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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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Technical Report
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I. INTRODUCTION

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

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

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

II. PLANT ENGINEERING

A. GENERAL

The conventional facilities program was continued throughout the quarter, marking the completion of three years of field construction work on the project. The present status of a number of facilities in the construction phase is shown graphically in Figs. 1 through 4. The final major facilities are now scheduled for completion as follows: End Station A and Beam Dump East, February 1966; End Station B, End Station Site Improvements and Utilities, and the Cryogenics Building, March 1966. The project design effort is largely finished.

The Atomic Energy Commission opened bids on April 15, 1965 for the construction of the overhead 220-kV power feeder line to the accelerator site. An award was made and procurement of the necessary hardware has started.

B. DESIGN STATUS

The project design effort was concentrated on completing the Cryogenics Building, Beam Dump East, and certain utilities in the target area. The status of major items at the end of the quarter is as follows:

1. <u>Cryogenics Building</u> - Design is complete, and bids have been invited. Bids will be opened in July 1965.
2. <u>End Station Site Improvements and Utilities</u> - Bids were opened June 17, 1965 and are being evaluated.
3. <u>Master Substation Equipment</u> - Shop Drawing submittals are being received and reviewed.
4. <u>BSY Materials Handling System</u> - Several minor change orders have been required. The contractor's work is on schedule, and erection of equipment under joint occupancy with the BSY contractor will commence in July.
5. <u>Beam Dump East</u> - Title II design is essentially complete. This facility package will be opened for bids in July.

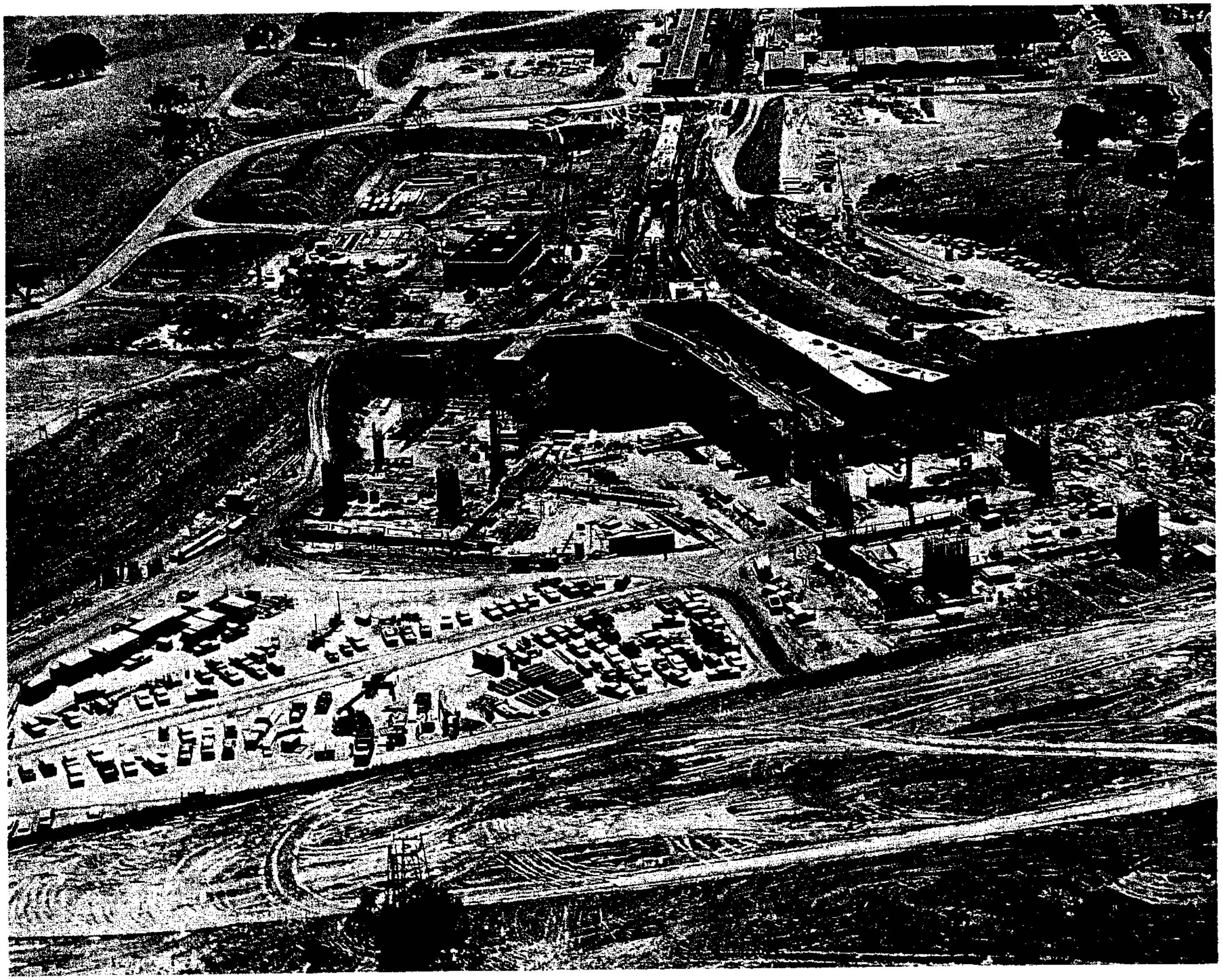

FIG. 1--Beam Switchyard and End Stations A and B under construction.

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

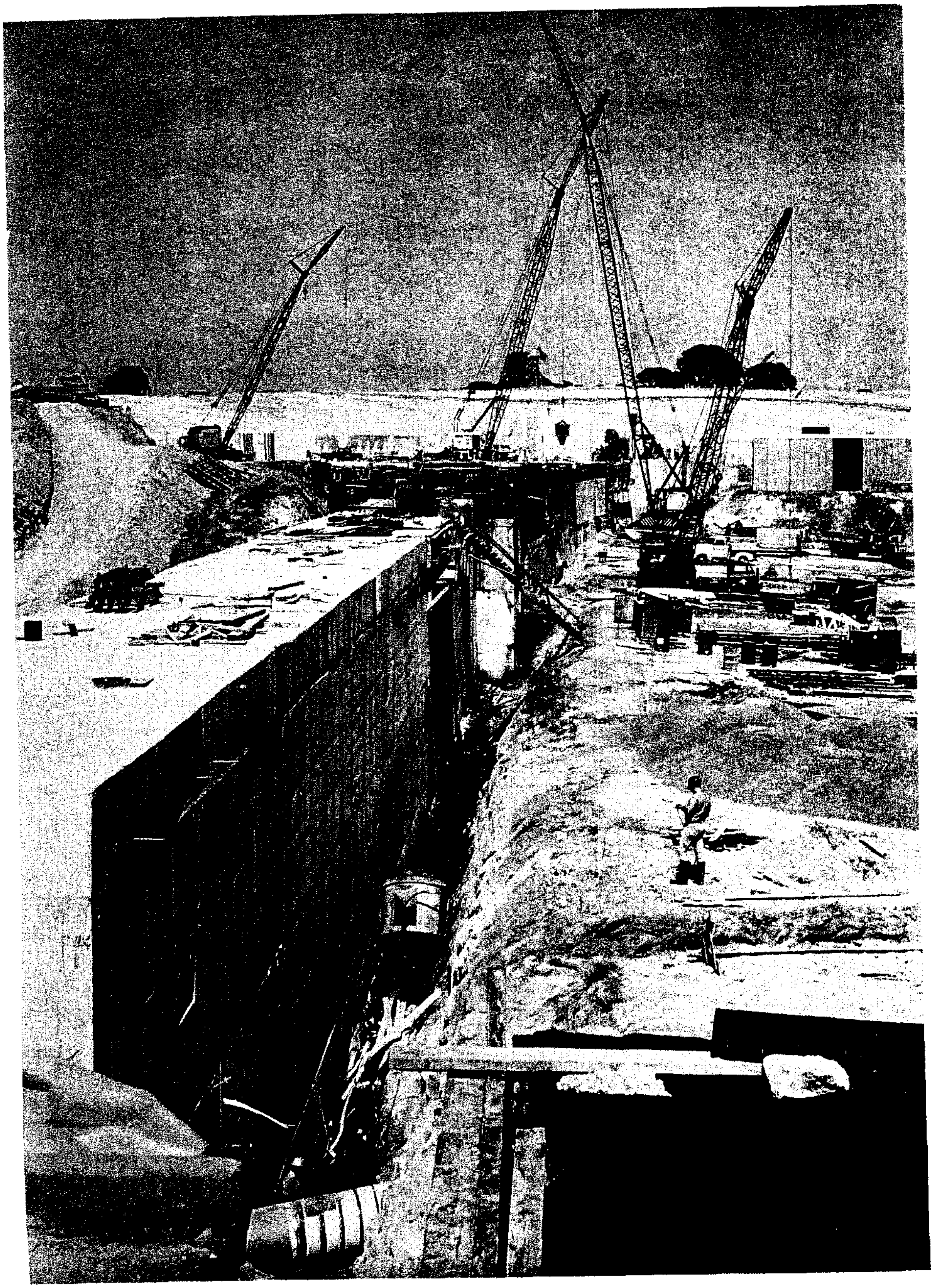

FIG. 3--Beam Switchyard with Data Assembly Building at right; looking east.

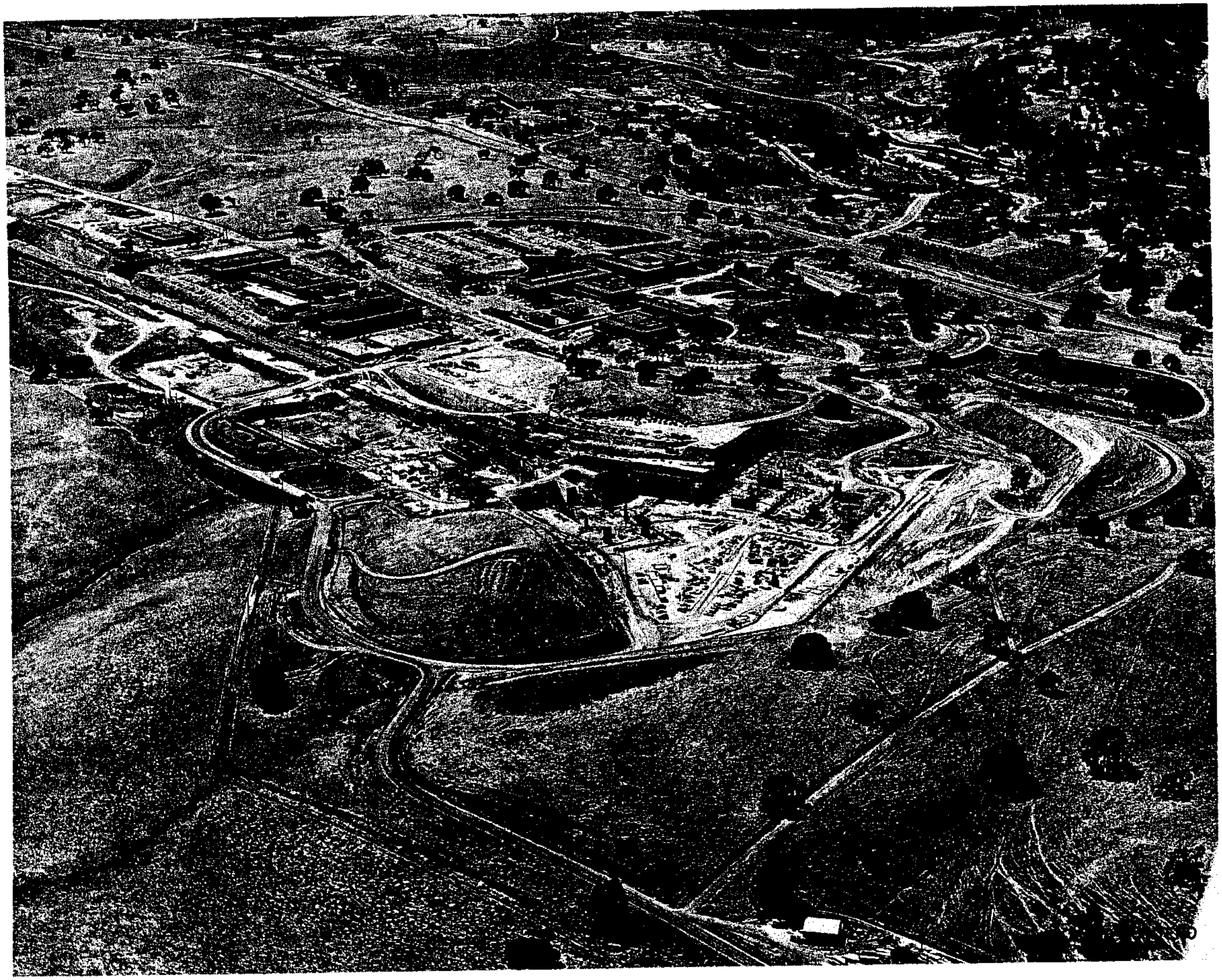

FIG. 4--Panoramic view of project; looking northwest.

6. Target Area Cranes - A contract was awarded for these four cranes on June 28, 1965. Detailed design and construction schedules have been requested of the contractor.

7. Target Area Substations - Shop drawings and test data have been received and reviewed.

8. 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. Proposals for design and construction were rejected and design work was iniated with the goal of obtaining lump sum bids for the doors.

9. Landscaping - Bids for increment IV were opened on June 9, 1965 and are being evaluated. Title II design work is in progress for increments V and VI.

10. Site Fencing - Title II design work is well along. The total package will consist of two increments (Klystron Gallery and target area). Final installation is scheduled for November 1965.

11. Geodetic Engineering - The geodetic survey group completed setting control markers along the Klystron Gallery and Accelerator Housing for elevation, alignment, and length to be used for SLAC installation of accelerator and waveguides. The work of the group was discontinued on June 30th.

C. CONSTRUCTION

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

Facility	Percentage of Completion
Central Laboratory	100
Klystron Gallery	100
Landscaping (Increment I)	99
Landscaping (Increments II and III)	49
Control Building	99
Data Assembly Building	99
Switch House (for Master Substation)	98
Klystron Gallery Utilities	
Piping and site improvements (600-Y-1)	87
Electrical (600-Y-2)	90
Cooling Towers (600-Y-3)	98
Cafeteria-Auditorium	78
Beam Switchyard	68
End Stations A and B	27
Central Laboratory (second floor addition)	23
BSY Site Improvements and Utilities	16
Master Substation	5

The major effort is taking place in the Target Area and this will continue for the balance of the project. The work is proceeding satisfactorily and on schedule.

Beneficial occupancy of all sectors of the Klystron Gallery had been taken by May 1965 in order that equipment installation and testing by SLAC could proceed. Exterior painting was completed during June.

Occupancy of the Central Laboratory and Control Building was continued and extended during the quarter. Construction of the Auditorium is proceeding on schedule and it is expected that beneficial occupancy of that facility will be made in July 1965.

Installation of the 12.47-kV electrical distribution system along the Klystron Gallery is proceeding rapidly. By mid-July this will largely replace the temporary overhead service to that facility.

Paving of the access roads on both sides of the Klystron Gallery is underway and will be complete early in the next quarter.

D. PLANT ENGINEERING SERVICES

The department continued its activities relating to facility planning, alterations, utility studies, and provision of craft support for all SLAC groups. Several items of significance are reported below.

An investigation of soil and foundation problems for the proposed electron-positron storage ring was completed in May, and the results were incorporated in a revised SLAC proposal for the overall facility and its equipment.

Plans and/or procurement of mobile space are underway for suitable housing on site for an interim computer facility and for SLAC personnel to be temporarily accommodated near the Central Laboratory. These requirements, and others which have developed since issuance of the General Development Plan in 1961, have led to an updating of that document. Phase I of the revision was issued in June 1965 and covers the contemplated program through 1967. A Phase II section, projected to 1980, will be issued later in the year.

Related to the above, preliminary planning has been commenced for a Fire House and a General Services Building to house needed SLAC service functions. Appropriate locations have been tentatively selected and design criteria are being developed.

A study has been commenced to determine peak electrical power demands for various modes of accelerator operation, and to predict the associated power costs.

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. General Accelerator Design

The chimney design was developed and the bid package completed for procurement. The penetration shielding was completed for Sectors 1 and 2. Serpentine aggregate has been emplaced for evaluation as a shielding material.

The laser room tank fabrication subcontract was awarded, and the laser room installation drawings issued for bidding.

Layout of the alignment observation room was initiated.

The overall department work is 66% complete.

2. Model Shop

Activity this quarter included the construction of models of the spark chamber magnet, cable trays for DAB and B-beam target area utilities and shielding, pivot pin for mass spectrometer for End Station A, the Data Assembly Building, 25 voltage divider housings, and the alignment target station, as well as the updating of the power line model and minor revisions to the End Station B model.

3. Vacuum

Eight SLAC controllers for the cold cathode gauges were installed in Sectors 1 and 2 and operated satisfactorily.

The layout for the alignment vacuum system was finalized, and work on detailed piping drawings started; installation is scheduled for completion in October 1965.

The positron source system design was modified to incorporate a separate 500-liter/second ion pump for the source area, isolated from the main vacuum system.

It was decided that a 50-cfm mechanical pump plus two-stage cryosorption pumps will be used for sector roughing. Procurement has been initiated.

Installation work on the accelerator vacuum system is 83% complete; work is in progress through 30 sectors.

4. Cooling Water

Redesign of the positron source cooling water systems is underway, owing to changed requirements relative to radioactive water and temperature considerations. Pumps and heat exchangers have been ordered.

Drawing and specifications for the drive line system were issued for quotations, bids were received and approved, and prefabrication of piping began. Installation of tracing lines for the drive line is underway in the first 15 sectors. The accelerator cooling water system installation is 91% complete, with work in progress through 30 sectors. Waveguide/drive line cooling water systems are running through Sector 15, accelerator cooling water systems through Sector 11, and klystron cooling water systems through Sector 12.

5. Electrical

Installation work is 93% complete. Variable voltage substation work is ahead of schedule; with the installation of five high voltage sections and two transformer-regulators, all sixteen substations should be near completion by August 1965.

Installation work on the new drive line supports is in progress. Installation of the modified inter-sector expansion joints has been completed in two sectors.

High voltage energization of substations V3, V4 etc. has not been possible because the 12-kV pole line has not been connected. Work is underway on a scheme which will permit energization of these substations with the underground feeder system at an earlier date than originally scheduled. This will permit elimination of a substantial section of the 12-kV pole line with its inherent rf noise generation problems. The existing installation for Sectors 0 through 4 permits energization of substations V1A, V1B, and V2 with the existing oil circuit breaker at Sector 2.

6. Electronics

Delivery of racks is ahead of schedule. A subcontract was awarded for the assembly and wiring of the alcove and Central Control status monitoring racks.

Electronics installation is 52% complete; work is in progress through 15 sectors. Installation of looped and long-haul cables continued. A second installation package was issued for bids. Installation of racks and cross-connects was started in Sectors 5 and 6.

Work on the auditorium audio-visual system was accelerated, with installation scheduled to begin the end of July.

Telephones have been installed in the center of each sector along the entire klystron gallery. An estimate was prepared for paging and telephone communications in the Cryogenics Building. A revised layout of speaker locations has been devised for the klystron gallery in order to improve paging coverage.

B. BEAM SWITCHYARD

1. Installation Subcontract

The equipment installation 100% submission was approved and pre-invitation notices sent to prospective bidders.

2. Vacuum

Fast vacuum switch shock tube tests were made on 100-foot pipe without the valve by bursting the six-inch diaphragm. The average shock wave velocity was approximately mach 4 (4,000 feet/sec). The maximum velocity of mach 6 was measured about 70 feet from the entrance. Two tests were made rupturing a three-inch diaphragm and letting water enter the evacuated tube. No shock wave was generated, and the speed of pressure was approximately 270 feet/sec.

A preproduction model of the vacuum pumping station is being tested by two suppliers.

Leaking has been experienced with the four-inch remote disconnect water couplings. The use of spherical or conical surfaces does not appear to improve performance, the next approach is to determine the proper gaskets to be used, and tests will be run in July.

Tests on the fast valves are continuing. Problems encountered were: collet did not engage with lower latching mechanism repeatedly; main spring assembly spring bridge and roller guide bars deformed, causing interference between these components and the cam assembly; and the lead ring seal deformed excessively. Redesign is underway to provide solutions to these problems, as well as the problem of energy absorption of the gate assembly. The prototype is scheduled for completion by September 1965; fabrication of production units will be deferred until the completed prototype and a review of BSY criteria for fast valve requirements are made.

3. Cooling Water

Bids for the installation of the system and for the heat exchangers were received and subcontracts were awarded.

4. Electrical

Bids were received on the electrical/electronic systems installation work and are being reviewed.

Tests have been made and witnessed at the vendor's plant on high and moderate radiation-resistant coaxial cable for photon beam services. Tests were also made on the effect of nitric acid vapor on cable joints and cable tray materials.

IV. ACCELERATOR PHYSICS

A. INJECTION

1. Main Injection System

a. Wiring and Electronic Assembly

Assembly and wiring of the injector electrical systems are progressing on schedule. The electrical contractor has practically completed the injector interconnection wiring. Some systems have been installed and tested. The status of each subsystem is described below.

The control console is about 50% complete. Checkout is proceeding on schedule.

The high current power supplies have been received and installed. The system is presently operating at full power into a dummy load in the Accelerator Housing. Operation is satisfactory.

The medium current power supplies are presently being delivered, and the power supply controllers are practically complete. As the supplies become available, the system will be assembled and tested.

All basic components of the vacuum system are installed and it is expected that a vacuum will be obtained in the system by July 15, 1965. Vacuum interlock and monitor circuitry is about 90% complete and will be installed in August.

The injector phasing system is about 70% complete. The remaining items involve the remote control and interlock functions on which the detailed circuit design is proceeding.

The Mark IV gun modulator will be used for initial injector tests. Controls will be remoted to the injector control console on temporary wires and control panel.

b. Waveguide Components

The installation of the main injector waveguide system, including water, vacuum and support, has been completed. The waveguide system consists of a high power waveguide switch, a power divider (directional coupler), a power actuator and phase shifter for the 0.75c buncher, and a straight section for the disk-loaded waveguide.

A klystron for the injector is scheduled to be installed in the early part of July. RF testing will follow immediately. The injector girder assembly is completed, excluding the beam profile monitor and the collimator. Installation of the girder in the Accelerator Housing is scheduled early in July. The beam profile monitor and the collimator are scheduled to be mounted on the girder at a later time. The completed girder assembly includes the following components: (a) the prebuncher section consisting of two gun lenses, a prebuncher with steering dipoles, and the differential vacuum system; (b) a 10-foot disk-loaded waveguide preceded by an integral four-cavity 0.75c buncher supported by a concentric stainless steel tube which also supports 34 focus coils, each approximately 3-$\frac{1}{2}$ inches wide; (c) the output section consisting of a magnetic lens, a beam position monitor, standard steering dipoles, and the bunch monitor.

The final configuration of the main injector is shown in Fig. 5. System checkout is scheduled to begin in mid July.

2. Electron Guns

Electron gun model 4-1 was tested to 100 kV dc this quarter. The vacuum envelope (with internal gun mount) was tested first; no arcing in air or in vacuum occurred. Next, the inner gun (bombarder, cathode, and grid focus electrode) and envelope were tested. With several hours of processing, it was possible to achieve 100 kV dc for short periods. The arc-outs occurred only in vacuum, between the anode corona ring and the grid focus corona ring and between the anode corona ring and the columns that support the grid focus electrode. Reworking to improve the surface finish eliminated the arcing in the first gap but was not successful in the gap to the columns. This was probably due to the shape of the braze joint between the ceramic column and the cupro-nickel column. In future designs, a corona ring will be added to encircle all four columns, which should solve the problem.

An attempt was made to hi-pot the gun while it was heated by the bombarder, but this test was unsuccessful because of the loss of the high voltage isolation transformers. However, the gun was pulsed to 55 kV with a three-μsec pulse while hot. No arcing was observed.

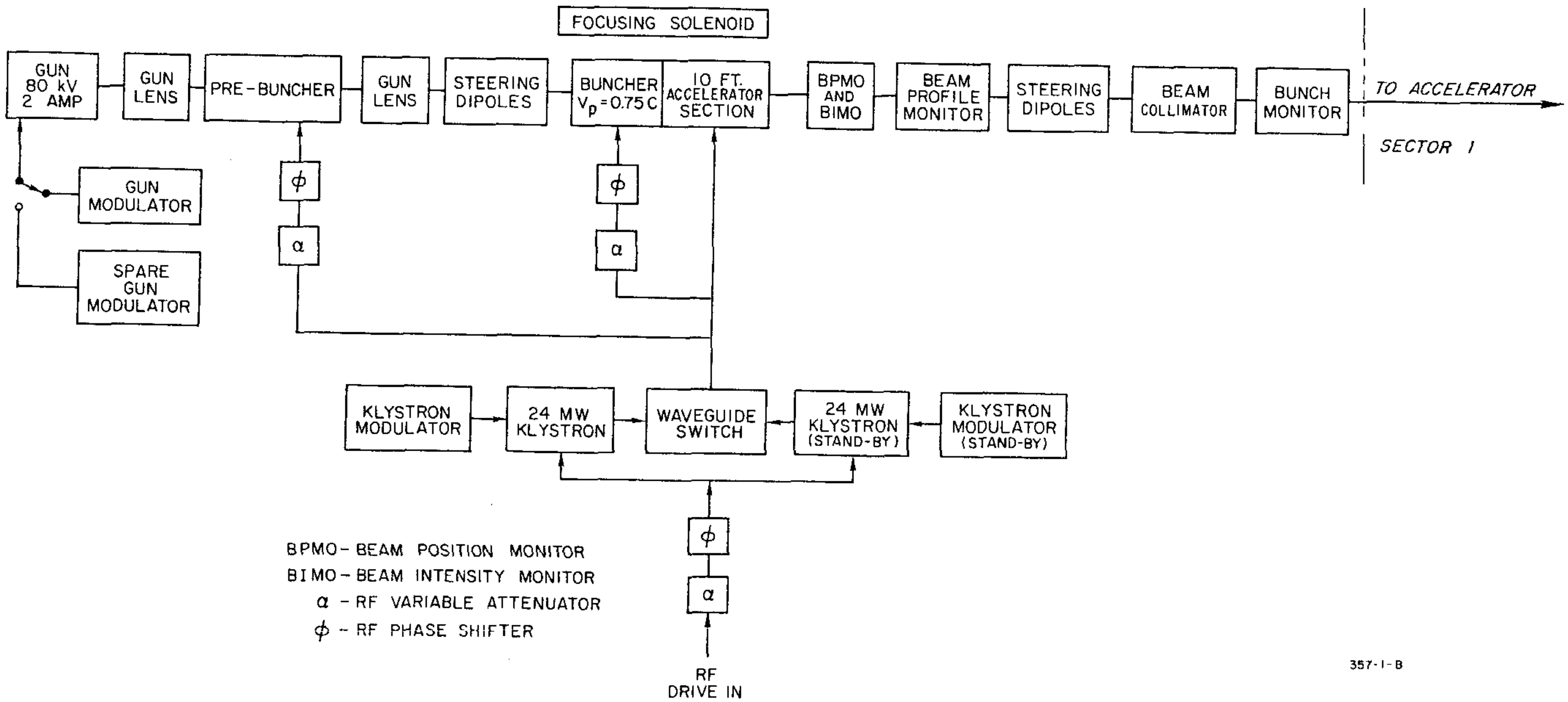

FIG. 5 -- MAIN INJECTOR BLOCK DIAGRAM

Emission tests were observed on two thoriated tungsten cathodes. The largest current obtained was 0.45 ampere peak at V_{AK} = 43.2 kV, V_{GK} = 350-volts pulse or V_{GK}/V_{AK} = 0.81 % grid drive, and a cathode temperature of about 1850°C.

Molybdenum mesh grids were successfully spot-welded onto grid-focus electrodes and heat-cycled with no observed defects. A thermocouple was used to measure the mesh temperature. With no beam and a nickel cathode temperature of 925°C, the mesh temperature was 325°C while the grid-focus electrode temperature was 180°C.

In June, nickel cathodes were prepared for carbonate spraying. Nickel cathodes will be used in the gun for Sectors 1 and 2 beam tests until October 15th because the present gun modulator does not have a bombarder supply.

3. Gun Modulators

The final gun modulator design is making progress. The high voltage deck of the second Manson modulator is being redesigned by the modulator group. The grid pulser circuitry is being worked on to improve rise time to better than 20 nanoseconds. It has been decided to leave the pulser in the gallery in the modulator cabinet and to drive the clipper diodes and gun in the Accelerator Housing by means of a set of pulse transformers and coaxial cable. The new gun modulator should be ready for installation during the October to December shutdown.

4. Injection Test Stand

The Injection Test Stand operated throughout the quarter and continued to be utilized for a variety of experiments.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

Acceptance tests on the drive lines have been completed.

Water tracers have been installed on the first ten sectors. Drive line installation on rollers has reached Sector 20. Delivery of A-frames is expected within two weeks. Tests on the modified installation will be carried out during the next quarter.

2. Varactor Frequency Multipliers

Multipliers are now being stripped and delivered at a rate of about two per week.

3. Main Booster Amplifiers

A failure of the rectifier stack in one amplifier occurred at approximately 4000 hours operating time. The amplifier is now repaired. The rectifier stack is being examined by the manufacturer. The units now have approximately 4500 and 5500 hours of beam time, without any known significant changes in klystron characteristics.

4. Positron Phase Shifters

Phase-shifters and drivers were fitted into twelve sub-booster isolator-phase shifter-attenuator units.

5. RF Drive System Control Circuits

The sub-booster transfer switch has been received, and a switching unit is being designed to transfer between the operating and the stand-by sub-booster in the injection area.

The master oscillator switching unit is approximately 80% complete.

6. Sub-Booster Modulators

During this quarter five production sub-booster modulators were received. Two units were installed in the Klystron Gallery and tests were completed.

7. Sub-Booster Klystrons

While extensive shelf-life tests have not been possible on sub-booster klystrons recently delivered, the results obtained so far show an improvement in shelf life.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

Delivery and testing is nearing completion on all production units.

Modification of the pre-production units will commence as soon as all components are received from the subcontractor. A few units will also be modified to meet the special remote manual/automatic requirements of Sector 27 and the beginning of Sector 1.

The procurement of three special control phase-shifters for the injector area is in process.

2. RF Detector Panels

Several production units have been delivered, tested, and found to be satisfactory. No problems are expected to arise.

3. Programmers and Electronics Units

Units of each type have been received. The programmers have been tested and accepted and tests are proceeding on the electronics units.

4. Linear Detectors

The contract for the thermionic diode housings has been awarded. Eight additional units have been ordered to cover immediate requirements.

Sectors 1 and 2 tests have shown that the performance of the thermionic diodes does not meet the full operational requirements of either the automatic phasing system or the beam-position monitoring system. The problems are:

(a) Diode balance cannot be maintained over the range of input signal power required by either system.

(b) The degree of balance changes with time.

(c) The diodes are non-linear at low signal levels.

Problems (a) and (c) have been overcome on the phasing system by switching additional attenuation into the signal path when phasing on the high-power klystron rf pulse. The two alternative paths are adjusted to have the same electrical length. The switching can be performed without any additions to the programmer logic.

This modification worked well during Sectors 1 and 2 tests, but further laboratory testing is necessary to determine the phase stability of the alternate paths and to check whether the change in diode balance with time remains a problem.

5. Overall Performance of the Phasing System

Sectors 1 and 2 tests have shown that the automatic phasing system works very reliably, provided that the thermionic diodes are balanced within the ±1.5-volt acceptance range of the gated voltmeter. The system is also very useful for diagnosing certain machine faults, such as beam mis-steering and klystron or sub-booster phase jitter.

D. BEAM POSITION MONITORS

1. In-Line Position Monitor Cavities

The design of the in-line cavity assembly has been finalized. A "two-way" dimpling system has been incorporated, providing a greater range of initial tuning, and permitting "on-machine" readjustment at a later date, should this be necessary. Parts procurement is well advanced and the production of completed assemblies for drift-section installation has begun.

2. Beam Position Monitor Detector Panels

Bids for the panels have been received and evaluated.

Sectors 1 and 2 tests have revealed that limitations in thermionic diode performance, as discussed above, reduce the reliability of the position monitoring system. Changes in diode balance with power level can result in an error of two millimeters in indicated beam position. The error introduced by changes in diode balance with time (due to diode aging) will vary from diode-pair to diode-pair. The rate of change of balance is not necessarily uniform, so that periodic rebalancing may not be an adequate solution. Diode non-linearity has two adverse effects. The lesser problem is the error in the "log Q" presentation. The error is negligible at high beam currents (above 50 mA) and increases to -20% at 1 mA. The error in the beam position presentations is much larger, increasing from a small value at currents above 50 mA to about +250% at 1 mA.

Solutions to these problems are being considered. They will be evaluated during the next quarter.

3. BSY Beam Position Monitors

One prototype assembly was tested on the injector test stand. Performance was satisfactory, but it was observed that the two-inch-diameter aperture perturbed the fields in the position cavities to the extent that the axial component of the electric field was essentially zero over a region extending approximately one millimeter each way from the cavity axis. However, it has been determined that the existence of this "blind spot" will not seriously affect the usefulness of the switchyard monitors.

Six cavity assemblies are scheduled to be completed by the end of the next quarter.

Procurement of components for the seven special microwave-to-video converters is nearly complete.

It is not anticipated that the use of thermionic diode detectors will pose the same problems here as in the in-line monitors, because provision has been made for remotely balancing the diodes before each measurement, and tunnel diode detectors will be used at low signal levels.

E. BEAM ANALYZER STATIONS

Some work has been done on improving the electronics for the permanent installation of BAS-1. The design and breadboard layout of a high input-impedance amplifier for transmitting video from monitor foils on the machine to the injector alcove has been completed. Circuits and a block diagram for a magnet-degaussing programmer have been designed.

It has been decided that BAS-2 will become a permanent instrument, and will be re-installed on the first girder in Sector 3. The "Y" vacuum envelope inside the magnet will be rebuilt to accommodate the broadest anticipated beam, but the present foil box, window, and dump will be retained temporarily. The design of these components will be reviewed during the next quarter.

F. STORAGE RINGS

Cost estimates for an ultra-high frequency and a high frequency rf system were prepared for the Storage Ring Proposal.

A detailed analysis of high efficiency rf amplifiers is being made to verify the feasibility of a 94% efficient amplifier system in the storage ring.

G. GENERAL MICROWAVE STUDIES

1. RF Separators

Two rf separators were designed during the past quarter. The first one, operating in the TM_{11} mode, will be used to separate electrons from positrons downstream of the positron radiator. The second structure, which uses the TM_{01} mode with an offset disk-hole, will be tested during the next quarter on the injection test stand.

H. OPTICAL ALIGNMENT SYSTEM

Design work has been completed on virtually all of those components which were added to the system by the decision to reverse the direction of the alignment system. These include the laser room, the revised laser support, the vacuum extension for the laser room, the remotely actuated baffles, and the revised west-end termination. A request for proposal has been issued for the large glass window at the west end of the alignment pipe. The vacuum system and the 24-inch manifold to connect the system to the light pipe have been redesigned to put the vacuum system in the room at the east end of the Klystron Gallery.

Targets are being received, checked, and installed on girders in the Mechanical Design and Fabrication assembly line and deliveries are on schedule. Targets, hinges, and actuators for the first five sectors, on which retrofit changes were required, are also being installed.

Target positions relative to the optical tooling holes are being checked by means of a target calibration fixture. Photographs are taken of the target pattern superimposed on a printed reticule plate.

The photographs are analyzed by reading the position of the holes relative to the reticule lines and by calculating the average shift of the actual position of the target relative to the theoretical position. The computer program used for the calculations performs checks for reading errors by comparing the actual pattern with the theoretical pattern for that girder.

I. THEORETICAL AND SPECIAL PROJECTS GROUP

A new group within the Accelerator Physics Department, the Theoretical and Special Projects Group, has been formed. The past activities of the members of this new group centered around electron optics, electromagnetic theory, and circuit theory.

Current projects handled by this group include the theoretical investigation of beam knock-out systems, the development of a ballistic ray tracing computer program, a study of generalized coordinate systems applied to electron-optical problems, and a fast (nanoseconds) pulse transmission system for the gun modulator.

Future plans include the general study of pulse shaping networks with applications to cable equalizers, PLIC (Panofsky long ion chamber) compensators, high accuracy current monitors, and modulators; the theoretical analysis of the spark chamber matching problem; a computer analysis of networks and circuits used on the project; and other consulting services.

V. INSTRUMENTATION AND CONTROL

A. GENERAL

The operational tests of Sectors 1 and 2 during the past six months have provided opportunities to check out most of the components and subsystems of the accelerator. Of the instrumentation and control equipment, beam guidance equipment, the trigger system, klystron protection circuits, and variable voltage substation controls have been checked out in detail. No significant operational tests have yet been made of the data handling system, personnel protection circuits, machine protection system, or any of the equipment in Central Control. A temporary personnel protection system was installed for preliminary rf tests in November 1964. The requirements of continuous operational testing prevented replacing the temporary system with permanent circuits. The data system, machine protection system, and Central Control equipment were not scheduled for early installation because the initial series of tests was based on the concept of local control.

These subsystems will be installed this summer. The next series of sector tests, scheduled for the latter half of August, will provide the first opportunity for operational evaluation of these subsystems.

B. DATA HANDLING

1. Status Monitoring

Binary status information at each sector will be transmitted to Central Control on a time-shared multiplex system. Delivery of production units is proceeding on schedule. After quality control inspection and testing at SLAC, the receiving equipment chassis are being shipped for assembly into racks.

2. Analog System

Slowly changing analog signals will be transmitted to Central Control by means of individual hardwire pairs, and will be read on standard panel meters. The first production unit will be ready in August 1965, and will be used in the series II sector tests in September.

3. Beam Monitoring

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

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

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

Preproduction units of fm transmitters and fm receivers have been tested and production release was given June 3, 1965. Delivery will commence in July 1965. The baseband transmitter and receiver have gone out for bid.

4. Remote Control

The remote control system consists of a transmitter which transmits binary codes and a receiver in each sector which translates the code into a signal to actuate a relay or motor. A contract for production of transmitters and receivers was issued in April 1965, and delivery of production units is expected in July 1965.

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.

Further work on the circuits to give an output linearly related to the charge in each beam pulse has been carried out. In particular, means to compensate for the droop introduced by the intensity toroid have been incorporated.

The beam monitor sector electronics package and the control units for the beam steering power supplies have gone out for bid. Steering supplies have been received and are being tested.

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 main trigger line has been delivered and is being installed.

Sector trigger generators are under construction. The injector trigger generator prototype is ready for delivery. The comparator, pattern generator, and beam switchyard trigger generators are scheduled for completion during the last half of 1965. The pattern generator and the comparator have been designed and breadboarded. Prototypes are under construction on schedule. The beam switchyard trigger generator design has started.

E. KLYSTRON INSTRUMENTATION

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

The experience gained in testing Sectors 1 and 2 indicated generally satisfactory performance. Nevertheless, in order to reduce interference with other units, it was found necessary to make a minor modification consisting of inserting diodes across relay coils in order to suppress inductive kicks.

F. PERSONNEL PROTECTION SYSTEM

The personnel protection system has a machine shut-off circuit, access controls, radiation monitors, and warning devices.

Beam tests were concluded with temporary personnel protection circuits still in operation. Permanent circuits will be installed during the summer so that series I and II tests will be conducted with the final equipment in operation, except for special circuits bypassing sectors still under construction.

The design of the personnel protection circuits for the beam switchyard and end stations has been started.

The design of radiation monitors are proceeding satisfactorily. Electrical design of the portable gamma monitor is complete. Design of the case has not yet been accepted. A procurement order for the fixed gamma monitor has been placed, with delivery of the first unit expected in September 1965. The design of the air monitor is complete and specifications are being written. The design of the water monitor is complete. A prototype is being built by Health Physics. A purchase order for the neutron monitor has been placed.

G. MACHINE PROTECTION

The machine protection system provides the 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. The first production units of the tone generator and receiver will be delivered in July 1965. Evaluation testing of the tone-interrupt unit has been completed and a bid package for production units is being prepared.

For the 50-microsecond network, a pulse train generated in the beam switchyard allows the gun to be turned on once for each pulse. Interlock circuits, acting on a pulse-to-pulse basis, interrupt the pulse train when it is determined that the switchyard cannot accept the beam for the next pulse.

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

The long ion chamber may also prove to be a useful detector for a scanning profile monitor. Such a profile monitor was tested at the end of Sector 1 during beam tests. In it a 0.050-inch by 0.050-inch cylindrical Mo target, hung on a 0.002-inch W(5% Re) wire was mechanically scanned over the cross section of the electron beam. The electrons which passed through the target were scattered, and some hit the inner surface of the accelerator pipe, producing a cascade shower. The shower was detected with an external air-filled ion chamber to give a measure of the relative number of electrons striking the target at that moment.

Figure 6 shows the result of a single scan, which took about five seconds to make. The picture is that of a storage oscilloscope face. The vertical and horizontal scan motions were measured by linear motion potentiometers, electrically connected to the vertical and horizontal inputs of the oscilloscope. The ion chamber signal was also connected to the vertical sweep input.

H. CENTRAL CONTROL

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

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

A contract for assembly of 30 status monitoring racks was awarded. Delivery of the first racks is scheduled for July 1965.

All presently known items of equipment for series II Central Control tests are on order and will be available by September 1965. Wire tables are being prepared so that installation and wiring can proceed as soon as the equipment is available.

I. COMPUTER CONTROL

Various pieces of interface equipment are now being studied so that when the control characteristics of the machine are known experimentally, some of these may be profitably assigned to control by the computer. This work involved breadboarding of certain system components to determine feasible procedures.

A further area of work has been the design of the logic to operate an automatic magnet mapping device. This device is currently being built by the magnetic measurements group and is designed to map the field of large magnets, such as bubble chamber or spark chamber magnets, automatically in two dimensions. The design of control and recording logic has been completed.

J. CONTROL SYSTEM

The first two sectors of the accelerator have been operated from the temporary control point in Sector 2 instrumentation and control alcove.

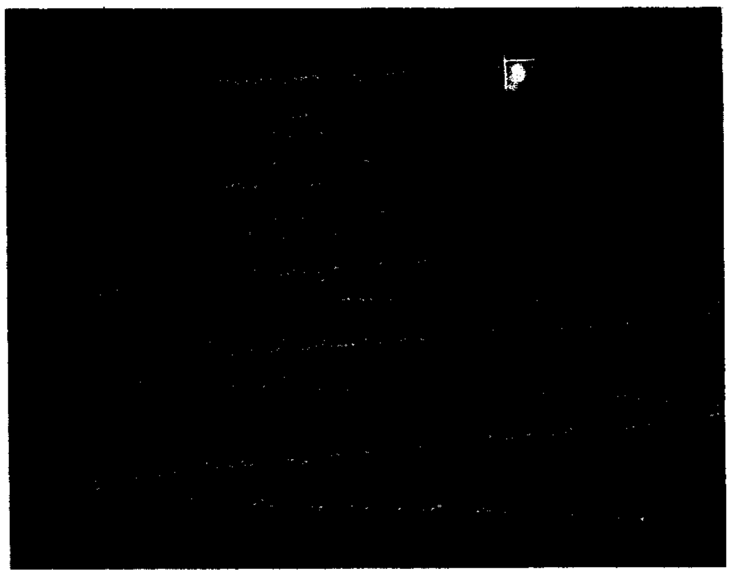

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FIG. 6-- Storage oscilloscope record of a profile scan. The instantaneous base line position corresponds (with some geometrical distortion) to the scanning target position (beam's eye view).

A list of the controls provided in Sector 2 is presented below:

1. Drift Section 2 spectrometer, including x, y plotter, foil scope, and bending magnet power supply.
2. Drift Sections 1 and 2 profile monitor including monitor TV, crystal insertion controls and status lights, light dimmer controls, and a camera selection switch.
3. Panofsky long ion chamber (PLIC), including readout oscilloscope and gallery electronics.
4. Log Q, x and y signals from the 30-foot point, DS1 and DS2, including baseband electronics with recorder output and a four-channel oscilloscope.
5. Quadrupoles at the 30-foot and DS1 points, including power supply on/off control, increase/decrease current control, current meters, and status lights for each supply.
6. Steering at the 30-foot point, Fiat 1-4, Fiat 1-6 and DS1, including controls, status lights and meters for each supply.
7. Degaussing at DS1 and DS2, including status and meters for each supply.
8. Klystron status lights for Sector 1, including mod available, mod not available, mod on, RF OK, Accelerate, and standby trigger modes.
9. Sectors 1 and 2 klystron accelerate and standby controls.
10. Sectors 0, 1 and 2 trigger controls, including sequence, rate and pattern selector switches.
11. Temporary controls and status lights for the personnel protection system in Sectors 0 through 5.
12. Accurate beam Q, including preamplifiers at beam monitoring racks 1 and 2 and a readout (termination) chassis in Sector 2 I/C alcove.
13. Variable voltage substation circuit breaker controls (V1A and V1B), as well as the reference and de-Q'ing systems for all modulators in Sectors 1 and 2.

Assistance was given to Systems Engineering and Installation in completing the documentation for the I/C alcove installation for Sectors 3 through 30. A major effort went into the signal documentation for the main injector installation and for the re-wiring of Sectors 1 and 2.

Some time was spent in tracing down spurious responses in the fast valve control circuit and the specification of protective measures.

A detailed check list and instructions have been prepared which will enable I/C personnel to quickly test the functioning of all remote control analog and status monitoring signals to and from the I/C alcove.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

1. Modulator Procurement

Seventy-five modulators were received and installed during the quarter, bringing the total number in-house to one-hundred thirty. This is over one-half of the required number. Deliveries were about six weeks ahead of schedule at the end of the quarter.

After installation, the modulators were started up and run about one hour each, using a water load. All modulators through Sector 9 were tested in this manner.

Life testing of modulators and associated components continued. Pre-production modulators, serial numbers 2 and 3, had 7978 and 7240 hours running time, respectively. Production modulators, serial numbers 21 and 22, had 2519 and 2797 hours running time, respectively. Serial number 3 is being used mainly for switch tube acceptance tests. Serial number 2 has been running into a diode load (which is equivalent to a klystron load as far as the modulator is concerned); all others use water loads.

Eighteen more modulators in Sectors 1 and 2 continued to be tested along with other accelerator components. Upon completion of the tests, all modulators had logged between 500 and 600 hours test time.

Life tests revealed that the pre-production main rectifier units were inadequate: the cards on which the diodes were mounted were made of phenolic material, which is not fire resistant. However, all production units had a fire resistant polyester glass material for the cards and another fire resistant material for the separators. Production rectifiers were supplied by the manufacturer to replace the pre-production units.

Work is being done to improve the performance of the pulse capacitors in the pulse forming network; some failures in the bushings and the development of internal gas within the capacitors have been experienced.

2. De-Q'ing

The contract for de-Q'ing switch assemblies was awarded, and by the end of this quarter the first 30 units had been received. Most of these have been installed in modulators in the Klystron Gallery.

The three sample de-Q'ing switch assemblies which had been on test during the previous quarter continued to operate satisfactorily, with each unit having operated over 3000 hours.

The problem of noise in the de-Q'ing voltage dividers was solved during the quarter. It was determined that most of the noise came from corona discharges off sharp points along the divider. The corona was eliminated by placing the divider in an oil bath. Twenty oil baths were made in-house, and were installed and tested in Sectors 1 and 2. The units now appear to operate satisfactorily.

3. Switch Tubes

Both suppliers are delivering tubes under the options exercised by the University.

4. Pulse Transformers

By the end of the quarter some 94 pulse transformers had been received. Life testing of pulse transformers continued. The problem of core shape shifting slightly with life has not yet been solved, but thus far none of the transformers has shifted enough to take it out of specifications.

5. Oil Expansion in Pulse Transformer Tanks

It appears that a solution has been found to the oil expansion problem in the pulse transformer tank. As reported previously, rubber tube expansion chambers had been installed in nearly all 64 completed assemblies to date, but this was considered a stop-gap measure because the rubber tube deteriorates in hot oil, and it results in a partial vacuum in the pulse transformer tank when the tank is not at full operation temperature. Sectors 1 and 2 tests demonstrated the effect of a partial vacuum in the tank: Small air leaks around the klystron "O" ring seals and/or the tank itself resulted in leakage of air into the tank with the possibility of an exposed klystron seal. Such exposure can result in an arc over the seal, with subsequent puncture and loss of the klystron.

A metal bellows air expansion chamber was next attempted, but we were unable to arrive at a solution with a bellows inside the tank. Several samples which met specifications were made, but a partial vacuum was present in the tank at room temperature and/or low operating power. A system which kept the tank under a slight positive pressure was needed.

A nested type bellows which was installed in place of the blow-off head was also tried. The system appeared to operate satisfactorily, giving a maximum positive pressure of about two pounds per square inch and no partial vacuum at room temperature. However, it was large and bulky, expensive, and might present handling problems with the klystrons.

Finally, a wrap-around oil reservoir mounted around the base of the klystron magnet and connected to the pulse transformer tank with a tygon tube was tested and appears to be satisfactory. Procurement of enough units to equip all klystron tanks is underway.

B. SUB-BOOSTER MODULATOR

The two pre-production modulators performed satisfactorily during Sectors 1 and 2 tests. They were operated 24 hours a day and had operated approximately 3000 hours at the end of the quarter.

The first production modulators passed in-plant tests and were shipped to SLAC.

C. GUN MODULATOR

Modification of the gun modulators is continuing. Two regulated power supplies were ordered to supply power to the bombarded cathode of the new gun. Specifications for 200 feet of special cable for carrying 100 kV dc, various pulses, and power circuits from the modulator in the Klystron Gallery to the gun in the Accelerator Housing were drawn up.

D. STORAGE RING INFLECTOR MODULATOR

This project is in the construction phase. The cabinet is in-house and various parts are being installed in it. Sub-assemblies are under construction.

E. MAGNET POWER SUPPLIES

Work on the 0.1° pulsed magnet power supply, the A and B beam quadrupole power supplies, the A beam dump power supply, and the A and B beam unregulated power supply is being done by the respective suppliers.

Bids for the A and B beam regulators, pulsed steering magnet power supplies, the dc steering magnet power supplies, and the 5800 kW power supply were opened.

Specifications for the photon clearing magnet power supply were drawn up and reviewed during this quarter.

A contract for the manufacture of positron source solenoid power supplies was awarded.

It was decided to pattern the End Station B beam transport power supplies after the Lawrence Radiation Laboratory SCR power supplies. Specifications were drawn up, and bidding is expected to begin during the next quarter.

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

A total of 55 forty-foot support girders was assembled and installed during the reporting period to bring the total number of installed girders to 105 by mid-year. (This does not include the 11 drift section girders that have been installed since only one of these is a completely assembled module.) The fabrication of the injector was also completed during the reporting period and installation was started.

B. ACCELERATOR STRUCTURES

A total of 220 ten-foot sections of disk-loaded waveguide was completed during the reporting period and readied for installation on support girders. One section was damaged and rejected during fabrication for a shrinkage loss rate of less than 0.5%. The 18 special seven-foot sections were also completed, tuned, tested and ready for installation during this period. This meant that, from the time of the fabrication of the first sections until the end of June, a total of 6,536 feet of disk-loaded waveguide had been fabricated and readied for installation.

C. RECTANGULAR WAVEGUIDE

A total of 49 crossbars and 116 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 total production of these components to 99 crossbars and 221 penetration waveguides. Also, approximately 60% of the rectangular waveguide components associated with the injector was fabricated and processed through high power rf testing during the reporting period.

1. Phase Measurements and Adjustment

During the quarter, rectangular waveguide networks were phase adjusted for the following girder stations: 6-3 through 9-8, and 12-7 through 15-8, excluding stations 13-4 and 14-4. No girders had been installed in the intervening stations. Phase adjustments were averaging five girder stations a week by the end of the reporting period.

Improvements continued to be made on the phase measurement console to permit coarse and fine phase adjustment and measurement of input reflection with only one waveguide connection to the girder station. Reflection modulator calibration is thus simplified and a reference modulator is provided to facilitate overall checking of the phase measurement system. It also allows checking of the components of the waveguide system that is under test. Waveguide and coaxial switches on the console permit rapid setup and phase comparisons.

Preliminary investigation of and design work for an automatic set of alarm circuits that would indicate incorrect frequency, cooling water temperature and flow, and vacuum during fine phase adjustment were also performed. It was found that commercially available devices did not give as much protection as desired because of the many possible sources of error in frequency measurement. It was also determined that specially-built devices would take too long to make and would be too expensive. Therefore, as an alternate system for possible use at a later time, the preliminary design of an all-digital frequency alarm of very simple circuitry was completed.

Twenty additional reflection-modulator flanges were fabricated during the reporting period, bringing the number now in service to 64, or 16 sets. These are enough to allow ease and flexibility in the scheduling of phase adjustment work and five girder stations were being completed per week by the end of the reporting period.

A quick-disconnect flange was developed for connection to the standard Skarpaas flanges on rectangular waveguide components. The flange will be used for non-vacuum cold testing in the tuning of such waveguide components as waveguide vacuum valves, directional couplers, power dividers, and loads. It will also be used in the coarse phase check of girder stations and in laboratory work.

2. Rectangular Waveguide Component Status

In general, all rectangular waveguide component fabrication, like the accelerator structures fabrication, is proceeding on schedule and it is estimated that all required parts will be available to complete accelerator installation during the last quarter of the year. The number of the various components completed during the quarter and the total number completed as of the end of June are as follows:

	Second Quarter	June 30th Total
Waveguide Vacuum Valves	56	108
Model A Directional Couplers	64	106
RF Loads (All Types)	390	390
Power Dividers (All Types)	316	656
S-Assemblies	108	212

D. MAGNET ENGINEERING

The design was completed on all magnets reported in the previous QSR. (Refer to SLAC Report 45, June 1965, pages 53 through 56 for the code designation of these magnets and to Fig. 14 for their location.) The majority of the magnets and their supporting components were either in fabrication or were out for bid. As a result, the main concern of the Magnet Engineering Group was in vendor followup and scheduling. The status of the various magnets is given below.

Toward the end of the reporting period, the group was also concerned with redesign of Brookhaven-type magnets that were being procured for use with secondary particle beams as reported in Section XI, Target Area Research. This redesign concerned the pressure drop and water system changes that were required for SLAC's use of the magnets.

1. Pulse Steering Magnets

The five pulse steering magnets were in fabrication before the end of the quarter. They were on schedule and delivery is expected near the end of the next quarter.

2. Emergency Bending Magnets

The two emergency bending magnets were also in fabrication and proceeding on schedule by the end of the quarter with delivery expected near the end of October.

3. Three-Degree Bending Magnets and Reference Magnets

The 13 three-degree bending magnets and the two reference magnets are being fabricated and the first delivery is expected near the end of August.

The coil fabricator has experienced difficulty in working with the radiation-resistant epoxy and has fallen behind schedule. It is still anticipated, however, that all magnets will be on hand in time to meet the installation schedule.

4. Pulse Magnets

The coils and packaging assemblies for the five pulse magnets are being fabricated by outside vendors. With AEC approval, the cores for these magnets are being fabricated in house. It is anticipated the assembling of the magnets, which will also take place in house, will be completed by the first of February of next year.

5. Quadrupole Magnets

The two 18.6-cm quadrupole magnets and the eleven 8-cm quadrupole magnets are being fabricated. Again, the coil fabricator has had difficulty in void-free coatings in working with the radiation-resistant epoxy and is somewhat behind schedule, but delivery is still expected to be in time to meet installation schedules.

6. Photon Beam Stripping and Bending Magnets

The design of the two photon beam stripping magnets was completed during the reporting period and bids for their fabrication had been received. The photon beam bending magnet, B-28, was redesigned so that it could be used as either a bending or a steering magnet. It was sent out for bid by the end of the period.

7. Dump Magnets

The four "A" system beam dump magnets were being fabricated during the period. The coil fabricator was also having epoxy troubles with these magnets but delivery here is also expected to meet installation schedule.

8. Associated Magnet Hardware

The contract was awarded for the ceramic water tubes and bellows connectors for the BSY magnets and fabrication was started. The design was also resolved for the quick-disconnect vacuum couplings associated with the magnets and other BSY equipment and they were being fabricated during the period.

E. PRECISION ALIGNMENT

1. Forty-Foot Girder Alignment

In addition to the optical alignment used when a 40-foot segment of the accelerator is installed, a stretched-wire technique has been used for additional verification of alignment. Briefly, this technique consists of the following procedures: First, a wire is stretched through the sight holes in each of the four strongbacks on a girder, with the wire being anchored at one end of the girder and connected to a gravity tensioner at the other end (Fig.7). Then, mechanical plugs are inserted in the first and last sight holes on the girder. These plugs act to precisely position the wire in the center of the sight holes. A third plug that has two mechanical micrometers attached to it and oriented at 90-degree angles to one another is then fitted, initially, into the center sight hole and subsequently into the 1/4-point sight holes of the strongbacks (see Fig. 8).

The micrometers, which are electrically insulated from the plug, are operated until their anvils make contact with the stretched wire which is at ground potential. A volt/ohmmeter (Fig. 9), which is connected electrically to the body of the micrometer, detects a small current when contact with the wire is made. The value read from the micrometer spindle when the small amount of current is registered indicates the position of the sight hole relative to the wire. (The mechanical position of the micrometer anvil relative to the outside diameter of the plug is determined precisely in the shop.) By making these contacts with the wire at the mid- and 1/4-sight points down the length of the girder, it is possible to determine the deviation from linearity from one end sight hole on the girder to the other end hole.

2. Sector Alignment

The stretched-wire technique of sector alignment was developed for both individual sector alignment and for inter-sector alignment between Sectors 1 and 2. In the first case, the wire is stretched from the sector reference point, a point located four feet, four inches south of the beam centerline at the beginning of one sector, to the sector reference point of the next adjacent sector. For inter-sector alignment of

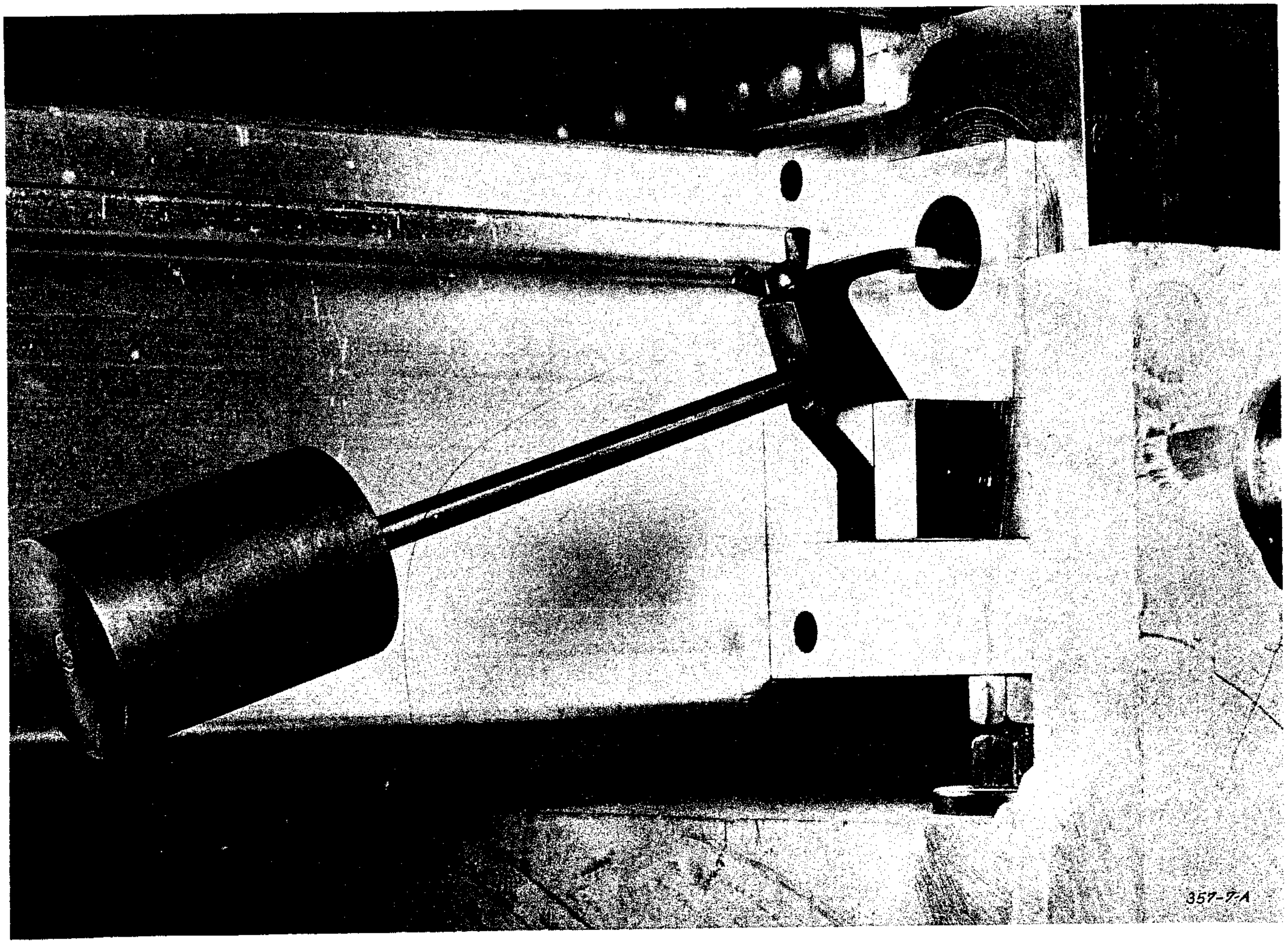


Fig. 7 - Gravity tensioner for stretched-wire alignment.

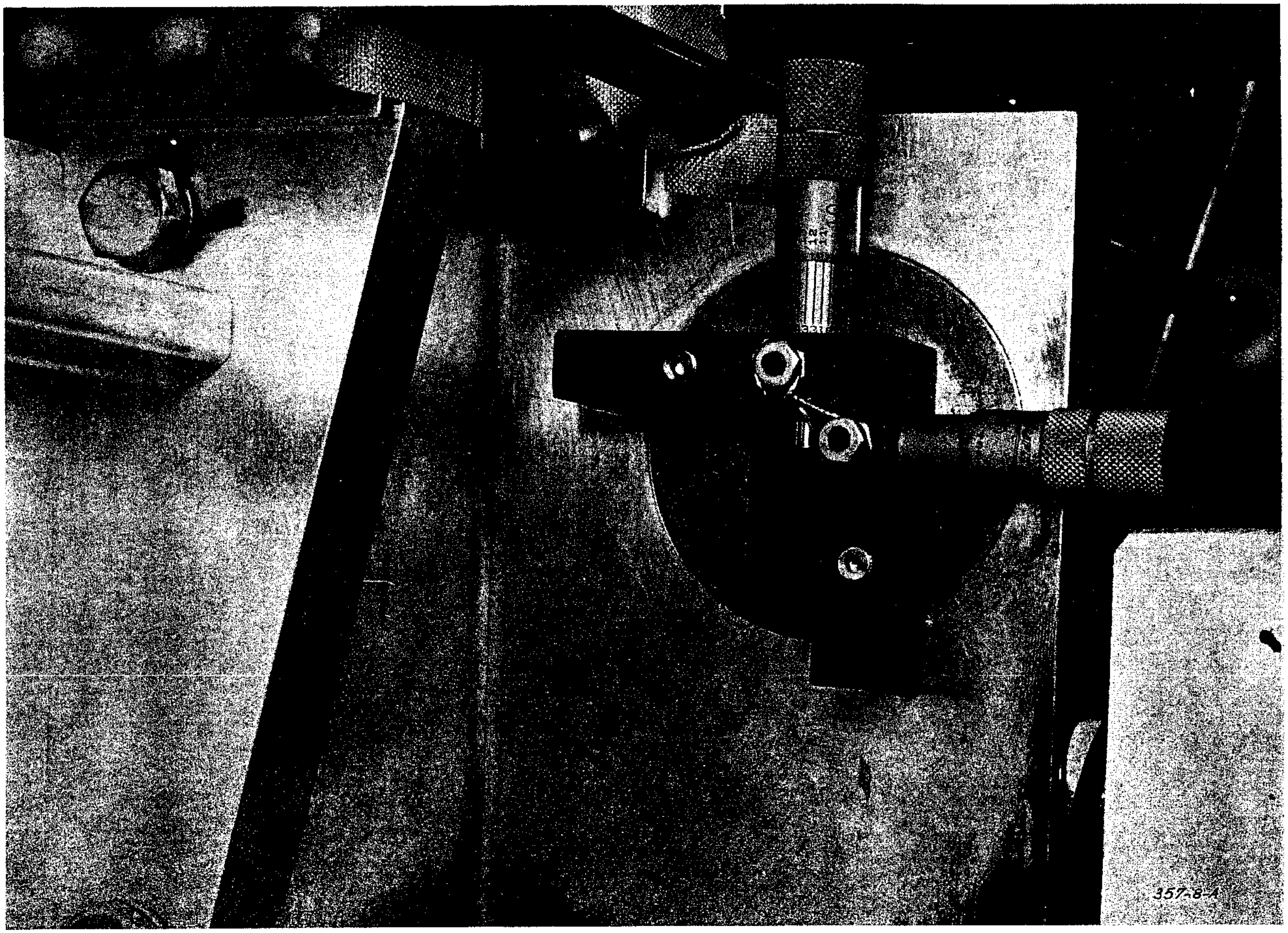


Fig. 8 - Micrometer and precision plug arrangement.

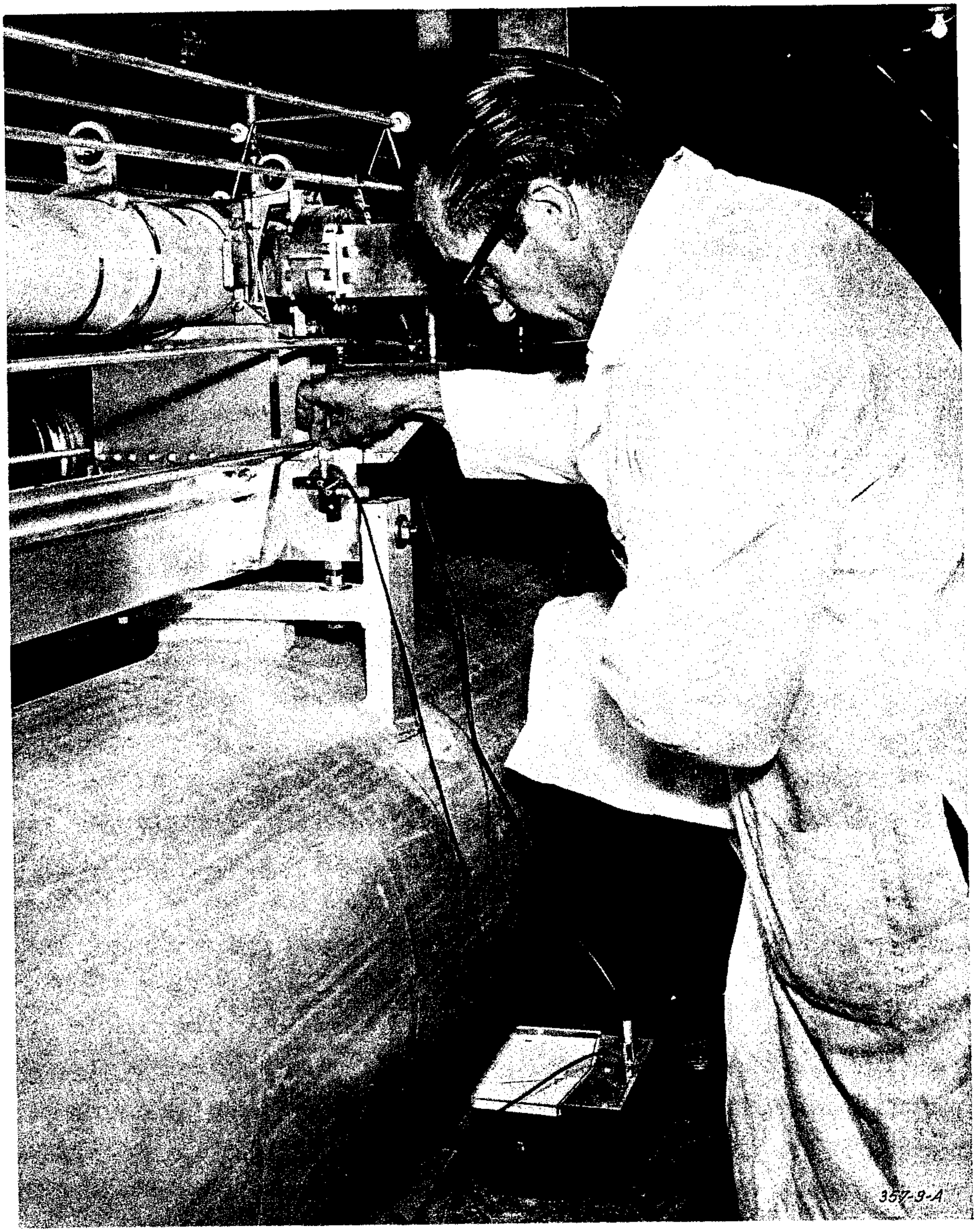


Fig. 9 - Micrometer and volt/ohmmeter arrangement.

Sectors 1 and 2, this is modified by stretching the wire from the Sector 1 reference point to the Sector 3 reference point and then later reestablishing the reference point at Sector 2.

The general alignment setup is shown in Fig. 10. The main instruments and other components used in the alignment procedure are a mounting arm that mounts and precisely positions an alignment telescope, a reel of 0.004-inch wire, a weight with a wire clamp, a vertical collimator, an optical tooling stand with a precision level, a 10-inch optical tooling scale with a calibrated, machined cup, and several adjustable stands. The general procedures that are performed are as follows: Sixteen hours prior to the alignment, all systems such as the 113-degree water and the rf are activated to stabilize the machine, and the accelerator housing is sealed off to quiet the air flow in the sectors to be aligned. The wire is tensioned with a clamp between two stands that are close to the sector reference points but not within the sectors to be aligned. Both ends of the stretched wire are then positioned precisely over their respective sector reference points with jig transits.

The vertical collimator is then located precisely over the wire at its mid-point (Sector 2 reference point) and is used to monitor the stability of the wire to assure a stable reference.

Following this initial setup, tooling ball precision plugs are inserted in the first sight holes in the strongbacks of the first 40-foot segment; the elevations of the plugs are determined with a tooling scale and precision sight level; and the elevations of the plugs are set to the design levels using the vertical support jacks. The alignment telescope and optical tooling stand with level vials are then used to check that the segment is correctly aligned in X coordinate with respect to the stretched wire. This general procedure is done with each successive girder in the sectors working in the beam direction. The same general procedures can then be repeated to check segment mid- or 1/4-points, and the strongback mounting bolts rather than the support jacks can then be adjusted for any intermediate alignment.

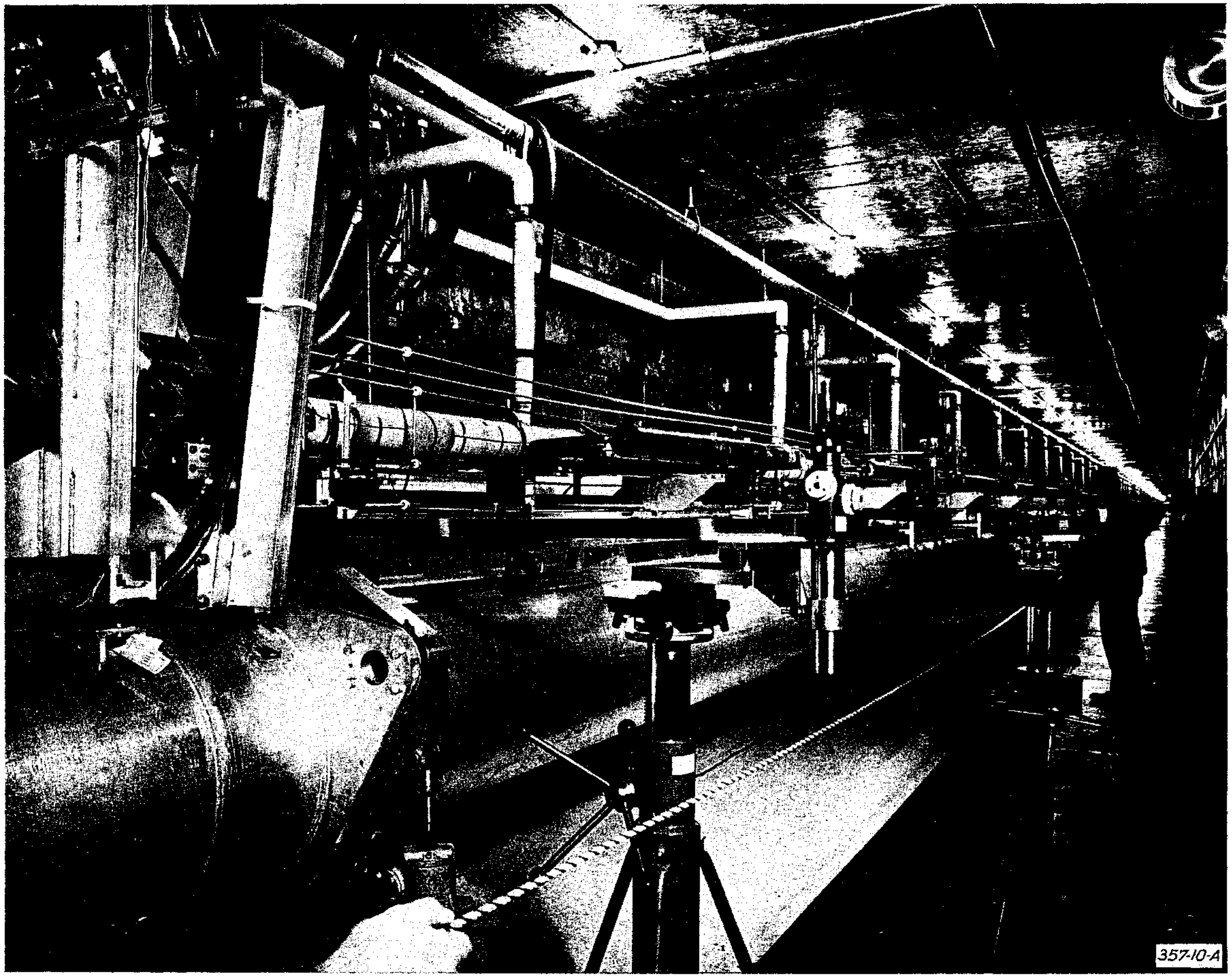


Fig. 10 - Simulated sector alignment setup.

3. Beam Switchyard Alignment

The temperature stabilized, precision alignment laboratory in the Heavy Equipment Building was ready for occupancy by the middle of June. The air-conditioning system, however, will not be completed until the middle of the next quarter.

The list of required optical instruments for second level alignment in the BSY was completed and all components were on order by the end of the reporting period. These include jig transits, theodolites, precision sight levels, and one telescopic and three optical transit squares.

It was necessary to go into bore targetry investigations regarding the magnets to develop a means of converting magnetic centers to physical locations. For this reason, two mechanical, magnetic center-finding devices were developed and fabricated during the period. The group also helped in the development of fixtures for magnetic core probes.

Two mounting stands of the same type that will be used for installed magnets in the BSY were on order by the end of the quarter and should be received early in the next period. These will be used in locating the alignment mirrors on both bending and quadrupole magnets before they are moved to the BSY for installation and alignment. The magnets, and other BSY components, which are to be set up for alignment in the precision alignment laboratory, will be brought into the laboratory by crane and lowered through the ceiling of the room and onto the mounting stands.

VIII. KLYSTRON STUDIES

A. SUMMARY

During the quarter, Sperry and RCA have continued to deliver tubes. Several RCA tubes are still in test; no Sperry tubes are in test at this time. To date, Eimac and Litton have not completed delivery under their subcontracts. Failures during acceptance test prevented completion of the Litton backup program. A procurement contract for 72 tubes has been signed with Litton.

The Stanford program to build tubes for installation in the Klystron Gallery has proceeded satisfactorily, and permanent magnets were being received at the end of the quarter to operate with the Stanford-built tubes. Eighteen tubes have been in use during Sectors 1 and 2 tests; seven tubes were changed in the Gallery because of potential troubles in the pulse transformer tank oil pressure. One tube was lost during test on a new pulse transformer tank. Fifty-three klystrons were in storage at the end of the quarter, ready for installation either in the Klystron Gallery or on pulse transformer tanks.

Window work continues with the main emphasis on coating and material improvements. Six windows have operated on life test for 5600 hours with no failures to date.

B. KLYSTRON PROCUREMENT

As a continuation of the overall klystron procurement plan initiated during the previous quarter by a contract option with RCA, the option has been exercised with Sperry for the procurement of spare tubes which would be needed during the first years of operation of the machine, and a contract has been signed with Litton Industries for the procurement of 72 tubes and magnets.

1. RCA Subcontract

Manufacturing problems have been high during the last two months of the quarter. The yield for these months has dropped from a previous 60%

to less than 30%. Primary problems have been temperature-limited cathodes and leakers, as well as instabilities in the power output. These instabilities usually appear as "glitches" on the output pulse. The glitches may take several forms. The most common form is pulse amplitude flutter, which may occur over only a small percentage of the pulse interval and which may move back and forth across the pulse as the drive level is varied. Other forms consist of a pulse breakup across almost the entire pulse width, or breakup on the trailing edge of the pulse. Besides causing a fluctuating power output during this phenomenon, these instabilities produce severe phase jitter during their occurrence. Another distinct form of instability is pulse ripple. This phenomenon appears as a smooth, distinct ripple or sine-wave-like disturbance along the top of the power output pulse. As in the case of the glitch, severe phase jitter is produced.

A number of factors which may affect the above instabilities have been uncovered. These are:

a. Magnet tuning, i.e., transverse field adjustment.
b. Cathode button temperature (affects beam geometry).
c. Cavity frequency setting.
d. Output waveguide tuner adjustments.
e. Multipactoring windows (open to argument).

Unfortunately, it is not possible to prescribe boundary conditions or settings for the above items which will guarantee an absence of instabilities. Changing or adjusting any of these items may change the behavior of the instability, but in most cases will not remove it entirely without having some other detrimental effect such as reducing gain and/or power output. Instabilities are produced by the extremely complex interrelation between these items, a relationship that is not completely understood at this time.

RCA has started working on the problem item by item in order to gain a better insight as to its mechanism. Their general conclusion is that such instabilities are generated by a feedback or oscillation which produces beats with the fundamental frequency, with the beat frequencies serving to modulate the power output in an unstable manner. Their specific investigations will cover a number of items, including:

a. Putting tuners in the first and third cavities in an attempt to "tune out" such instabilities.

b. Increasing the tuning range of the output waveguide tuners.

c. Attempting to determine if there are certain discrete tube geometries along the drift tube that are ideal for supporting multipactor.

d. Examination of a life-tested tube to see if beam scalloping or other beam misbehavior can be determined.

e. Determination of the bandpass characteristics of the tube, starting at the output gap back through to the input, in order to find a possible frequency (or frequencies) which will encourage the reflection of primary or secondary electrons.

The problem of scrap due to leaks, gas, and temperature-limited cathodes is perhaps more nearly related to relaxed inspection on the production line and/or substantial changes in production personnel. The problem can probably be solved only by "over-inspection" until yield is high and then a relaxation of inspection up to the point where inspection costs are about equal to scrap costs. This program has been started now at RCA.

It might be noted that the windows observed in acceptance tests on RCA tubes have been completely dark and showed no signs of multipactor.

Engineering specifically to improve power output is not planned for the present. One attempt to duplicate the Stanford design during the quarter did not have much success; in view of the present power performance of the RCA tube, it was decided to retain the current design rather than investigate further the reasons for the poor performance of the experimental tube. An average over the last six RCA tubes accepted showed 21.7 MW at 250 kV. The best tube performance in this group was 22 MW at 250 kV.

2. Sperry Subcontract

During the course of the last quarter, a problem of excessive load gassing arose over a series of Sperry tubes. This particular group of tubes was exceptionally difficult to bring up to full power due to what was apparently dirty or contaminated output waveguide sections. In some cases, the fault was determined to be a type of rubber cement used to seal off the output waveguide section for shipment. Extensive cleaning of the contaminated tubes in the output waveguide section, however, did nothing to improve the problem. A viewport was then installed in the load so that the window could be observed during operation. Every one of the tubes showing gassing also had a substantial amount of glow (multipactor activity) on the output window. This activity started at the 150-kV level and became greater as power and beam voltage were increased. During initial runup, considerable shut-offs occurred due to poor load pressure. Some of these shut-offs were accompanied by a "normal" type gas burst which usually occurs as a load is cleaned up and appears as a glow discharge filling the entire waveguide, and other shut-offs occurred with no visible glow discharge in the output sections. Presumably, these latter shut-offs were due to localized gas bursts at the window, and were too fast to permit ionization of the entire gas volume within the output load section.

The conclusions reached from the above observations were that the major problem with the output sections was window multipactor due to insufficient window coating. It was also determined on at least one window that the center temperature was around 125°C and, since the window is edge-cooled to around 20°C, the gradient across the window is quite high.

Sperry was informed of this problem, and samples of their coatings on two windows adaptable to the Stanford window ring tester were obtained. In addition, several Sperry klystron windows have been coated at Stanford for use in their klystrons. We expect to determine shortly just how deficient in coating their windows are.

Another problem occurring with Sperry tubes during the past quarter was excessive tube sparking during acceptance tests at Stanford. A detailed examination of all phases of tube processing at Sperry and of acceptance test methods was made. No single specific item was uncovered; however, on general principles, changes were made both at Stanford and at Sperry. During acceptance tests, the tank oil level was increased to reach a point two or three inches above the top of the magnet flange.

Sperry has additionally reviewed final test procedures and is now overvoltaging the heaters by 5%, as called for in the acceptance test procedures, so that sparking tubes are recognized and rejected before shipment to Stanford. Cathode processing has undergone a continuing review at Sperry, but no single item has been uncovered that could be blamed directly for the sparking phenomenon. In any case, the incidence of sparking tubes has been reduced to about one mild case out of 15 tubes recently tested at Stanford. Sperry is also directing efforts to improve yield.

Additional engineering is not planned for future Sperry tubes. An average power output taken over the last six tubes showed 11.9 MW at 200 kV and 21.1 MW at 250 kV. The best tube gave 21.9 and 12.2 MW. These readings were all obtained with G. E. magnets. It is expected that the new Arnold magnets will provide sufficient improvement to give a better safety margin in power outputs.

Various minor problems have been uncovered and generally corrected during the last quarter. Shipping container problems, moisture problems, and mechanical problems have occurred in transit. These items have all been corrected at this time.

3. Eimac Subcontract

Two tubes under the six-tube subcontract remain to be received. The performance of the tubes delivered by Eimac has been extremely good, with an adequate margin of safety over the full specifications.

4. Litton Subcontract

A contract was signed with Litton Industries effective May 18 for the procurement of 72 tubes and magnets. Litton has already built a product design of the SLAC design which incorporated some changes from the tube delivered under their initial six-tube contract. All loading has been removed from the cavities, the 4th cavity is tuneable, and a low pass filter has been incorporated in the input structure. To reduce cost, Litton will not deliver ion pumps on their tubes. A stainless steel water jacket has been added to the tube body and the collector design has been modified to improve its performance. Additional testing facilities are under construction at Litton to allow better scheduling of processing and testing of Stanford tubes.

5. Stanford-Built Klystrons

During the quarter 14 new tubes were built and baked and seven reworked tubes were built and baked. In general, only minor modifications were introduced in the tube design, with two exceptions. Several tubes were built with an in-house designed and built appendage pump so that pressure can be monitored during operation, and several tubes included the addition of a titanium plug near the tip of the collector.

Performance of the Stanford tubes in electromagnets continues to be satisfactory, with typical power outputs of between 22 and 25 MW.

Permanent magnets for Stanford tubes began to be received late in April. However, after installing the magnets in tanks for testing it was found that the silastic bands used to hold the field shaping magnets in place deteriorated rapidly, with subsequent variation in field shaping magnet position and field shape in the cathode region. The magnets are being reworked.

As in the past, Stanford tubes are used to perform necessary high power rf tests. A total of nine sockets use SLAC klystrons in electromagnets, in addition to the one or two sockets using diodes for modulator testing.

C. FACILITIES

Tube fabrication facilities have been improved by the addition of a 6-inch horizontal push-through hydrogen furnace to ease some of the problems on brazing and annealing small components.

In the klystron handling area, the equipment has been rearranged to improve floor space utilization and to allow the plans for installing klystrons on pulse transformer tanks in that area to be realized. A vacuum pump and test tank for checking of magnets and tubes have been added.

The cryosorption vacuum pump trailer has been tested. It appears that the capacity of the pumps should be adequate to change at least six klystrons in a single day, although it may be necessary to add liquid nitrogen once during the day. It has been necessary to install klystrons in special enclosures in the Klystron Gallery because of the lack of storage space next to the Test Laboratory. Because of the shelf life warranty which imposes tests in the Test Laboratory, additional handling of tubes before they can be installed for operation will result.

D. KLYSTRON FABRICATION AND DEVELOPMENT

Fourteen new tubes and seven reworks were baked during the quarter. Including these tubes baked during the previous quarter and a number of retests (including permanent magnet tests), a total of 30 performance tests were performed in the Test Laboratory on Stanford-built tubes.

As mentioned previously, the major modifications introduced in the tubes at present have to do with improvements in processing rather than with changes in body design for further efficiency enhancement. These improvements have consisted of adding a getter-ion pump to the tube; at present there is no evidence that the getter-ion pump tubes have significantly better vacuum performance than those without. Similarly, tests have been run on tubes which incorporate a titanium getter plug inserted in the tip of the collector. The principle of operation is as follows: If the vacuum deteriorates, ion focusing will increase the electron beam current density at the tip of the collector, resulting in temperature increase of the titanium with possible evaporation and melting. The evaporated titanium will deposit on the cooler parts of the collector and act as a getter to improve the vacuum. Again, insufficient evidence has been obtained to fully evaluate the titanium plug, but the preliminary results are encouraging.

A modification in the processing schedule, including a very high temperature prebake of the cathode structure and a higher conversion temperature, has also been attempted. The results appear to be satisfactory from the standpoint of electromagnet operation. However, two of the tubes processed satisfactorily in electromagnet under these conditions exhibited a serious problem in permanent magnet. After a few minutes of operation at voltages in excess of 200 kV, the beam voltage dropped, the beam current increased, and the anode temperature soon became sufficient to burn the rubber O-ring making the seal to the permanent magnet. It is believed that this behavior is caused by a small amount of electron emission from the sides of the focusing electrode looking at the anode pot. Under electromagnet focusing conditions there may be a few milliamperes of current going directly to the anode pot, and no detrimental effects are noticed and no current difference can be measured from what would be expected. In the case of permanent magnet focusing, however, there is a reasonably strong magnetic field in the region between the cathode and the anode pot. Because of this field, electrons emitted at a sufficiently low voltage will return to the cathode focusing ring by cycloid motion and contribute some energy to the focusing electrode. Hence, the focusing electrode temperature will gradually increase, the emission gets gradually higher, and the electrons emitted above the critical voltage reach the anode and heat it.

Two window failures were experienced (one during final acceptance test in permanent magnet). One tube went down to air and had to be reworked.

A total of 17 tubes went through processing tests in electromagnet. Six of these have given peak power outputs in excess of 24.5 MW at 250 kV; the curve of Fig. 11 gives the average electromagnet performance for these six tubes.

Four tubes were tested in permanent magnet. Of these, one suffered a broken window at the end of acceptance testing, and the other three had to be removed from the magnet because of the difficulties experienced with the positioning of the field shaping magnets in the cathode region. By the end of the quarter, five tubes were reinstalled in permanent magnet, but only two of the five had been tested and were ready for final acceptance.

A second tube was built with extended interaction output; the results were similar to those obtained previously; that is, the efficiency is somewhat lower than that of the average "standard" Stanford tube. Further studies of different extended interaction structures and cold tests are being carried out in an attempt to improve the performance.

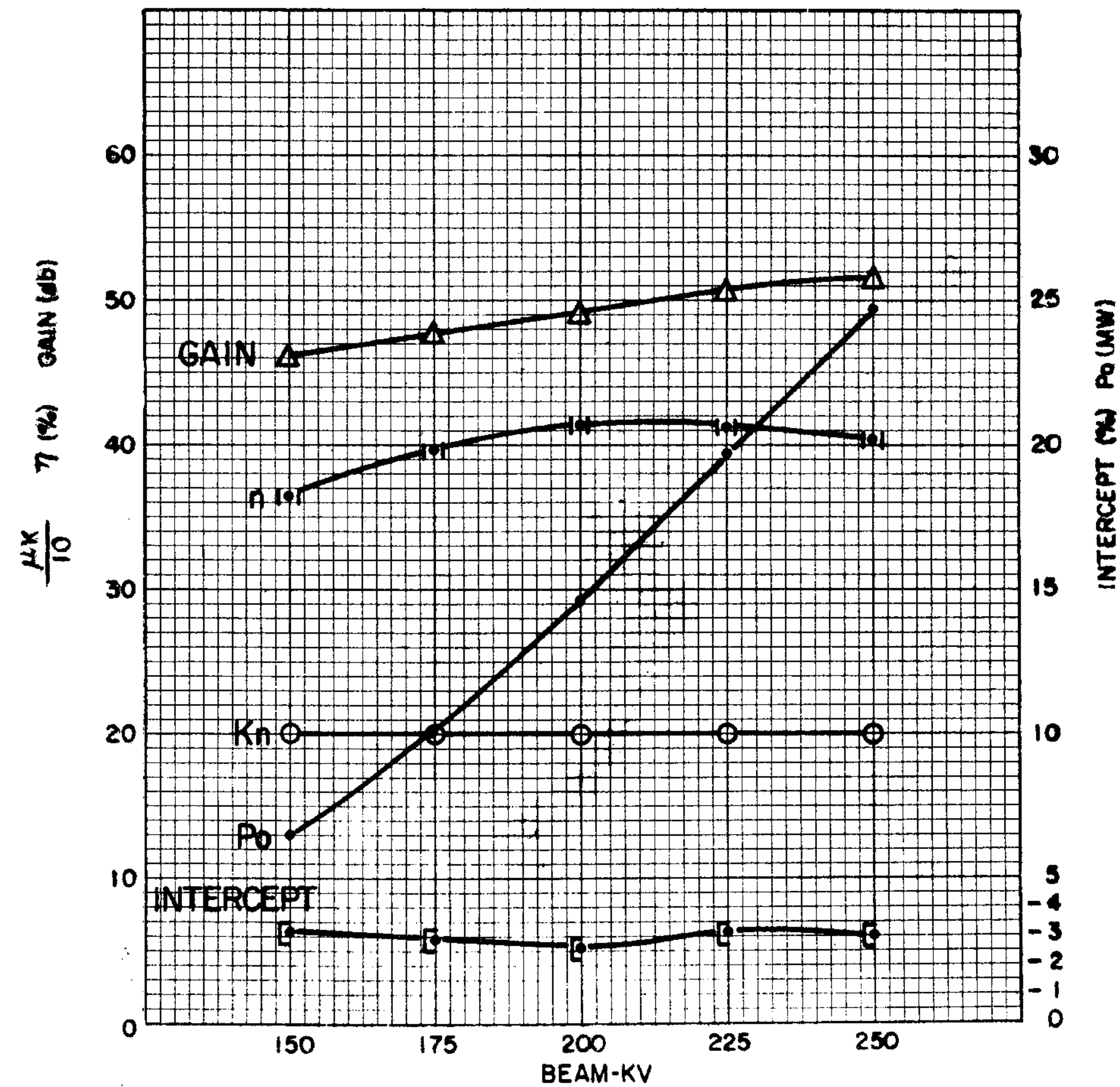


FIG. 11 -- STANFORD KLYSTRON AVERAGED DATA: TUBES K-91A, K-93A, K-95A, K-94A, H-79B, H-80A

E. KLYSTRON MEASUREMENTS

There are two main areas of measurements with which the Klystron Group is concerned: One is the accurate measurement of the tube performance in the Test Laboratory to determine its acceptability; the second is the need to obtain quick but reasonably accurate measurements of klystron performance after the tubes are installed in the Klystron Gallery.

1. Accurate Measurements

The need for accurate measurements of tube performance is based not only on the desire to have a good knowledge of their performance but also on the necessity of accuracy, because tubes not meeting specifications cannot be accepted, and the majority of the tubes accepted appear to have only a small margin of safety to pass the specifications. One of the major concerns has been the measurement of the beam voltage, since a 1% error in beam voltage measurement will result in a 2% to 3% error in peak output power readings.

Of particular interest is the correlation between the measurements taken by Stanford and by the vendors. The following correlation appears to hold on the average: At 200 kV the power measured by Stanford is 2.9% lower than measured at RCA, 2% lower than at Sperry, 0.5% higher than at Litton. At 250 kV the power measured at Stanford is 2.1% lower than measured at RCA, 0.2% higher than at Sperry, and 1.1% higher than at Litton.

At this time it is not clear why the percentages are different at 200 and 250 kV, nor why the difference is always in the same direction.

In an effort to resolve the power measurement problems on the incoming tubes, a great deal of effort has been exerted in recalibration of the capacity dividers used at Stanford. It is felt that SLAC's methods of measurement are consistent with the present state-of-the-art. However, it was decided to further refine the capacity divider calibration techniques; a bridge using two GR precision capacitors was built to calibrate the capacity dividers. The results indicated a close correlation with previous values, but some variation as a function of oil temperature was observed which might have affected some of the previous readings. One of the same dividers was also calibrated by SLAC's Electrical Standards Lab;

the agreement between results was better than 0.1%. Two other dividers were sent to the National Bureau of Standards for calibration there. One of the voltage dividers was damaged in shipment to the Bureau, but their calibration on the other agrees within approximately 0.1% with that measured by the Klystron Group. It is felt that the present accuracy of the bridge system is approximately 0.3%, but could be improved to approximately 0.1%. It is unfortunately a rather tedious method, and it is planned to keep an accurately calibrated divider as a secondary standard for direct comparison.

2. Gallery Measurements

It will be necessary to obtain most of the information on the performance of the 250 klystrons operating in the Klystron Gallery by direct reading meters. Experience gained in initial tests of Sectors 1 and 2 have confirmed the fact that it would be too time consuming to obtain the desired information in any other way.

To the best of our knowledge, no peak reading voltmeters exist which would have satisfied the needs of the SLAC Gallery measurements. We were able to obtain a prototype built by Light Electronics which was designed specifically for this purpose and received extensive tests both in the Gallery and in the Test Laboratory. A complete evaluation of the meter is not finished yet, but it appears to be entirely satisfactory, so much so in fact that the addition of another circuit in the meter has been requested so that it can also be used to read directly the peak cathode current of the klystrons. We believe an accuracy of approximately 2% is possible.

Similarly, it is desirable to be able to measure both drive and output power on a regular basis at each station in the Gallery. A thermistor could be used for this purpose, but it would be time consuming to take into account the variations in repetition rates. Hence, a peak reading meter was sought, and a microline meter was found which has been tested. On the least sensitive scale (300 mW peak), it appears to be reasonably free of noise problems. Some barretter reliability problems have been encountered, and a final decision to use this meter has not yet been made. In any case, to simplify the data acquisition in the Gallery, it has been suggested that an adjustable pad be added at each station so that direct power readings can be achieved without introducing the possibility of calculation errors.

F. KLYSTRON INSTALLATION AND MAINTENANCE

The complement of 18 klystrons in Sectors 1 and 2 operated generally satisfactorily during the quarter. Seven tubes had to be changed, six of them due to pressure problems in the pulse transformer tanks. The seventh failed because of gradual increase in tube pressure. One of the tubes tested on the new transformer tank failed during those tests because of cathode seal puncture, which might have been started by low oil level in the tank.

Radiation surveys indicated that the radiation of the tubes exceeded the initial specification at full power after some time of operation. The same phenomenon had been observed in life-tested tubes in the Test Laboratory and was reported last quarter. Fortunately, the measured radiation is of very low energy so that an initial lead shielding 1/16-inch thick around the pulse transformer tanks was adequate to reduce the radiation below the limit of 3/4 mr at 3 feet.

Additional storage cages have been built in the Gallery for completed klystron assembly storage. At the end of the quarter 28 tubes were stored in the Gallery ready for installation.

The klystron registration and control system is still undergoing modifications to satisfy the needs of rapid and up-to-date information on the klystron status. A new movable index will provide a ready reference of the tube status (in test, ready for test, in use, ready to return to vendor, etc.). In addition, the total hours of use should be easily obtainable.

G. KLYSTRON OPERATION IN THE GALLERY

Twenty-five tubes in all were used in the 18 sockets of Sectors 1 and 2 during the quarter. Klystron personnel worked with the sector test team on a regular basis to obtain data on the continued performance of the tubes and associated equipment, as well as to help the test team in the operation of the accelerator.

Some minor problems were encountered in associated equipment and were corrected as a result of the information obtained during the tests. There were such questions as stability of beam voltage as a function of time, variable voltage substation operation, etc. At the end of the test period a systematic run was made during which records of klystron beam voltage and power output were taken under the various conditions of repetition rate and reference voltage. As a result of these tests it appears that the setting on the variable voltage substation should be increased to allow operation of all tubes at 250 kV. Figures 12 and 13 give the comparison between the measured peak powers as functions of beam voltage in the Test Laboratory and during the Sectors 1 and 2 tests. It can be seen that the agreement is good, although the slight difference in slope has not been explained yet.

H. HIGH POWER KLYSTRON WINDOWS

1. Resonant Ring Tests

a. Klystron Window Pre-Testing

Sixteen klystron windows underwent routine pre-testing in the all-metal resonant ring during the quarter. All 16 were operated at powers up to 43 MW (at 36 kW) with no indication of multipactor or other operating difficulty which would prevent satisfactory performance in tube service. All but three of the pre-tested windows had sputtered titanium coatings which had been measured during application by means of the crystal resonance shift technique described in a previous report. Eventually, it should be possible to use crystal resonance measurements as a criterion for coated window serviceability in place of routine ring pre-tests. Confidence in the credibility of the crystal technique must first be established by continuing correspondence between crystal monitoring measurements and ring pre-test observations.

b. Investigation of Klystron Window Overheating

Two SLAC klystron windows suffered thermal failure during the quarter. These windows, along with the two hot windows observed on reprocessed klystrons last quarter and one other hot window observed this quarter, bring to a total of five the examples of window overheating which have

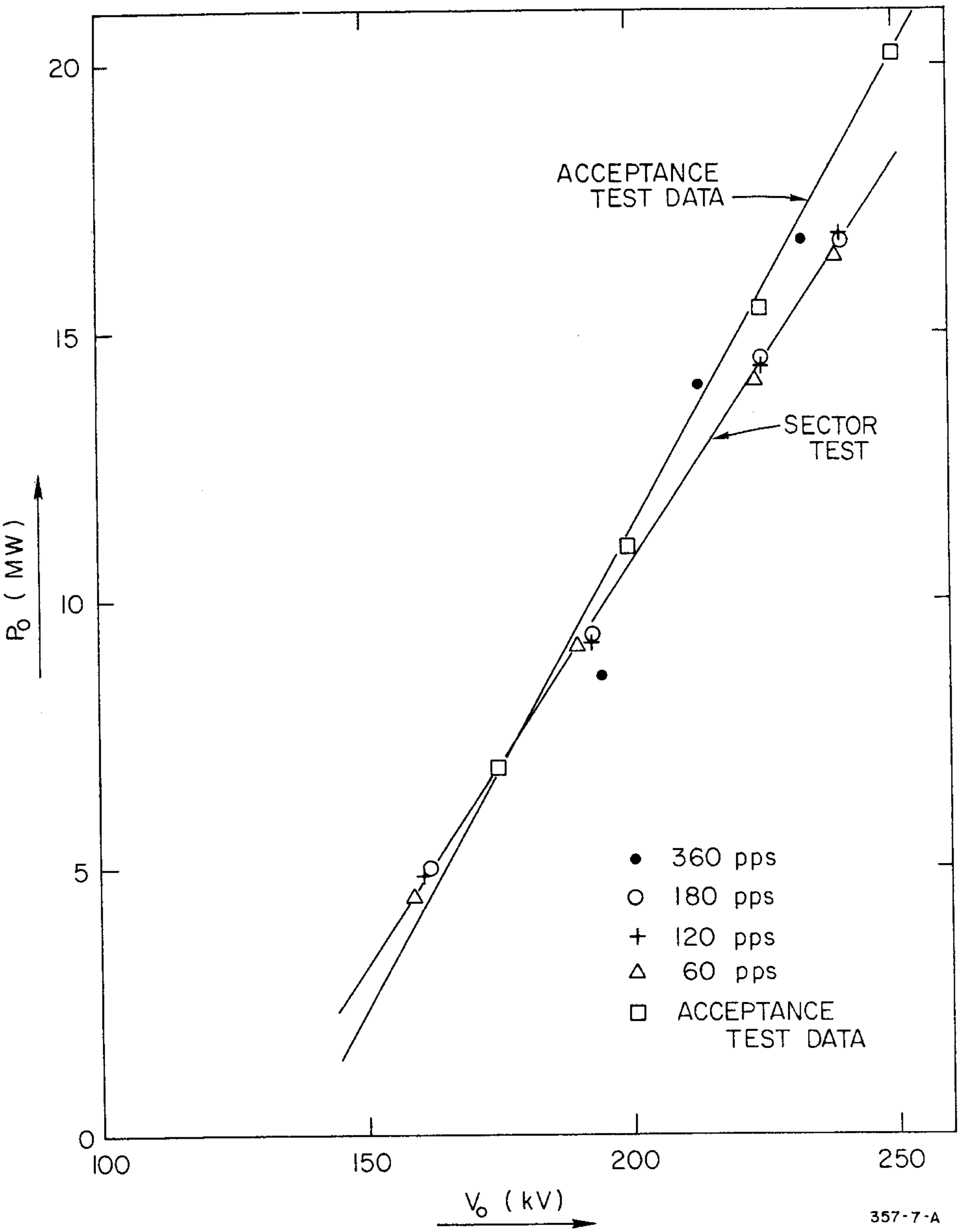


FIG. 12-- SECTOR 1, AVERAGE PEAK POWER OUTPUT vs AVERAGE PEAK BEAM VOLTAGE.

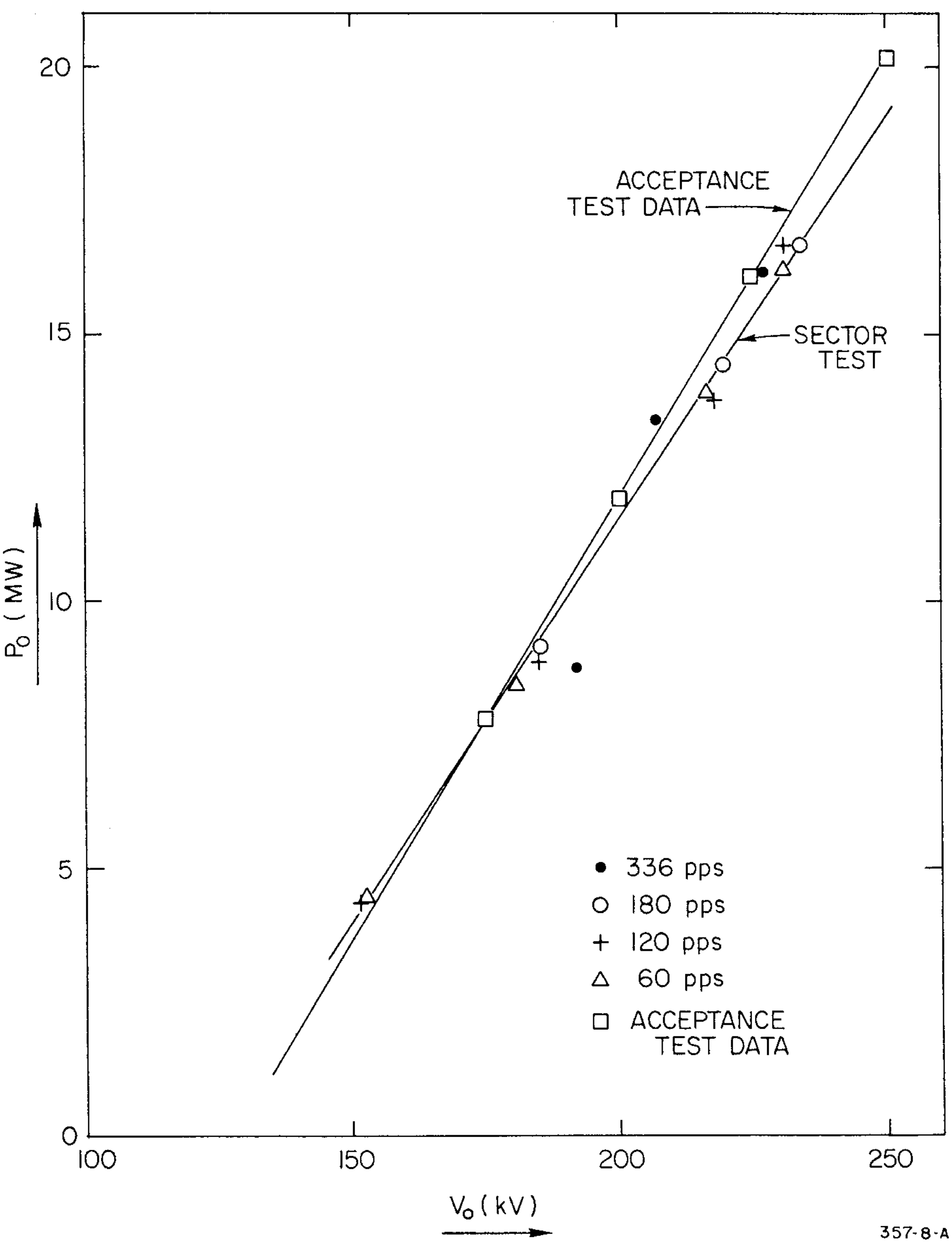


FIG. 13 -- SECTOR 2, AVERAGE PEAK POWER OUTPUT vs AVERAGE PEAK BEAM VOLTAGE.

been noticed since window temperature measurements during tube test were begun in February. Window edge temperatures in excess of 100°C and temperature gradients of 80° to 130° were measured on these windows. Visual observations made on two of these windows did not indicate that multipactor was responsible for the high temperature. To date, it has not been possible to account for the behavior of these windows, all of which had performed quite satisfactorily during ring pre-tests. Several hypothetical explanations for the window overheating have been suggested and investigated by ring tests.

Earlier suspicions that the formic acid cleaning rinse used during tube reprocessing was responsible for coating deterioration and consequent window heating have proved groundless. The initial ring test of the effect of the cleaning rinse in combination with the high temperature tube bake had resulted in a large increase in window temperature. However, this test was invalidated by the fact that the test window had suffered contamination while hanging uncovered in the vacuum bake station. In subsequent tests, the window was baked while mounted between two waveguide pieces and operating temperature increases of approximately 10°C were observed following each rinse-bake cycle. That these slight temperature increases were caused by the bake rather than by the rinse was made evident by the retest of three klystron windows which were removed from tubes to be reworked. Each of these windows operated at 10 to 15°C higher temperature than during its pre-test operation; none of the three was exposed to the cleaning rinse. A slight decrease in the effectiveness of the window coating as a result of the tube bake is indicated by these tests, but the magnitude of the temperature increases observed certainly does not account for the extreme temperatures required to produce thermal failure of the ceramic.

Attempts have also been made to associate window multipactor and/or overheating with magnetic fields or poor vacuum in the window region. The magnetic fields and field gradients at the SLAC klystron window during its operation in a permanent magnet were simulated in the ring test section by means of an electromagnet. Qualitative effects on visible window behavior were observed on windows exposed to magnetic fields, and very slight increases in window temperature (up to $5^{\circ}C$) were detected. Increased operating pressures were produced by reducing the orifice of the ring ion pump, but no significant increases in window activity or window temperature could be induced by this means. Neither magnetic field nor poor operating pressure could be shown to produce excessive window heating by themselves, but their influence in combination with the effect of the high temperature bake cycle is yet to be tested.

c. Material Study Tests

The evaluation of Pyroceram (9606) was resumed this quarter after consultation with the supplier showed that the windows tested as Pyroceram 9606 during the previous quarter had actually been Pyroceram 9608. The relatively high dielectric loss factor of the latter material accounts for the poor performance of the samples tested last quarter. A corrected shipment of Pyroceram 9606 has since been received and is now being evaluated.

Three Pyroceram 9606 samples were tested in the original ring during the quarter. Two windows were subjected to peak power operation only (at 60 pps) and suffered apparent failure at 70 MW and 40 MW. In both cases, failure was indicated by persistent electrical breakdown on one side of the window; however, no physical damage could be found upon examination of the windows, one of which was fragmented to look for internal damage. Apparently, the breakdown occurring on these windows is a surface phenomenon which is probably related to slightly reduced surface resistivity that has been measured in the immediate areas of most severe electrical breakdown. A third 9606 window was tested for average power capability at 360 pps and failed thermally during operation at 35 MW, 30 kW. The temperature gradient of this window was measured in excess of $800^{\circ}C$ and must have reached nearly 1350° because the center actually became molten.

Further tests of this material are presently in process. Coated samples are being tested to determine whether multipactor is associated with either the surface breakdown suffered at high peak power or the runaway dielectric loss failure at high average power.

d. Window Coating Tests

Investigations begun last quarter of variations in the sputtered window coating have been delayed, with the exception of tests described above of coating stability of windows subjected to the high temperature bake cycle. Now that crystal monitoring data is available to provide meaningful control of the coating process, these experiments should be of even greater significance and will be resumed as soon as possible.

As part of the investigation of multipactor observed on Sperry klystron windows, two ceramics coated by Sperry were tested in the ring in a shrink-fit model of the SLAC window geometry. One sample had been furnished with the normal Sperry coating, the other with triple the normal thickness. Neither window suffered significant multipactor heating; however, localized activity probably associated with multipactor was observed on the window with the standard coating, which also had a slightly higher temperature gradient than the triple-coated ceramic. Further tests of the Sperry coating are planned which will use a test geometry more similar to the Sperry klystron window structure.

2. Window Life Test

Operation of the window life test facility reached the 5000-hour mark early in the quarter, the last 1900 hours having been at 20 to 23 MW peak power. Interrupted operation (five minutes on, one minute off, full peak power applied instantaneously at the end of the interruption) was resumed at the 5000-hour mark and had continued for about 600 hours when the water load failed. The test stand has been restored to operation with the water load repaired, but full power operation has not yet been resumed. No windows failed or showed significant increases in operating temperature after a total operating time of 5600 hours.

3. Other Window Work

a. Window Coating Activity

The crystal resonance measurement technique described in a previous report, using 8.5-megacycle crystals, is now being used to monitor all window coating applications. Crystal data has been taken during coating of the last 15 SLAC windows and the six half-wave windows coated for

Sperry. A multiple feedthrough recently installed in the base-plate of the bell jar permits crystal measurements to be made inside the sputtering chamber, so that a crystal monitor may be measured before as well as after the coating has been oxidized by exposure to the atmosphere. Analysis of crystal coating monitor data taken to date indicates that the SLAC window coating is an oxide of titanium rather than the metal itself, even before the coating has been oxidized further upon exposure to air. It is hoped that more precise experimental investigations may eventually permit definite identification of the molecular make-up of the coating. Calculations based on crystal resonance data indicate that SLAC window coatings are typically about 100 angstroms thick. The normal distribution of coating thickness generally runs from 70 Å to 140 Å, but windows with much lighter coating (as little as 25 Å) have behaved quite acceptably.

As a means of comparing the various coatings and coating techniques being used by the outside tube manufacturers, monitor crystals are being coated at Litton, Eimac, RCA, and Sperry. Measurements of the typical window coating thicknesses as applied to these crystals along with a general understanding of the particular coating technique employed should provide a basis for comparison with the SLAC coating and with each other. Since Sperry also uses the crystal monitoring technique, it should be possible to cross-check quite closely between the SLAC and Sperry coatings. This comparison with Sperry may prove useful in present attempts to diagnose the multipactor which has appeared on some of the Sperry klystron windows recently.

b. Material Study

High power testing of window material is continuing with ring tests of Pyroceram 9606. Based on test results to date, this material appears to have possibilities as a low power window material, but does not measure up to the requirements for SLAC klystron window service. Samples of borosilicate glass (Corning 7070) are also on hand and will be evaluated in the near future.

All of the parts for the high vacuum envelope to be used in continuation of secondary emission investigation have been fabricated and are presently being assembled. This improved system will be equipped with an ion pump and cryogenic roughing, and should be capable of operation at about 10^{-8} torr.

I. SUB-BOOSTER KLYSTRONS

The shelf life problem has not yet been resolved with the sub-booster tubes. Toward the end of the quarter a retest of the tubes for shelf life was begun and seven tubes failed to meet acceptance specifications during this test. In addition, three tubes failed in operation outside of operating life warranty.

After the delivery of the 28th sub-booster klystron, Stanford had exercised its option for an additional quantity of 40 tubes. For these tubes, the running time for shelf life test has been increased to a minimum of ten minutes. It is also planned to review the shelf life problems to insure that a minimum of six tubes a month are delivered, so that the spares on hand will not decrease to a dangerous point during the Gallery installation and initial phases of operation.

IX. SECTOR TESTS

An electron beam was sent through the first three sections, or 30 feet, of the accelerator for the first time at 0215 on January 6, 1965. These first 30 feet differ from the remainder of the accelerator in that there is a klystron for each 10-foot section rather than for each four sections. Also, there is a beam monitoring, or drift section, at the end of the 30 feet that is similar to the drift section at the end of each sector. This drift section also has a deflecting magnet and a spectrum analyzer.

The beam was injected into the first 10-foot section at 80 keV using, as a temporary installation, the gun and gun modulator previously used on the Mark IV accelerator. After two weeks of experiments with the 30-foot section, a successful attempt was made to accelerate the beam through the full two sectors. This occurred on the evening of January 22, 1965. There were a number of problems with the equipment and wiring and all klystrons weren't operating at that time, nor was it possible to get an energy spectrum.

By February 4th, however, operation was relatively smooth and an energy of 1.22 BeV had been reached. The operation and testing of the first two sectors continued until June 17, 1965. At that time, a scheduled two-month shutdown began for the installation of the permanent injector and its associated electrical equipment. Major rework of Sectors 1 and 2 control wiring also began at that time.

At first, the operation was in the evenings only, primarily because of the work going on during the day in the Accelerator Housing. By the middle of March, however, it was possible to run rf tests during the day shift with beam operation in the evenings. And, by the last month of operation it was also possible to run the beam during the day shift. The total rf on-time for the period was 700 hours and the total beam on-time was 335 hours. Throughout the period, the operation was generally with an rf pulse rate of 360 and a beam pulse rate of 60 to minimize the radiation level. The beam energy was in the range of 1.3 to 1.45 BeV and the peak beam current was 25 milliamps.

During most of the same period of operation, the trigger generators, the complete drive system, and the water, vacuum and electrical power systems were in operation 24 hours a day.

Much useful information and experience were gained in this six-month period. The equipment was operated for the first time under most of the conditions that will prevail during full accelerator operation. Much of this type of operation could not be duplicated on test stands at the time of equipment fabrication or on receipt from vendors. This applied, in particular, to operation with a beam where it had not been possible previously to completely check out such equipment as the automatic phasing equipment and the beam position and intensity monitors. (The operation of this equipment and other systems during the testing period are described elsewhere in this report and in the previous issue of the QSR.) As a result of these tests, it was possible to find cures for problems that arose and to insure that additional equipment to be provided for the accelerator could be made more nearly trouble-free.

After the shutdown of June 17th, the installation of the permanent injector and associated equipment and the rewiring of Sectors 1 and 2 control and status rooms to conform with the wiring of Sectors 3 through 30 began. Also, the completion of mechanical work on the accelerator such as the installation of sight-tube girders was to start. It is planned that Sectors 1 and 2 will be operated again late in August. At about the same time, Sectors 5 and 6 should be ready for rf testing.

X. BEAM SWITCHYARD

A. GENERAL

The Beam Switchyard housing construction proceeded on schedule.

Bids were received on the cooling water system installation and the contract was awarded to the low bidder.

Bids were received on the electrical distribution system installation. The bids were considerably above the engineer's estimate, partly because of uncertainties in the copper market. Alternate methods of doing the work are being considered.

B. INSTRUMENTATION AND CONTROL

1. Beam Monitoring Instruments

a. Cerenkov Light Beam Profile Monitor

The first Cerenkov monitor has been completed, except for a few auxiliary parts, such as reference marks for alignment and the gas supply system. The monitor, together with other instruments, is shown in Figure 14. An overall test is to be carried out. Two more monitors of this type will be built.

b. Optical Equipment and Closed Loop Television Systems

Three mirrors remotely adjustable in the X and Y directions are completed and operate satisfactorily.

Specifications on the TV requirements are finished. Material concerning radiation-resistant television cameras and pan and tilt units will be sent to prospective bidders in July.

c. Beam Spectrum Analyzer

The final spectrum analyzer is shown in Figure 15. It still requires in-line fast-disconnect flanges, vacuum feedthroughs, and cable connectors.

d. Secondary Emission Foil Beam Centering Devices

A prototype of a four-quadrant secondary emission beam centering device is ready for testing.

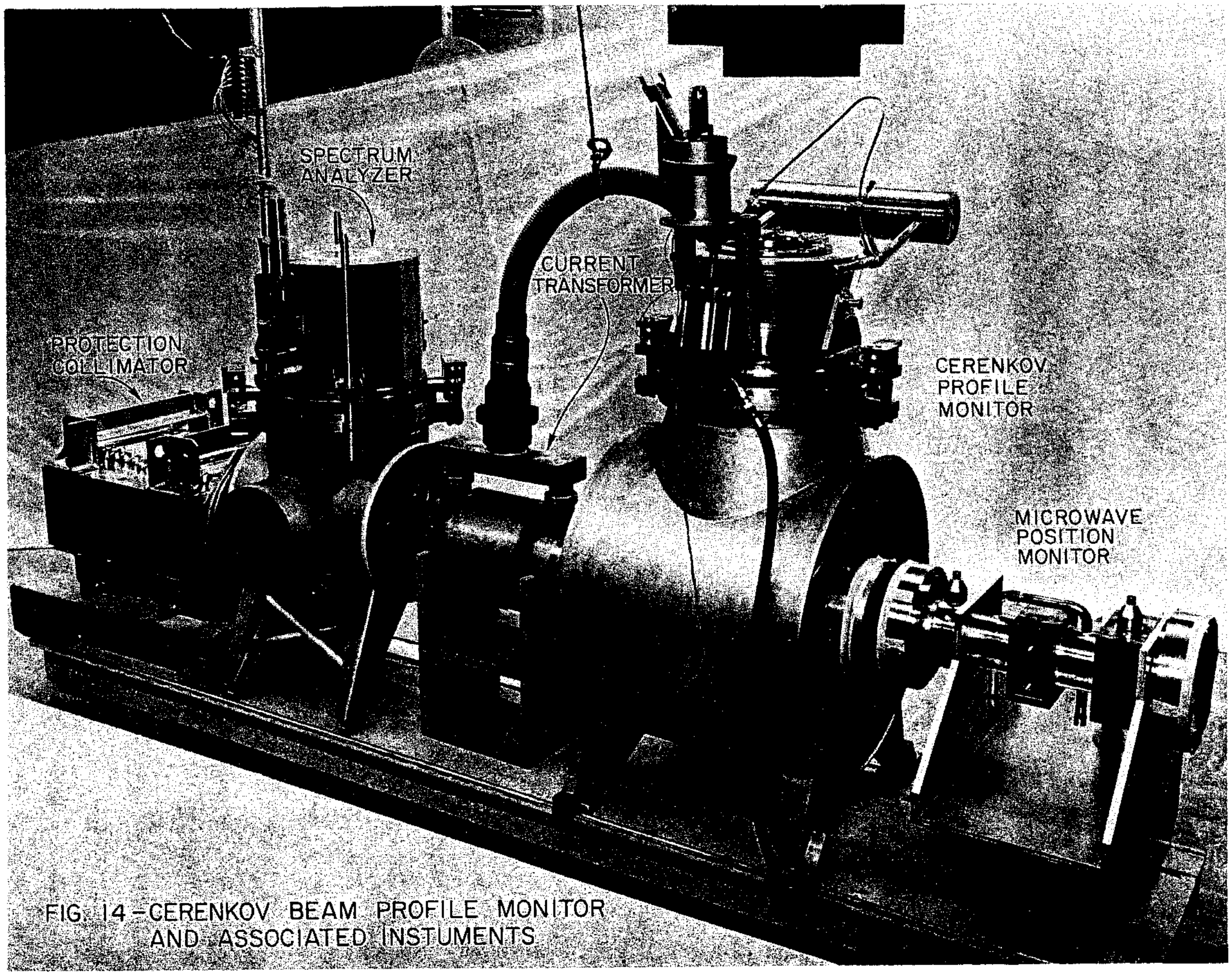


FIG. 14 – CERENKOV BEAM PROFILE MONITOR
AND ASSOCIATED INSTUMENTS

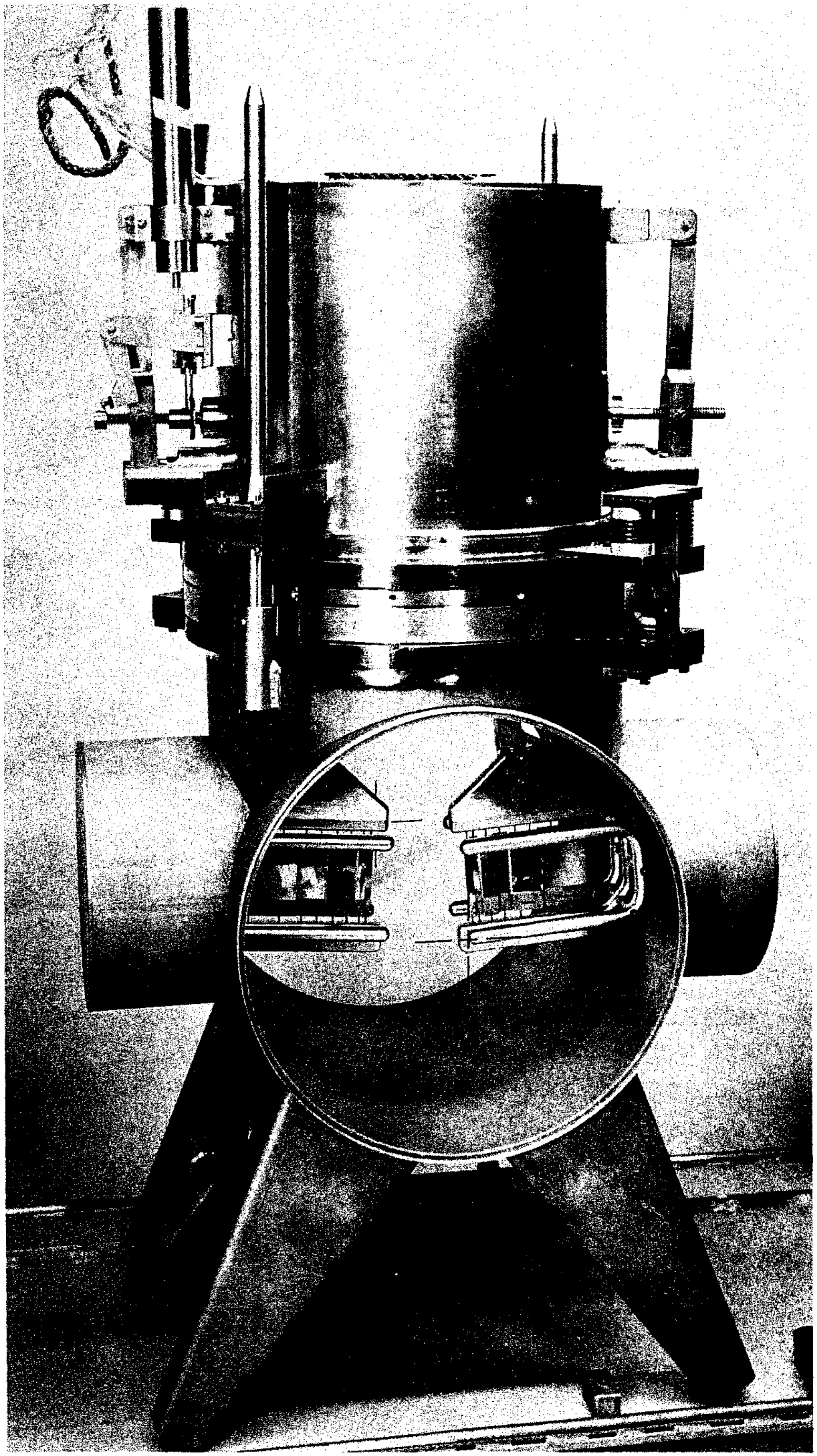


FIG. 15- SPECTRUM ANALYZER

2. Group Equipment Protection Instruments

Five early production models of the ionization chambers for equipment protection have been received and are being tested. The signal integrating and comparator circuits associated with the ionization chambers are completed.

3. Control Room Layout

The rack layout has been modified in order to accommodate information from the end stations and to provide for more expansion. Preparations for installation work in the control room are well underway, and installation will be started in August. Forty percent of all the electronic chassis associated with beam interlocks and status are completed and have been tested.

4. Control System

Good progress was made with the design of the control circuits for magnets, slits, and collimators. Auxiliary equipment for this system has been ordered with the IBM 1800 computer. The interlock signal scanner associated with the computer is expected to be ready within a few weeks.

Computer programming has been started on the interlock signal scan routines and on magnet current adjustments.

C. VACUUM CHAMBERS AND EQUIPMENT

1. Ceramic Chambers for Pulsed Magnets

No bids were received for ceramic chambers with resistivities in the range from 10^4 to 10^{11} ohm-cm. The bids for alumina chambers were several times the engineer's estimate and were rejected. It is now planned to buy alumina chambers and arrange for grinding and brazing on separate contracts.

2. Remote-Disconnect Vacuum Couplings

The contract for the manufacture of the remote-disconnect vacuum couplings was awarded to the low bidder. The indium will be installed by SLAC.

3. DC Magnet Vacuum Chambers

A contract was awarded for the fabrication of one group of stainless steel chambers. A second group was sent out for bids. Watercooled chambers for the A-Beam dump magnets are being designed.

4. 36-Inch Tune-Up Dump Flanges

The drawings for all components of the 36-inch-diameter tune-up dump flange cover and quick-disconnect vacuum seal have been released. Long lead time materials are on hand. The completion of the first assembly and the start of testing are planned for the third week of August. The aluminum-to-steel transition pieces have been finalized, using Arthur Tickle aluminized steel welded to the aluminum divergent chamber flanges. Cast aluminum skirts and dip-brazed transitions were also evaluated.

D. BEAM DUMP

The contract for two dump tanks and one carriage was awarded to the low bidder. The second carriage is designed.

Delivery of one complete dump vessel and carriage is scheduled for November 30.

E. SLITS AND COLLIMATORS

1. High Power Slits and Collimator

Bids on the fabrication of the modules were received. The low bidder proposed to use tape-controlled machining; the modules were redesigned to take full advantage of their machine capacity, and by negotiation, the price was reduced. Aluminum forgings have been ordered for the modules and will be shipped to the supplier early in July.

A sample of the most complicated module was built, pressure tested, and then vacuum tested. Livermore's Astron has a short and hot enough pulse to simulate the thermal shock of the SLAC beam, so a watercooled aluminum model was built and tested in the Astron beam. Results of all tests were good.

The tanks for all of the slits and collimator are on order. The frame for each is almost designed; and for the first half of the collimator, the frame is out for construction.

2. High-Z Slits and Collimator

Tank and actuator design has been completed and parts are being fabricated. Additional parts will be added as they are designed. The flexible water circuits to the copper blocks are now almost ready for test. The tubes are Everdur, a high strength copper alloy.

F. ALIGNMENT

1. Equipment Targeting

Intensive development work was carried out on the alignment of the prototype 8-cm quadrupole magnet in the Heavy Assembly Building. Final alignment targetry and procedures were worked out during this period. Tests indicated that by using the magnet center detector (a colloidal suspension of ferric oxide) as a bore target, transferring from this bore target to external alignment targets on the magnet, then closing the loop by transferring from the external targets to the bore target, the repeatability was on the order of 0.001-inch. Long-term stability tests were not run on the external targetry. Alignment targeting procedures were written for all the magnets.

2. Targetry Procurement

The purchase order for the alignment mirrors has been let. The bid package for the mirror alignment stage was finished and sent to Purchasing.

3. Alignment Room

The temperature-controlled alignment room situated in the Heavy Assembly Building was contracted for and completed except for the air conditioning gear. Tooling bars were ordered to facilitate the production alignment of the magnets and instruments.

4. <u>24-Inch Light Pipe</u>

The drawings for the 24-inch light pipe transition into the Beam Switchyard were completed, and a request for change was initiated with the supplier for delivery in early September of the four Beam Switchyard girders.

5. <u>10-Inch Light Pipe</u>

Final project review was held and detailed drawings were being prepared for scheduled delivery in early October.

G. SUPPORTS

1. <u>7-, 10-, and 12-Foot Instrument Stands</u>

Designs were completed and the contract awarded. Additional rails for the 24-inch girder sections, a 3-foot master alignment stand, and closer tolerancing of the instrument stand rails were incorporated into the contract.

During this period layouts were completed of instrument clamping feet and alignment targets.

2. <u>Magnet Supports</u>

A contract for the 3^{o}, 8-cm, 18.6-cm, and dump magnet supports was let in April. One hundred-twenty 25-ton and one hundred-twenty 5-ton worm gear jacks were received in late May. These jacks were supplied to the magnet support fabricator on schedule. In late May an addition to the magnet support contract was requested for magnet supports for the pulsed magnet, B-29 (photon beam), PM-30, and B-36-37 (B-Beam switching).

The pulsed magnet support is 46 feet long and weighs 12 tons. First deliveries of magnet supports are scheduled for early July.

XI. TARGET AREA DEVELOPMENT

During the first two quarters of the year, work continued on the detailed specification, design and procurement leading toward an inventory of general use equipment for use in support of the experimental program. Planning is aimed at having such an inventory ready for beam utilization in July 1966. In March 1965, organization of a Research Area Operations Group was started, which will administer and operate this complement of general use equipment to satisfy the needs of the experimental program. In April, the management of this procurement program was transferred from the Research Division to this group. Senior personnel of the group have been nominated and the growth of the group is being planned to match both the procurement program and the availability of personnel from other activities within the project. The group will eventually operate the Beam Switchyard and the primary beam systems in the end stations and serve in a supporting role to both SLAC and visiting experimental teams.

The major items in the procurement program are discussed below.

A. SECONDARY BEAM TRANSPORT SYSTEMS

A fund of Brookhaven-type magnets is in procurement for general use in secondary particle beams originating in End Station B. The quantity will be sufficient to mount the preliminary experimental program envisaged next year. Power supplies and distribution systems for use with the magnets are in the final stages of design.

B. SHIELDING

A general fund of shielding for both the End Station walls and for use as beam shielding is in the final design stage. A program of clean-up machining on the steel billets procured through surplus disposal contracts has begun and will continue. It will provide an initial fund of 2000 tons of this type of steel.

C. HEAVY RIGGING EQUIPMENT

Procurement of certain heavy rigging tools for handling elements of shielding and beam transport systems in the 30-ton to 50-ton range has begun.

D. LIQUID HYDROGEN TARGET SYSTEMS

A liquid hydrogen target system has been ordered from Lawrence Radiation Laboratory, Berkeley, and the fabrication of this item is being followed by SLAC personnel with the aim of developing these skills at SLAC. It is expected that a SLAC design effort will be mounted later this year toward a SLAC target system being available at start-up time.

Recruiting of personnel for a liquid hydrogen operations section has begun, and an engineering effort to provide a liquid hydrogen storage facility and the associated transfer systems is expected to begin soon. This section will carry the responsibility for liquid hydrogen safety within the Research Area.

E. PRIMARY BEAM INSTRUMENTATION

Establishment of criteria for general use primary beam instrumentation systems in the End Stations is almost complete. These instruments are similar in kind to those already designed for use in the Beam Switchyard and will require only repackaging to satisfy the less stringent environmental situations. This instrumentation will be displayed in the Data Assembly Building, and some local electronics installations in portable enclosures are envisaged.

The nucleus of an experimental beam layout group has begun assembling information from the SLAC experimental groups. Some engineering design work of vacuum chambers, targets, instrumentation and supports has been done.

XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. EXPERIMENTAL GROUP A

1. General

In the past six months Group A has been engaged in an intensive design effort on both the 8-BeV and the 20-BeV spectrometers. Procurement has begun on magnets, supports and parts of the detecting and data-handling systems. Responsibility for a portion of the end station preparation originally undertaken by the group has been transferred to the Research Area Operations Group which will ultimately be responsible for end station operation (see Section XI above). A proposal for a third smaller spectrometer was approved and will be constructed by Group F. This instrument will be mounted on the same pivot as the larger spectrometers and will share many of the facilities being constructed by Group A.

2. Spectrometers

a. 8-BeV

A complete report on the optics has been written.* Colleagues at DESY have independently computed the behavior of the system, and agree with the TRANSPORT computations performed here. The magnet arrangement for this spectrometer is shown in Fig. 16. Many of the items on this spectrometer are similar to, or duplicates of, the counterparts in the 20-BeV/c spectrometer, so that the design and procurement is carried along concurrently.

The magnets for this spectrometer have been completely designed and are out for bid at the present time. The main supporting structure design is complete and procurement will begin soon. Designs are being considered for the shielding and shielding carriage for the detectors.

b. 20-BeV

Early in the first quarter of 1965, the "twisted quad" design initially proposed for the 20-BeV instrument was abandoned, and a system making an

*L. Mo, "8-BeV Spectrometer," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).

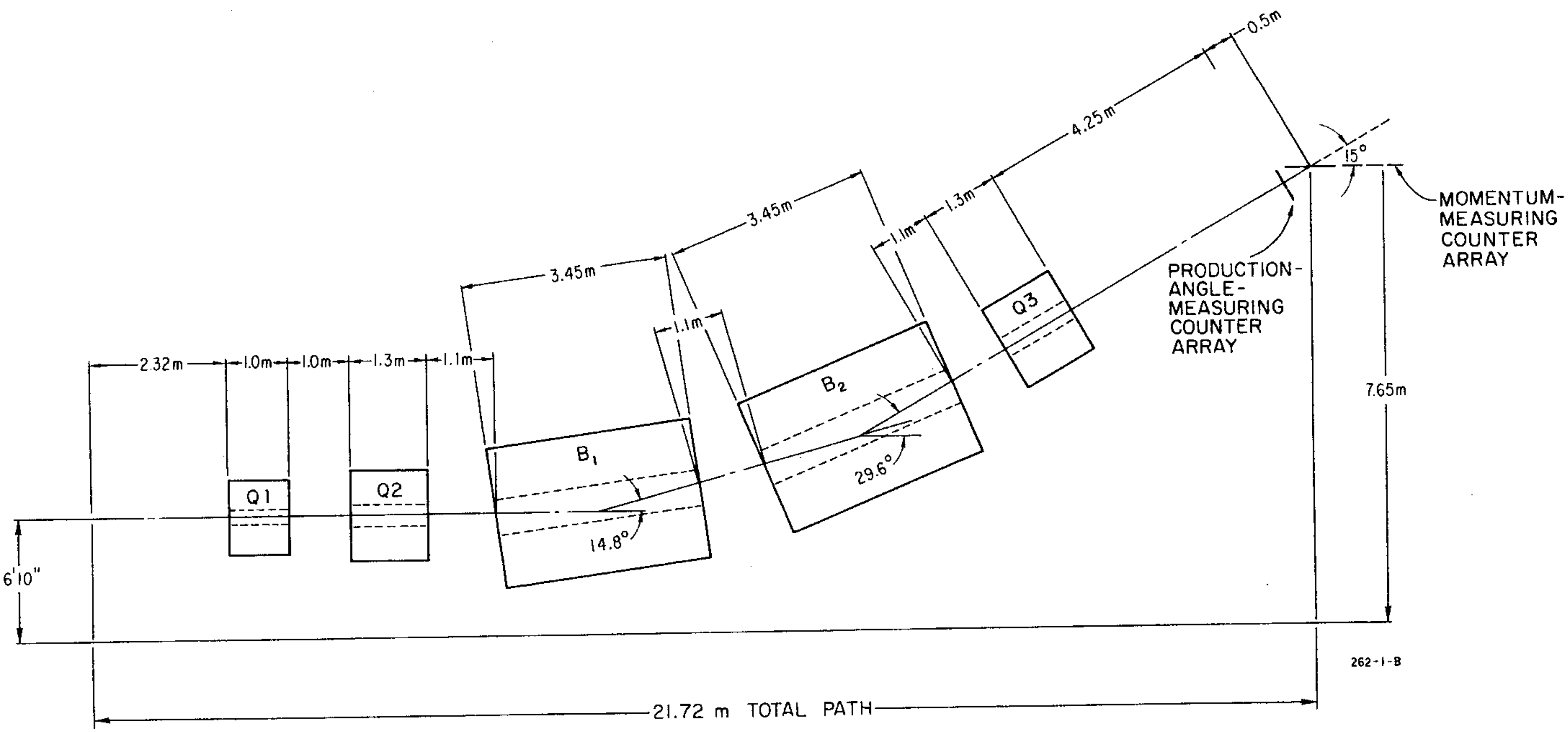


FIG.16-- MAGNET ARRANGEMENT, 8-BeV/c SPECTROMETER.

S-bend in the vertical plane was adopted. First- and second-order analysis of the optics showed that the aberrations could be reduced to a satisfactory degree using the upward S-bend configuration, providing three additional sextupoles were used as corrective elements. The final magnet arrangement shown in Fig. 17 results in a horizontal particle beam at the detector, 17 feet, 4 inches above the floor.

A conceptual sketch of the spectrometer and its shield is shown in Fig. 18. A major difficulty with this spectrometer is that it must operate within 2° of the primary beam. The sketch indicates the several points of interference which necessitated notching the first magnet and providing clearance on the support frames.

In order to keep the magnets aligned to the required accuracy, a taut-wire system is being planned for both the 20-BeV/c and the 8-BeV/c spectrometers. A high-frequency (10 kc) current is carried in the wire, and the proximity to the wire is measured with an electromagnetic pick-up. Tests have indicated that the device will measure displacements of less than 0.001 inch reliably.

Each magnet is supported on jacks which are arranged to give orthogonal movements. These jacks will be hand-operated initially, but can be motorized later.

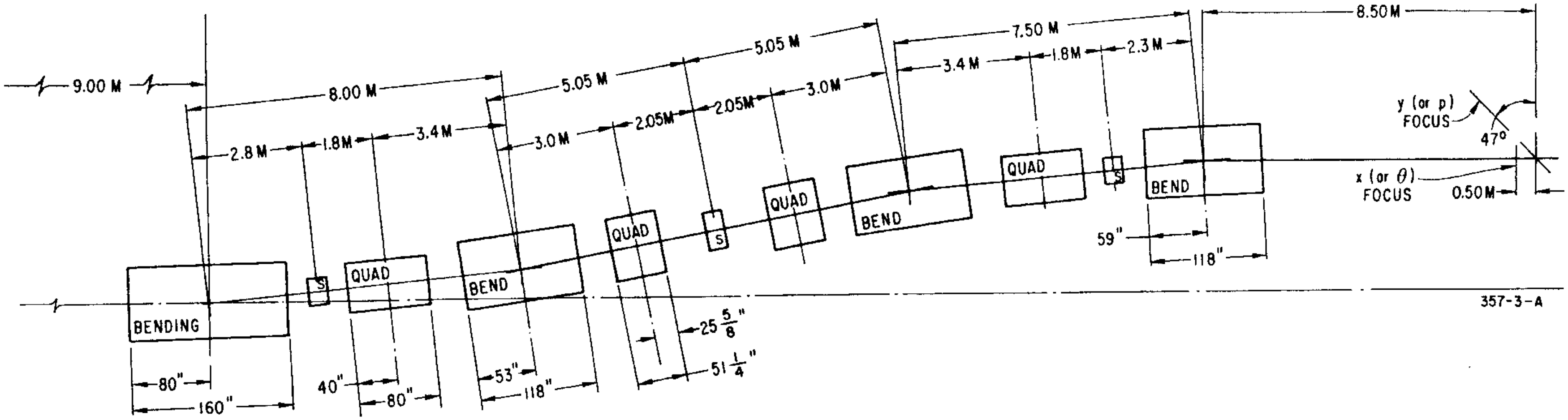
By the end of this quarter, all of the magnets except the sextupoles were designed and out for bid. The copper conductor has been placed on order separately in order to expedite the magnet deliveries.

The structure design is in the layout stage. The wheels and bogies which represent an important portion of the structure have been designed and are out for bid.

The vacuum chambers and adjustable aperture are being designed.

3. Power Supplies

The power supplies have become one of the most critical items in the schedule. Intensive design work will begin next quarter. The power supplies for both of the spectrometers will be located outside the end station, about 200 feet from the pit. Since the magnets have a total requirement of about 35,000 amperes, the installation of these leads in the service tunnels, through flexible connections at the pit, and along



MAGNET ARRANGEMENT OF 20 BeV/c SPECTROMETER

FIG. 17

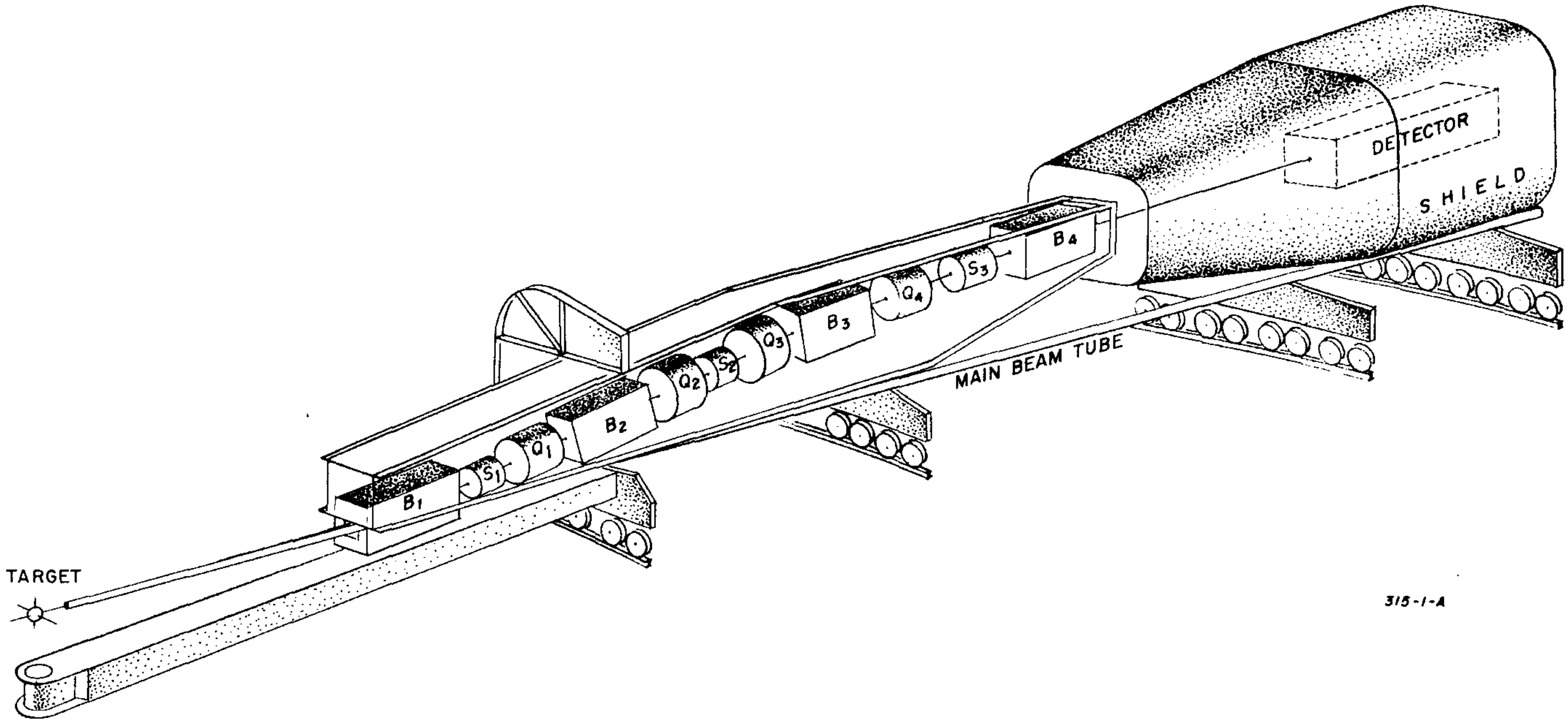


FIG. 18 -- Pictorial view of 20 GeV/c spectrometer.

the spectrometers to the magnets, is a major problem. Water-cooled cable appears to be the best choice, and a proposal has been sent out for bids.

4. Detectors and Data Analysis

Counter systems for particle detection are being designed and constucted at Massachusetts Institute of Technology by Professors H. W. Kendall and J. I. Friedman, who intend to collaborate with Group A in the physics program at SLAC. A subcontract has been let to MIT to finance this arrangement. They will construct hodoscopes for each of the spectrometers, which determine the position of particles as they pass through the focal plane, and a single set of counters designed to discriminate between electrons and pi-mesons. They are also providing suitable fast electronics for the system.

A contract has been let for a computer system to form part of the data-handling system. The final system consists of an SDS 9300 processor and associated peripheral equipment. Delivery is expected during the next quarter.

5. End Station Preparation

Although some of this work has been transferred to the Research Area Operations Group, Group A has retained considerable responsibility for beam monitoring, counter house, utilities, etc. During the reporting period, design of the east beam dump has been completed, shielding studies have begun, and work has begun on the counting house conventional facilities.

6. Positron Source

The positron radiator in Sector II of the accelerator will provide single pulses of positrons by means of a wand target, or continuous positron pulses by means of a wheel source. The two sources retract out of the beam centerline for electron pulses and both may be disconnected remotely from the vacuum chamber and replaced by blank flanges.

a. Wand Target

The wand presents a stack of water-cooled target plates to one electron pulse as its end is snapped through the beam. Two concentric welded bellows permit this oscillation and maintain vacuum integrity. The space between bellows will be pumped to 1/2-atmosphere to reduce the pressure load on the bellows and increase their life. Failure of either bellows will not compromise the vacuum. A third bellows allows retraction of the wand from the beam area.

b. Wheel Target

The wheel is composed of eleven water-cooled target discs of high thermal conductivity. The exit window, separating the water from the vacuum chamber, cannot be fixed at full beam power -- that is, successive pulses on the same window area will overheat the material. It was necessary to design a moving window to present a cool area to each successive pulse. The wheel target therefore has been given a trolling motion (a circular motion without rotation) at two cycles per second. The exit window is then an aluminum ring which moves so that a pattern of 180 pulses is spread out around the circle before repeating.

It is unnecessary to rotate target plates already subject to a trolling motion; moving parts within the target are thus eliminated. Measurements of eddy-current drag with model target discs have shown that each disc must be cut into "pieces-of-eight" in order to reduce the drag to a reasonable level.

The two water connections to the wheel arm are tubes with flexible (bellows) joints. The support and drive tubes are inside the water tubes, avoiding the need for bearings in the vacuum chamber. All bearings are in the water system and are oversize to compensate for the low lubricity of water. A large-diameter bellows provides for retraction of the wheel target.

c. Edge-Cooled Coils

Design of the six edge-cooled double pancakes, four upbeam and two downbeam of the source chamber in solenoid A, was completed. An invitation for bids covering fabrication of 11 double pancakes, including a prototype and four spares, was issued. Bids are scheduled to be opened in July.

d. Housing for Solenoid A

With the edge-cooled coil design out for bid and the wand and wheel source configurations rapidly firming up, design effort was concentrated on the housing, which combines the source chamber with water-cooled upbeam and downbeam coil chambers. Basic design of the housing follows the ASME Code for Unfired Pressure Vessels. It is to be fabricated by brazing and welding from type 316L stainless steel and, where a high magnetic permeability is required, 1010 low-carbon steel protected by nickel and chromium plating.

e. Hollow-Conductor Coils

Design of the hollow-conductor coils used through the balance of the tapered field section and throughout the uniform field section was completed, and an invitation for bids for the 163 hollow-conductor double pancakes, including a prototype, was issued. Bid opening is set for July. A subcontract for hollow conductor to be supplied to the coil fabricator was placed, with delivery scheduled early in August. Difficulty in procuring copper, which is currently in short supply throughout the country, led to redesign of the hollow-conductor coils on the basis of a conductor of 0.395-inch-square cross section, the same size conductor being used for all coils.

f. Frames for Hollow Conductor Coils

Design was completed and an order placed for August delivery.

B. EXPERIMENTAL GROUP B

A plan for installing a monochromatic photon source in End Station B for use in the 40-inch SLAC hydrogen bubble chamber has evolved. Positrons from the accelerator will be incident upon a thin hydrogen target placed near the center of the end station, and unannihilated positrons will be dumped using a sweeping magnet. Shielding problems are minimal because of the relatively low positron intensity. Both photons from the annihilations will emerge from the shielding, although a plug will absorb annihilation and bremsstrahlung photons of under 5-milliradian production angles. The process will be detected and alignments effected using coincidences between photons, and a pair spectrometer will be used to establish the actual energy spectrum and the effectiveness of a beam hardener.

In collaboration with Group E, we expect to receive and analyze about 250,000 photographs of high-energy proton, π, and K^+ interactions in the Brookhaven National Laboratory 80-inch hydrogen bubble chamber.

The analysis of photographs already on hand (K^-D interactions at 2.7-BeV/c from LRL, and K^+p interactions at 2.8-BeV/c from BNL) will continue using the new program TVGP from the LRL. This system has been made to run on the Stanford 7090 computer, and debugging is in progress.

An investigation of the problems of on-line checking of conventional measuring machine output is in progress, and the setting up of such a system will be undertaken in collaboration with the Conventional Data Processing Group in the coming quarters.

C. EXPERIMENTAL GROUP C

1. Colliding-Beam Vacuum Studies

Effort during the quarter was concentrated on the assembly and testing of the prototype 10-foot section of the proposed 600-foot storage-ring vacuum chamber.

a. In-Situ Processing Techniques

Preliminary qualitative investigations were made using techniques that might enable cleanup and outgassing of the chamber after installation or following accidental introduction of water, etc. The test system was subjected to the following insults and corrective measures:

1. Introduction of a cryopanel that had been cleaned and saturated with water at room temperature.
2. Purposeful introduction of 10 cc of liquid water into the chamber.
3. Glow discharge cleaning with helium and argon (300 volts at $\approx$ 0.9 amps at 20-150 microns).
4. Heating synchrotron absorber with flowing hot water ($\approx 95^{\circ}$C).
5. Local cleaning of synchrotron absorber by bombarding with electrons at 10-20 kV.
6. Removal of water by flushing (at 100 microns) with nitrogen while moderately heating cryopanel at 90°C.
7. Heating by means of passing large currents ($\approx$ 3000 amps) through the chamber walls.

8. Argon processing of ion pump at 10^{-3} torr.

9. Helium processing of ion pump at 10^{-3} torr.

10. Baking of ion pump to remove buried helium.

The above techniques were employed singly and in various combinations. In general, each process resulted in changes in partial pressure in a predictable way. It appears that thermal outgassing and electron bombardment cleaning were most effective in reducing the gas load. Glow-discharge purging with flowing helium did reduce the partial pressure of water; however, ammonia was produced in the process.

b. Cryopanel

The cryopanel cooling systems have proven effective, and temperatures near $10^{\circ}K$ were attained. Actual thermal loads from the system will be measured during the next quarter. Some difficulty was experienced because of the large amount of residual water introduced with the glass-bead-coated cryopanel; other possible black coatings are being studied, such as:

1. Molecular sieves
2. Sputtered metallic coatings
3. Black gold

c. Low-Energy Electron Desorption

Using the diode system, total-desorption measurements on stainless steel were extended to higher electron energies. Some measurements were also made at grazing incidence by employing a solenoidal field. Only a small energy dependence was found above 500 volts up to 2700 volts, in support of earlier measurements made on the movable target system. Again, grazing incidence yields were nearly three times as great as normal incidence at the lower energies, but only slightly higher at the highest energy measured (2700 volts).

Exploratory probing with very low energies (< 10 volts) at grazing incidence did not show any peaking as observed earlier on the movable target system. The system has been modified for measuring electron desorption from evaporated aluminum surfaces.

2. Streamer Chamber Studies

Various gases have been introduced into a small streamer chamber in order to study the effects of a small concentration of electron-attaching gas on the normally long memory of such chambers. Of the few gases studied, it was found that Freon-12 was the most effective in reducing the memory time of the chamber without seriously affecting the quality of the streamers. Memory times of less than 1 microsecond were obtained with less than a factor of two decrease in the streamer light intensity. Some of the detailed measurements are described below.

a. Freon-12

In order to obtain very small concentrations of Freon-12 necessary for reducing the memory time, the Freon-12 was first diluted by a factor of 1.4×10^{-3} (partial pressure) with the usual neon-helium mixture. This mixture was then further diluted by flowing with pure neon-helium (flow rates measured with Matheson series 600 flowmeters) down to mixtures of 10^{-4} to 10^{-5}, i.e., ten to a hundred parts per million. It was found that the memory time τ of the chamber could be approximately expressed as

$$\tau = (60 \pm 10)\ \mu\text{sec}/f$$

where f is the Freon concentration expressed in parts per million. The number of streamers does not suddenly die away after a delay τ, of course, but falls off gradually. The lifetime as expressed above is the time at which the chamber, if pulsed, would exhibit approximately half the number of streamers that it would normally exhibit if pulsed immediately after the passage of the track. The effect of the Freon on the light intensity of the streamers was estimated by observing the shortest length streamer (side view) which registered on 2475 film with an f stop of f/1.5. With no Freon at all present in the chamber, the shortest streamer length visible was approximately 2 mm in real space. At the highest concentration of Freon studied, 140 parts per million giving τ less than 0.5 μsec, the shortest visible streamers were approximately 3.5 millimeters in length. A separate study of the minimum visible streamer length as a function of f stop number indicated that the light intensity of a streamer is roughly proportional to its length. Using this result, combined with the 3.5 mm, indicated that the streamer intensity is perhaps down by a factor 1-1/2 to 2 for a concentration of Freon giving $\tau = 0.5$ μsec. Smaller concentrations of Freon resulted in shorter streamers being visible; the minimum length for 25 parts per million ($\tau = 2.5$ μsec) was approximately 2.5 mm.

b. SO_2

It was found that a rather large concentration of SO_2 was necessary to reduce the memory time to the levels desired. For example, it was found that for 1/4% concentration of SO_2 the lifetime was approximately 4 μsec. Unfortunately, the SO_2 had a secondary effect on the operation of the chamber, namely, it decreased the light intensity from the streamers enormously. The minimum streamer length observable for the concentration of 1/4% was 10 mm instead of the usual 2 or 3 mm. Similar effects were observed when bubbling the neon-helium mixture through ethyl alcohol; again, the streamers became less intense for a given streamer length.

D. EXPERIMENTAL GROUP D

1. Two-Meter Spark-Chamber Magnet

Some changes have been made in the design of the magnet reported in a previous status report.* The number of coil packages has been reduced from 14 to 10 and the iron returns reduced to give the same one-meter gap. The power supply has been increased from 4 to 5.8 megawatts. This gives the same ampere-turns as the original design but results in slightly higher fields. The design of the magnet has been completed. Bids for the construction of the coil and the iron should be received in about a month. The 5.8-megawatt power supply has been contracted and should be delivered by May 1966. Design of the staging for working on and in the magnet is starting, and design of the water cooling manifolds is virtually complete.

2. Streamer Chambers

A 50-cm × 50-cm × 10-cm streamer chamber has been operated successfully with streamers approximately 1.5 mm long by 1 mm in diameter. A

*"Two-mile accelerator project, Quarterly Status Report, 1 October to 31 December," SLAC Report No. 42, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).

chamber 50 cm wide, 1-1/2 meters long, with two 12-1/2 cm gaps, is under construction. Development is continuing on a high-voltage pulser capable of generating a pulse of over 700 kV of about 7 nsec width. A three-stage image intensifier is being set up to aid in the study of the streamers. A pulser (20 kV) is under construction to allow gating of the image intensifier.

3. Mark III Program

A wide-gap spark chamber is under construction for use with a small magnet at the Mark III accelerator. Its Marx generator is now complete. A small wide-gap chamber has been used with a TV system to study the location of the low-intensity photon beam at Mark III. A similar system should be useful at SLAC.

In collaboration with a group at the Stanford High Energy Physics Laboratory, an investigation is being made of $\gamma + p \rightarrow N^{*}_{+} + \pi^{-}$ using polarized bremsstrahlung. If the production is via the Drell process,* the asymmetry should be along the electric-field vector.

E. EXPERIMENTAL GROUP E

1. Proton-Proton Interactions at 6 GeV/c

A 200,000-picture exposure of 6-GeV/c protons in the 72-inch Lawrence Radiation Laboratory hydrogen bubble chamber was carried out. This experiment is being done in collaboration with W. Chinowsky and J. Schultz of LRL. Scanning and measuring have begun. Conventional methods are being used on strange-particle events. Non-strange-particle two-, four- and six-prong events are being measured by the Flying Spot Digitizer System developed and operated by H. White of LRL.

Particular reactions of interest to us are those which may contain "two-baryon" resonances and those which contain deuterons.

2. Neutron-Proton Elastic Scattering at 1 to 6 GeV/c

Measurements of the spark chamber film continued throughout this period.

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*S. D. Drell, Phys. Rev. Letters 5, 278 (1960).

3. K$^-$-Deuteron Interactions

Measurement and analysis of this bubble chamber film continued throughout this period in collaboration with Group B.

4. Deuteron Production in Proton-Proton Interactions

The analysis of this counter experiment, a collaboration with O. Overseth and D. Pellett of the University of Michigan, was carried out and almost completed at the University of Michigan in this period.*

5. Muon-Proton Inelastic Interactions, Muon-Proton Elastic Scattering and Muon-Electron Elastic Scattering

The construction of spark chambers and a hydrogen target for this experiment was begun. This experiment will be proposed for the SLAC accelerator and, depending upon the initial operation of the accelerator, will cover the momentum range from 2 to 14 (or higher) GeV/c. The initial muon beam rough design was completed, and a final design using a computer is now being carried out.

6. Search for New Heavy Leptons

The design work was continued for an experiment to search for new heavy leptons at SLAC. Some of the spark chambers being built for the muon-proton experiment will also be used here.

7. High-Energy, Small-Angle Gamma-Proton Elastic Scattering

The work on this experiment was continued.

8. Large Spark Chamber Magnet

The over-all design was completed of a 54-inch pole diameter, 36-inch-wide gap electromagnet for use in the aforementioned three experiments. The copper tubing for the coils has been ordered.

9. 30-GeV/c and 16-GeV/c Proton and Pion Exposure in the BNL 80-Inch Bubble Chamber

Design of the beam in collaboration with Group B was completed in this period.

10. Bubble Chamber and Spark Chamber Film Scanning and Measuring

Group E started and operated a facility for the laboratory for the building and maintenance of bubble chamber and spark chamber film

*D.E. Pellett, O.E. Overseth and M.L. Perl, Bull. Am. Phys. Soc. 10, 422 (1965).

scanning machines, conventional measuring machines, and automatic measuring machines. During this period this operation began to work very successfully. This enables us to separate this facility from the experimental work of Group E by the end of this period, and to organize it as a separate effort. Physicists from Group E will continue to assist with this effort.

11. Electronic Development

The construction of a simple photomultiplier testing facility was completed. Light pulses with 1-nsec width from a commercial pulse generator have been utilized.

A prototype of a transistor-tunnel diode coincidence circuit with a resolving time of 300 picoseconds was constructed. Detailed evaluation of the circuit is in progress.

The development and construction of a digital data scanner-recorder referred to in a previous report* was completed. The unit has been used in a recent experiment at the Lawrence Radiation Laboratory Bevatron. A paper describing the instrument, A. Barna and D. Horelick, "A Scaler Printout System" (SLAC-PUB-113), was accepted for publication in Nuclear Instruments and Methods.

12. Publications During the Quarter

1. M. L. Perl, Y. Y. Lee, and E. Marquit, Phys. Rev. 138, B707 (1965).
2. M. N. Kreisler, "Plastic Luminescent Panels Using Pulsed Fiducials," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 July to 30 September 1964," SLAC Report No. 34, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965); p. 104.

F. PHYSICAL ELECTRONICS

During this quarter gain (δ) and lifetime measurements were continued on transmission-type field-enhanced secondary-emission dynodes. Measurements were carried out in a diffusion-pumped vacuum system (DPS) and in an ion-pumped vacuum system (IPS) with low energy (0-20 keV) and minimum ionizing (100-1000 MeV) electrons as the primary current. The results to be presented below were obtained on dynodes prepared by evaporation at 4 torr of argon in a DPS with a base pressure $\approx 2 \times 10^{-7}$ torr. Transfer of the dynodes to an IPS, base pressure $\approx 5 \times 10^{-9}$ torr, was carried out in an atmosphere of dry nitrogen; the IPS was sorption-roughed, so the only hydrocarbons present in the system were on the dynode as a result of preparation in the DPS.

In order to understand more fully the secondary emission from these dynodes, the apparent internal multiplication measurements, discussed in the previous report, were extended to CsI and LiF, and the attenuation length of "hot" electrons (0-10 eV above the vacuum level) in bulk density KCl and CsI was determined.

1. Low-Density KCl Dynodes

The δ of low-density KCl dynodes is strongly dependent on the vacuum system in which the measurements are carried out. As discussed in previous reports, δ initially decreases exponentially with time in a DPS. Results obtained this quarter in an IPS free from hydrocarbons indicate that δ is constant with time at a value characteristic of the $\delta(t = 0)$ in a DPS. For the one sample for which complete measurements are available, δ was constant for two months in an IPS. In a DPS, breakdown of the dynode is observed for collector voltages (V_c) ≈ 75 volts; breakdown is characterized by the secondary current becoming very noisy and increasing very rapidly with V_c. In an IPS, breakdown occurs for $V_c \approx 300$ volts. A comparison of δ vs V_c results obtained in an IPS and a DPS for KCl dynodes prepared under the same evaporation conditions is shown in Fig. 19.

2. Low-Density CsI Dynodes

While carrying out the internal-multiplication measurements (discussed in subsection 5 below), the following very interesting properties of

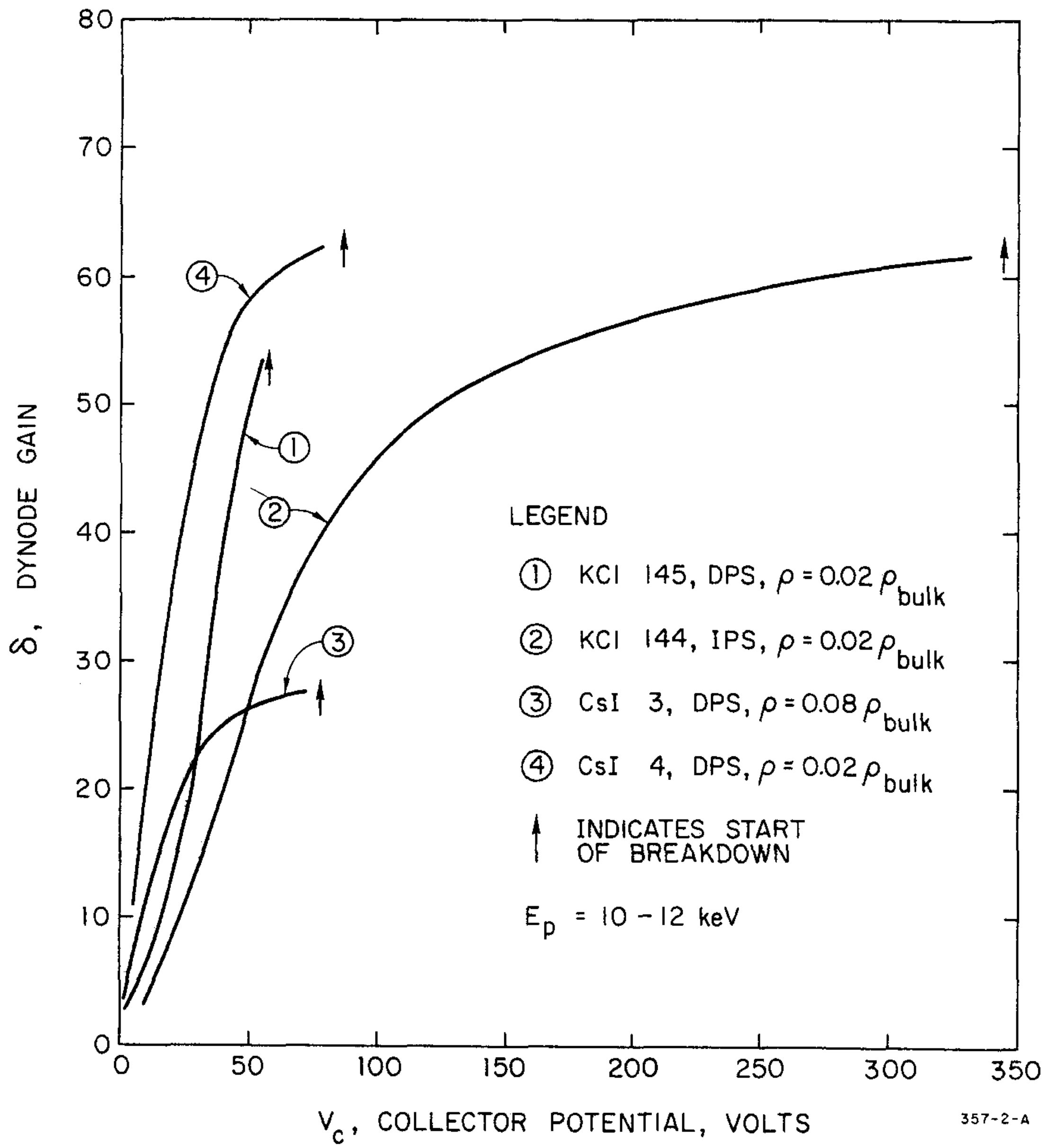

FIG. 19--GAIN vs COLLECTOR POTENTIAL FOR LOW-DENSITY DYNODES

low-density ($\approx$ 10% of the bulk density) CsI dynodes of thickness $\approx 300\ \mu g/cm^2$ were observed:

a. Constant δ at a value of about 25 in DPS up to total measured charge through the film of $\approx 0.5\ C/cm^2$. This is qualitatively the same as reported,* $\delta = 55 \pm 2$, for a smaller transmitted charge of $0.08\ C/cm^2$ in the case of low density KCl, as measured in a hydrocarbon-free vacuum system. Typical low-density CsI dynode characteristics, δ vs V_c, are shown in Fig. 19.

b. Low-density CsI dynodes can survive prolonged exposures to the atmosphere with no deterioration of δ. One CsI dynode was exposed to the laboratory atmosphere ($\approx 75^{\circ}$F, 30% relative humidity) for seven days with no change in δ. As mentioned in previous reports and as reported by Goetze, et al.,** low-density KCl dynodes cannot survive even short exposures to the atmosphere. Thus, this property of low-density CsI dynodes makes them of great interest for many applications.

3. δ for Minimum-Ionizing Primary Currents

Measurements of δ for low-density KCl with minimum ionizing primary currents have been carried out at the Mark III accelerator. It was found that δ is dependent on the beam intensity, especially for currents $\gtrsim 5 \times 10^9\ e^-$/pulse (60 pps), as shown in Fig. 20. This is probably because bombardment-induced conductivity limits the internal field necessary for high gain. In addition, δ depends on dynode orientation with respect to the beam, as shown in Fig. 21, δ being higher when the beam is incident on the KCl side of the dynode ("upstream") than when incident on the substrate side of the dynode ("downstream"). Also apparent in Fig.21 is the increase in δ with increasing energy due to the relativistic rise in the ionization loss. The relativistic rise results for "upstream" orientation are in good agreement with B. Richter's (SLAC) unpublished results on metal foil SEM's, although δ is a factor of approximately 100 higher than for a single-foil SEM. That the relativistic rise is less pronounced for "downstream" orientation is consistent

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*G.W. Goetze, A.H. Boerio, and M. Green, J. Appl. Phys. 35, 482 (1964)
**Ibid

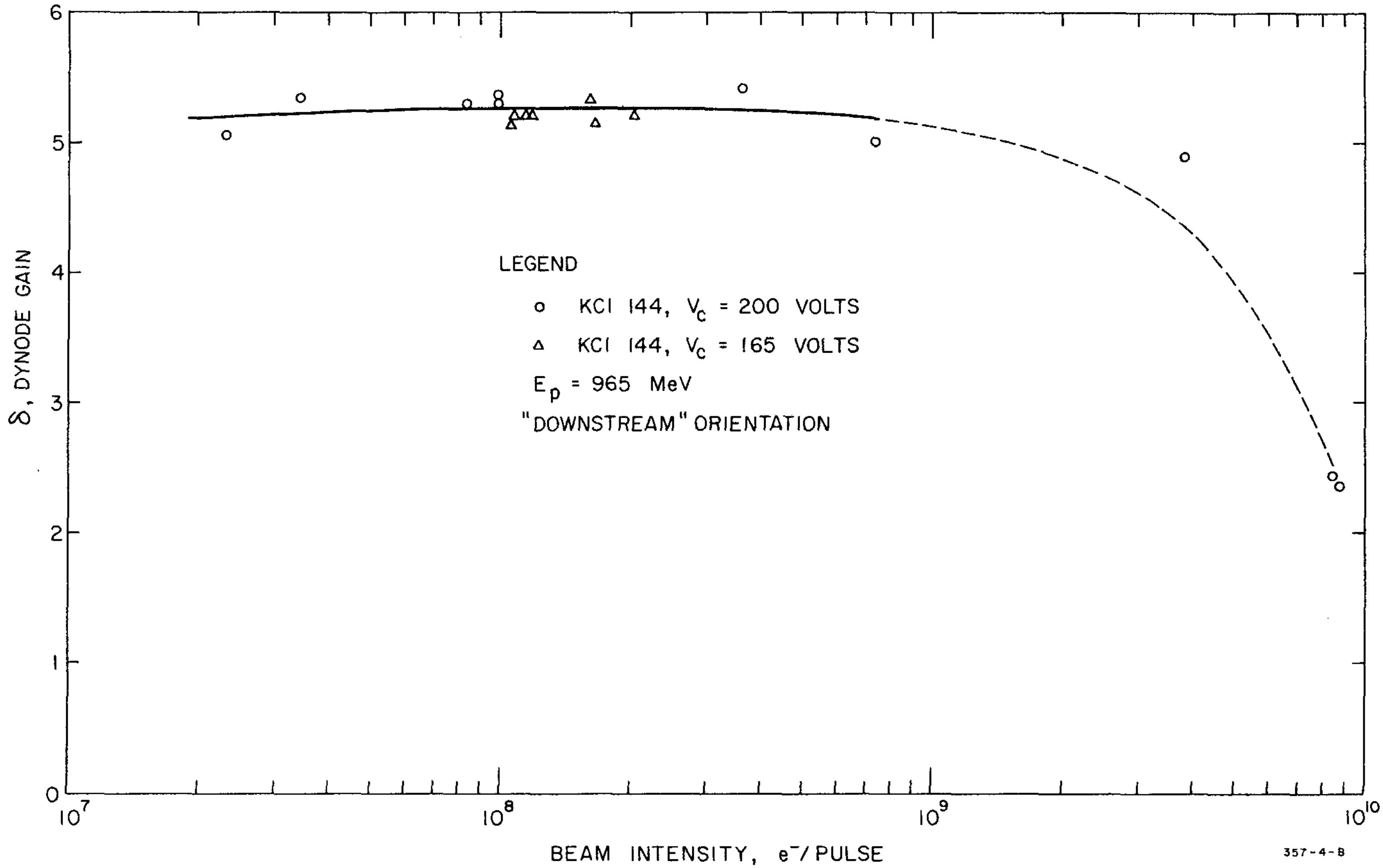

FIG. 20--INTENSITY DEPENDENCE OF δ FOR LOW-DENSITY KCl DYNODE

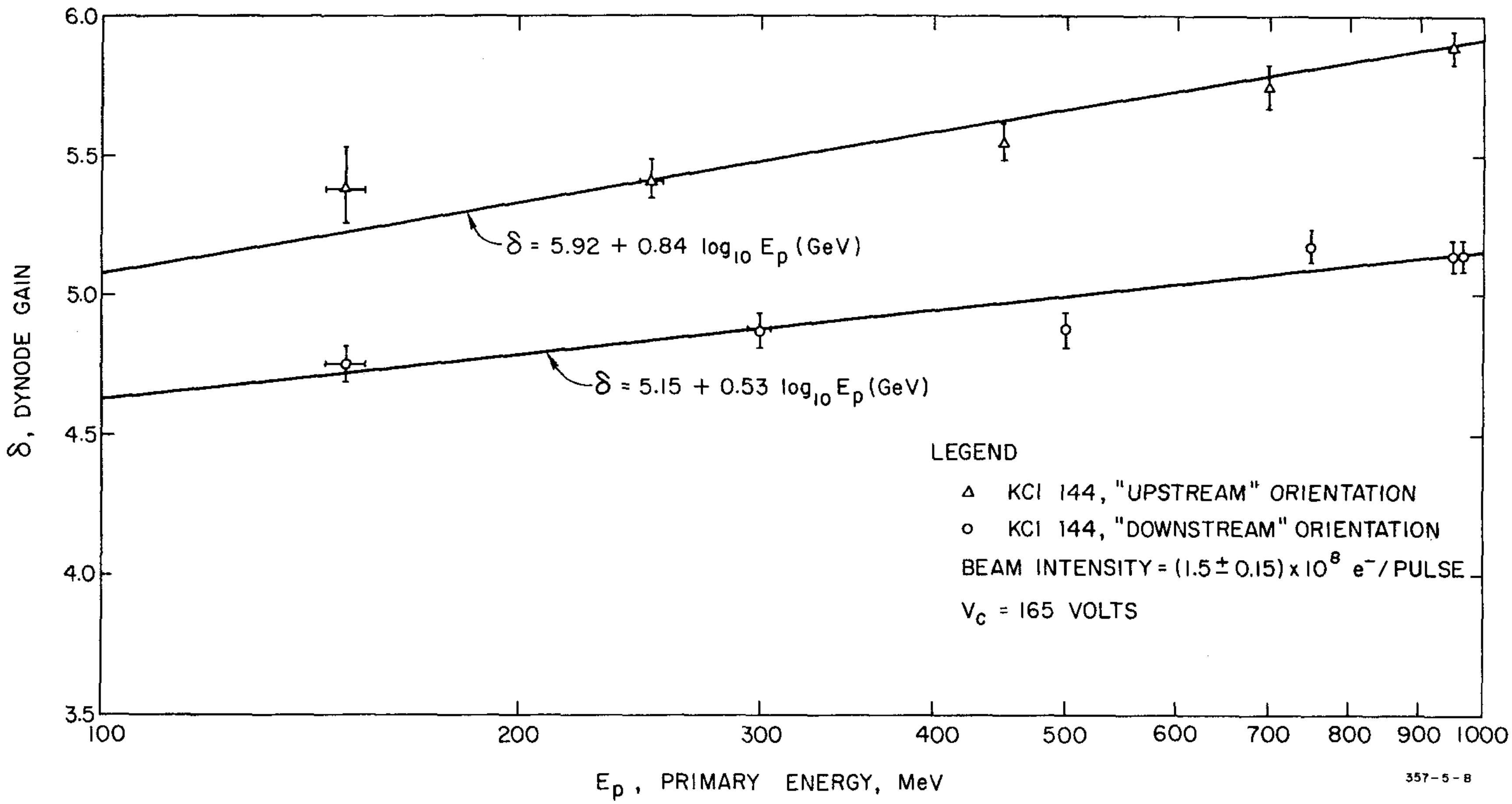

FIG.21-- GAIN OF LOW-DENSITY KCl DYNODE FOR MINIMUM IONIZING PRIMARIES

with the Vanhuyse and Van De Vijver theory* and may be due to the density effect. This data on the relativistic rise indicates that velocity determination of high-energy particles (and, thus, rest-mass determination if the momentum is known) is possible with these dynodes unless the statistics of the process are so pathological that they give, for example, ≈ 50 secondaries for 10% of the incident electron and ≈ 1 secondary for the rest.

Limited results on low-density CsI dynodes with minimum-ionizing primaries have been obtained. These results show that for energies between 100 MeV and 1 GeV δ is higher for CsI than for KCl by a factor as large as 1.4. This is consistent with the attenuation length data presented in subsection 4 below.

4. Attenuation of "Hot" Electrons in KCl and CsI

The attenuation length (L) of "hot" electrons (0-10 eV above the vacuum level) in bulk density KCl and CsI was determined by measuring δ vs thickness, τ, at energies where the transmission of the primaries $(\eta_\tau) \to 1$. With appropriate assumptions, the gain at constant primary energy is

$$\delta = c(1 - e^{-\tau/L}) + \delta_s$$

where c = constant, L = attenuation length, and δ_s = gain of the substrate. By using the measured values of δ_s and $\delta(\tau \to \infty)$, L can be determined by fitting the measured δ vs τ curve using L as an adjustable parameter. All evaporations and measurements of δ were performed in a DPS without exposing the sample to the atmosphere between evaporations. Thickness was determined using the quartz crystal monitor mentioned in the previous quarterly report. For minimum-ionizing primaries, δ is strongly influenced by the attenuation length, since the distribution of secondaries is constant throughout the film at very high energies and the only secondaries which can escape are those at distances $\approx$ L away from the exit surface.

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*V.J. Vanhuyse and R.E. Van De Vijver, Nucl. Instr. and Methods 15, 63 (1962).

For bulk density materials, it was found that $L_{KCl} = 350 \pm 50$ Å and $L_{CsI} = 500 \pm 50$ Å. This result for KCl is about a factor of seven lower than reported by Sternglass and Wachtel,* but is in agreement with our data showing that the maximum δ is independent of KCl thickness above ≈ 500 Å. Since $L_{CsI} > L_{KCl}$, and $\delta_{CsI} \approx \delta_{KCl}$ for keV primaries (see Fig.19), one would expect $\delta_{CsI} > \delta_{KCl}$ with minimum ionizing primaries. This was observed, as reported above.

5. Electron Multiplication in Low-Density Dynodes

Measurements of electron multiplication, as indicated by changes in slope of the δ vs V_c characteristic, have been extended to CsI and LiF. The abrupt changes in slope observed for low-density KCl with Al conductive backings, discussed in the previous report, at $V_c \approx E_g + \chi$ and $2(E_g + \chi)$ (where E_g = band gap, χ = electron affinity) have been found to be much less pronounced with Au conductive backings. CsI ($\approx 8\%$ of bulk density) and LiF evaporated under the same conditions as the low-density KCl showed no abrupt changes in slope. Be evaporating CsI very slowly, the density has been reduced to $\approx 2\%$ of bulk density and abrupt changes in slope have been observed at V_c about 2 volts less than for low-density KCl. This is in agreement with the difference in $(E_g + \chi)$ for KCl and CsI and supports our interpretation of these changes of slope. The above data also indicates that the secondary-energy distribution is strongly peaked just above the vacuum level.

In the coming quarter more measurements are planned, especially on CsI, for minimum-ionizing primary currents at the Mark II and Mark III accelerators, using a more conventional SEM tube structure. Design of multi-dynode structures will be considered, and preliminary rise-time measurements on the dynodes will be made.

*E. J. Sternglass and M.M. Wachtel, Phys. Rev. 99, 646(A) (1955).

G. MAGNET RESEARCH

1. Water-Cooled Magnets*

a. Positron Solenoids

A contract for the upstream magnet has been awarded. Tapered solenoids have been ordered. Bids for the homogeneous field solenoids are expected shortly.

b. Magnetic Slit

Design of the magnetic slit was completed, and specifications and drawings were sent to prospective manufacturers.

c. Spark Chamber Magnet

Coil design for the spark chamber magnet was completed. Bids for copper conductors are expected by the end of July 1965. Tests with a 1/10-scale magnetic model utilizing the SLAC pulsing facilities have been completed successfully. The magnet core and yokes are laminated and the coils air cooled. A capacitor bank of ≈ 50 kilojoules energizes the magnet to the desired peak field in the center of the bore. The pulse duration had been chosen to be 70 msec and the repetition rate one pulse per 15 seconds.**

A complete field map inside and outside the bore was provided to Group D, and the two-meter spark chamber magnet design finally frozen.

d. One-Meter Bubble Chamber Magnet

The overall size of the magnet has been decided. The specifications for the copper conductor are written. Detail drawings for the coil and iron yokes should begin during the next quarter.

e. Computer Program for Iron Bound and Iron Core Magnets

The computer program for two-dimensional iron configuration had been tested with success for magnets with a gap area of 50 cm^2. For larger magnets the program is still inefficient.

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*"Two-mile accelerator project, Quarterly Status Report, 1 October to 31 December 1964," SLAC Report No. 42, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).

**H. Brechna, R. Mizrahi, A. Wolff, "A Pulsed Model Magnet for the Two-Meter SLAC Spark Chamber Magnet," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).

2. <u>Pulsed Magnet Laboratory and Magnets</u>

The installation of the capacitor banks, wiring and connections in the laboratory, is near completion. The SLAC facility has a peak energy of 300 kilojoules at 5 kilovolts, but may be extended later if desired. The main advantage of this installation is to build and test pulsed magnets as prototypes and to study difficult geometries and field configurations, as well as to build magnets which can produce fields in bores of 10 inches or more in excess of 100 kG.

3. <u>Superconducting Magnet Research</u>

a. Cryogenic Laboratory

As preparatory measures for the presently designed 70-kG, 12-inch supercoil, the liquid helium storage capacity will be increased threefold. Preparations for building an appropriate dewar, winding and cabling machines, and direct transfer of liquid helium from the cryostat to the magnet are underway.

The laboratory has acquired a power supply which provides 1000 amps and can be motor driven by means of a drive generator from 1.5 – 1000 amps linear. This enables us to sweep the field in any desired way by using a chosen current pattern to fit with the field shape.

b. Supermagnet

A series of small coils (total 18) with an i.d. of 0.4 inch and an o.d. of 3 inches has been built to investigate the behavior of coil performance, insulation, cooling, joints, and protection. These preliminary investigations lead to a metal coil design utilizing stainless steel screen and medium-weave glass fiber layer insulation, protection of lamination areas, and joints with low resistance (10-100 nΩ). The coil is self-protecting; it is wound bifilar with a high-resistance wire parallel to the superconductor.

A coil with an i.d. of 2.5 inches, an o.d. of 7.5 inches, and 6 inches long, producing about 70 kG, is under construction. This coil is the prototype for the planned 12-inch coil and can serve for small sample testing as well.

c. Heat Transfer of Liquid Helium Through Very Small Channels

In order to investigate the thermodynamic properties of two-phase liquid and gaseous helium passing through the layer insulation (stainless steel screen and glass fiber cloth), a model is under design. By using a shock-section test specimen, feeding it from a liquid helium dewar and maintaining the cool-down and phase stability, we should be able to study the thermodynamic properties of liquid helium and the stability problems of superconducting magnets.

4. Glass Epoxy Structures

The test program will be terminated by July 15. A report of the investigation will be presented at the 1965 Cryogenic Conference at Houston, Texas.*

H. THEORETICAL PHYSICS

The following papers have been prepared since the last report:

1. M. Bander and C. Itzykson, "Group Theory and the Hydrogen Atom," SLAC-PUB-120 (to be submitted to Journal of Mathematical Physics).
2. J. D. Bjorken and J. D. Walecka," Electroproduction of Nucleon Resonances" (presented at the International Symposium on Electron and Photon Interactions at High Energies, DESY, June 8-12, 1965).
3. S. D. Drell and H. R. Pagels, "Anomalous Magnetic Moment of the Electron, Muon, and Nucleon," SLAC-PUB-102 (submitted to Phys. Rev.).
4. S. D. Drell, "Special Models and Predictions for Photoproduction Above 1 BeV," SLAC-PUB-118 (Invited paper presented at the International Symposium on Electron and Photon Interactions at High Energies, DESY, June 8-12, 1965).
5. Y. S. Tsai, S. M. Swanson, and C. K. Iddings, "High Energy Gamma-Ray Source From Electron-Positron Pair Annihilation," SLAC-PUB-112 (presented at the International Symposium on Electron and Photon Interactions at High Energies, DESY, June 8-12, 1965).
6. H. P. Noyes, "Dependence of the Nucleon-Nucleon $^1S_0$ Effective Range Expansion Parameters on the Pion Mass and Coupling Constant Splittings" (to be presented at the Conference on Nuclear and Particle Physics," Liverpool, September 15-17, 1965).

*H. Brechna and W. Haldemann, "Physical Properties of Filament-Wound Glass Epoxy Structures as Applied to Possible Use in Liquid Hydrogen Bubble Chambers," to be presented at the 1965 Cryogenic Engineering Conference, August 23-25, 1965, Rice University, Houston, Texas (SLAC-PUB-121).

7. H. P. Noyes, M. J. Moravcsik, R. Arndt and R. Wright, "Unique Energy-Dependent Phase-Shift Analysis of p-p Scattering Between 9.68 and 382 MeV" (submitted to the Oxford Conference on Elementary Particles, September 20-24, 1965).

8. W. I. Weisberger, "Renormalization of the Weak Axial Vector Coupling Constant," SLAC-PUB-108 (Phys. Rev. Letters 14, 1047, 1965).

In view of the recent applications of higher symmetry groups to elementary-particle physics, a study is being made, as a model exercise, of the application of group theory to the non-relativistic hydrogen atom. In the terminology of M. Gell-Mann, a "physical transformation group" has been found such that the levels of the hydrogen atom fill up an irreducible representation of this group.[1]

The study of absorption corrections to peripheral models is being continued. Specifically, the effects of spin dependence in the initial and final state interactions are being investigated.

Calculations on the general form of the cross section for the process $e + p \rightarrow e + p_r$, with p_r a resonance of spin J, have been completed and presented.[2]

The problem of exploiting the information contained in the $U_6 \times U_6$ current algebra proposed by Gell-Mann is under study. Difficulties with singular terms involving gradients of delta-functions, of the type noted by Schwinger, have been studied and somewhat clarified. Sum rules relating magnetic moments to photoproduction cross sections have been derived and appear to disagree with experiment, but the logical basis for these derivations is still fragile.

The anomalous magnetic moment of the electron has been successfully computed using dispersion theory.[3] The approximation method in this work is based on a threshold expansion; the fourth-order moment is recomputed successfully and the sixth order has been obtained. A review of photoproduction calculations has been presented.[4]

The work on W boson production by electron-positron annihilation previously mentioned has been completed and submitted for publication. The energy and angular correlation of e^- and μ^+ in the final state are investigated in detail, especially the kinematical correlation for the W mass determination and the dynamical correlation for the determination of the W magnetic moment; these are exhibited by numerical examples. The symmetries of the problem are also worked out.

The energy-angle distributions of the following four processes were calculated[5]:

(a) $e^+ + e^- \rightarrow 2\gamma$

(b) $e^+ + e^- \rightarrow 3\gamma$

(c) $e^+ + e^- \rightarrow e^+ + e^- + \gamma$

(d) $e^+ + p \rightarrow e^+ + p + \gamma$

Numerical results for 15-BeV incident positron energy are given. An expanded version for the positron energy from 0.5 BeV up to 30 BeV is being considered, so that the results will be useful for workers in other laboratories.

Detailed investigation by means of different methods of calculation reveals that the $a_{nn} - a_{np}$ difference can only partially be accounted for by the pion mass splitting; a small coupling-constant splitting or some other small charge-dependent effect is also required.[6] This conclusion is model-insensitive, as is the conclusion that the measured n-p total cross sections at 0.5 and 3.2 MeV have less than a 5% probability of being consistent with the hypothesis of charge-independence, after all known charge-dependent effects have been included. An experimental redetermination of these cross sections has been undertaken at another laboratory as a consequence of these investigations.

Although unique p-p phase shifts have been obtained at several energies, no unique way of connecting these sets together in a continuous manner had been found. However, when an energy-dependent parameterization which includes the branch cuts required by scattering theory is used, the phenomenological parameters <u>are</u> uniquely determined, and an error matrix can be computed.[7] The effect of data selection on the values of the parameters, and the particular experiments which are inconsistent with this unique prediction, are under study.

It has proved possible to separate all the singular and complex behavior of the two-body scattering matrix into a term which depends only on the on-the-energy-shell scattering (which is accessible to direct measurement) times a real function of momenta in the problem. Hence, the effect of the model-dependent behavior off the energy shell on the three-body problem can be explicitly studied for models which give identical results for the two-body system. Further, a non-singular integral equation of the Fredholm type has been derived for this off-shell function. This is an improvement over solving the usual Schroedinger (or N/D) equations because of (a) the absence of singularities, (b) an explicitly unitary representation of the partial wave amplitude which also has the correct ($k^{2\ell+1}$) threshold and asymptotic behavior, and (c) the fact that non-local or energy-dependent interactions are just as easy to compute as local interactions. The method readily lends itself to separation of effects due to two-body scattering outside the range of the third particle (which are presumably understood) from genuine three-body effects, which are model dependent. A relativistic generalization appears to be feasible.

From the assumption that the equal time commutators of the vector and axial-vector current octets obey the algebraic relations proposed by Gell-Mann, and that the axial-vector current is partially conserved, a sum rule expressing the absolute ratio of the renormalized axial-vector and vector coupling constants of beta-decay in terms of pion-nucleon total cross sections is obtained.[8] A numerical evaluation using experimentally determined cross sections yields good agreement with the observed value of $|G_A/G_V|$.

I. HEALTH PHYSICS

The prototype peripheral monitoring station is now working properly. Power lines have been laid to the seven permanent stations and the prototype is installed at one of these. Drawings are being prepared for the construction or purchase of the seven final units.

The final version of the survey meter is nearly completed. It will be evaluated and 50 or a smaller number constructed, depending on the degree of success.

Two of the gamma wells have been loaded - one with a three-curie and one with a 200-curie ^{60}Co source. These will be used for instrument calibration and sample irradiation work. For small items we can obtain dose rates up to about 10^6 r/hr.

A final design for the air monitors was chosen and procurement started. A prototype detector for the water monitor is ready for testing. Design for the research area remote-area monitors has been started. Two neutron Rem-Counters have been ordered.

Two designs for ozone detectors have been fabricated and a calibration facility is being made to test them. Some sampling chambers for tritium monitoring have been purchased but not tested.

A thermoluminescent dosimeter system has been purchased. It will be used as an accident dosimeter, and some miniature capsules are being obtained for a dosimeter to be carried in the billfold. It has also been used in a preliminary experiment for measuring shower development. A further shower experiment will be done at the Mark III accelerator in July using this dosimeter system.

Equipment put into useful operation during this period includes a vacuum system, low background γ-ray spectrometer, and a lithium drifted germanium detector.

Assistance was provided other groups on questions of shielding design, radiation-damage studies, radioactive source procurement, and tracer experiments.

J. AUTOMATIC DATA PROCESSING

The development and construction of an automatic spark-chamber film reader "COLIBRI" (hummingbird) has been completed. The device digitizes the location and width of dark areas on film such as fiducial marks and sparks. A small spot of light on the face of a high-resolution cathode-ray tube is moved in a raster scan mode and is projected onto the film. A photomultiplier behind the film detects the presence of less transparent areas. In order to keep the device simple and the cost low, no buffering is employed at the expense of speed. Every time a dark area is traversed by the spot, the sweep is interrupted, and the location of the trailing edge and the width of the area are subsequently recorded onto magnetic tape by means of an incremental tape unit.

The time per digitization is 4.5 msec. Film from Group E's p+n elastic scattering experiment is digitized at an average rate of 300 frames per hour. The tapes generated are processed on the 7090 of the Stanford Computer Center. Fiducial marks and sparks are recognized from the individual digitizations, while the latter are being pieced together into tracks before geometric reconstruction and physics analysis can take place.