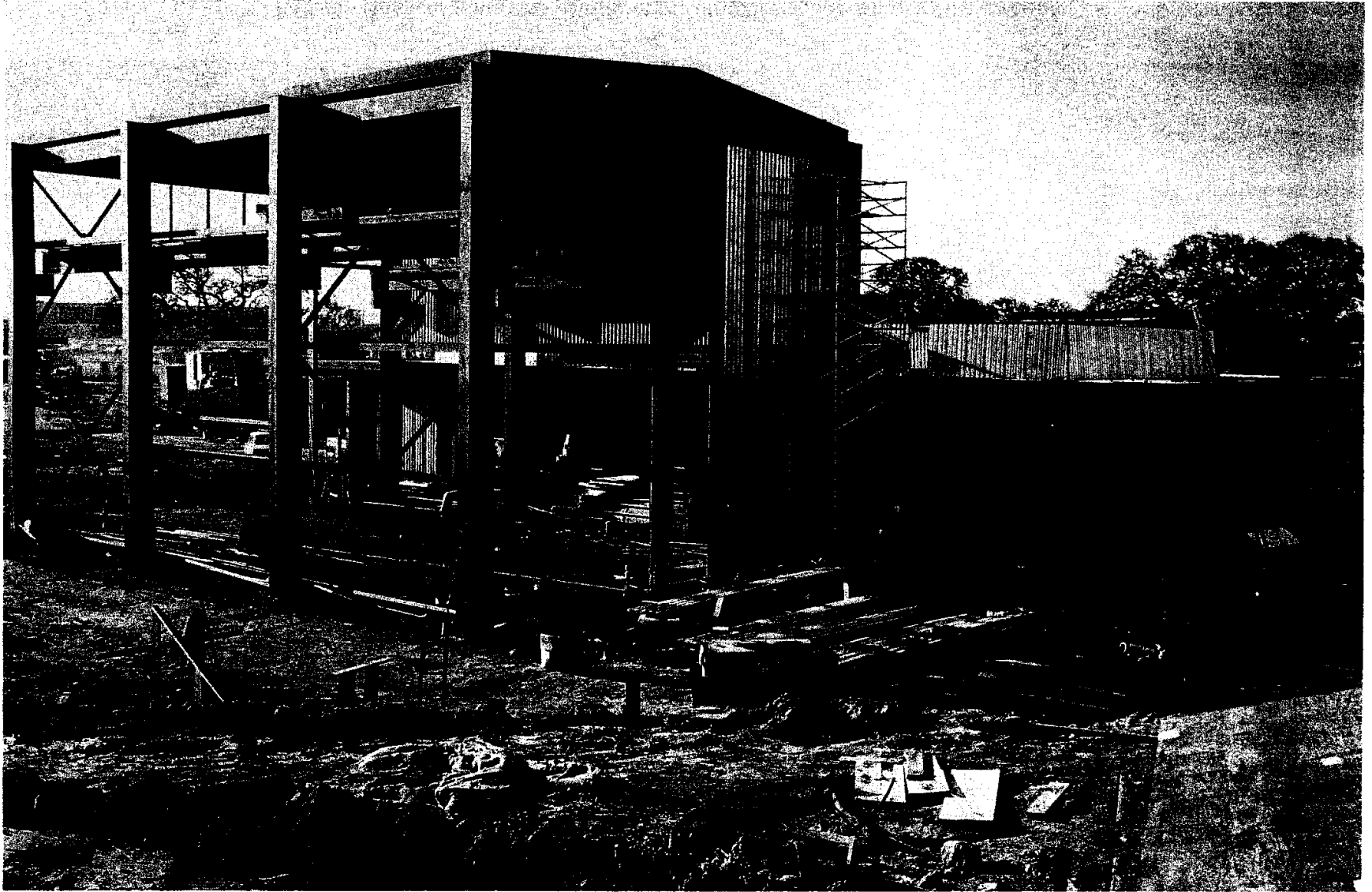


Fig. 3--Cryogenics facility under construction



Fig. 4--Instrumentation and control support structure; south side of  
Beam Switchyard fill

#### 4. Landscaping

Bids for the final two increments (V and VI) were received and evaluated. Notice of award of the contract was made on December 31, 1965.

#### 5. Site Fencing

Title II design is essentially complete; bids for the installation will be invited in February 1966.

#### 6. End Station A

A change order is being processed to relocate the spark chamber magnet rail system from an interior position to one outside the east wall of the building. This will provide greater flexibility for the preparation of experiments.

#### 7. Target Area Cranes

The contractor's corrected 100% design submittal was received. The first two of the four cranes in this package are scheduled to arrive early in February.

#### 8. Target Area Substations

Installation of equipment in the BSY station is essentially complete. Construction of the Research Area Substation building has commenced; a revision of the 12-kV switchgear being procured is underway to provide for additional research requirements.

#### 9. Mezzanine Design - Electronics and Fabrication Buildings

ABA was requested to design an office-type mezzanine for the two buildings against the very likely requirement of needing more of this kind of space at SLAC. The potential for this type of expansion was inherent in the original design and will draw to a considerable extent on calculations already made.

### C. CONSTRUCTION

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

<u>Facility</u>	<u>Percentage of Completion</u>
Central Laboratory (2nd-floor addition)	100
Klystron Gallery Utilities	
Piping and site improvements (600-Y-1)	100
Electrical (600-Y-2)	99
Cooling Towers (600-Y-3)	99
Beam Switchyard	99
Landscaping (Increment IV)	98
Area Lighting	98
Master Substation	94
End Stations A and B	85
BSY Site Improvements and Utilities	76
Cryogenics Facility	37
End Station Site Improvements and Utilities	17
Beam Dump East	10

The principal construction effort during the balance of the project will be concentrated in the Target Area. The final major facilities under contract by ABA are now scheduled for completion by May 1966. The construction of the project Site Fencing is the only remaining contract to be awarded.

The 220/12.47-kV transformer and the 60/12.47-kV transformer were installed at the Master Substation site. This overall facility is rapidly nearing completion and will be tied into the existing SLAC facilities in January 1966.

Two of the three cells of the BSY Cooling Tower were damaged by fire on November 18, 1965. Repairs are in progress and will be finished during the next quarter. No delay in necessary cooling water services is anticipated.

#### D. PLANT ENGINEERING SERVICES

The department continued its service activities in support of SLAC's operational program and the acquisition of new facilities. Several items of significance are reported below.

A Fire Station and a General Services Building are needed on site to house various service functions. The basic criteria have been firmed up and proposals have been invited from a number of architect-engineer firms to perform the design. Selection of the architect-engineer will be made next quarter.

Work continued in preparation of the revised SLAC conventional facilities Master Plan, after a preliminary draft had been reviewed and generally approved. It is expected that the document will be issued early next year.

An additional 8000 square feet of "relocatable classroom units" are being obtained to house an interim computer facility. The first of the units will arrive and be set in place in the North Yard area of the site on January 4, 1966.

Several additional facilities needed for physics research in the Target Area are being processed for procurement. Their status is as follows:

1. Proposals for a 2000-square-foot housing for the 40-inch hydrogen bubble chamber will be received in January 1966.
2. Specifications for a 3200-square-foot building to house spectrometer power supplies are being prepared and will be issued to bidders in February.
3. Specifications for a 4000-square-foot building to house the 2-meter-volume spark chamber magnet are nearly complete. They will be issued to bidders in January.
4. Scoping and cost estimating are underway for a metal housing to enclose the 54-inch magnet.

### III. SYSTEMS ENGINEERING AND INSTALLATIONS

#### A. SUMMARY

Overall department work is 84% complete. Progress during the quarter was adequate but slowed somewhat due to holidays and weather. Accelerator design work is 94% complete; construction work is 93% complete. Beam Switchyard design work is 87% complete; construction work is 44% complete.

#### B. ACCELERATOR

##### 1. Design Coordination

Laser room installation is underway. Installation work on the positron source contaminated water disposal system is partially complete. Filling of penetrations 4 through 30 with serpentine aggregate is underway.

##### 2. Vacuum

All gauges have been received except for the five replacement gauges for rejected units. One hundred ninety-four of the 230 total SLAC designed controllers have been received. Gauge guards and cables are on schedule.

The alignment vacuum pumping station installation is 90% complete. Preliminary vacuum valves will be replaced with the final version in the next quarter.

A subcontract for two identical cryosorption systems was awarded. Each system will consist of two 150-pound molecular sieve pumps and six-kW heaters.

Subcontract work was completed on the two-mile vacuum system installation.

A problem of feed-throughs and cable connectors has arisen in connection with the ion pumps. Apparently, corona exists in the connector configuration, creating ozone; the resulting corrosion of feed-through bushings and arcing ultimately causes the ceramic to crack. Solutions are being pursued.

Vacuum system work is 96% complete.

##### 3. Cooling Water

Subcontract work was started on the positron source concrete shielding. The heat exchanger and pumps have been received.

Installation of the tracing lines for the drive line was completed. Application of epoxy was completed on the main drive line in Sectors 25 to 30, to allow rf testing. Continuation of epoxy application and insulation is being held up pending completion of the rf tests.

A checkout of the cooling water systems in Sectors 25 to 30 was completed, including back-flushing. Cleaning and back-flushing are continuing throughout the remaining sectors.

Piping installation for the alignment vacuum system began.

Cooling water work is 96% complete.

#### 4. Electrical

Miscellaneous work such as installation of control racks, sub-boosters, modulators, and terminal cabinets is being completed in Sectors 3 through 30.

Modulator installation work continued in Sectors 19 through 23 and 27 through 30.

Fifteen of the sixteen variable voltage substations have been tested. Substation VII will be ready for first energization tests in mid-January 1966. A number of defects were found during preliminary tests and corrections made.

Positron source electrical work is underway. Design of 1200-, 2000-, and 4000-amp buses for the three solenoids is underway.

Alignment vacuum station electrical work in Sector 30 is 80% complete, with tests scheduled for the middle of January. Accelerator electrical work is 98% complete.

#### 5. Electronics

Delivery of fiat racks was completed. The first delivery of beam monitor racks was received in November. The balance of the order will be received in January. Delivery of all status monitor and alcove racks under one subcontract was completed.

A second subcontract was modified to include assembly of two racks for the alignment observation room.

Work was started on the drawings modifying fiat racks in Sectors 11 through 14 to incorporate positron source requirements.

Work was started on rack drawings for beam analyzing station 2.

Sectors 30, 3, 4, 7, 8, and 9 were cold-checked in December and turned over to the Instrumentation and Control Group for hot-checking. Installation of beam monitor racks in Sectors 25 through 30 was begun.

Increments of the telephone and public address systems continued to be installed in the Klystron Gallery. Work is underway to change all Klystron Gallery telephones from temporary facilities to permanent cables. The public address system is connected into Central Control so that all sectors can be paged from that location.

Electronics work is 88% complete.



## C. BEAM SWITCHYARD

### 1. Design Coordination

Survey work for the equipment layout was started by the subcontractor. A study is being made of collimator utilities space allocation. The design coordination effort during November and December was diverted to BSY shielding work.

### 2. Vacuum

Shock tube tests were performed on three foils by rupturing a six-inch diaphragm by one gallon of water. The 1/2-mil-thick foil was partially damaged; the two-mil and five-mil foils suffered no damage.

Material for the B-beam divergent chamber was ordered, and 20-inch stainless steel pipe for the vacuum fingers was delivered to the subcontractor.

In connection with the six-inch isolation valve, two tests were run on six-inch indium seals with remelt between tests. In both cases 500 cycles was achieved with maximum leakage of less than  $6 \times 10^{-7}$  std. cc/sec. Further review of the beam transport systems showed that four inches would be adequate, and a decision was made to purchase four-inch isolation valves.

A decision was made to use a four-inch fast valve. Quotations were received and a recommendation made to purchase five valves.

Differential pumping station components are essentially completed, including supports, strongback, and thin valves. A subcontract was awarded for two tri-ethyl phosphate refrigeration systems.

Vacuum system work is 52% complete.

### 3. Cooling Water

Material submittals were received, reviewed, and returned to the equipment installation subcontractor. Welding procedures and examination of new welding equipment were reviewed at the vendor's plant.

The general arrangement of the piping around the main collimator, slits and dumps was determined. After discussions with suppliers and users of remote couplings, with particular emphasis on corrosion problems, a decision was made to use the same type of vendor-supplied couplings for both removable piping sections and for the radioactive equipment. Subsequently, the subcontractor was notified as to the number of remote couplings and flexible metal hose assemblies to be purchased.

X-rays of longitudinal welds of stainless steel pipe were begun at the subcontractor's plant.

Installation of pipe supports and piping started.

Leak testing of stainless steel heat exchanger units commenced. Bronze units have been fabricated and will be delivered early in January.

Drawings for magnet cooling water pumps were approved for fabrication.

Cooling water system work is 55% complete.

#### 4. Electrical/Electronics

Several deficiencies in substations 1, 2, 3A and 3B were substantially corrected. The 120-volt-dc battery and charger was purchased for installation at the BSY substation building and will be reassigned later to the target area.

Review of vendor drawings continued.

Work continued on wire lists for terminal connections to all electrical devices and distribution frames.

Review of electrical installation details which have been issued to the subcontractor was continued in order to provide a final opportunity for updating the installation drawing package before the final electrical connections are made. Many details have changed, but rate of change is decreasing as equipment designs near completion.

Work to determine the electrical wiring needed for use internal to all BSY equipment continued. A purchase program was established and some radiation-resistant wire purchased. Purchase of stainless-steel-jacketed magnesium oxide insulated cable and glass-fiber (or quartz)-insulated coaxial and twinaxial cable is underway.

Electrical installation in the Data Assembly Building is essentially complete.

Work in Sector 30 on the BSY cable tray requirements is complete.

Ground bus and cable tray installation is underway along the west cableway. A delay in placing stanchion footings is holding up work on the east cableway. Trays and framing are being installed in the housing and tunnels.

The main feeders were pulled in from the BSY substation. Distribution panels are on site and connections underway.

The first power supply (PQ12) was delivered and installed in the Data Assembly Building.

Temporary telephone service was provided to the Beam Switchyard. Four photos showing progress in the Beam Switchyard area are given in Figs. 5, 6, 7, and 8.

Electrical work is 39% complete; electronics work is 43% complete.

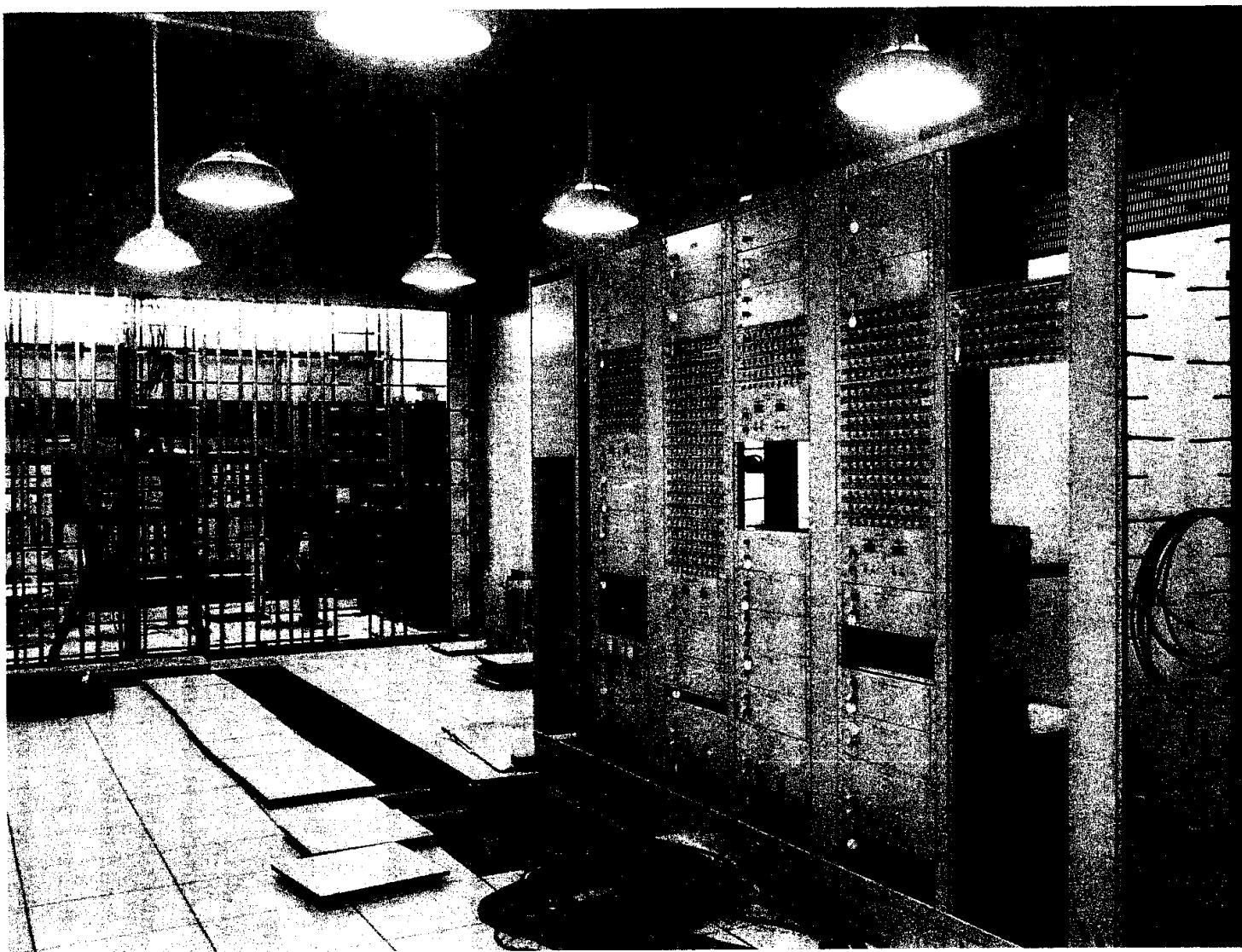


Fig. 5--Beam Switchyard Data Assembly Building Control Room showing equipment racks and main distribution frame

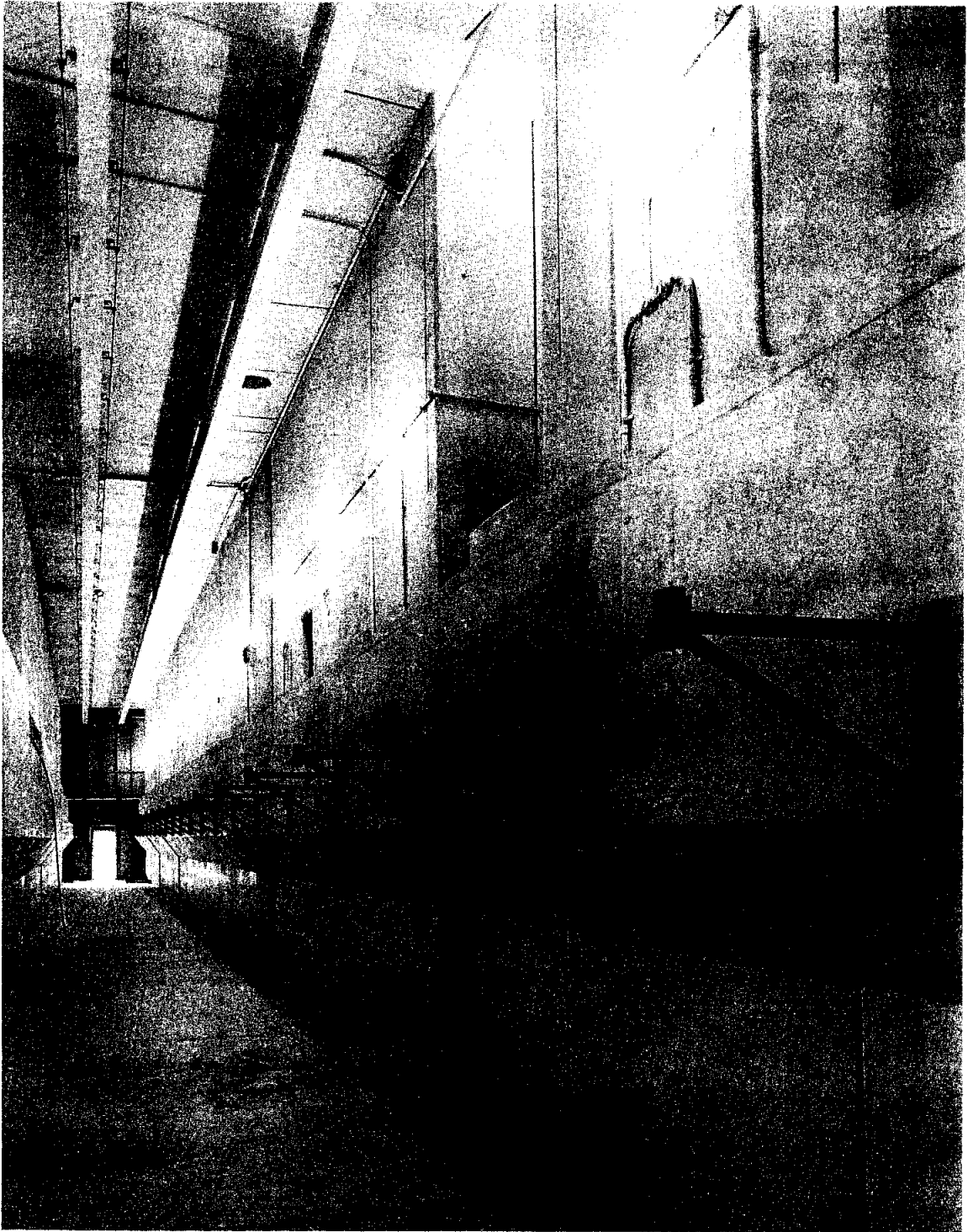


Fig. 6--Beam Switchyard central beam area looking east from the main access-way, showing A-beam at left, central beam openings, and B-beam housing at right

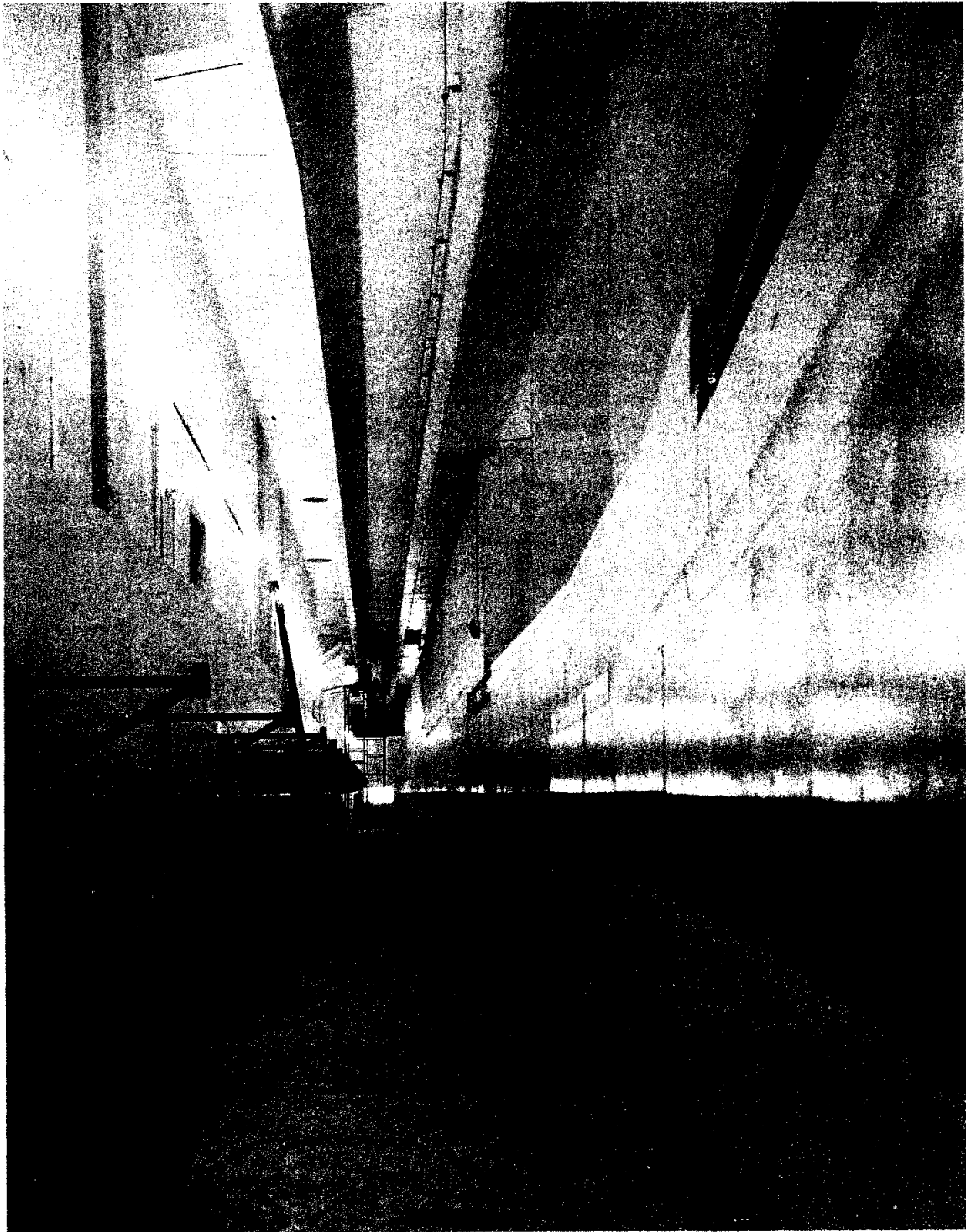


Fig. 7--Beam Switchyard A-beam housing looking east toward End Station A;  
catwalk supports show at left

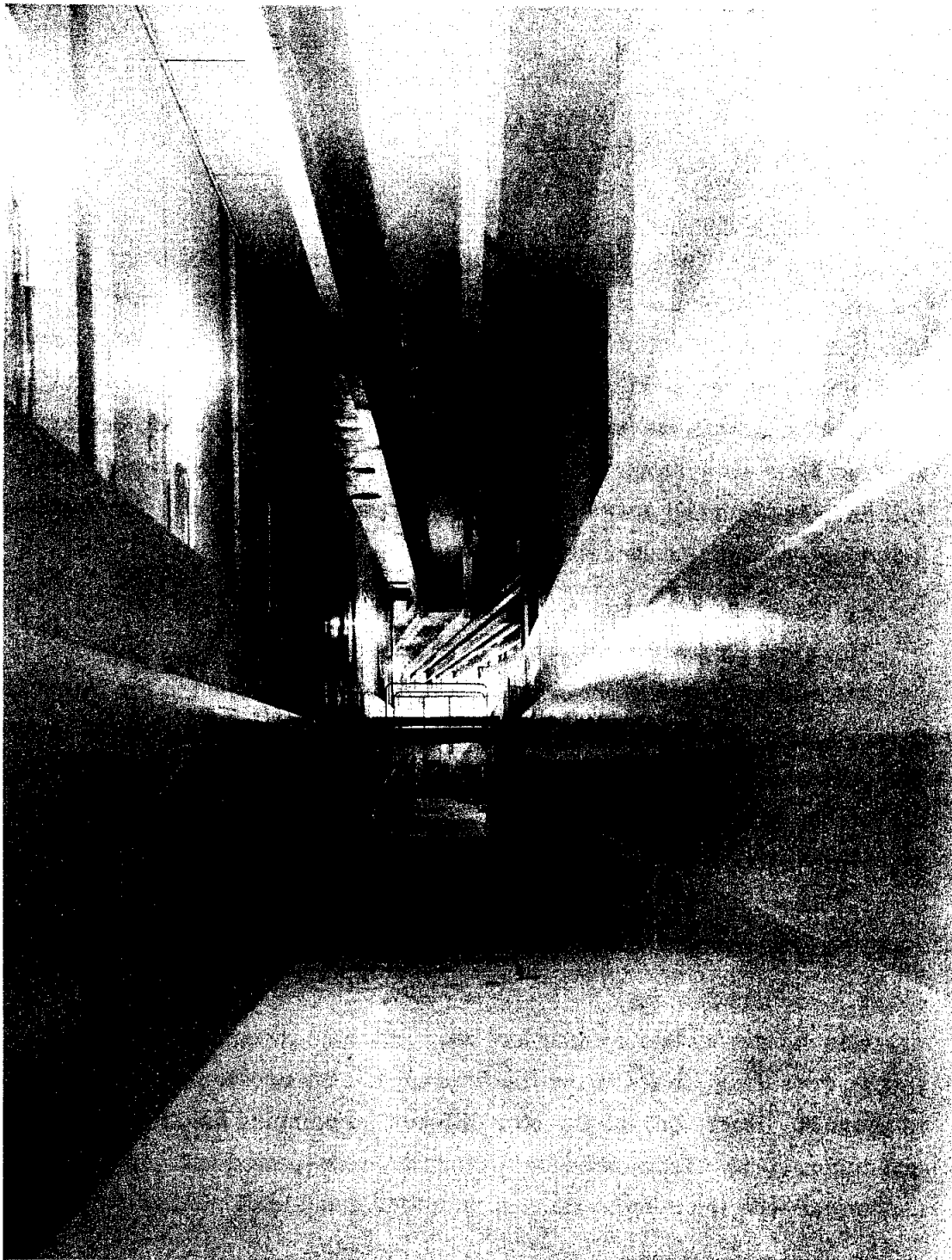


Fig. 8--Beam Switchyard B-beam housing looking west toward central beam area

## IV. ACCELERATOR PHYSICS

### A. INJECTION

#### 1. Main Injection System

In November 1965, beam tests in Sectors 1 and 2 were discontinued to allow for new installation and rework in the injector and in Sectors 1 and 2. The final installation and testing of the injector is now in progress. Checkout procedures are being prepared and drawings updated so that the systems can be turned over to regular maintenance personnel. This effort will continue through April 1966, at which time all systems except the gun modulator and the beam knockout system will have been turned over to regular maintenance personnel. The status of individual systems is described below.

##### a. Power Supply Systems

The high current power supply system is complete.

All medium current power supplies have been returned to the manufacturer to be retrofitted and should become available at the beginning of next quarter. The zero sense circuit in the controllers has been redesigned successfully and the motors have been changed to provide lower speed programming. Provisions are being made to accommodate the change of control signals from the Central Control Room (CCR). The system checkout will be completed when the power supplies are returned by the manufacturers.

##### b. Vacuum System

The vacuum in the injector has been excellent throughout early operation. On two occasions, leaks in the machine caused the accelerator pressure to drop to about  $10^{-4}$  torr, but the injector differential pumping held the pressure in the gun region to  $10^{-7}$  torr, thereby saving the oxide-coated gun. The electronics associated with the remote vacuum monitoring and interlocking is now being built.

##### c. Control Console

Sufficient information is now available to design and fabricate the status boards, and this work is proceeding. All other control surfaces are either installed or fabricated. Their installation takes place when their associated systems are checked out. Work is proceeding on the remote control system from CCR.

#### d. Other Injector Systems

Checkout and testing is continuing on the following systems: klystron phasing, buncher-prebuncher phasing and attenuator, TV monitor, profile monitor, collimator, communication, variable voltage substation control, video and rf monitoring.

### 2. Electron Guns

Design and testing of the SLAC gun continued throughout the quarter. A second gun was assembled with a nickel cathode which had been coated with barium strontium. After conversion, the gun was pulsed and gave a peak current of 463 milliamps at 40 kV and 1% grid drive, when operated at a filament power of 40 watts.

This gun was then moved to the beam analyzer and "x" and "y" profiles were recorded at various axial positions and for various beam perveances. The beam diameter minima at 0.01 and 0.03 microperveance were 0.060 inches (50% pts) and 0.10 microperveance were 0.220 inches.

Two abnormalities were discovered in the gun electronic characteristics. One was a leakage resistance between grid and cathode due to surface contamination of the ceramic supporting the grid deck. The other was a poor adherence of the oxide coating to the nickel cathode which had not been sintered.

Further emission tests of the 2% thorium-tungsten cathode were limited this quarter by the difficulties imposed by the vertical vacuum system. With the gun in a vertical position and the filament operated as a tungsten emitter (2000°C), the filament sags and eventually shorts out. A right-angle tubulation will be fabricated for horizontal mounting for future emission tests. Further tests of bombarder emission and control were also performed. Emission efficiencies somewhat better than 50% have been obtained with carburized filaments, but only at low bombarder power levels (less than 30 watts) or in transient testing where the bombarder voltage is on long enough and high enough to measure the emission current. A bombarder diode has been operated for over 400 hours at 50 mA and 2 kV, with a filament temperature of 1450°C to 1475°C and an emission efficiency of from 18 to 21%.

### 3. Gun Modulators

The temporary Mark IV gun modulator has been moved aside to allow installation of the permanent modulator. That part of the modulator which is to be located in the housing has been fabricated and is being installed. The high voltage



cable has been received and tested. The grid pulser has been modified and is undergoing tests. The existing controls, logic and low-level pulser circuitry will be used temporarily until the new low-level circuitry is completed. Design and fabrication of this circuitry, which incorporates the capability of operating three different beams and remote control from CCR, are underway.

#### 4. Beam Knockout System

The purpose of the system was described in the previous report. The deflection system will consist of two sets of deflectors, one in the injector, adjacent to the prebuncher, and the second in the drift section at the end of Sector 1. The first deflector, to be installed in the next few weeks, eliminates all but a few electron bunches. The second deflector, to be installed at a later date, should reduce transmission to a single bunch and eliminate the "dark current" generated in the first sector of the machine.

The modulator for this system, a 50-kW peak power, 300-watt average power, 40 Mc/sec Class C linear amplifier, will be built in-house. Design is well underway.

#### 5. Magnet and Electron Gun Design Program

A report\* was published which describes the use and application of the SLAC gun design program and of the magnet design version of that program. Binary decks are available for other installations which may like to use either program.

### B. DRIVE SYSTEM

#### 1. Main and Sub-Drive Lines

The main drive line was installed and connected for the full 10,000 feet and tested. With an input power of 17.5 kW, the power available at the end was 50 watts, an improvement of more than 10 dB over the 4 watts minimum power that was specified. The availability of this amount of power makes the transmission to the End Stations somewhat easier and allows for some long-term deterioration of the line.

Sectors 25 through 30 have been completed except for the thermal insulation. Four of these sectors have 90% of the insulation installed.

\*W. B. Herrmannsfeldt, "Poisson Equation Solving Program," SLAC Report No. 51, Stanford Linear Accelerator Center, Stanford, California (1965).

Tests during this quarter show that the A-frame anchors and improved drive line clamps are maintaining their position within design specifications. No further significant mechanical drifts are expected. Group velocity and phase drift tests due to slow temperature changes of the main drive line are proceeding. If the water tracing and the thermal insulation of the lines succeeds in stabilizing the temperature within 1°F, the total cumulative phase shift over two miles at 2856 Mc/sec should amount to only 4 electrical degrees. This phase shift is caused entirely by the temperature changes of the air filling the main drive line at a constant pressure. It is not possible to hermetically seal the line to achieve a constant effective dielectric constant. If the temperature stabilization should not be as effective as expected, it would be possible to control this change in dielectric constant by changing the pressure of the air in the line or by filling the line with helium.

Tests on the main drive line will be continued and hopefully completed during the next quarter.

All 30 sub-drive lines have been installed and tested. Some of the water tracing lines remain to be epoxied on these sub-drive lines. Electrical specifications seem to be met everywhere.

Concerning the extension of the main drive line into the Beam Switchyard and Research Areas, a recent decision was made to use a simplified system requiring neither anchors nor expansion sections. A 1-5/8-inch line of the semi-flexible type will be used, and temperature stabilization will be achieved by burying it underground.

## 2. Varactor Frequency Multipliers

Twenty-nine varactor multipliers have been received to date. All have been tested, and twenty-one have been installed in the Klystron Gallery. Continuing difficulties in the procurement of varactor diodes have delayed complete delivery of the multipliers. However, a second source of acceptable diodes was recently developed, and a third source is being investigated. An accident in one of the main boosters caused a power surge in the main drive line which damaged a number of the diodes in multipliers installed on the machine. Some diodes have been recovered by retuning the multiplier circuit. Others will be replaced as further diodes become available.

### 3. Main Booster Amplifiers

The defective klystron was repaired and a spare tube was installed in its place. Except for a few kickouts, operation has been essentially continuous throughout the quarter. During a violent winter rainstorm at the end of the year, a leak in the roof allowed water to drip into the vicinity of the high voltage rectifier and caused an arc which burned out a plastic insulating hood. This damage caused the main booster to kick out. The damage was noticed immediately, and the unit was quickly repaired.

### 4. Positron Phase Shifters

Sub-booster isolator-phase shifter-attenuator units, modified to include the 180° phase-shifting circulator, have been installed in the first two fiat racks in Sector 11. Adjustment of the circulators to provide the correct phase shift will be completed during the next quarter.

### 5. Rf Drive System Control Circuits

The switching systems for the master oscillator and the sub-booster are available and will be installed. The final system for the main boosters and the logic status panels remain to be completed.

### 6. Sub-Booster Modulators

All sub-booster modulators have been delivered and are undergoing final installation and testing. The units have been operating satisfactorily except for the switch tube blowers, which have developed excessive vibrations and caused several switch tubes to fail.

### 7. Sub-Booster Klystrons

Improvements in shelf life of the sub-booster klystrons seem to have been obtained, but present results are not yet entirely conclusive. Further tests are required.

## C. PHASING SYSTEM

### 1. Isolator-Phase Shifter-Attenuator Units

Modification of the pre-production units is 90% complete. RF tests are being repeated on these units. The special control phase shifters for the injector have been received and tested. One unit failed to meet the VSWR specification and will be returned to the subcontractor. Units will be modified to meet the special requirements of Sector 27 as soon as all components become available.

## 2. RF Detector Panels

The modification which allows the reference signal (needed for the automatic phasing) to be derived from either the varactor multiplier or the sub-drive line has been completed on all units.

## 3. Programmers and Electronics Units

All units have been received and tested, with the exception of one programmer.

## 4. Linear Detectors

All 300 diode housings have been received. Diodes are being aged for 500 hours to stabilize their characteristics before fitting them into the housings. After diodes are fitted, the assemblies are subjected to rf tests and then installed in rf detector panels and beam position monitor detector panels.

## 5. Installation of Phasing Equipment in the Accelerator

One hundred ninety-seven standard isolator-phase shifter-attenuator units have been installed in the machine. Twenty-four sectors have been equipped with sub-booster isolator-phase shifter-attenuator units, control phase shifters, rf detector panels, programmers, and electronics units. The complete phasing systems have undergone preliminary tests in 16 sectors, and these have been handed over to the Accelerator Operations Group.

# D. BEAM POSITION MONITORS

## 1. In-Line Position Monitor Cavities

Production and testing of the in-line cavity assemblies has been completed ahead of schedule. Some work remains to be done on the last of four assemblies which will be held as spares for the machine.

## 2. Beam Position Monitor Detector Panels

All 33 panels have been received. A number of systematic defects were found and corrected. Acceptance testing is proceeding on these units. Before installation on the machine, the units are being modified to permit remote switching of the rf position signals, so that the error due to diode unbalance may be observed in Central Control.

## 3. Beam Switchyard Beam Position Monitors

One BSY beam position monitor detector chassis has been completed and tested. Those remaining are 90% complete and will be tested as they become available.

The cavity assemblies are being fitted with quick-disconnect vacuum couplings and temperature sensors, and are being installed into support and alignment castings.

There was no vendor response to the request for bid on the special rf cable plugs required for the switchyard cavities. A quick-disconnect plug using polystyrene dielectric has been designed, and 25 are being made in-house.

#### 4. End Station A Beam Position Monitors

A microwave beam position monitor is being developed for use in End Station A. The requirements are that the device should have a three-inch-diameter aperture, and be able to detect the displacement of a 0.1-mA (peak) beam by 0.1 millimeter from the electrical center.

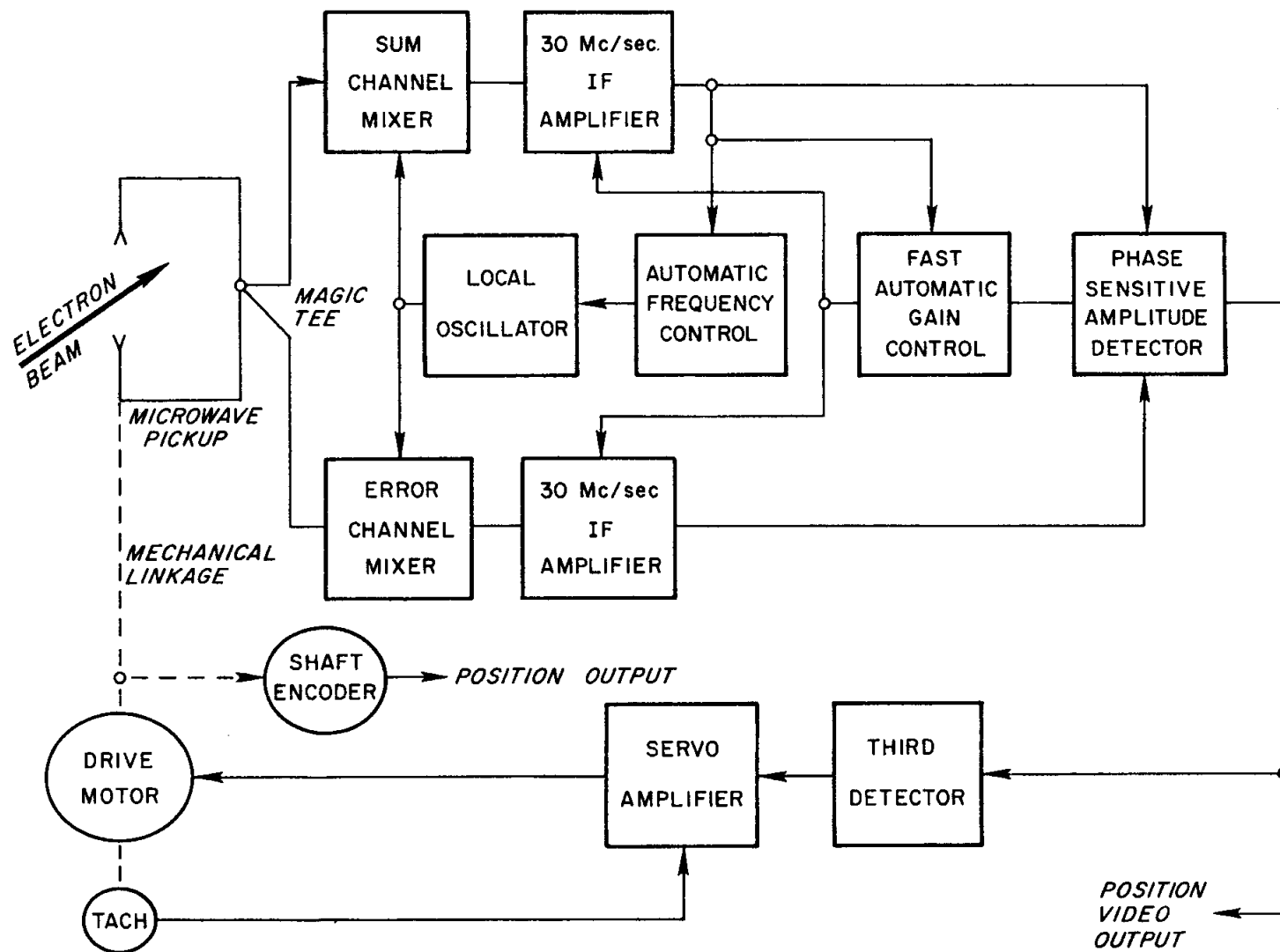
Preliminary calculations have indicated that a non-resonant device consisting of two rectangular waveguides connected to opposite sides of the three-inch-diameter beam tube will have the necessary sensitivity, when followed by a high-gain rf amplifier. A closed loop beam-tracking system, similar to a tracking radar, has been proposed. Figure 9 shows a simplified block diagram of the system. The beam-induced signals enter a Magic Tee, and the resultant sum and difference signals are fed into a dual channel receiver with automatic frequency control and automatic gain control. The output of the phase-sensitive amplitude detector will be a video signal giving the amplitude and sense of the beam position error. This output will be used either (a) to drive a servo system which will cause the microwave monitor to mechanically track the beam or (b) to feed a computer which will cause the beam to be steered back to center.

A prototype microwave monitor has been built and will be tested on the injector test stand during January 1966.

### E. BEAM ANALYZER STATIONS

#### 1. Beam Analyzer Station 1

The station is still in the process of being modified in the light of experience gained during beam tests. Work is being done on the power supply to increase the available current and to improve the stability of the supply. The new scan foil assembly is nearly complete and will be installed during the next quarter. The automatic degaussing system has been redesigned. Components are on order.



484-1-A

Fig. 9--Simplified block diagram of Eng Station "A" beam position monitor

## 2. Beam Analyzer Station 2

It has been decided to install beam analyzer station 2 on girder 20-1 instead of 3-1, so that low energy beam transmission tests may be carried out at an early date on the first 19 sectors of the accelerator. Consequently, the station has been modified to permit analysis of the highest energy beam which can be conveniently handled by the available magnet and power supply. The foil box has been lowered to make an angle of  $3^{\circ} 45'$  minutes with the accelerator axis, and its length has been increased to 38 feet. With this modification, the magnet will be capable of focusing a 3-GeV beam on the central (sweep) foil when operated at 15 kilogauss (300 amps). The foil box will extend over accelerator sections 20-1 C and D. A beam stopper has been designed and built, and will be installed immediately downbeam of the magnet. Further modification of the station has been kept to a minimum. The same beam dump will be used, but peripheral water cooling tubes have been added. A comprehensive interlock system for personnel and machine protection has been designed. The girder is scheduled to be installed during January 1966. Cabling to permit local and remote (CCR) control is being installed. Equipment for control, readout, beam-interlocking and degaussing is being built.

## F. GENERAL MICROWAVE

An rf deflecting structure for the separation of electrons and positrons downstream of the positron source has been constructed and matched. This structure is of the LOLA II type described in the previous status report. It is 52.5 cm long.

## G. ALIGNMENT

### 1. Optical Alignment System

The laser room, located under the roadway at the east end of the accelerator, has been completed. Installation of equipment between the laser room and light pipe girder number 31-1 is in progress. The laser and power supply for the accelerator system are ready for installation.

The laser and associated equipment for the beam switchyard system have been ordered.

Optical components for the alignment system are being fabricated. The first delivery on this order has been made and the balance of the order, including

the large window at the west end, is expected to be delivered before the components are actually required for initial operation of the alignment system.

The light pipe vacuum pumping system is essentially complete and is being checked out.

Installation of equipment and facilities in the alignment observation room is progressing. The traverse system, the mirror supports, and the grid plate support are all essentially complete and in place. Relay racks and most of the electronic equipment have been delivered. The balance of the electronic equipment is due to arrive in February 1966.

Fresnel target position measurements using the photographic calibration technique are continuing. Including necessary retakes and calibration shots, about 600 sets of five pictures will be required for the entire operation. Twenty-four measurements are made from each set of pictures. In special cases, such as the girders in which the hinges were retrofitted, two or more sets of pictures were made and results averaged.

The target order was completed on schedule. Installation of accelerator targets is essentially complete, and installation of beam switchyard targets is starting.

## 2. Beam Switchyard Alignment

The preparation and review of procedures for the installation and alignment of the magnets and other components in the Beam Switchyard are underway. Also being studied are tape bench facilities, tape handling equipment, and associated instrumentation for beam switchyard alignment. Work has begun for the placement of the alignment targets on the first of the three-degree bending magnets.

## H. THEORETICAL AND SPECIAL PROJECTS GROUP

The following studies are presently underway.

### 1. Wave Propagation Studies

Some progress has been made in understanding wave propagation and wave-beam interaction in dispersive structures. The theory of coupled electromagnetic cavities given, for example, by Bevensee,\* yields a dispersion equation which

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\* R. M. Bevensee, Electromagnetic Slow Wave Systems (John Wiley and Sons, Inc., New York, 1964).



after some simplification may be stated in Fourier-transformed form as

$$(\omega_{om} + i\alpha_m - \omega)E_m - \frac{1}{2}(\Omega_{m+1/2} E_{m+1} + \Omega_{m-1/2} E_{m-1}) = -2\pi i \frac{c}{\tau} \int_{cav.} \vec{\psi}_m^* \cdot \vec{J} dV$$

where

$E_m(\omega)$  is the field amplitude in the  $m$ -th cavity;

$\omega_{om}$  is a characteristic frequency;

$\alpha_m = \omega_{om}/2Q_m$  is a measure of wall losses;

$\Omega_{m+1/2}$  is related to the coupling between the  $m$ -th and  $(m+1)$ -th cavities;

$\vec{\psi}_m$  is a characteristic electric-field wave function such that

$$\vec{E} = E \vec{\psi} \quad \text{and} \quad \int_{cav.} |\psi|^2 dV \equiv \tau ; \quad \text{and}$$

$\vec{J}$  is the electron beam current density.

If the parameters are constant in  $m$ , it follows readily that the transfer function for the homogeneous part of the equation is  $e^{-\Gamma}$  where  $\cosh \Gamma = (\omega_o + i\alpha - \omega)/\Omega$  which is equivalent to the model used for wave propagation and beam loading calculations by J. Leiss of the National Bureau of Standards.

The theory adapts readily to problems involving beam loading (accelerating mode), beam blowup (deflecting mode), propagation at or near  $\pi$ -mode cutoff, and structures in which the parameters vary as a function of length.

## 2. Accelerator Transmission Studies

The TRANSPORT program has been used to optimize the setting of the first few quadrupole triplets (BAS, DS-1, DS-2). The maximum admittance area at the output of the injector is then found to be approximately 0.19 cm-mc, or at least a factor of 10 larger than the area of the 90% intensity contour of the injector emittance as measured by R. Miller.\* Thus, according to this idealized calculation, there should be no beam loss at all, unless the initial phase space match (injector focusing) is spectacularly bad. Some possible mechanisms for the observed beam losses (up to 15% loss in Sector 2) might be:

\*R. Miller, R. Koontz and D. Tsang, "The SLAC Injector," IEEE Trans. on Nuclear Science NS-12, (No. 3), 804 (1965).

- (1) poorly tuned injector
- (2) poor focusing in injector
- (3) beam focused to too small a spot at Beam Analyzing Station No. 1
- (4) coupler asymmetry, stray fields, and poor steering in Sector 1
- (5) accelerator misalignments

### 3. Long Ion Chamber Cable Equalizers

Two equalizers, one for four miles of RG319 A/U + 75 feet of RG214, the other for one mile of RG319 A/U, have been designed and turned over to the Light Electronics group for construction. Four of the one-mile version can be cascaded in the control circuits, assuring flexible operation.

### 4. Video Cable System Equalizers

To accommodate changes in the cable length, new equalizers have been designed.

### 5. Storage Ring Feedback System

A feedback system, consisting of transformers, filters, amplifiers, and remotely switched phase shifters, has been designed for the suppression of vertical beam oscillations in storage rings. The components are being procured or constructed and tested.

## I. MAGNETIC MEASUREMENTS

During the past quarter, the Magnetic Measurements group accomplished the following tasks:

1. The measurements and tests on the machine quadrupole triplets and the pulsed steering dipoles were finished, except for two spare triplets.
2. Measured, tested and analyzed in considerable detail were the first six  $3^\circ$  bending magnets for the Beam Switchyard. The last eight magnets will be measured in the next quarter.
3. The five pulsed steering magnets were measured under pulsed conditions and with vacuum chambers in place, except for the three having Hastelloy vacuum chambers. These were measured without the chambers in place.
4. The field of the Beam Analyzing Station No. 2 magnet was remapped, using the recently completed precision semi-automated three-axis positioner.

5. Preparations and the mechanical hardware for the alignment of the positron source solenoids were completed.

6. The field of the  $15^\circ$  scale model bending magnet for the 8-GeV spectrometer was mapped.

7. The electronic logic and drive components for the rapid magnet mapper to be used for the spark chamber magnets were completed and tested. The mechanical components for the rapid magnet mapper are about 90% complete but have not been tested.

#### J. RESEARCH AREA PHYSICS GROUP

A new group, the Research Area Physics Group, is being formed in the Accelerator Physics Department. This group will contain several members of the present ad-hoc Beam Switchyard Group which is being disbanded, and will thereby insure continuity of knowledge and experience in this area into the operating phase. The new group will have the following responsibilities:

(a) The group will be responsible for the initial testing of all devices and systems in the Beam Switchyard (BSY) directly related to beam handling, guidance, and control, and will perform experiments to insure their proper performance and consistency with the design criteria. The group, working with Research Area Operations personnel, will establish operating limits and practices for such systems.

(b) In collaboration with Research Area Operations, the group will analyze performance data, define and carry out experiments required to understand the operation of the BSY and Research Area, and propose changes of operating procedures, modification of systems and components, or development of new components as may be judged appropriate.

(c) The group will carry out analysis and basic research necessary for the development of new systems or components required to increase the general utility of these areas for research. The responsibility includes but is not limited to beam monitoring devices and high power beam absorption equipment (e.g., slits, collimators, and special targets).

(d) In cooperation with Research Area Operations, the group will generate criteria for the development of improved systems and components required in the BSY and Research Area. The group will work cooperatively with other groups in the development of these systems.

(e) When requested, the group will assist the various groups of the Research Division and the Users Research Groups in the development of various instruments, devices, and systems needed to carry out their experimental programs.

The responsibilities listed above are given in the rough chronological order in which the group will likely undertake them. During the initial operating period it is expected that the major efforts of the group will involve responsibilities (a) and (b) above. Limitations of time and manpower will probably allow relatively little effort to be devoted to responsibilities (c), (d), and (e). At a later date, however, when the initial shakedown of the BSY and Research Area has been completed, it is expected that time will become increasingly available for the latter three responsibilities.

## V. INSTRUMENTATION AND CONTROL

### A. GENERAL

Installation and testing of control equipment in the Klystron Gallery is virtually complete in 16 sectors. All subsystems tested operate satisfactorily. Tests of the beam guidance and machine protection systems have been delayed pending delivery of equipment. It is expected that all subsystem tests will be completed in the coming quarter.

Interface requirements for the Positron Source and the Beam Switchyard are being firmed up. Design of interfaces for the End Stations has started.

### B. DATA HANDLING

#### 1. Status Monitoring

Binary status information at each sector is transmitted to Central Control on a time-shared multiplex system. Delivery of production units should be complete by January 21, 1966. Transmitting units have been installed in 16 sectors.

Receiving equipment for continuous display of 32 signals has been installed for all 30 sectors.

Receiving equipment for display of the remaining signals on a switched sector-by-sector panel has been installed. Two more such panels remain to be implemented.

All the equipment has been checked and is in use for Sectors 1, 2, 5, 6, 13-18, and 25-30.

#### 2. Analog System

Slowly changing analog signals are transmitted to standard panel meters in Central Control by means of individual hardwire pairs. Up to 15 signals are switched to the sector-by-sector display panels. The switching chassis have been installed in the Central Control Room and are operating satisfactorily.

Signals have been received and displayed from 16 sectors.

#### 3. Remote Control

The Remote Control system consists of three transmitters which transmit binary codes, operated through the sector-by-sector console panels, and a receiver in each sector which translates the code into a signal to actuate a relay

or motor. Steering dipole controls are transmitted from a separate panel on individual hardwire pairs.

Receivers have been installed in 16 sectors and are operating normally.

Three transmitting systems (operated by the switched sector-by-sector panels) have been installed and used for operational checks in the 16 completed sectors. Transmitters have also been installed for the Main Injector and Beam Switchyard.

The steering controls for Sector 1 were tested and it was found that the beam could be successfully steered from Central Control.

#### 4. Beam Monitoring

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

- (1) An FM signal which gives an accurate representation of the charge per pulse (Q) at each sector, and
- (2) A multiplexed baseband signal which transmits pulses representing  $\log Q$ , x, y for each beam pulse.

Delivery of FM equipment is complete and all receiving units have been installed in the Central Control Room. Installation of sector transmitters is in progress.

Baseband receiver cabinets have been installed in the Central Control Room and six plug-in units have been received from the vendor.

### C. BEAM GUIDANCE

Beam Guidance equipment includes the electronics for intensity and position monitors and the power supplies and controllers for degaussing, quadrupoles and steering dipoles.

Installation of nearly all of this equipment has been delayed. One card in the Beam Monitor Electronics package was found to be incomplete and had to be replaced. The steering and quadrupole power supplies have had thermal drift and reliability problems to be solved. The shunts were installed upside down in the controllers for the Beam Guidance supplies. Most of these conditions will be corrected and the equipment ready for installation in January 1966.

The scanning beam profile monitor was tested in the electron beam at Drift Section-1 again. Various improvements had been incorporated: a smaller bellows, some changes in cranks and linkages, and silicon-controlled rectifier

speed control for the drive motors. It was found possible to run the scanner slowly enough so that at 60 pps it would advance the target by less than 1 mm per pulse. It now appears that the achievement of 1-mm x 1-mm resolving power to 5% accuracy at 60 pps will depend upon the background due to beam scraping and the pulse-to-pulse beam profile stability. It will be possible also to increase the scanning speed by a factor of 6, for 360-pps operation, if that should prove desirable.

#### D. 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.

The comparator, pattern generator (programming equipment), and Beam Switchyard trigger generator were developed and fabricated during the quarter and are now undergoing final checkout. Delivery will be in January 1966.

Trigger generators for the Central Control Room, for pulsed steering, and for use in experimental areas will be designed in 1966.

#### E. CHECKOUT OF KLYSTRON GALLERY INSTRUMENTATION

Instrumentation/Control provides supervision of the systems tests of wiring and subsystem operation in the sectors.

Sectors 5 and 6 were the first sectors in which the bulk of the instrumentation was tested as a whole before commencing operations. A detailed test procedure was developed and "trouble tickets" were written up for each malfunction observed. The technicians performing the tests are in training to be members of the maintenance team in the future.

All of the obvious types of troubles were found: short circuits, missing wires, transpositions, drawing errors, and errors of interpretation of the test procedure. The number of errors ranged from 8 to 20 per sector. After the errors had been corrected, few new troubles were found after commencement of operations.

Two weeks were spent in Sector 5. In later tests, the test routine was shortened to four days. By the end of the quarter, 19 sectors had been checked-out -- the 16 operational sectors listed above, and Sectors 3, 4 and 7. Testing was underway in Sectors 8 and 9.

Equipment delivery delayed installation of beam guidance and monitoring equipment and the Machine Protection System. Pre-operational testing included the instrumentation in the Gallery for the Personnel Protection, Trigger, Drive, Remote Control, Status Monitoring, Analog Metering, Klystron Instrumentation, Variable Voltage Control, Water, and Vacuum Systems. Instrumentation equipment has not yet been tested for Beam Guidance, Beam Monitoring, Alignment, Machine Protection and Vacuum Valves.

The circuits to Central Control have been tested for 16 sectors during operations tests.

#### F. PERSONNEL PROTECTION SYSTEM

The Personnel Protection System has a machine shut-off circuit, access controls, radiation monitors, and warning devices.

When the personnel protection system checks were accomplished in Sectors 13 through 18, the Central Control Building had not been equipped with the final personnel protection equipment, and a temporary control was designed, built, and installed in Sector 18. The Personnel Protection System in Sectors 25 through 30 was later checked using the Central Control Room equipment. The Personnel Protection System in these sectors very closely represented the final Personnel Protection System; the only exception was that the transmitters for the "Sector Secure" tone loop and the "All VVS Off" tone loop were located in Sector 25 rather than at the Main Injector. Sector 28 was designated by the Accelerator Operations Group as a controlling sector, so a temporary key switch panel was constructed and installed to reset the tone loop receivers in Central Control. The display and control equipment in Central Control was temporarily disconnected for this operation. The Operations Group checkout of the Sectors 25 to 30 Personnel Protection Systems was accomplished from Central Control in less than four hours.

#### G. 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.

The one-millisecond network consists of a tone generator and tone receiver, and a set of tone-interrupt units, one at each sector. Tone-interrupt units are



installed in eight sectors. The tone transmitter will be installed in the CCR in January 1966.

A rather crude system of ion chambers was assembled to detect radiation in a few places in the Accelerator Housing in Sector 1. The output signals, which were dc ranging upward from below 1  $\mu$ A, were successfully transmitted to CCR on wire pairs in a "noisy" cable, where they were helpful in remote adjustments of the electron beam trajectory in Sectors 1 and 2. The installation of the remaining 12,000 feet of the accelerator waveguide protection long ion chamber was begun, and schedules were prepared to complete the installation by February 20, 1966, with minimum interference with other activities.

#### H. CENTRAL CONTROL

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

During the last quarter equipment installation and rack wiring has been completed for the status racks, the analog rack, remote control, beam monitoring, dc and ac distribution, and personnel protection. In addition, display panels and meters have been installed and wired for analog channels on the backup console. Operational tests with a beam in Sectors 1 and 2 were conducted successfully. These tests included steering and beam monitoring.

Checkout of data transmission and control equipment in Sectors 1, 2, 5, 6, 13-18 and 25-30 has been accomplished from CCR.

#### I. CONTROL SYSTEMS

In October the control and display requirements for the Positron Control from Sector 11 alcove had become sufficiently firm that a cost estimate of the instrumentation involved could be made. The control concept is a compromise between desirable requirements and permissible cost. It was decided that control of the Positron Source would be entirely local, from the I/C Alcove in Sector 11. Remote control from CCR may be installed at a later date when requirements have been determined from operational experience. As a result of this decision, detailed design could be completed for the control and display panels for Beam Guidance and Beam Monitoring. Design work for the voltage

control of positron modulators and the solenoid power supply control is progressing.

The list of signals to be exchanged between Central Control and the Data Assembly Building has been brought up to date. Remote control and status monitoring channels have been assigned. Although some of the signal interface connections are firm, a number of incomplete interfaces were uncovered; the details are being worked out with the Beam Switchyard Instrumentation Group.

## VI. HEAVY ELECTRONICS

### A. MAIN MODULATOR

The balance of the modulators were received and installed this quarter. Checking and testing of modulators in the Klystron Gallery on water loads continued in preparation for sector tests. All modulators in Sectors 13 through 18 and 25 through 30 were checked out and tested ahead of schedule. After the modulators in Sectors 13 through 18 had been run up to operating voltage into klystron loads by the Sector Test Team, they were tuned for a flat output voltage pulse. In addition to the above, modulators had been checked out and tested in Sectors 3 and 4 and 7-1 through 7-3. By the end of the quarter almost two-thirds of all the modulators on the machine had been checked out and tested.

The operation of the modulators was improved by the addition of shrouds around the fans to increase the airflow around the airflow switch paddles, thus making them less marginal in their operation. Also, a fire alarm circuit was designed and tested in one of the test modulators in the Test Laboratory.

The four test modulators in the Test Laboratory (serial numbers 2, 3, 21 and 22) continued to run around the clock for life testing. At the end of the quarter they had 11,590, 10,800, 5,980 and 6,560 hours of running time, respectively.

#### 1. Switch Tubes

Both manufacturers continued to deliver tubes this quarter. One company had almost completed its order; the other has progressed into its production order. Deliveries continued to be ahead of our requirements.

#### 2. Pulse Transformers

Pulse transformer deliveries, while slightly behind schedule, remained ahead of our requirements.

#### 3. Pulse Cable Assemblies

The log jam on this item was broken this quarter. All the manufacturing problems were worked out, and by the end of the quarter almost all of the items under contract had been received.

#### 4. Pulse Transformer Tank Assemblies

Assembly of these units continued. Production was slowed a little because a problem with some of the phenolic disks which support the klystron socket was

discovered. It seems that the material from which the disks are made has a small amount of air trapped in it, which causes corona development in the high voltage fields existing in the tanks. Such corona eventually causes complete breakdown of the insulation and the support insulation. The disk material was changed from phenolic to Lexan. Despite the production delay caused by the changeover, tanks were supplied to the klystron group ahead of their requirements.

#### B. SUB-BOOSTER MODULATOR

The balance of the sub-booster modulators were received this quarter. They were installed, checked out, and tested ahead of the sector test schedule. The main problem encountered with these units was in the blowers which cool the switch tubes and series-pass tube. Many of them vibrated excessively, leading to early failure of the blowers; in some cases, the vibration shook the tube elements apart, causing early failure of the tube. At the end of the quarter steps to remedy this situation had been taken.

#### C. GUN MODULATOR

The modification of one of the Manson gun modulators for use on the accelerator continued. Cable and bushings were procured for feeding various voltages and pulses to the circuitry to be located in the Accelerator Housing. At the end of the quarter the modified modulator was undergoing test in the Test Laboratory in preparation for delivery to the Klystron Gallery.

#### D. STORAGE RING INFLECTOR MODULATOR

This modulator was delivered to the Research Division for further testing on their magnet load. Thus far, their tests indicate that they do not need to operate at full voltage, so the diodes in series with and across the thyratrons to prevent arc-back are not necessary.

#### E. IMAGE INTENSIFIER TUBE PULSER

A pulser which delivers 20-kV, 2-microsecond output pulses with  $\pm 0.1\%$  stability and flatness was designed, built, and delivered this quarter.

## F. MAGNET POWER SUPPLIES

### 1. 0.1<sup>0</sup> Pulsed Magnet Power Supplies

Two power supplies were delivered this quarter. They were set up and tested in the Heavy Assembly building. Two more were shipped before the end of the year.

### 2. A- and B-Beam Quadrupole Power Supplies

One 27-kW power supply was delivered this quarter. It was installed and tested in the Heavy Assembly building.

### 3. A-Beam Dump Power Supply

This power supply was delivered, installed in the Heavy Assembly building and tested this quarter.

### 4. A- and B-Beam Unregulated Power Supplies

All three of these power supplies were delivered this quarter. They are installed in the Heavy Assembly building for further tests with their associated regulators.

### 5. A- and B-Beam Regulators

The 35-kW regulator was delivered this quarter. It is installed in the Heavy Assembly building for further testing.

### 6. Pulsed Steering Magnet Power Supplies

These power supplies continued to be constructed this quarter. Delivery is planned for January 15, 1966.

### 7. DC Steering Magnet Power Supplies

These power supplies continued to be constructed this quarter. Delivery is planned for early January.

### 8. Photon Clearing Magnet Power Supply

This power supply continued to be constructed this quarter. Delivery is planned for February, 1966.

### 9. Positron Source Power Supplies

These units were all nearly finished at the end of the quarter. The 800-kW power supply was shipped before the end of the year.

### 10. 5800-kW Spark Chamber Power Supply

This power supply continued to be designed this quarter. Some parts were on order. Delivery is planned for May 1966.

11. 1590-kW Power Supplies (Experimental Group A)

A contract was let on November 22, 1965. The successful company began its design of the power supplies.

12. 567-kW Power Supplies (Experimental Group A)

A contract for these power supplies was signed on December 16, 1965. Design work was begun and the rectifier transformers were out for bid.

13. End Station B-Beam Transport Power Supplies

Two of these power supplies were shipped this quarter. The remaining units should follow closely in January.

14. 3400-kW Power Supply (Experimental Group B)

Bids were opened December 1, 1965, and negotiations leading to a contract are underway.

## VII. MECHANICAL DESIGN AND FABRICATION

### A. GENERAL

Seventy-two girders were completed and 71 installed during the reporting period, to bring the installed total to 225. All drift sections, with the exception of the spares, were completed by the end of the year and 13 of these were installed during the quarter, for a total of 30. This meant that 9,300 feet of the accelerator had been installed by the end of the year.

With the machining of all parts for the disk-loaded waveguide completed by early November, much of the work in the group at the end of the year involved retooling, dismantling equipment, and preparing for such activities as target development and fabrication, and BSY component fabrication. The status of the work performed to prepare for new component fabrication and/or assembly is described below, while the status of the component development and procurement of materials for the components is given in other sections of this report.

### B. ACCELERATOR STRUCTURES

All of the remaining ten-foot sections of disk-loaded waveguide for the accelerator plus 16 spare sections were fabricated during the reporting period, with the last section being completed in November. In total, 120 sections were fabricated during October and November to bring the final total to 976 (not including the 32 sections made for the Mark III machine). No sections were damaged or rejected for failing to meet tolerances during the final period of fabrication.

With the completion of section fabrication, the quality-control phase measurement machine in the low-power rf test room was dismantled and put into storage. Test stand No. 3 in the high-power test area was also dismantled and stored.

### C. RECTANGULAR WAVEGUIDE

A total of 75 crossbars and 125 thirty-eight-foot penetration waveguides were fabricated, tested, and either installed and tuned during the reporting period or were ready for installation and tuning. This brings the number of these components completed to totals of 242 for crossbars and 487 for penetrations. The parts remaining to be fabricated are for spares only and all should be done shortly after the first of the year.

### 1. Phase Measurements and Adjustment

During the reporting period, 67 rectangular waveguide networks were phase adjusted for the following girder stations: 3-1, 12-2, 21-7, 21-8, and all of sectors 22 through 29 with the exception of station 23-7.

### 2. Rectangular Waveguide Component Status

The number of the various components completed during the quarter and the total number completed by the end of the year are as follows:

	<u>Fourth Quarter</u>	<u>Total to Date</u>
Waveguide Vacuum Valves	70	250
Model A Directional Couplers	62	237
RF Loads (All Types)	411	1,387
Power Dividers (All Types)	208	1,042
S-Assemblies	132	443

## D. NEW COMPONENT FABRICATION

Preparations were being made for the fabrication of positron source hardware. It was anticipated that this equipment would be completed during the first quarter of the next year. Hydrogen target tooling was also being set up by the end of the period.

Work on magnet piping and the cores for the 0.1-degree bending magnets was also being performed during the reporting period. It was estimated that this would be completed during January of the new quarter.

## E. PRECISION ALIGNMENT

Alignment of components for installation in the BSY continued during the reporting period. Figure 10 shows the setup for the alignment of a bending magnet, and Fig. 11, the alignment of a high-Z collimator. In Fig. 10, the external targetry for alignment is in place with the tooling balls and the mirror stage target shown, together with the telescope used to control the line of site on the beam axis by observing a target inside of the magnet gap. The adjustment screws in the magnet support stand will be used for positioning the magnet precisely in the BSY.



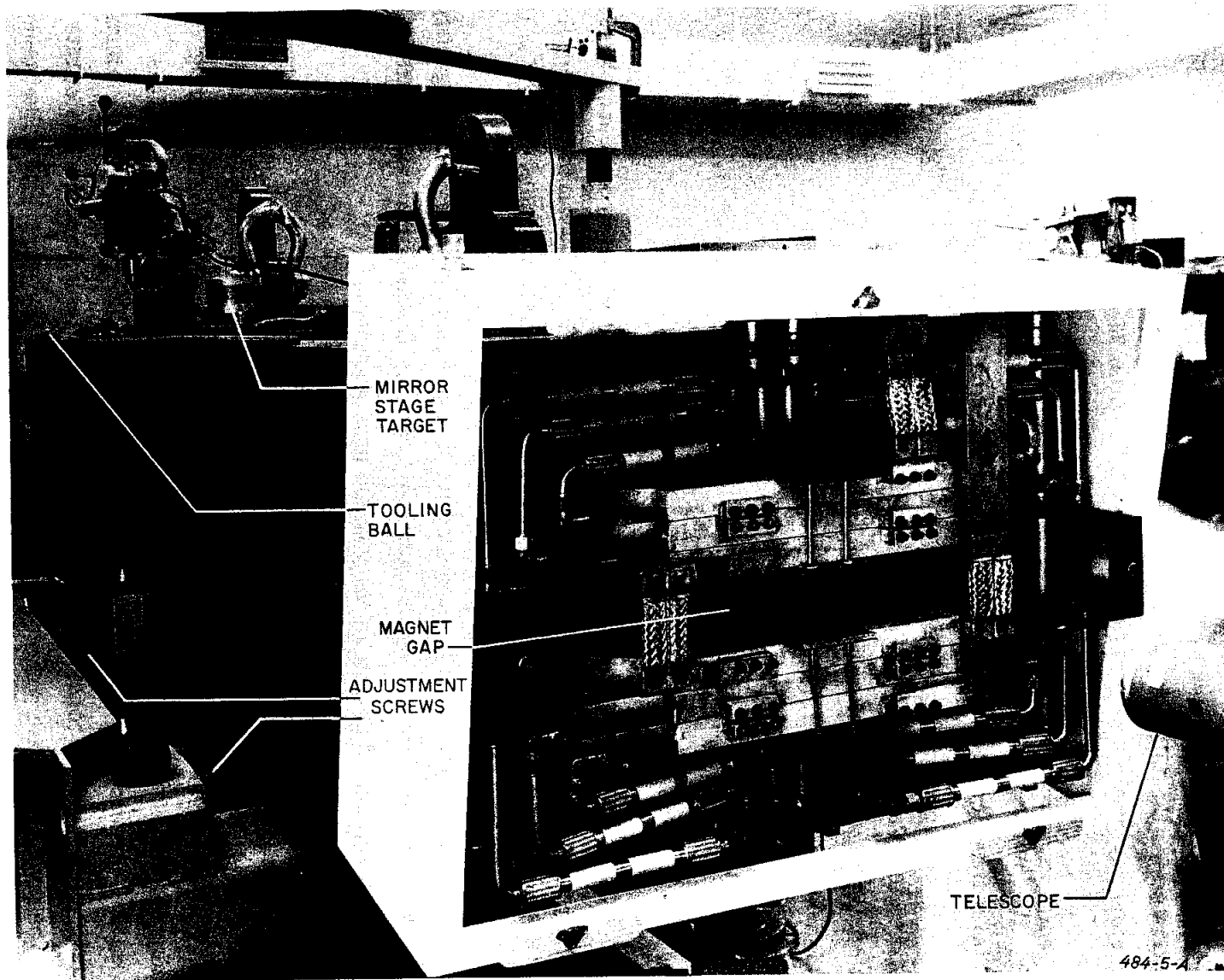


Fig. 10--Laboratory alignment of bending magnet

Figure 11 shows the tooling bar bay arrangement and the external target arrangement for the collimator. The optical tooling works with the bars to provide optical lines of sight that are used in evaluating relative points on components being aligned so that they can be precisely controlled.

The design of the tape bench facility was completed during the reporting period and construction was started. It was anticipated that the facility would be completed by the end of February. Also, with the completion of the hardware design, the tape scribe and the Vernac\* measuring assembly were fabricated and assembled by the end of the year.

The tape and stretched wire hardware prototype design for second level alignment was completed and the hardware partially fabricated by the end of the quarter. This will be evaluated early in the next period before the final design is resolved.

A study was made of second level installation procedures. It was decided to go to concrete block shielding slabs with appropriate plugged penetrations that would allow for optical lines of sight directly downward from the second level to the lower BSY transport chamber. Blocks were fabricated and delivered at the end of the quarter for preliminary second level alignment procedure tests.

The end station grids were delivered, calibrated, and evaluated during the reporting period.

#### F. MAGNET ENGINEERING

The magnet engineering group continued to be primarily concerned with vendor follow-up and scheduling during the last quarter of the year. For the most part, it appears that all components will be delivered in time for testing and installation to meet the scheduled dates for beam turn-on for all systems.

##### 1. Pulse Steering Magnets

All of the pulse steering magnets were received during the reporting period. Their vacuum chambers will not be on hand until the first month of the next quarter, however, so final magnetic checks on the magnets cannot be made until that time. Tests to date show the magnets performing to specification and it is anticipated that final checks will be made on them in time to meet the installation schedule.

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\* Registered Trademark

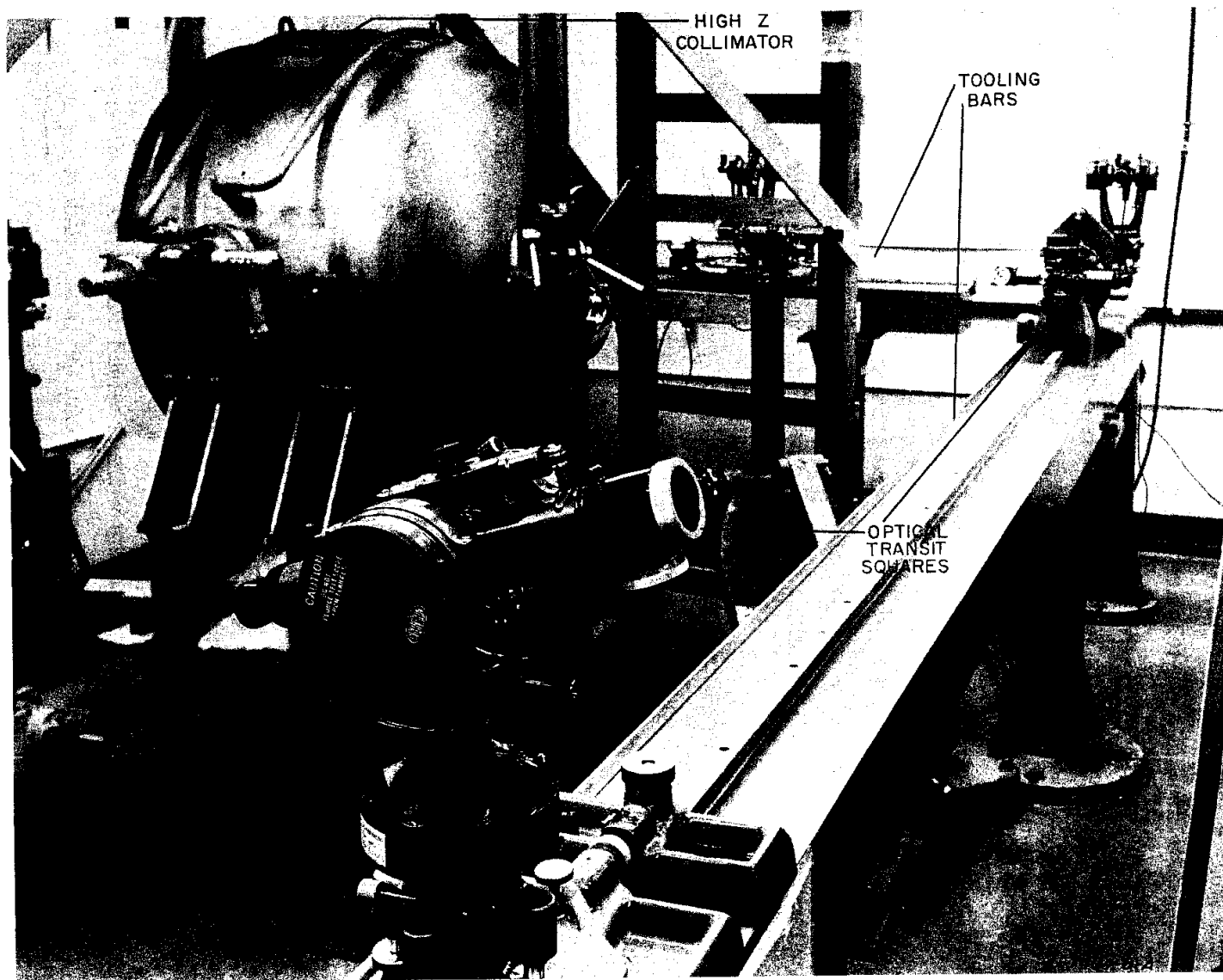


Fig. 11--Laboratory alignment of high-Z collimator

## 2. Emergency Bending Magnets

The delivery of all emergency bending magnets is expected during the first quarter of the new year in time to meet installation schedules.

## 3. Three-Degree Bending Magnets and Reference Magnets

Eight of the three-degree bending magnets had been received by the end of the year and all of them had been magnetically measured. Only magnet B-33 had been assigned a position in the Beam Switchyard, however, as the magnets must be selected for position in the beam line very carefully. This is to minimize perturbations in the beam and to assure their similarity in characteristics for tracking. It is anticipated that position designations will be assigned during the first month of the coming quarter and that preparations for installation can continue. The remaining five magnets are expected to be delivered early in 1966.

## 4. Pulse Magnets

One core for the 0.1-degree pulse magnets was constructed in-house during the reporting period. The techniques for producing these cores were being improved so that all cores are expected to be completed during the next quarter.

The coils and packaging assemblies for these magnets have been somewhat delayed because of a heavy vendor workload. It is anticipated, however, that the coils will be ready for all five magnets by the first of May, with two magnets ready by the first of April. This should not delay any beam testing in that the emergency bending magnets, B-1 and B-2, can be used as substitutes for the pulse magnets during initial tests.

## 5. Quadrupole Magnets

The fabrication of the 8-cm quadrupole magnets was behind schedule both because of a heavy vendor workload and because the vendor was having difficulties with fabrication techniques. The delivery schedule is being accelerated, however, and it is expected that the magnets will be here during the first quarter of next year in time to meet installation schedules.

The vendor for the 18.6-cm quadrupole magnets has also had difficulties in the production of the core shapes. These are complicated parabolic hyperboloid shapes which are difficult to check. The magnet core and coil assemblies are expected in time for installation during the first quarter of next year, however.

#### 6. Photon Beam Stripping and Bending Magnets

The core for the B-28 bending magnet, which was fabricated in-house, was completed during the reporting period. The coil is expected to be delivered in February, on schedule.

The B-29 stripping magnets are not expected to be delivered before February. This will not hold up the installation and test schedules.

#### 7. Dump Magnets

Progress on the fabrication of the dump magnets was slow during the reporting period, but was improving by the end of the year. One magnet was expected to be delivered by mid-January and the other three by the end of the next quarter.

#### 8. Associated Magnet Hardware

Approximately 80% of the ceramic water tubes and bellows connectors for the BSY magnets were delivered during the reporting period, and the vendor is well ahead of the demand for these components.

The delivery of quick-disconnect couplings for the vacuum chambers was slightly behind schedule and held up vacuum chamber production. The chambers themselves could have been completed had couplings been available. All couplings are expected during the first quarter of 1966 and no delays in installation are anticipated.

The vendor for the ceramic vacuum chambers experienced a great deal of trouble during the reporting period and had not produced chambers that were within the specified tolerances. Isostatic press problems and furnace problems were the main difficulties, and the vendor was rebuilding his tooling to try to control the tolerances. Hopefully, all chambers will be fabricated and delivered by the end of the next quarter.

The contract was let for the bellows for the vacuum chambers. It is expected that they will be delivered and the chambers completed by the end of the next quarter.

## VIII. KLYSTRON STUDIES

### A. SUMMARY

During the quarter, 96 klystrons were installed in 12 sectors in the Klystron Gallery, bringing the total of installed klystrons to 132. The deliveries from our three vendors (RCA, Sperry, and Litton) continued at a satisfactory rate, and availability of magnets for use with SLAC-built tubes contributed to the total number of tubes installed.

Three tubes failed during operation in the Gallery, bringing to 12 the total number of failures during operation to date. Shelf life failures totaled nine for the quarter and 16 cumulative to date. The number of failures may appear high until it is realized that the total number of klystron hours accumulated in the Gallery through the end of the year was in excess of 27,000. Five tubes have operated in the Gallery in excess of 800 hours and 30 in excess of 200 hours.

The SLAC klystron activity resulted in successful operation of "standard" tubes in permanent magnets with a cumulative total of 27 SLAC-built tubes having met all specifications and an actual 31 SLAC tubes installed in the Gallery. In addition, an extended interaction output tube was tested which shows promise of giving higher efficiency than the "standard" tube.

### B. KLYSTRON PROCUREMENT

In general, the manufacturers' yield is improving but is not yet as high as desirable. Several specific problems might be mentioned.

#### 1. Sperry Subcontract

As mentioned previously,\* the initial Sperry window was constructed such that a window failure could let water vapor and possibly water into the vacuum system of the accelerator, as well as in the tube itself. A new window design was put into production by Sperry, and all tubes being delivered currently do not present this danger to the accelerator. On the other hand, Sperry tubes have also experienced a rather high number of window failures, and many discussions were conducted with the Sperry engineers in an attempt to improve the window

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\* "Two-Mile Accelerator Project, Quarterly Status Report, 1 July to 30 September 1965," SLAC Report No. 53, Stanford Linear Accelerator Center, Stanford, California (1965).

coating technique. It is believed that the technique has been improved so that fewer windows now show signs of multipactoring and an improvement in the window life is expected.

During the quarter, Sperry initiated a direct shipment of magnets from their vendor to SLAC. After a few problems regarding field measurements and initial performance of the tubes in magnets, the magnet interchangeability problem appears to be well resolved. In fact, the performance of the later tubes shipped from Sperry in the magnets available has been as good or somewhat better at SLAC than at Sperry. However, should the need arise it is possible to improve power output by minor adjustment of the output waveguide tuners to establish true interchangeability.

## 2. RCA Subcontract

The manufacturing yield at RCA appears to be improving gradually in spite of occasional problems such as temperature-limited cathodes, leaks, and/or "glitches." The main deterrent to high delivery rates from RCA has been the availability of magnets from their vendor, which has continued to be low. RCA has ordered additional magnets from a second vendor in an attempt to speed up their total deliveries in the first quarter of 1966. In general, tube and magnet interchangeability is good and the operation of the "standard" magnet as a tube acceptance vehicle has proved very satisfactory.

RCA has experienced unexpected difficulties on the tube rework program. It appears that erosion was produced in the collector by excessive power density, resulting in only a small section of the collector being really useful. As a result the collector surface becomes spongy, affording an excellent source for trapped gas which could not be eliminated by standard bakeout and processing. A collector redesign has been put into manufacture to eliminate this problem in future tubes.

## 3. Litton Subcontract

During the initial manufacturing process, Litton experienced some difficulties caused by oscillations and instabilities in the tube, which appear to have been cured at this time; that is, if the instabilities are still visible they are within specifications. In addition, Litton has experienced a window problem which appears to result from inadequate control of the coating process or deterioration of the coating during tube processing. Here again, we have worked in

close cooperation with Litton to understand their problems and help in the evaluation of the window coatings. No tests on magnet interchangeability have been run yet.

### C. KLYSTRON RESEARCH AND DEVELOPMENT

During the quarter, a special effort was made to increase the number of SLAC tubes built and tested through permanent magnets. As a result, 28 new tubes and 7 reworks went through processing; of these, 11 failed during or following the processing tests: 4 of the 7 reworks (2 for lack of emission, 2 by window failure) and 7 of the 28 new starts (3 windows, 2 gassiness, 2 poor operation in permanent magnet). Thirty-one SLAC tubes were delivered to acceptance tests this quarter; one failed because of broken window, 22 met all specifications, and 8 were useable under limited conditions.

In addition, a second experimental extended interaction output cavity tube was tested in electromagnet. For electromagnet focusing conditions and with optimized focusing at each voltage, the efficiency stayed substantially constant at between 45% and 47% at voltages between 150 and 250 kV. Figure 12 gives a history of the klystron development at SLAC during the past few years. The data is plotted for optimum focusing and drive at all voltages in electromagnet. Curve 1 gives the average of 9 tubes tested during the fourth quarter of 1963 using a Picquendar gun and an old body design. Curve 2 gives the performance of tubes with the same body as Curve 1 but with the new Merdinian gun design. Curve 3 is the average performance of 10 tubes measured during the fourth quarter of 1964, which incorporated the Merdinian gun and an improved body design XM3. Curve 4 is the average of 25 tubes tested during the fourth quarter of 1965, incorporating the Merdinian gun and a slight modification from the XM3 body. Curve 5 gives the results on the one extended interaction output tube built and tested during the last quarter of 1965. This tube uses the same gun as those of Curves 2, 3, and 4.

The slight improvement in performance between the fall of 1964 and the fall of 1965 may be attributed to the modifications in the drift distances, the fact that the perveance averages a few percent higher, and a slight decrease in the external Q of the output cavity. It appears that the extended interaction tube is worthwhile pursuing further; it is planned to build three such tubes during the first quarter of 1966 to determine whether the excellent performance shown by



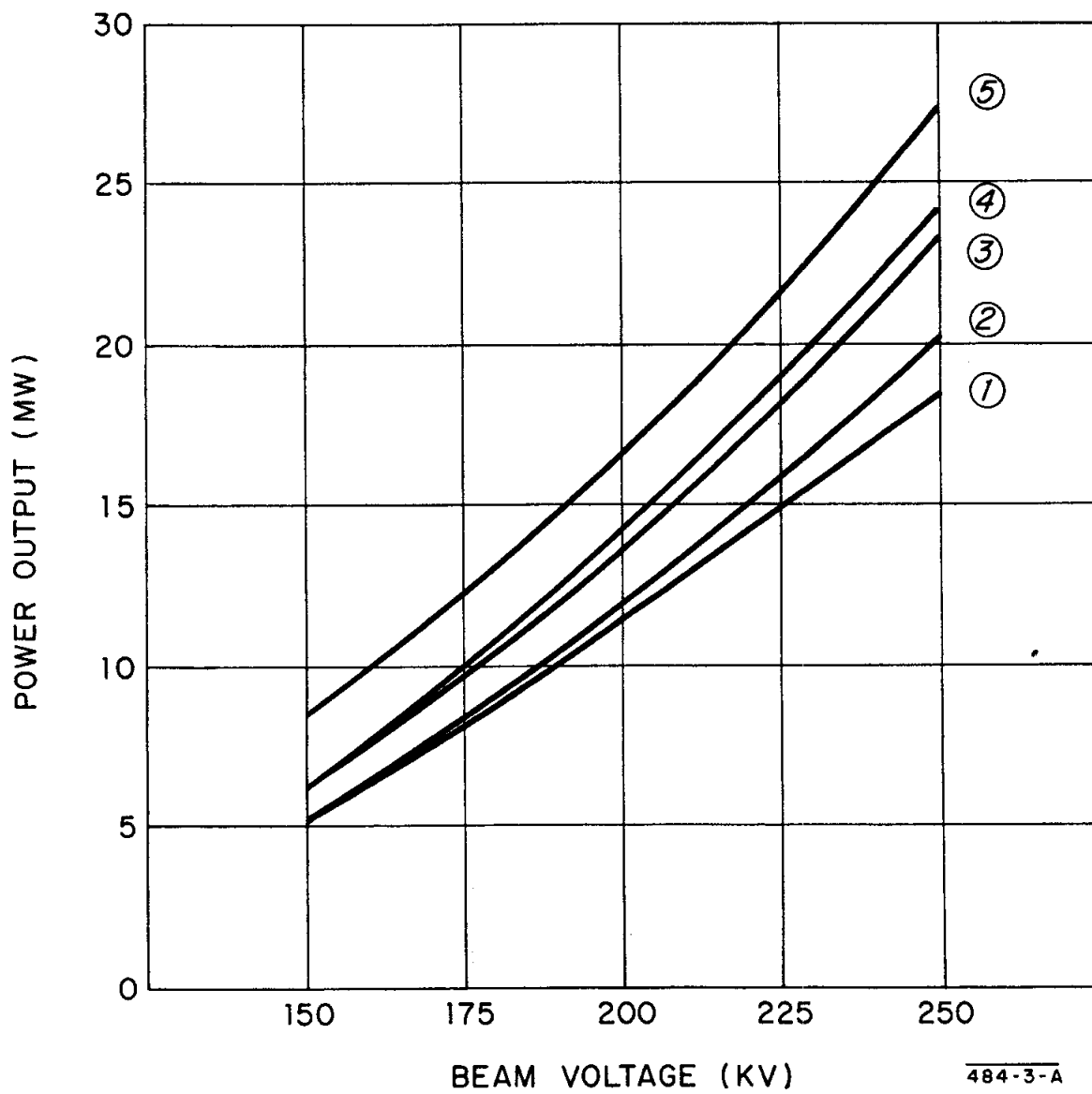


Fig. 12--History of klystron development at SLAC

Curve 5 is an "early bird effect" or a repeatable phenomenon due to improved design.

Figure 13 shows the average performance in permanent magnets of SLAC tubes accepted during the quarter. Curve 1 is the average of the 22 tubes accepted. Curve 2 is the average of the 11 tubes built and accepted during the quarter. Whether the difference is significant is not certain at this time. What is significant is that the power output is on the average 2 MW lower than that measured in electromagnets for the same tubes. We believe that this difference is caused by the entrance conditions of the beam, because the net interception in the body is small with either permanent magnet or electromagnet focusing for these tubes. Additional work on gun design and entrance conditions will be done in an attempt to bring the tube permanent magnet performance up to the level of the electromagnet operation.

#### D. KLYSTRON TESTS AND MEASUREMENTS

During the quarter, the mock-up test stand was dismantled and the modulator and auxiliary equipment reinstalled in the area of test stand 08. This was made possible by a space reduction in the window test area, which is at present not using the old low vacuum resonant ring. At the present time, five of the 10 test stands are earmarked for acceptance, heat run, and final tests; three for SLAC tube processing (both electromagnet and permanent magnet), one to window life test, and one to window tests. In excess of 400 individual tests on klystrons were run this quarter where, for example, acceptance on a given tube is counted as one test, the heat run on the same tube is another test, and the final test prior to installation in the Gallery is a third test. The total number of high voltage hours of operation in the test stands was approximately 7250 for the quarter. Of these, 1400 hours were for window life test, where SLAC tube H-56A operating in electromagnet has now reached 5000 hours of operation. The tube is still performing satisfactorily although the perveance appears to have decreased to approximately 1.85 and the power output to 18-19 MW.

The major failures in the test stands involved eight trigger generators, four 5-kV driver switch tubes, one KU-75 thyratron, one pulse transformer, one klystron filament transformer, and one powerstat. In the sub-booster modulators we experienced eight switch tube failures, five rf drive failures, and three high voltage rectifier failures. In general, the availability of equipment continues to be excellent.

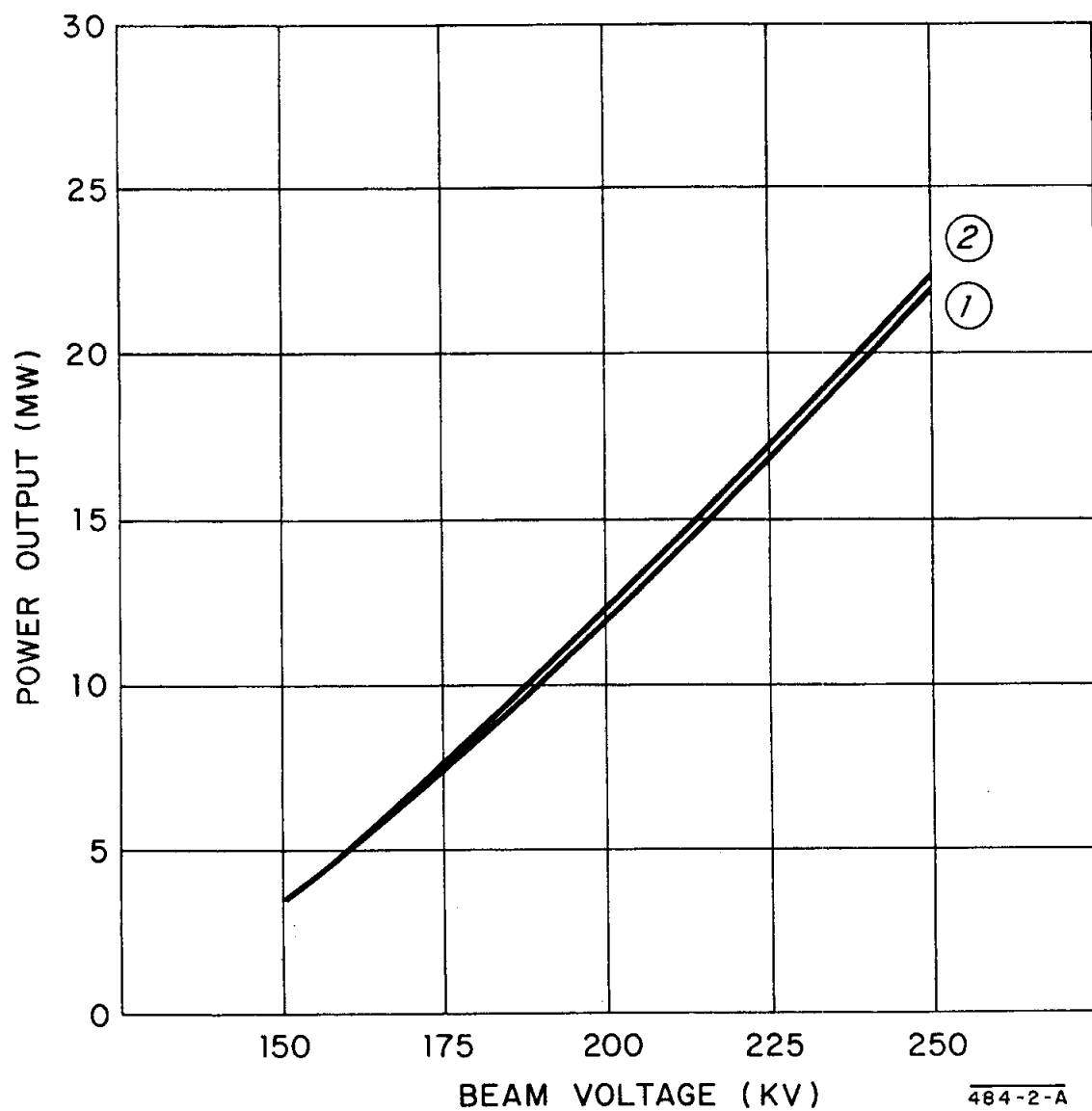


Fig. 13--Average performance in permanent magnet of SLAC klystrons accepted during quarter

The efforts of cross-calibration with vendors are apparently continuing to be fruitful. In general, our readings check with those of the vendors to within a few percent. The only possible exception is in the case of the Sperry tubes where we appear to be, on the average, measuring more power output at 250 kV than Sperry. It is possible that the difference is the result of our tests in magnets which, on the average, have higher fields than those used at Sperry during their tests.

#### E. GALLERY OPERATIONS

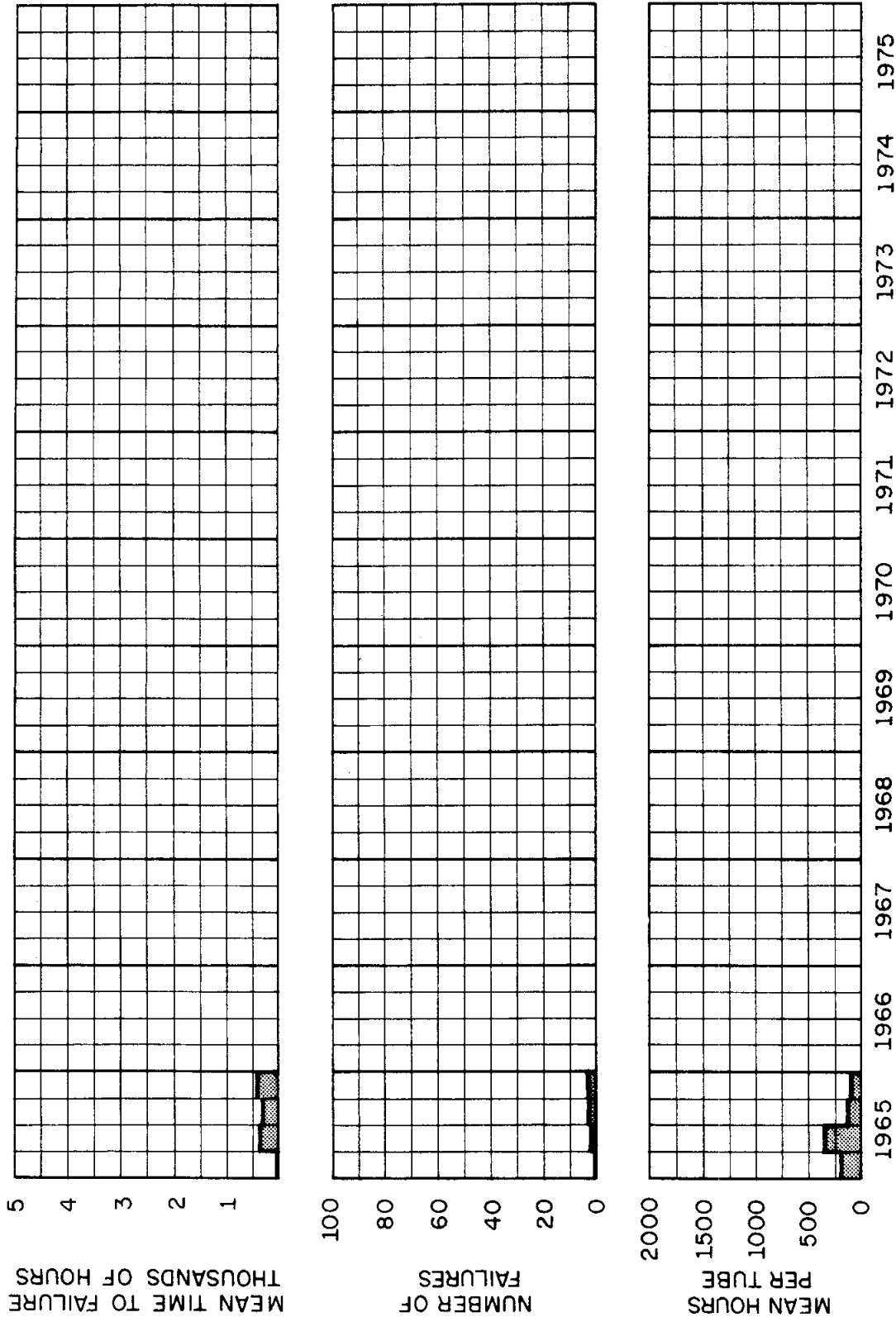
In general, the operation of klystrons during sector tests has been satisfactory. As mentioned earlier, 27,000 tube hours have been accumulated in the Gallery, with cumulative klystron failures of 12 tubes during Gallery operation. Of the three failures incurred during the quarter, two were caused by broken windows. Figure 14 gives the mean time to failure of the tubes which had to be replaced, the total number of tube failures, the total number of tube replacements in the Gallery, and the average number of hours of operation per quarter per socket installed. The difference between the number of total replacements and total failures is caused either by failures in the pulse transformer tanks or by minor difficulties such as water cooling leaks or oil level variations in the pulse transformer tank, which can readily be repaired without considering the tube a failure.

Early during the operation it was discovered that low energy radiation was detectable outside the pulse transformer tank. Additional lead shielding has been ordered and has been placed on the klystron tanks in service.

The klystron handling equipment in the Gallery consists of a special fork lift, Hovair, and special mechanical carts. The fork lift now in use is extremely marginal in operation and we are investigating different types of handling devices.

At the end of the third quarter and the beginning of October, extensive operation of Sectors 5 and 6 was carried out to ascertain the potential problems in running the machine. Although the data has not been fully analyzed yet, the following general statements can be made.

1. In general, the beam voltages and power outputs tracked the reference voltage extremely well throughout the tests.
2. Some discrepancy was observed between the Gallery power readings and corresponding values measured in acceptance tests.
3. Some difficulties were experienced with variations in drive level in one sector.



442-2-A

Fig. 14--Klystron quarterly operating experience—all high power klystron vendors

4. The vacuum system normally operates in the  $10^{-7}$  torr range; however, the pressure at some stations increased to  $10^{-6}$  torr at full power, causing many shutdowns.

5. Some rf pickup was detected in a few vacuum gauges. Appropriate measures have been taken to prevent this leakage in the future.

6. The number of faults observed is extremely small at all repetition rates and beam voltages up to 230 kV. From 230 to 250 kV there is a very rapid increase in number of faults (approximately tenfold for a 20-kV beam voltage increase in that voltage range).

With respect to item 2, very careful checks were made after the endurance runs on two stations. It was discovered that the readings obtained from the directional couplers agreed very closely with water load readings, and the apparent discrepancy was presumably caused by an unexpected variation in rf pulse length. With respect to the number of faults (item 6), we could not gather sufficient data to indicate the specific causes of fault, but it would appear that in general between 50% and 80% of the faults recorded were caused by excessive pressure in the waveguide near the klystron window.

#### F. HIGH POWER KLYSTRON WINDOWS

During the quarter, the window problem in SLAC-built tubes was considerably reduced; in spite of the additional number of tubes built and tested, only five SLAC window failures were observed (there were nine the previous quarter). On the other hand, vendor tubes continued to experience window failures. We believe that the rate of failure on Sperry tubes will be decreased by improved coating techniques and handling of the window after coating. Two RCA windows failed, one of which was of 1964 vintage, prior to the initiation of window coating. Two Litton windows failed during acceptance test, and careful ring studies of their coatings indicated a serious decrease in resistance (and consequently, increase in losses) as a function of vacuum bake cycle. We are continuing to run resonant ring tests for vendors if they have special problems which their facilities do not allow them to resolve.

## 1. Resonant Ring Tests

### a. SLAC Window Pre-Tests

Thirty-seven klystron windows were processed and checked on the ring for operating conditions after coating. The results appear to be consistent and it appears that coating thickness measurements by crystal monitoring will soon be sufficiently reliable that the pre-testing in the resonant ring can be discontinued.

### b. Other Ring Tests

In an attempt to avoid decreased resistance of the coated surface after the window is vacuum baked, some tests are being run on windows on which a striped coating is applied. The alternate coated and uncoated stripes are oriented normal to the major axis of the electric field. During tests the uncoated portions were evident in the glow pattern but the temperature behavior of the window was similar to those with standard coatings. In addition, no significant increase in operating temperature was noted following vacuum bake cycles. Further tests of this technique will be carried out as a means of allowing us to rebake tubes without the necessity of removing and recoating the windows.

It has been observed on SLAC klystrons that the window operating temperature decreases significantly when the tube is operated in permanent magnet rather than electromagnet (at the same power level). This phenomenon is not understood, but we intend to carry out tests on the ring to study the effect of magnetic fields which would duplicate the fringing field of the permanent magnet in the window area.

## 2. Window Life Test

The window life test stand was operated for an additional 1400 hours during the quarter, bringing the total life test time to approximately 8000 hours. The power level delivered to the life test window string has fallen off slightly (to 18-19 MW) in the past three months, as its klystron has now operated for more than 5000 hours. No window failures have been observed since the single casualty which occurred in the last quarter of 1964; and the window whose high temperature had become noteworthy several months ago, before the tube power began to decline, is now operating at a safe level, along with all other windows in the stand. A higher operating power will probably be required before further failures occur.

### 3. Other Window Work

#### a. Coating Activity

The coating equipment has been cleaned and overhauled. After adding insulation on many of the metal surfaces, and improving the alignment and location of the monitoring crystals, the coating control has been improved, and it appears that the crystal monitoring data (coating thickness) shows much better consistency with the ring tests.

Probably the most significant work done on coating during the quarter was the investigation of the relation between coated surface resistance and temperature during actual or simulated vacuum bake cycles. Included in the test specimens were an uncoated ceramic, standard and heavy sputtered coating, a striped sputtered coating, and Litton evaporated coatings. Sixteen resistance-versus-temperature runs were made, some windows being subjected to as many as three bake cycles. In addition to showing that coated surface resistance does not return to its original high value when it cools in vacuum following a bake cycle, these tests indicate that cumulative resistance decreases result from repeated bake exposures, that resistance decrease is greater for thicker coating layers, and that evaporated coating (based on the Litton samples) is less stable through a bake cycle than is the SLAC sputtered coating. Additional tests are planned which should confirm these conclusions, provide better quantitative information, and analyze the temperature stability as affected by other variations in coating material or coating technique.

In addition, other materials are being investigated for coating and multipactor reduction. A coating apparatus has been completed in which different coatings can be tested. Our first attempt has been to coat a window with tungsten carbide, but electrical test results have not yet been obtained.

#### b. Window Replacement

The statistical evidence continues to mount that with our present coating technique it is essential to remove the window from a rework tube, sand blast the old coating, and recoat on both sides of the window. Similar evidence has also been shown in the ring tests. While we are working on new coating schemes either to improve the coating stability or to prevent the instability from being detrimental, we are also investigating a method by which the window can readily be removed from the tube.



Although we are using bolted-on windows, a diffusion bond forms between the copper gasket and the stainless steel at the joint. To date, no completely effective method has been found, although thin oxide layers on the copper or the steel or sputtered films on the steel appear to offer possibilities.

#### G. SUB-BOOSTER KLYSTRONS

Yield on this klystron usually runs at a fairly high level (around 90% to 95%); however, during the last quarter, a series of tubes was built that showed serious temperature limiting. Discussions with Eimac personnel did not reveal any obvious reasons for the emission slump. However, in true tube building tradition, several of the processes were changed; at the end of the quarter yield was again up and temperature limiting seemed to have disappeared. Subsequent tubes do require a longer age-in time than those made previously.

The shelf life problems previously experienced at Stanford have been reduced substantially, primarily because the installation rate of sub-boosters has been high, and secondarily because it appears that many of the corrective measures taken by Eimac have indeed proved useful. Of those few tubes rejected for shelf life failure during the last quarter, all were low in power at the specification frequency and acceptable in power at another frequency, indicating that the tuners had evidently taken a new set. Retuning those tubes brought them back into specification.

## IX. ACCELERATOR OPERATIONS

### A. SUMMARY

During the quarter the injector and Sectors 1 and 2 of the machine were operated with an electron beam up to a maximum energy of 1.54 GeV, which was reached November 11, 1965, and formal sector tests were completed in Sectors 5 and 6 and Sectors 13 through 18. Sector tests were then started in Sectors 25 through 30 with completion scheduled for mid-January, 1966.

### B. SECTOR TEST

Formal sector test, at this time, is made up of a series of tests intended to determine the completeness and correctness of construction and wiring of the sectors and at the same time serves to process the rf structures of the machine. RF processing serves two functions: Contaminated waveguides or accelerator sections can be discovered and replaced before beam operation commences (with roughly half of the accelerator tested, only one contaminated waveguide has been found and has been replaced); and turn-on of the entire accelerator will be simplified and hastened by the pre-processing that has gone on.

Sector testing begins when a group of sectors is turned over to the Accelerator Operations Group with a sheet checked off by all concerned, indicating that installation and wiring have been completed and tested for proper operation. Schedule requirements have made it necessary to begin tests even though a large list of exceptions has been noted. Most of the exceptions apply to items which are not necessary for rf processing, but rather are necessary only for beam operation—such as beam intensity and position monitors, beam steering and focusing supplies, etc.

The formal sector test procedure includes an initial "walk-through" by members of the Accelerator Operations Group, recording equipment serial numbers, and checking such items as the communication system, building security, main system water flows, etc. Following this "walk-through," the personnel protection system undergoes a rigorous and complete checkout. RF processing then commences, and the power from each modulator/klystron station is increased as rapidly as possible. The pulse-forming network in each modulator is then tuned for the correct pulse shape at an operation level corresponding to a klystron output of about 12 megawatts peak rf power, and the stations

are run up to full power. A sixteen-hour run at 250 kilovolts on the klystron and a pulse repetition rate of 360 pulses per second completes the operational testing. During the period of rf processing a complete checkout of all other components and apparatus installed in the sectors under test has been going on. This includes such tests as make-up and drop-out flows of all the water flow switches, Modulator/Klystron package settings, etc.

Twenty-five and twenty-six working days, respectively, were scheduled for the sector test of the six-sector blocks of 13 through 18 and 25 through 30. Sectors 13 through 18 tests were completed in 20 days, and it is probable that the same length of time will suffice for Sectors 25 through 30.

#### C. OPERATION WITH BEAM AND INJECTOR, SECTORS 1 AND 2

After several months of rework and rewiring, the permanent injector and Sectors 1 and 2 were again turned on, essentially coincident with the beginning of the report period. During the first week in October, the accelerator from the injector to the end of Sector 2 was processed up to full power and the pulse-forming networks in all modulators were tuned for proper pulse shape. On October 7, a beam of 1.36 GeV was obtained. The period October 7–November 17 was used for accelerator experiments requiring an electron beam. Summaries of this work will be found in Sections IV and X of this report. On November 17, this portion of the accelerator was shut down to allow further installation of equipment and wiring in the injector area. The beam analyzing station at the end of Sector 2 was removed and will be reinstalled on the first girder in Sector 20.

#### D. OPERATION—SECTORS 5 AND 6

Sectors 5 and 6 were first turned over to the Accelerator Operations Group on August 31, 1965. A long period (11 weeks) was allotted for sector test work to try out and perfect the series of tests that were being worked up as a "formal" sector test procedure. The long sector test period made it possible to use this pair of sectors for other purposes. The 100-hour run at the end of September was mentioned in the previous quarterly report;\* a follow-up to this run, designed to examine in detail the operation of the modulator-klystron system at high power,

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\*"Two-Mile Accelerator Project, Quarterly Status Report, 1 July to 30 September 1965," SLAC Report No. 53, Stanford Linear Accelerator Center, Stanford, California (1965); p. 52.

was carried out, and operation of the variable voltage system under load was examined. Testing and operation of Sectors 5 and 6 terminated November 16, 1965.

#### E. OPERATION—SECTORS 13 THROUGH 18

The first block of six sectors to be given a formal sector test was the group of Sectors 13 through 18. These sectors were turned over to the Accelerator Operations Group on November 11, 1965; testing was completed (as far as was possible, excluding equipment not yet installed) on December 10, 1965. In general, the testing went smoothly and the equipment operated satisfactorily.

#### F. OPERATION—SECTORS 25 THROUGH 30

Sectors 25 through 30 were turned over to the Accelerator Operations Group on December 15, 1965. Testing proceeded normally to the end of the quarter, with all indications that the tests would be completed about January 14, 1966, a week before the end of the scheduled period.

## X. BEAM SWITCHYARD

### A. GENERAL

The Beam Switchyard housing was essentially completed during this period. The materials handling system was installed and tests begun. Installation of electrical and water systems and of mechanical equipment was also begun.

Design and drafting of vacuum equipment, beam transport system equipment, instruments, supports, and alignment system equipment neared completion. Fabrication of this equipment continued into this period at a high level.

### B. INSTRUMENTATION AND CONTROL

#### 1. Instruments

The construction of the various instruments for the switchyard is progressing well. It is estimated that at the end of this quarter the instrument construction was 50% completed.

We will review the status of the various instruments with reference to the switchyard component layout in Fig. 15.

#### a. Cerenkov Light Beam Profile Monitors (PR-1, PR-2, PR-14)

A prototype was tested satisfactorily in the 1.4-GeV beam at the end of Sector 2 of the accelerator. Two additional monitors are 80% completed. Some work remains to be done on reference marks and alignment procedures.

#### b. Zinc Sulfide Screen Profile Monitors (Type 1: PR-10, PR-30, PR-34; Type 2: PR-11, PR-31)

Type 1 is the "screen-changer" with 48 independent zinc sulfide screens. Several small modifications were made on the first production type in order to improve the reliability of the mechanism. The two other units are 60% completed.

Type 2 is a ten-inch-wide single zinc sulfide screen of conventional design. A prototype is being tested. A second one has to be constructed.

#### c. Synchrotron Light Observation [P(S)-10, P(S)-30]

The modified vacuum chambers for observing synchrotron light are ready except for the vacuum flanges. The mirror inside the vacuum chamber and the observation window for P(S)-10 have to be assembled.

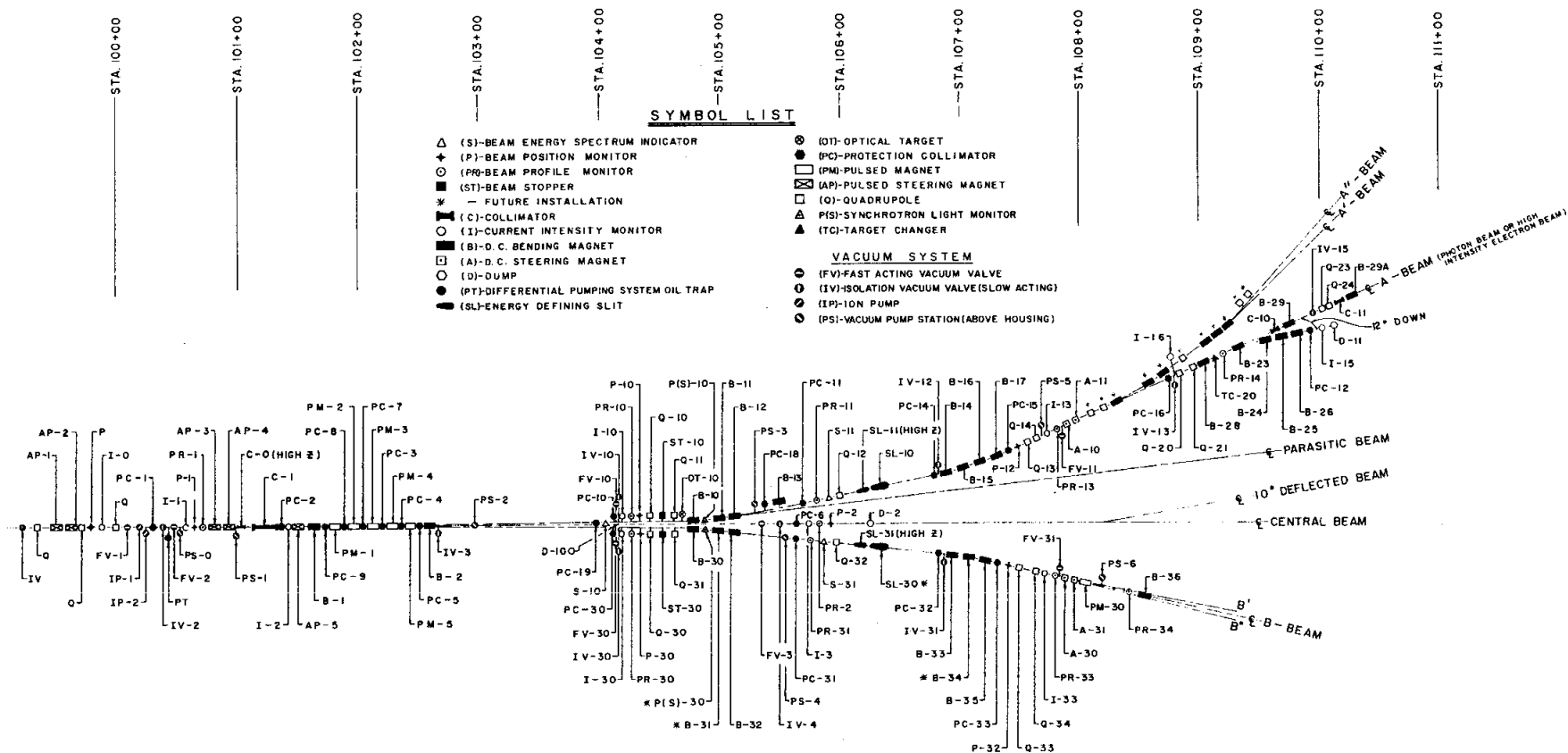


Fig. 15--Beam Switchyard transport system component layout

d. Remotely Adjustable Mirror Boxes

These mirrors, which are used to observe light from the various beam profile monitors, are all completed and tested mechanically. The actual mirrors have not been delivered yet.

e. Telescopes

The light from the profile monitors is observed by telescopes using aluminized spherical mirrors. For comparison purposes, some dielectric mirrors consisting of several  $1/4$  wavelength layers of titanium dioxide and magnesium fluoride will be installed. A first production model is being tested; all other units are under construction.

The radiation-resistant television cameras form an integral part of the telescope. All television cameras have been ordered; the first unit was delivered in early January and is now being tested.

f. Tune-Up Spectrum Monitors (S-10)

This monitor has been assembled but needs some additional mechanical work to improve the guiding and the cable termination clamps.

g. Spectrum Analyzers (S-11, S-31)

The two spectrum analyzers are well underway. The first one has been equipped with the microswitches, the positioning motors, the LVDT position transducers, and with all internal wiring. Considerable difficulty was experienced with the multi-pin ceramic vacuum feedthroughs. Some work has to be done on the cable clamps. The 12-inch quick-disconnect vacuum flanges are currently being welded on.

h. Microwave Position Monitors (P-1, P-2, P-10, P-12, P-30, P-32)

The microwave cavities (2-inch aperture) are ready. Special structures have been made to mount the cavities on the instrument alignment supports. The first two units are complete except for minor details. Vacuum flanges, thermometers, fast-disconnect water connectors, and special microwave connectors have to be mounted on the four other units.

i. Beam Current Monitors (Types 1 and 2)

Type 1 consists of a current transformer with a three-inch aperture (monitors I-1, I-2, I-3, I-10, I-13, I-16, I-30, I-33). Type 2 consists of a transformer with a 6-inch aperture (monitors I-15, I-400).

Difficulties were experienced on Type 1 with vacuum feedthroughs and with the design of the flexible copper tubing that serves as shielding for the cables. However, three of the current monitors have been completed and are now being tested.

The aperture in two of the monitors (I-13 and I-33) may have to be enlarged slightly to avoid beam interception under some conditions.

The mechanical parts for the 6-inch transformer have been machined. The delivery of the large ferrite cores has been delayed due to manufacturing difficulties; the cores are now due early in February.

j. Four-Quadrant Secondary Emission Foil Monitor

This monitor is built integrally into a vacuum housing with the 6-inch current transformer mentioned above.

The purpose of the four-quadrant SEM's is to center the beam on the 2-megawatt underground beam dump. An assembly of the four-quadrant SEM foils was tested with a beam from the injector test stand. The results were confusing, but this was largely due to the inadequate test facilities.

We will proceed with the final assembly as soon as the 6-inch current transformer becomes available.

k. Secondary Emission Foils on the Jaws of Collimators and Slits

A part of these foils has now been coated with a thin layer of dielectric material. The dielectric layer is covered with a pattern of vacuum deposited strips of gold (electrodes). The pattern of these electrodes is arranged in such a way that the signals from them provide information on the position and size of the beam intercepted by the jaws. The principle of the device is based on a change in conductivity of the dielectric when traversed by the beam.

A set of these foils for the collimators is completed and will be mounted shortly.

l. Miscellaneous Instrumentation Problems

Much time was devoted during this quarter to finalizing technical details and construction methods in view of the radiation damage and corrosive atmosphere expected in the switchyard housing.

It was decided to use stainless steel jacketed magnesium oxide cable for connection to high power collimators, slits and dumps. Vacuum feedthroughs for connections inside the collimator tanks were avoided by welding the stainless steel cables directly into a vacuum flange.



Wire connections on instruments in areas of high radiation will be covered by quartz-loaded, cold-setting epoxy.

## 2. Electronics

### a. Microwave Beam Position Monitoring System

The six special boxes containing diode detection circuits are completely designed and are now being built. They will be located in the alcoves close to the cavities.

### b. Beam Current Transformer Monitoring System

The pre-amplifiers which will be located in waterproof cabinets in the service areas are being made and should be ready in January for installation. The beam current display circuits are all designed and most of them are in fabrication. A precise (0.3%) beam current integrator is nearly finished. We plan to calibrate the integrator against the Faraday Cup at Stanford University's Mark III Accelerator.

### c. Tune-Up Dump Spectrum Monitor

The electronic scanner for the 34 signals from the spectrum monitor is being tested. Signal integration circuits are in fabrication. The control circuits are finished.

### d. Energy Spectrum Analyzer

The gated integrator circuits and the electronic scanner for the spectrum analyzer are still under construction.

### e. Various Secondary Emission Foil Circuits

The electronics associated with these devices are under construction.

### f. Magnetic Measurements

The remanent field detector electronics is ready. The mechanical design of the second harmonic probe has to be improved in order to fit in the available space of some of the magnet gaps.

### g. Control of Slits and Collimators

The chassis associated with the position read-out of slits and collimators are ready and are being tested.

The design of the circuits (manually and via the computer) is completed and will go into production in January.

#### h. Control of Magnet Currents

The electronics to control magnet currents via the computer is all designed and 70% is constructed. The manual back-up controls (emergency controls) for the magnet currents are not yet designed.

### 3. Computer System

The SDS 925 computer was delivered November 4 and has been working for several weeks. The card punch is expected to arrive early in 1966.

Most of the interface equipment has been designed and is now either on order, in production, or ready and being tested.

The interlock scanner (1024 channels) has been tested and is working through the computer. The scanner program has been de-bugged. Work on the overall computer program is underway. Some work has been done on the program which will set up the currents in all the magnets.

Some work was done on a data link with the SDS 9300 computer used with the spectrometers.

### 4. Data Assembly Building

Installation of the 45 electronic equipment racks in the control room for the switchyard is well underway. All interlock and equipment status panels have been installed and the cables are being connected.

About 50% of the chassis which have to go into these racks are now ready for installation.

### 5. Instrumentation for End Station Beams

The instruments referred to in this section are mostly modified versions of an existing instrument design used in the switchyard.

The current transformers and Cerenkov cells for the end stations are in fabrication. Design is continuing on several other instruments.

Good progress has been made on the electronics and on the interfaces between the switchyard and the end stations.

## C. REMOTE-DISCONNECT VACUUM COUPLINGS

By the end of the year, approximately three-fourths of the flanges and ring springs for the remote-disconnect vacuum couplings had been delivered. The coil springs were being made of chrome-silicon steel to provide for greater strength, and these were also being delivered by the end of the reporting period.

The bellows assemblies were being delayed because of casting difficulties but it was anticipated that they would start arriving in the next reporting period. A number of sealing tests were performed on each of the three sizes of couplings and these are reported in a SLAC Internal Report, together with descriptions of the couplings and the indium gasket behavior and installation.\*

#### D. BEAM DUMPS

The design of tune-up beam dumps, or beam stoppers, ST-10 and ST-30 (see Fig. 15) was essentially completed by the end of the year and they were to go into fabrication in the first month of the new quarter. These two units are to be fabricated internally.

The design of the permanent beam dumps, D-2 and D-11, was also completed by the end of the year and the dump vessels were to be fabricated by an outside vendor. The vacuum windows, window removal equipment, and the support structure for one dump are to be fabricated internally, however.

#### E. SLITS AND COLLIMATORS

##### 1. High Power Slits and Collimators

The first modules for the high power collimators began arriving during the reporting period. They were both pressure tested and leak checked. The first units were found to leak and were returned to the vendor for repairs but the later units all tested satisfactorily.

Approximately three-fourths of the hardware associated with the slits and collimators had been received by the end of the year. The frame for the A-beam collimator had also been received and holes had been drilled for attaching the alignment jacks.

##### 2. Hi-Z Slits and Collimators

Approximately 70% of the parts for high-Z collimator C-10 and slits SL-11 and SL-31 had been delivered by the end of the year, and collimator C-O, shown in Fig. 16, was approximately 85% completed. The test setup for cycling the modules of slit SL-11 is shown in Fig. 17.

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\* R. S. Miksch, "Quick Disconnect Vacuum Couplings for the Beam Switchyard," Internal Report, Stanford Linear Accelerator Center (December 1965).

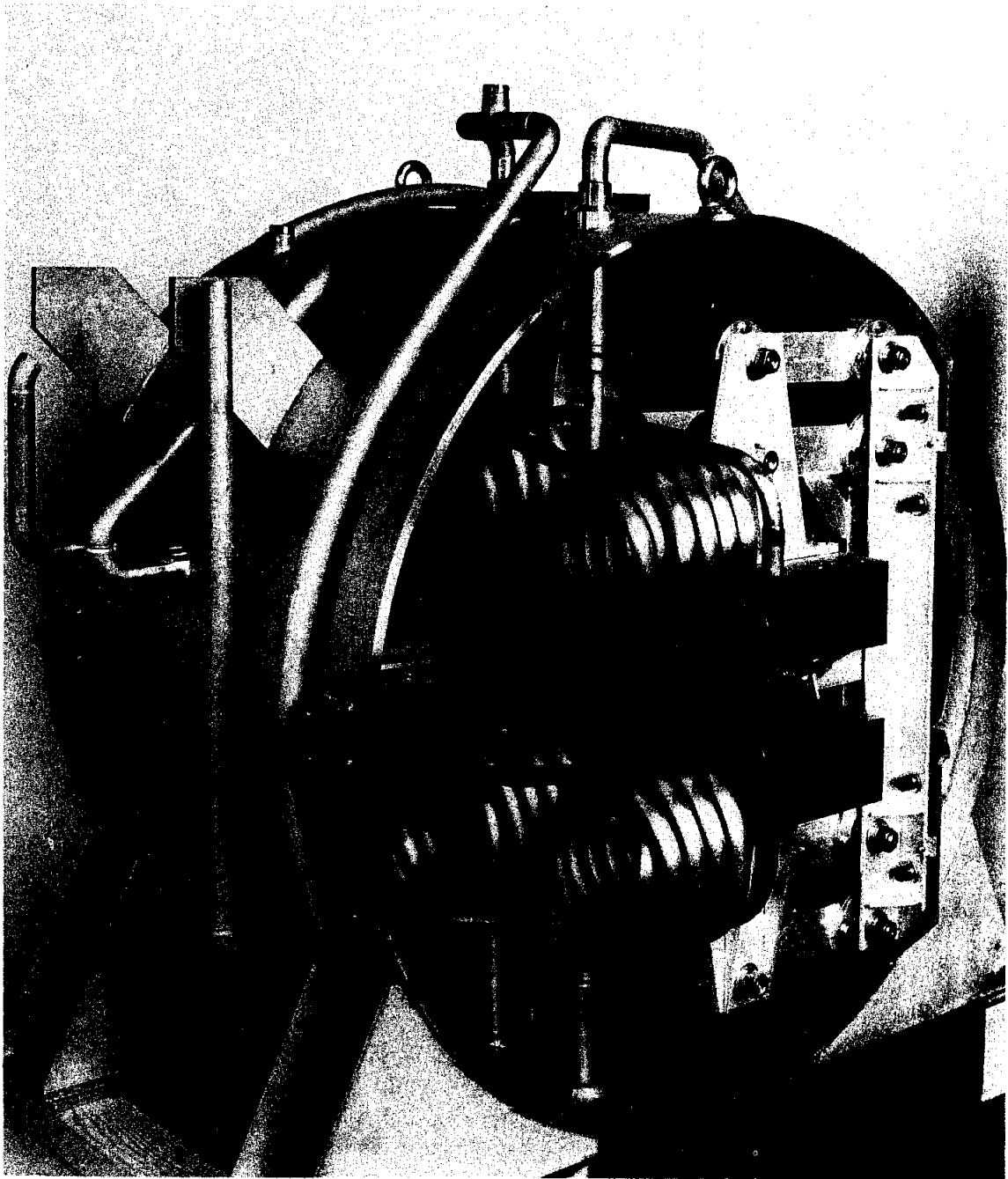


Fig. 16--Partially Assembled Hi-Z Collimator C-0

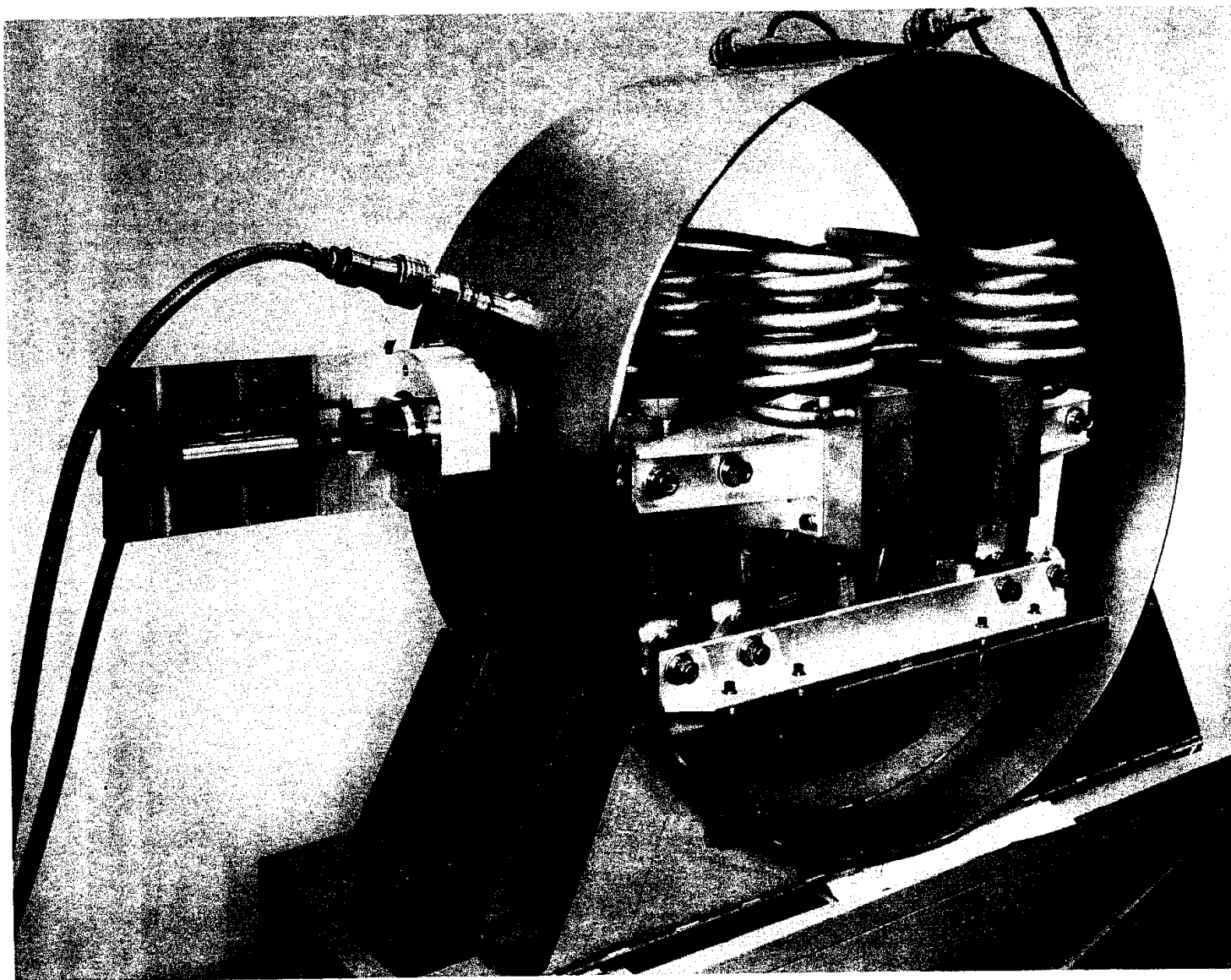


Fig. 17--Test Setup for Cycling Slit SL-11

### 3. Protection Collimators

By the end of the year, 12 of the 21 protection collimators had been brazed and were in final assembly where blocks, supports and external water guards were being brazed. Approximately 10% of this final assembly had been completed on these 12 units, and approximately 60% of the brazing for the remaining nine collimators had been done. Approximately 70 to 80% of the parts required for final assembly of all protection collimators were on hand.

#### F. SUPPORTS

By the end of the year, 30 instrument stands had been delivered and 12 had been inspected and tested. All magnets supports had also been delivered by the end of the year and were being installed.

## XI. RESEARCH AREA OPERATIONS

During the quarter the growth of the group which will be responsible for the management of experimental operations continued and new personnel were assigned. All major items of equipment necessary to carry out the critical physics program are in procurement or fabrication, and attention was turned to the more detailed problems involved. Some areas of work are discussed below.

### A. MUON BEAM

Detail design of the muon beam proposed to be built in End Station B was continued, including fabrication drawings of those special pieces of equipment which are necessary to mount the beam.

### B. LIQUID-HYDROGEN SYSTEM

Detail design and fabrication of components of the general purpose  $\text{LH}_2$  target system was carried forward during the quarter with assembly scheduled for early in 1966. Design studies for special target elements required for experiments were begun. Decisions on the setting and facility design of the 15,000-gallon  $\text{LH}_2$  storage vessel were completed, and procurement of various items of support equipment initiated.

### C. INSTRUMENTATION

Work continued toward detail design and fabrication of instrumentation for use in the end stations. This instrumentation will be summarized in racks mounted close to the end stations, and information will be distributed from there to both the Data Assembly Building and to experimental control rooms.

### D. MAGNETS

All general purpose magnets and power supplies required for the initial physics program have been ordered. Deliveries will commence early in 1966.

## XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

### A. EXPERIMENTAL GROUP A

#### 1. Spectrometers

All of the magnet coils and yokes for the 20-, 8-, and 1.6-GeV spectrometers have been ordered. Roughly three-quarters of the copper conductor has been fabricated and delivered to the coil vendors. The fabrication of the steel yokes for the quadrupole magnets is proceeding on schedule, and delivery should begin early next quarter. The fabrication of the steel yokes for the bending magnets has not yet begun, since the vendors have not received the raw steel from the mills. The coil vendors spent most of the quarter trying to qualify on conductor splices and on epoxy coil potting as required in the coil contracts.

The main girders for the 8- and 20-GeV spectrometers have been ordered. Several structural-steel packages containing miscellaneous bulkheads, wheel assemblies, etc., are now out for bid. The shielding carriage for the 8-GeV spectrometer will go out for bid very early in the next quarter, with the 20-GeV spectrometer shielding carriage following about a month later.

#### 2. Power Supplies

Proposals were received for four sizes of power supplies early in the quarter. As a result of the evaluations, we decided not to purchase the two smaller sizes of power supplies, but instead to order two 1.59-MW and six 567-kW supplies. Negotiations were completed with the vendor, and contracts were awarded. Criteria were developed for a 40-foot  $\times$  80-foot power supply building that will be located just south of End Station A. This building should go out for bid early next quarter.

The design of the dc-power and low-conductivity-water-distribution systems are fairly complete, and components are being ordered. The design of the Instrumentation and Control system is just getting underway.

#### 3. Detectors and Electronics

The final design of the 8-GeV hodoscope is nearly complete. Detailed drafting is about to begin on the 8-GeV  $\pi$ -e discriminator and the 20-GeV hodoscope. Block-diagram design for the electronics that will be used in conjunction with the detectors and the on-line SDS 9300 computer is over 90% complete, and nearly half of the required components have been ordered.



#### 4. Positron Source

About half of the double pancakes for the uniform-field solenoid are here, and the procedure for aligning the double pancakes on the frames was tested. The prototype edge-cooled double pancake for the tapered-field solenoid arrived and still tests satisfactorily after a month of soaking in water.

Most of the parts for the housing for the tapered-field solenoid are here, and final assembly has begun.

It was decided to view the size, shape, and position of the positron beam at each of the special quadrupole triplets with fluorescent screens and TV cameras. Instead of putting the screen inside the machine vacuum and viewing through a window, we will run a capped, thin-walled pipe on a bellows into the beam line and put the screen in this pipe. The screen is in air and can be easily changed. The pipe is 40-mil copper for good heat conduction.

The wand radiator will be delayed, but is scheduled to be ready for final tune-up of the annihilation gamma beam.

The aluminum exit window (6061) on the wheel radiator is joined to the stainless steel case (304) in an interesting way. Both parts are about a quarter of an inch thick and have a 5° taper. The aluminum gets a zincate dip and then 1 mil of cyanide copper; the stainless gets a Wood's nickel strike, then 1 mil of sulfamate nickel, and then 1 mil of gold. The two pieces are pressed together and heated to 500°F for four hours. The joint is vacuum tight and mechanically robust. To inhibit corrosion, especially of the aluminum, the water side gets 1 mil of sulfamate nickel and 0.5 mil of hard chrome after final machining.

#### B. EXPERIMENTAL GROUP B

Efforts to establish a set of data-analysis programs for bubble-chamber events are nearing completion. These are programs originally written at LRL: TVGP, for space reconstruction; SQUAW, for kinematical fits; and ARROW, for data summary. Our effort has gone into debugging and modifying these for the analysis of the K<sup>-</sup>D experiment.

We have completed a detailed study on the performance and measuring capability of a fast measuring machine, the Spiral Reader, as developed at LRL. This initial study has begun with a view to establishing a Spiral Reader System at SLAC when conditions are suitable. As part of the study, events containing charged sigmas, lambdas, and short-recoil protons and zero-prong-V<sub>0</sub> type events have been submitted for test measurements.

The study of 4-prong events in  $\pi^-p$  interaction has been completed as part of an LRL-SLAC collaboration effort. A paper has been submitted to Physical Review Letters on the "Analysis of the B Enhancement," by S. U. Chung, M. Neveu-Rene, O. I. Dahlz, J. Kirz, and D. H. Miller from LRL and Z.G.T. Guiragossian from SLAC.

Determination of the beam-transport parameters has been completed for the coming SLAC experiment of the 16-GeV/c  $\pi^-$  in the 80-inch Brookhaven National Laboratory hydrogen bubble chamber. We expect 60,000 pictures in January or February.

Proposals have been requested for an on-line computer to run film-measuring machines. Planning of interfacing and programs has been started.

Detailed planning of the monochromatic photon beam has been completed and a proposal submitted for consideration by the SLAC Program Advisory Committee, covering test running of the beam.

## C. EXPERIMENTAL GROUP C

### 1. Colliding Beam Vacuum

#### a. Prototype Vacuum Chamber

During this quarter the ten-foot prototype vacuum chamber was chemically cleaned and reassembled with a new uncoated, unblackened cryopanel and a new ion pump. Outgassing and electron desorption rates were significantly reduced by precluding organics and further reduced by bake-out and electron bombardment.

Following pumpdown the initial desorption rate was  $\approx 1$  molecule of gas per electron at 350 volts. After 100 hours bombardment at 5 kV—4 mA, the desorption rate was reduced to  $\approx 2 \times 10^{-3}$  molecules/electron and showed only slight energy dependence over the range 100 volts to 6000 volts.

Helium-glow discharge bombarding of the internal surfaces for several hours resulted in no measurable improvement in either outgassing rate or electron desorption rate.

Baking the entire system by resistance heating for seven days at temperatures varying from 125 to 275°C reduced both the outgassing rate and the electron desorption rate by an order of magnitude. Further electron bombardment for 20 hours at 5 kV—4 mA reduced the desorption rate to  $5-8 \times 10^{-5}$  molecules/electron. The desorbed gases were mainly hydrogen and carbon monoxide in about equal amounts.

#### b. Electron Desorption Studies

Electron desorption measurements on pure aluminum continued. The previously reported maxima at  $\approx 500$  eV persisted independent of temperature over the range 77 to 500°K. With 500-volt electrons the desorption rate increased with temperature from  $10^{-6}$  molecules/electron at 77° K to  $10^{-4}$  molecules/electron at 500°K. The increase in desorption rate is probably not due to changes in the interaction cross section but may reflect changes in the rate at which gases diffuse to the surface being irradiated. This hypothesis is being explored.

A third system was assembled for the purpose of studying desorption rates as influenced by secondary and tertiary electron production at the surface being bombarded. Measurements with aluminum are under way.

#### c. Cryopanel Fabrication and Heat Balance

A new cryopanel was fabricated to replace the panel which was damaged during the previous quarter's tests. Minor revisions were made in order to facilitate fabrication. Single unit fabrication and brazing procedures are still crude, and it was necessary to fabricate two panels in order to produce one which was acceptable. The "visible" surfaces of this panel were wet blasted with aluminum oxide in lieu of the previous black coating.

A flow orifice was installed in the helium refrigerator return line so that the heat load to the helium-cooled fin can be measured directly. A leak in the refrigerator bayonet vacuum jacket was discovered and repaired. Extensive tests were made to determine that the heat leak to the cold helium transfer lines is  $22 \pm 2$  watts. The LN<sub>2</sub> supply system was modified and a level recorder was installed.

A photo-analog was constructed in order to check the thermal radiation interchange within the cryopanel. Preliminary results from these tests indicate that about 5% of the energy incident at the face of the panel is reflected onto the helium-cooled fin. This energy may be reduced by a factor of 4 if the "visible" surfaces are bead blasted and a further factor of 10 if the surfaces are blackened. With red light incident on a bead-blasted surface, 5% of the incident energy is reflected onto the helium-cooled fin.

A computer program had been previously written in order to determine the thermal radiant interchange within the vacuum chamber. This program has been refined and now indicates that the heat load to the cryopanel face will be about 1 kW for 0.25% reflection from the radiation absorber and 20 kW for 6% reflection.

## 2. Beam Transport and Injection

During the fourth quarter of 1965, study of the transport and injection problems associated with the storage ring project was divided into three categories, which are summarized below.

### a. Theoretical

The whole injection concept was reviewed, and a new scheme based on a rapid distortion of the equilibrium orbit was investigated. This scheme has the advantage of making available additional field-free regions of the machine in which inflection apparatus can be located as well as easing the requirements on the field strength and field fall-off characteristics of the fast inflector magnet. These changes were found to be desirable in view of the need to inject positrons and electrons on vertically separated equilibrium orbits.

The orbit-perturbing magnets are of simple design, and their electrical requirements are well within the capability of a previously constructed high-voltage pulse-power supply. It is felt that the main problems have been removed from the ultra-high vacuum environment and placed on the construction of a high-field septum inflection magnet located outside the vacuum enclosure.

The transport system from the linear accelerator exit point to the storage ring has also undergone revision. The main features are: (i) capability of transporting, on alternate pulses, both electrons and positrons so that the ring can be filled simultaneously with both beams. This is accomplished without reversing any transport-system component fields; (ii) revised points of entry to the ring at points of minimum momentum amplitude; (iii) study of a completely symmetric achromatic transport system which helps to standardize components and ease tuning during operation; and (iv) a rotation of the building structure improving clearance to the access road. The parameters of the transport systems were fixed through extensive use of the SLAC TRANSPORT computer program.

### b. Perturbator Magnet

A model of the kicker magnet of full cross section and of  $1/3$  length was constructed of ferrite blocks. Following installation of the hydrogen thyatron pulser, successful tests were carried out in air, confirming design calculations. No heating problems were found. An ultra-high vacuum test pot, previously constructed, was installed in the laboratory, and preliminary baking tests were carried out. This tank will be used to study the desorption properties of new ferrites in ultra-high vacuum environment.

### c. Septum Magnet

Two possible configurations of the more difficult septum magnet were designed and transformer steel laminations for model tests ordered. Vacuum window and component designs were completed.

### 3. Storage Ring RF Design

The rf cavity design work continues. The cavity is designed to have a shunt impedance of 0.36 megohms, and at full power and full beam loading to present 110 kilovolts rf peak power to the beam. The cavity is single-gap with added capacity loading and is approximately 36 inches long and 48 inches in diameter. Detailed engineering design work is now being carried out prior to the fabrication and assembly of a prototype cavity. The ceramic window which isolates the rest of the cavity from the vacuum system has to be capable of withstanding 160 kV. In order to test a ceramic sleeve of the type which is planned to be used in the prototype, a quarter-wave test cavity at 30 megacycles has been designed and will be constructed during the next quarter. This cavity, when driven by 40 kilowatts, will generate the several hundred kilovolts of rf voltage necessary for testing the ceramic pieces. It is proposed to use a 40-kW transmitter from the Radio Sciences Laboratory of Stanford University for these experiments; and arrangements with the laboratory are underway. A current loop coupler for the prototype cavity has been designed. Also, an experimental model tuner utilizing ferrites has been built. A very small amount of ferrite material produces sufficient tuning for our purposes.

### 4. Princeton-Stanford Storage Ring

An LH<sub>2</sub> supply system was designed for the new cryogenic pump in the interaction system. The special 50-liter dewar was returned to the manufacturer twice because of faulty fabrication. Fabrication has commenced on a coaxial, vacuum-jacketed transfer line. A carbon-resistor LH<sub>2</sub> level indicator was fabricated and is being tested. A model of the cryofinger was constructed, and the heat leak was measured to be between 3 and 5 watts, for LN<sub>2</sub>.

Design of a feedback system to control coherent vertical oscillations of the stored beams was completed, and construction has begun. The system uses the clearing-field plates in the vacuum tank as sense and feedback electrodes, and will allow the betatron operating frequency to vary over a range of 20% while still maintaining the proper phase shift to damp the coherent oscillations.

## D. EXPERIMENTAL GROUP D

### 1. Modulator

A Marx-generator-powered modulator has operated, delivering 600-kV pulses into a 20-ohm load with a rise time of 2 nsec and a width of 10 nsec. This has not yet been operated with a spark chamber due to problems with rf shielding around the total configuration.

Dr. Ian Smith has visited us from AWRE, Aldermaston, England, and has helped us in developing a modulator using a single spark gap and pulse transformer to provide pulses similar to those developed by the Marx generator. In doing this we have used a pulse transformer built by the British group and a solid dielectric spark gap. The pulse transformer approach seems intrinsically superior to the use of a Marx generator and will be explored further by our group. In particular we are exploring the use of a high pressure SF<sub>6</sub> gas spark gap.

### 2. Mark III Program

Pictures (see Fig. 18) have been obtained with a small (40 cm × 40 cm × 12 cm) spark chamber operating in an 8-kG field with 200-MeV electrons incident. No problems attributed to the magnetic field have been observed.

Data taking is continuing in the experiment investigating  $\gamma + p \rightarrow N^{*++} + \pi^-$ .

## E. EXPERIMENTAL GROUP E

The following experiments are being analyzed:

1. Proton-proton interactions at 6 GeV/c, in the 72-inch Lawrence Radiation Laboratory hydrogen bubble chamber (J. Brown, F. Martin, M. Perl, T. H. Tan).

2. Neutron-proton elastic scattering from 1 to 6 GeV/c, in spark chambers (M. Kreisler, F. Martin, M. Perl).

3. K<sup>-</sup>-deuterium interactions, in the 72-inch Lawrence Radiation Laboratory bubble chamber (F. Martin).

Running continued on the following experiments.

1. Proton-proton interactions at 6 GeV/c, in the 72-inch Lawrence Radiation Laboratory hydrogen bubble chamber (J. Brown, F. Martin, M. Perl, T. H. Tan).

2. Proton-antiproton annihilation to  $e^+ + e^-$  and other modes, in spark chambers at the Brookhaven National Laboratory AGS (T. Zipf).

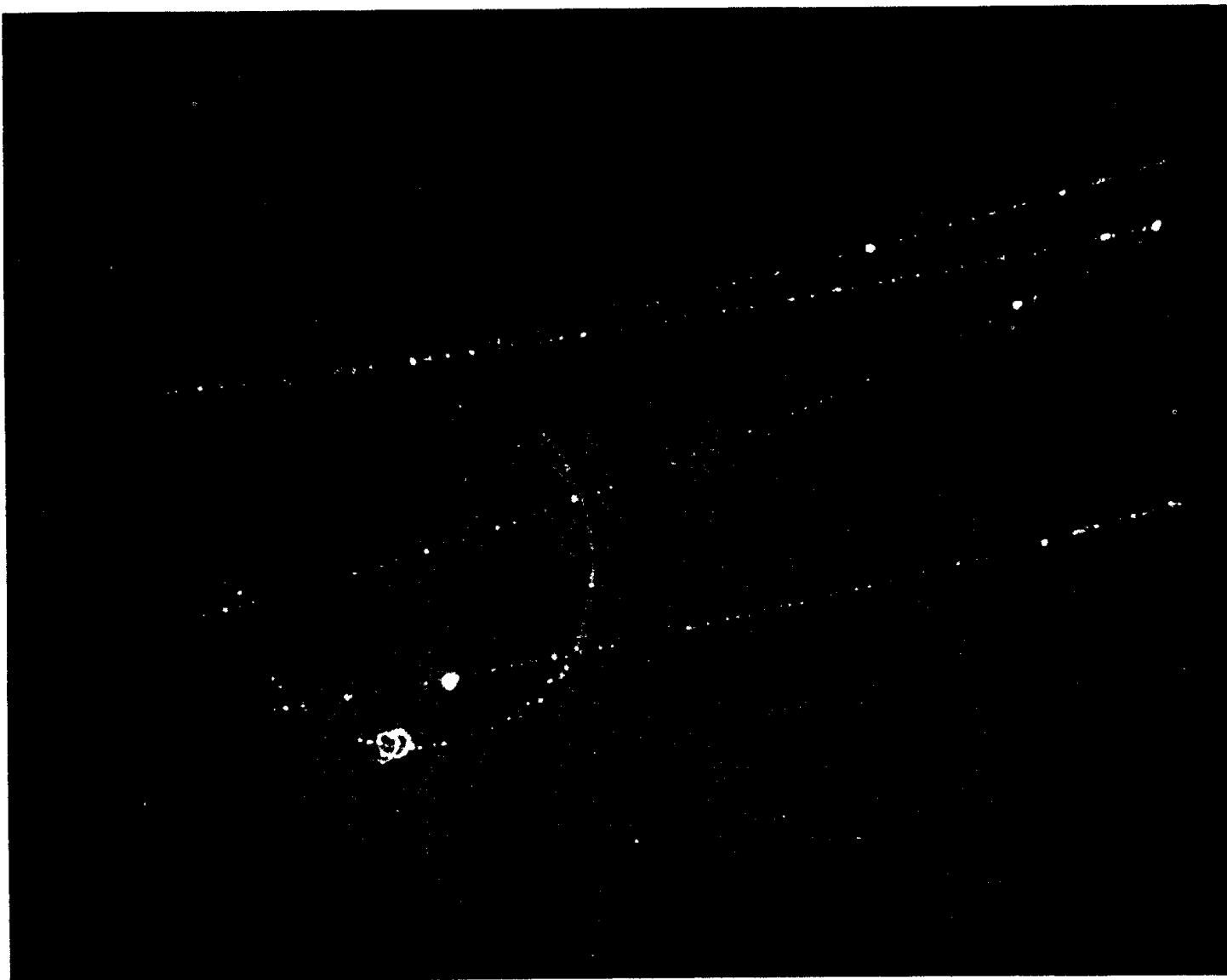


Fig. 18--Spark Chamber photo obtained at the Mark III Accelerator

Design construction continued on the following:

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).

The development of a coincidence circuit with a resolving time of  $\tau = 0.3$  nsec was completed. Results are reported by A. Barna in "A Subnanosecond Coincidence Circuit," SLAC Report No. 52, Stanford Linear Accelerator Center, Stanford, California (December 1965).

#### F. EXPERIMENTAL GROUP F

The work of this group will be reported in the next Quarterly Status Report.

#### G. PHYSICAL ELECTRONICS

During this quarter the following papers were submitted for publication:

1. "Thin Film Densities," J. Edgecumbe, to be published in J. Vac. Sci. and Technol.
2. "The Attenuation Length for Secondary Electrons in KC1 and CsI," J. Edgecumbe and E. L. Garwin, submitted to Appl. Phys. Letters.

Measurements on low-density dynodes were continued during the quarter. A low-density KC1 foil is now in the process of being life-tested in a hydrocarbon-free vacuum system. The gain of this dynode has remained constant at 50 to within  $\approx 10\%$  for a total charge leaving the exit surface of  $\approx 0.2 \text{ c/cm}^2$ . Low-density CsI was life tested at the Mark III Accelerator and showed a possible 10% deterioration (data was somewhat obscured by intensity dependence of gain) for  $\approx 0.5 \text{ c/cm}^2$  incident at 800 MeV. More data has been obtained for relativistic primaries at the Mark III linear accelerator using the SEM structure discussed in the previous quarterly\* report. This data indicates significantly lower gains than the results obtained initially for the low-density foils.\*\* At present this

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\* "Two-Mile Accelerator Project, Quarterly Status Report, 1 July to 30 September 1965," SLAC Report No. 53, Stanford Linear Accelerator Center, Stanford, California (1965).

\*\* "Two-Mile Accelerator Project, Quarterly Status Report, 1 April to 30 June 1965," SLAC Report No. 48, Stanford Linear Accelerator Center, Stanford, California (1965); p. 95.



is believed to result from not baking the SEM under vacuum (the earlier tube was baked); this will be checked in the coming quarter. With slight modifications in the SEM (smaller spacing between the foils), better rise time has been obtained. Using the chopper at the Mark III accelerator, an indicated rise time  $\approx 1.5$  nsec has been observed (low-density CsI), which is the rise time calculated for the chopped beam pulse.

The technique for preparing the self-supported  $1000\text{-}\overset{\circ}{\text{A}}$ -thick  $\text{Al}_2\text{O}_3$  substrates used for deposition of the alkali-halide dynode has been changed. Substrates to date have been prepared on Al rings. Films are now prepared from household Al foil and can be glued to any desired holder using potassium silicate. Self-supported  $1000\text{-}\overset{\circ}{\text{A}}$ -thick  $\text{Al}_2\text{O}_3$  films as large as 2-inches i.d. on ceramic holders have been prepared using this technique and films as large as 2-3/4-inches i.d. seem to be readily possible.

Work has started on the design of a tube structure to measure the statistics of the field-enhanced secondary-emission process. Using the single electron pulses available at the Mark III (running parasitically) it appears that  $P(0)$ , the probability for emission of no secondaries, can be determined, thus giving another check of the applicability of Poisson statistics to secondary emission. The design of the electron optics for the tube is essentially completed, and the electronic instrumentation is being assembled; data should be available late next quarter.

## H. MAGNET RESEARCH

### 1. Water-Cooled Magnets

#### a. Positron Source Magnets\*

The double pancakes for the homogeneous field section are manufactured. They have been tested with a SLAC-developed impulse tester under water and have passed the high-voltage tests. Magnetic-field measurements and the aligning of the double pancakes are being completed. One high-field upstream solenoid (prototype) has been immersed in water for more than two months. Repeated tests on the coil under water were: impulse tests to determine any kind of interturn shorts; change in  $Q$ ; and, if energized, the change of magnetic field. The  $Q$  values ( $\omega L/R$ ) changed in the first three days and decreased from an initial value of 14 to about 8 and then held constant. No change in axial field and no interturn shorts could be detected. The coils for the upstream solenoids have been manufactured and should arrive at SLAC during January 1966.

\*See SLAC Report No. 53, op. cit.

b. Bubble Chamber Magnet

Coils and iron have been ordered. In order to boost the field in the chamber slightly and decrease the eddy-current losses in the movable back wall, a 9% Ni-steel was used as an auxiliary pole. The magnetic behavior of this material, which has superior mechanical properties at cryogenic temperatures as compared to low carbon steels, has been investigated.\*\*

Using the SLAC Nutcracker program, the axial and radial field components were computed. Due to field inhomogeneities along the movable back wall the losses at 21°K seem to be high ( $\approx 90$  watts). Further work in correct shaping of the 9% Ni plate is necessary to reduce this loss to a value of  $\approx 30$  watts.

c. Spark Chamber Magnet

The calculations and model tests have been finished. A SLAC report on the subject will be forthcoming in January 1966.

2. Superconducting Magnet Research

a. 12-inch Superconducting Split-Coil Magnet

The main efforts have been preparation of the 12-inch, 70-kG split-coil magnet. The coil is divided into eight sections in order to obtain optimum design parameters and to operate the different sections at various current levels and at different field strengths acting at each section. Figure 19 shows the coil configuration.

Section IV is wound with Nb(25%)Zr, and the three inner sections with Nb(48%) Ti, or Nb(22%)Ti. The Nb(25%)Zr has already been acquired. Short sample tests have been started in order to obtain best performance at minimum cost.

b. Direct-Cooled Superconductors

In large, high-field magnets enormous forces act on the coils between the iron body and the coils. It is desirable to find a coil configuration which withstands these forces without degrading the superconducting behavior.

A possible solution which leads to a compact and reliable coil was investigated at SLAC. The superconductor is imbedded in a hollow conductor, and liquid helium is pressurized through a system of double

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\*\* H. Brechna, "Magnetic Properties of 9% Nickel Steel at Room and Cryogenic Temperatures," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford California (1965).

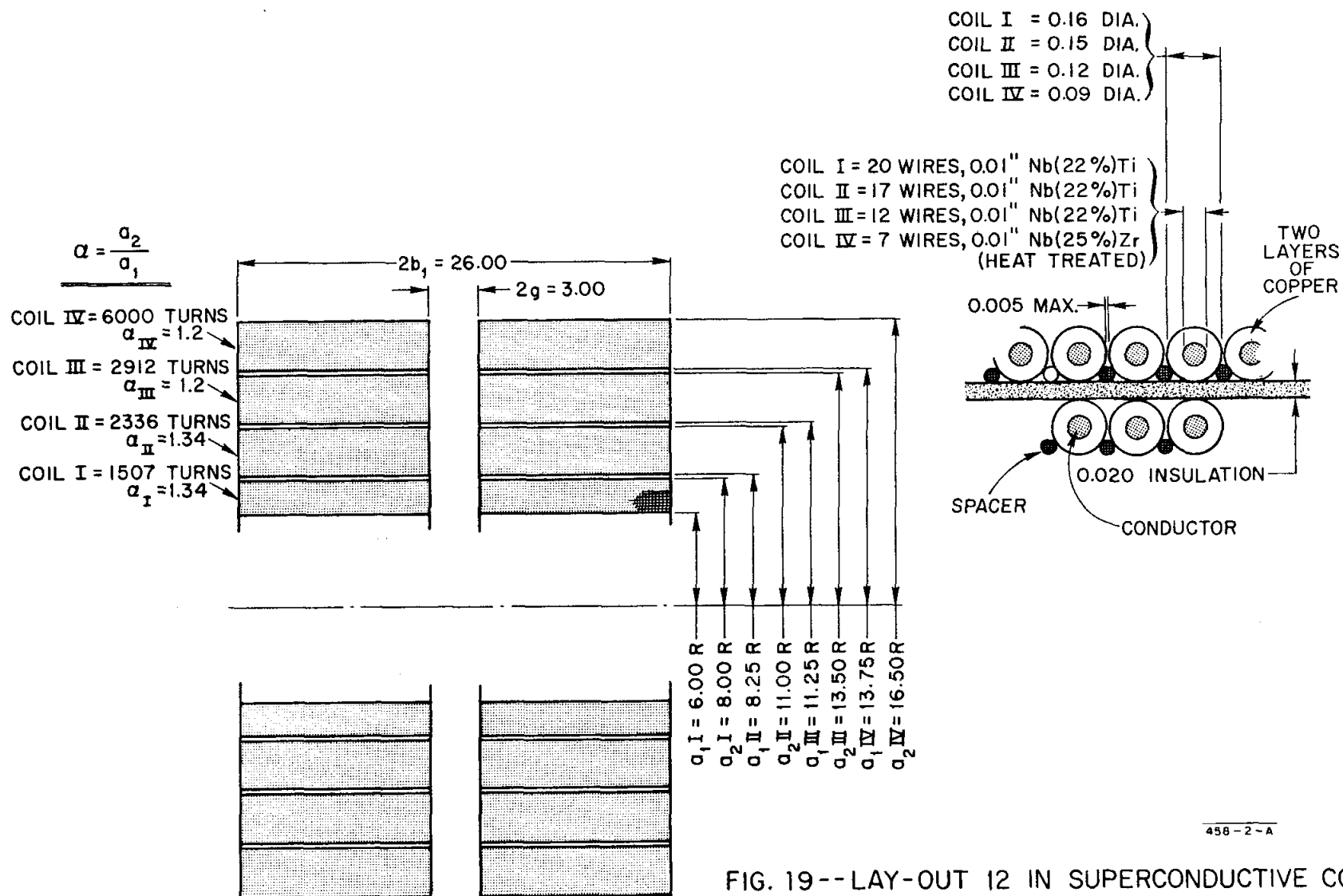


FIG. 19--LAY-OUT 12 IN SUPERCONDUCTIVE COIL

pancakes. The liquid helium dewar is eliminated. The coils may be wrapped in superinsulation and placed in a vacuum jacket.

A short sample test has been performed successfully. The design of a 6-inch coil consisting of several double pancakes is currently under investigation.

A cryogenic pump capable of pumping helium through the system is in a developmental stage.

## I. THEORETICAL PHYSICS

Items 1 through 5 below have been discussed in previous reports.

Work on the secondary-beam yields for the SLAC Users Handbook is almost completed. This work contains the following:

1. The bremsstrahlung spectrum from a target of arbitrary thickness (0 to 20 radiation lengths). The formula is good for any material and is most reliable for the high-energy end of the spectrum ( $k/k_{\text{max}} > 0.7$ ). The result shows that the maximum number of photons in the energy range  $0.7 < k/k_{\text{max}} < 1$  is reached when the thickness is about 0.6 radiation lengths.

2. If the electron beam is used directly on a thick target to produce both bremsstrahlung and secondary particles, it is found that in order to produce strongly interacting particles  $Z$  should be as small as possible. Further, for each target material and kind of particle produced, there is an optimum thickness independent of production mechanism. For example, the optimum thicknesses for producing high energy  $\pi$ ,  $K^+$ ,  $K^-$ , and  $\bar{P}$  from beryllium are 2.0, 2.2, 2.2, and 1.6 radiation lengths, respectively.

3. Formulae for the energy and angular distributions of  $\mu$ 's at small and large angles are derived. If electrons are used directly in the production, it is found that 90% of the maximum obtainable yield (infinitely thick target) is reached at 4.0 radiation lengths. The formulae derived here can also be used in estimating the energy-angle distribution of electron pairs.

4. For the monochromatic photon beam from  $e^+ + e^- \rightarrow 2\gamma$ , the spread in energy due to radiative corrections, and the backgrounds due to  $e^+ + e^- \rightarrow e^+ + e^- + \gamma$  and  $e^+ + p \rightarrow e^+ + p + \gamma$ , are tabulated and formulae derived.

5.  $\pi^\pm$  yields from  $\gamma + \text{Be} \rightarrow \text{Be} + \rho^0 \rightarrow \pi^+ + \pi^-$  have been computed. First it is shown that only three components out of nine parameters in the vector particle density matrix are required to specify the polarization state of the  $\rho^0$  if one assumes:

- a. target particle spin can be ignored
- b. transversality of the photon
- c. rotational invariance
- d. parity conservation or time-reversal invariance

These parameters are chosen to be (1) the probability that the  $\rho$  is polarized perpendicular to the production plane,  $A_{\perp}^2$ , (2) the probability that the  $\rho$  is polarized in the production plane,  $A_{||}^2$ , and (3) the angle  $\delta$  which specifies the direction of  $A_{||}$  in the production plane. We have assumed  $A_{||}^2 = A_{\perp}^2$  and calculated for  $A$  perpendicular to the  $\rho$  polarization in the lab, the  $\rho$  polarization in the center-of-mass, or to the incident momentum. It is found that the angular distribution of the  $\pi$  is very sensitive to the direction of  $A$ . More pions fall in the forward cone in the first case than in the other two. The parameters are chosen to fit the available experimental data from CEA and DESY. The same parameters are chosen to predict the  $\pi$  energy and angular distributions at SLAC energies. Thick-target corrections (2 r.l. of Be) are considered.

6.  $K^+$  and  $K^0$  yields from  $K^*$  exchange are computed essentially by squaring the matrix elements in Drell and Jacob's paper (previously reported), which contains the final-state interaction corrections to the Born approximation.

7. The cross sections for the photoproduction of anti-protons as determined independently (with large theoretical uncertainties) by Drell and Tsai have been compared numerically. Both the anomalous shape of the Drell cross section and its lack of positive definiteness favor the validity of the Tsai calculation. This latter was also shown to be compatible with data obtained experimentally near 5 GeV by CEA (private communication).

Further investigation is being made of some discrepancies between an exact integral evaluation of the cross section  $e^+ + e^- \rightarrow e^+ + e^- + \gamma$  and expected results.

Previous theoretical calculations of the proton size correction to the ground-state hyperfine splitting in hydrogen have been re-examined in an attempt to resolve the present  $40 \pm 20$  ppm discrepancy between theory and experiment. A Schroedinger-theory model of the proton, while not quantitatively reliable, is found to give quite strong evidence that the discrepancy is due to the neglect of terms which describe the "polarizability" of the proton. An attempt is being made to estimate the size of these polarization contributions in a fully relativistic treatment.

Studies on the asymptotic behavior of the form factors for  $q^2 \rightarrow -\infty$ , extending the work from the Schroedinger equation to the Bethe-Salpeter amplitude, is being continued. Calculations of asymptotic  $\mu$  pairs has continued. Experimental resolutions relevant for SLAC spectrometers are used. A K-matrix analysis of absorption corrections to a multi-channel peripheral model has been completed and prepared for publication and a Ph.D. thesis. The energy dependence disagrees with experiment in the absence of Reggeized potentials. The  $\rho^0$ -nucleon total cross section was deduced by an eikonal approximation from the nucleon dependence of coherent photoproduction. The result is  $\sigma_{\rho n} = 37 \pm 8$  mb. A review of peripheralism for "Advances in Physics" has been completed.

Work continues using the Faddeev equations to study competing resonance productions. An investigation of multiparticle scattering has been extended to study separable interactions and amplitudes for two-body subsystems using variational techniques. A formalism has been developed for optical use of two-particle scattering data in multiparticle kernels. An investigation of coherent droplet models in high-energy scattering has begun.

The application of group theory to the hydrogen atom is extended to the scattering case.<sup>6</sup> As in the bound-state case, the larger group which connects different levels was found to be  $O(1,4)$ ; however, solutions for both attractive and repulsive potentials were found necessary in order to construct an irreducible representation. This fact makes the whole procedure suspect in its possible application to other physical problems.

The transformation properties of the mass-splitting strong interaction were analyzed in the framework of the  $SU(6)$  symmetry scheme. Using the experimental masses of the low-lying baryons and mesons, the reduced matrix elements of all possible mass tensor operators were calculated. It was pointed out that the terms which break  $SU(3)$  are dominated by the contribution of the 35-dimensional representation of  $SU(6)$ , whereas the  $SU(3)$ -conserving,  $SU(6)$ -violating terms do not have simple transformation properties.<sup>7</sup>

A detailed survey of the present situation of experimental tests of the collinear  $SU(6)_W$  group was prepared, together with a general review of the problem of finding a relativistic version of the "static"  $SU(6)$  scheme.<sup>8</sup>

The breaking of collinear  $SU(6)_W$  by non-collinear intermediate states was studied. It was shown that in some cases, such as forward meson-baryon elastic scattering, the predictions of the collinear group are not changed when a large

class of non-collinear diagrams is included. These diagrams include the exchange of a two-meson ladder in the  $t$ -channel.<sup>9</sup>

A large number of new SU(3) predictions for scattering processes with three outgoing particles have been derived and compared with the experimental data. Exact SU(3) is, again, in disagreement with the low production rates of strange particles. Some predictions of the broken symmetry were also obtained, assuming that the S-matrix for the discussed processes transforms like a combination of SU(3) singlet and octet. These predictions are, in all cases, in agreement with the data.<sup>10</sup>

The possible algebraic relations between the algebra of currents and the proposed spectrum-generating non-compact algebras were studied. It was suggested that the algebra of currents might be identified with the compact form of the spectrum-generating algebra, and that a finite number of rungs of the non-compact ladder form an irreducible representation of the compact algebra of currents. The examples of SU(3) and SU(2,1), SU(4) and SL(4,R), SU(6) and SL(6,R) were studied in detail.<sup>11</sup>

1. Y. S. Tsai and A. C. Hearn, "Differential Cross Section for  $e^+ + e^- \rightarrow W^+ + W^- \rightarrow e^- + \bar{\gamma}_e + \mu^+ + \gamma_\mu$ ," Phys. Rev. 140, B720 (1965).

2. S. D. Drell and J. D. Sullivan, "Axial Meson Exchange and the Relation of Hydrogen Hyperfine Splitting to Electron Scattering," Phys. Letters 19, 516 (1965).

3. S. D. Drell and H. Pagels, "Anomalous Magnetic Moment of the Electron, Muon, and Nucleon," Phys. Rev. 140, B397 (1965).

4. S. D. Drell, D. Speiser and J. Weyers, "Test of Role of Statistical Model at High Energies," Preludes in Theoretical Physics, in Honor of V. F. Weisskopf (North-Holland Press, 1965).

5. S. D. Drell, "Special Models and Predictions for Photoproduction above 1 GeV," Springer Tracts in Modern Physics (Germany, 1965).

6. M. Bander and C. Itzykson, "Group Theory and the Hydrogen Atom (II)," submitted to Rev. Mod. Phys. (SLAC-PUB-141).

7. H. Harari and M. A. Rashid, "Particle Masses and SU(6) Symmetry Breaking," to be published in Phys. Rev. (SLAC-PUB-153).

8. H. Harari, "The W-Spin Relativistic Version of SU(6) and its Experimental Tests," to be published in the Proceedings of the Symposium on High Energy Physics, Boulder, Colorado (University of Colorado Press)(SLAC-PUB-148).

9. H. Harari and H. J. Lipkin, "Non-Collinear Diagrams and the Johnson-Treiman Relations," Phys. Rev. Letters 15, 983 (1965).

10. I. M. Bar-Nir and H. Harari, "Three-Particle Final States and Unitary Symmetry," submitted to Phys. Rev.

11. H. Harari, "Infinite Ladders and the Algebra of Integrated Current Components," SLAC Report No. 58, Stanford Linear Accelerator Center, Stanford, California (1966).

#### J. COMPUTATION GROUP

The work of this group will be reported in the next Quarterly Status Report.

#### K. HEALTH PHYSICS

Two peripheral monitors are now in place and operating. Two others are completed except for one minor component which has not arrived.

A portable version of the chemiluminescent ozone monitor is being built. It will use an MOS FET electrometer circuit and should have about the same sensitivity as the fixed version, i.e. 0.02 ppm. Measurements with the fixed version during the last beam tests showed ozone concentrations of 0.09 ppm when operating at 1.3 BeV, 60 pps and 32 mA.

The shower experiment done at the Mark III accelerator will be presented at the New York meeting of the American Physical Society. It will be submitted to Physical Review for publication.

A variety of ion chambers have been tested for use in the Research Area Monitors. These have been either tissue-equivalent or quasi-tissue-equivalent chambers. The selection of commercial chambers is very meager and all have been rejected. The chambers will be made in-house and will be our own design. The electronics have been designed in concept, and construction of the central station and a prototype monitoring station will start almost immediately. It is planned to have the central station and at least three monitoring stations in operation by May beam tests.

The truck has been fitted with a 60-cycle ac supply to make neutron flux and  $\gamma$ -ray background spectrum measurements. A group of monitoring sites have been selected and a first measurement made. The small pulse height analyzer had not yet arrived so an integral  $\gamma$ -ray measurement only could be made. A high-pressure integrating ion chamber is nearly completed to supplement the above measurements.



A prototype beam scraper shield was filled with both water and borated paraffin. Tests were made with it both on the accelerator and with neutron sources. Result indicated that the reduction in activation of the concrete would be only about one-third. This is too little to justify the cost, and it was decided not to use the shields.

A search was made for activation in the cooling water in Sectors 1 and 2. The only activity found was  $\text{Be}^7$  in one de-mineralizer. The total activity was about  $50 \mu\text{Cu}$ , which agreed very well with predictions.

A paper was presented at the First AEC Symposium on Accelerator Radiation Dosimetry and Experiences at Brookhaven National Laboratory.

Assistance was given to several other groups, primarily on problems of radiation shielding and radiation damage.

#### L. AUTOMATIC DATA ANALYSIS

The "Hummingbird" off-line film digitizer has been used this quarter for the development of programs to measure automatically film from Group E's n-p spark chamber experiment. Programs have been written to display either the "raw" digitizings, or sparks and registration marks formed from these digitizings, or sparks and registration marks formed from these digitizings. Work is almost complete on programs needed to calibrate the digitizer, i.e., transform the distorted cathode-ray-tube coordinates into a rectilinear coordinate system.

Experimental use of the machine has also been made by the Computation Group for evaluation of wide-gap streamer chamber film. Improvements are now being made to enhance the device's resolution and measuring precision.

The expected arrival of an IBM 360/50/1800 for graphic data processing has prompted development of a new film-reader to operate on-line to this computer system. As in the "Hummingbird," a high-resolution cathode-ray tube will be used to scan and measure the film, this time under computer control. Initially, only the number, sequence, and density of complete scan lines to be used will be under computer control. Computer control of scan line length and orientation can be gradually incorporated later. Preliminary investigations have been made into the programs needed to use this second-generation device to analyze film from two spark-chamber experiments to be performed in 1966.

#### M. HYDROGEN BUBBLE CHAMBER

This group will report in the next Quarterly Status Report.