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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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Technical Report

Prepared Under

Contract AT(04-3)-400 and

Contract AT(04-3)-515

for the USAEC

San Francisco Operations Office

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I. INTRODUCTION

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

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

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

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

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

II. PLANT ENGINEERING

A. GENERAL

Considerable progress was made on the conventional facilities program during the quarter. Principal design effort was placed on the buildings and utilities of the target area and the Auditorium-Cafeteria. Construction of the accelerator housing, klystron gallery, research complex buildings, and the Control Building continued. The present status of a number of these facilities in the construction phase is shown graphically in Figs. 1 through 5.

Under contract to the Atomic Energy Commission, the Rogers Engineering Company commenced the design of the overhead 220-kV power feeder line to the Sand Hill site. Rights-of-way have been acquired by the government by condemnation and field survey work has begun.

The California State Division of Highways began construction of the overpass bridge at Accelerator Station 83 as part of the Junipero Serra Freeway. A view of this activity is shown in Fig. 5.

B. DESIGN STATUS

Preliminary design was completed on the Cryogenics Facility, the area lighting program, and the second floor addition to the one-story wing of the Central Laboratory. Except for minor items, this essentially completes the Title I effort by ABA.

Final design (Title II) is well along on several major facilities. These, together with their percentages of completion, are:

End Station A (90) — The 90% drawings are being reviewed.

End Station B (70) — This facility and End Station A will be combined into one construction package. Specifications and 90% drawings will be available early in the next quarter.

Auditorium-Cafeteria (92) — The 90% drawings and specifications have been reviewed.

Target Area Substations (75) — Two substations are planned.

Beam Switchyard Site Improvements and Utilities (15) — This and the

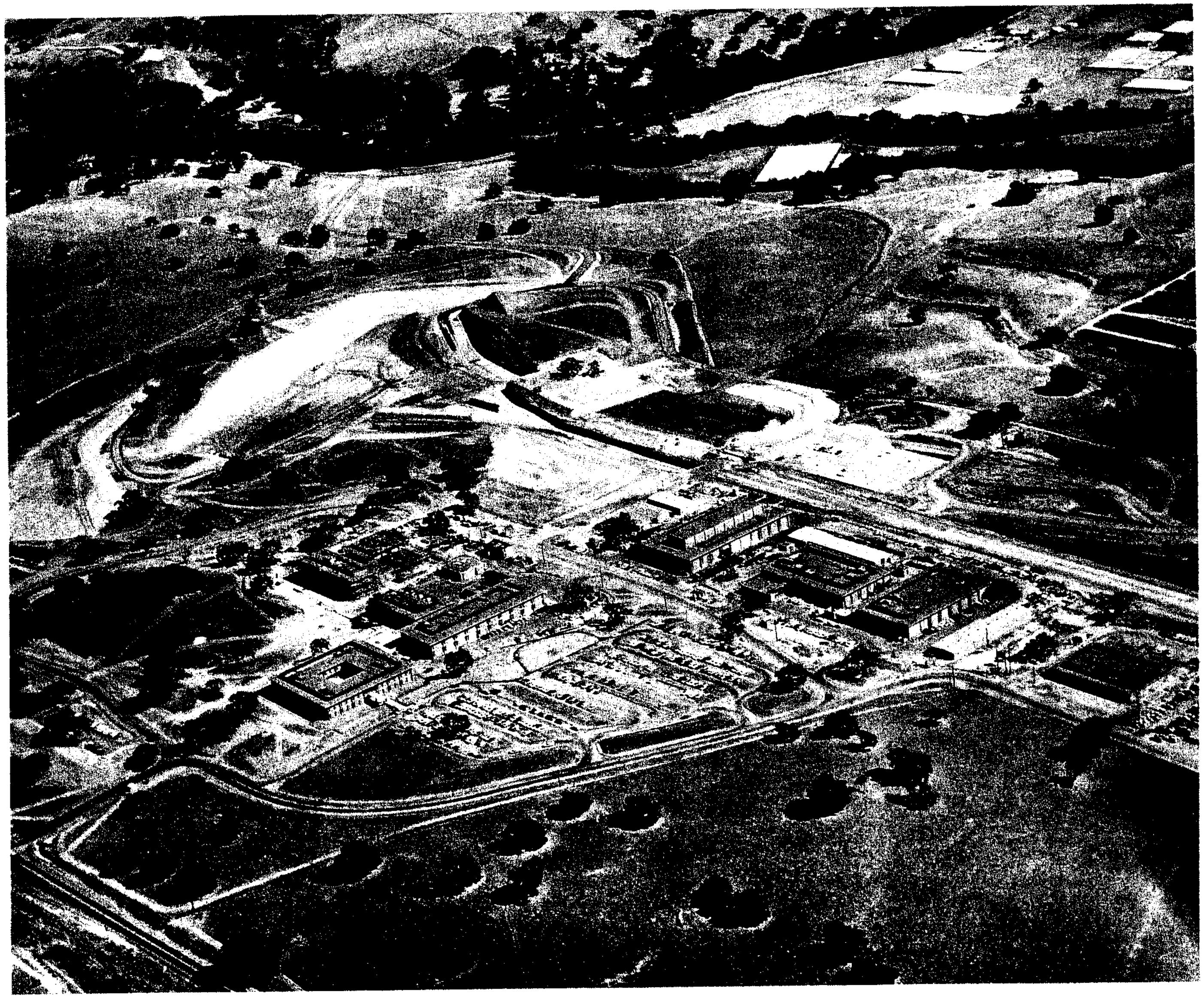

FIG. 1--Aerial view of SLAC buildings; target area in background.

FIG. 2--Construction status of Central Laboratory.

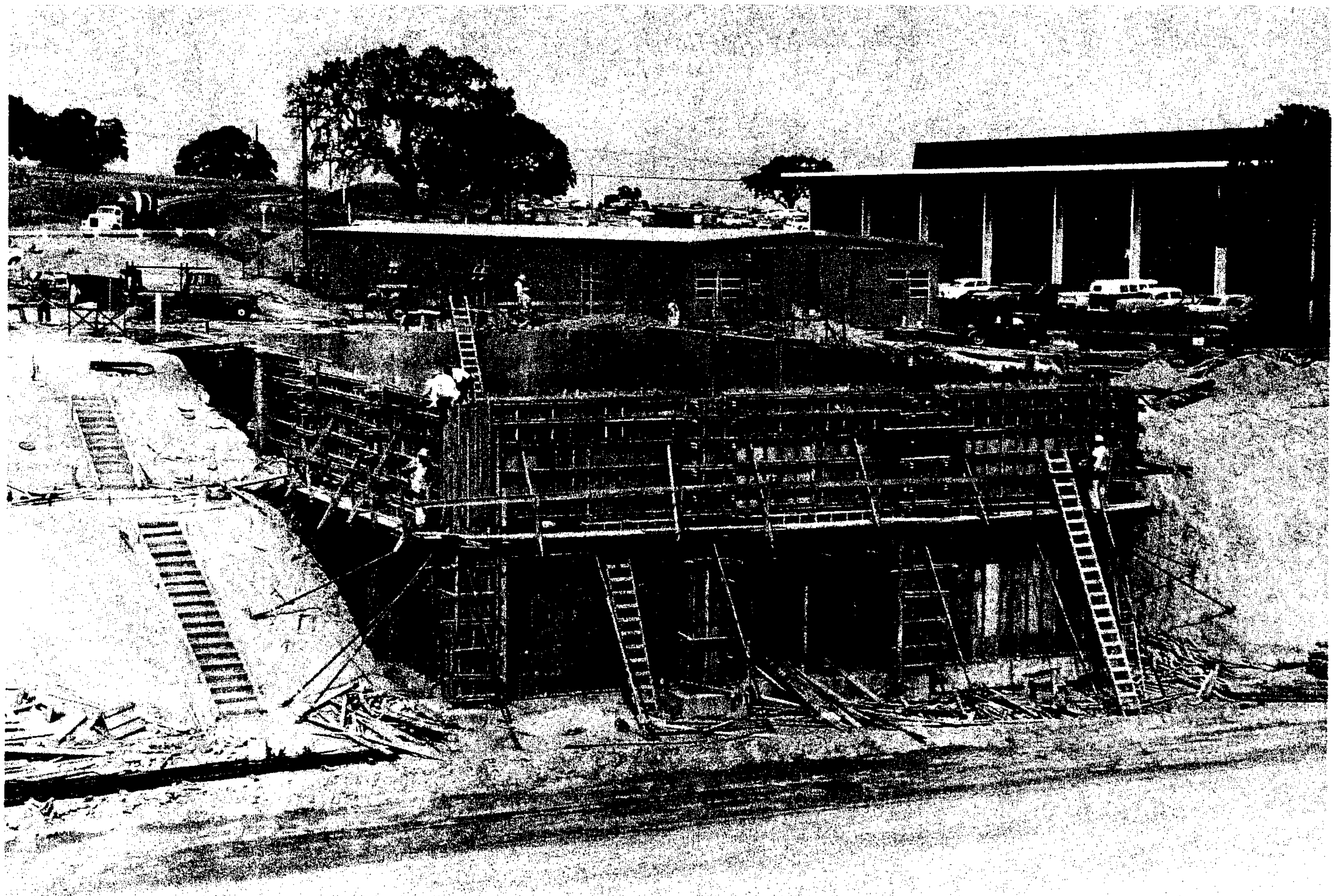

FIG. 3--Construction status of Control Building.

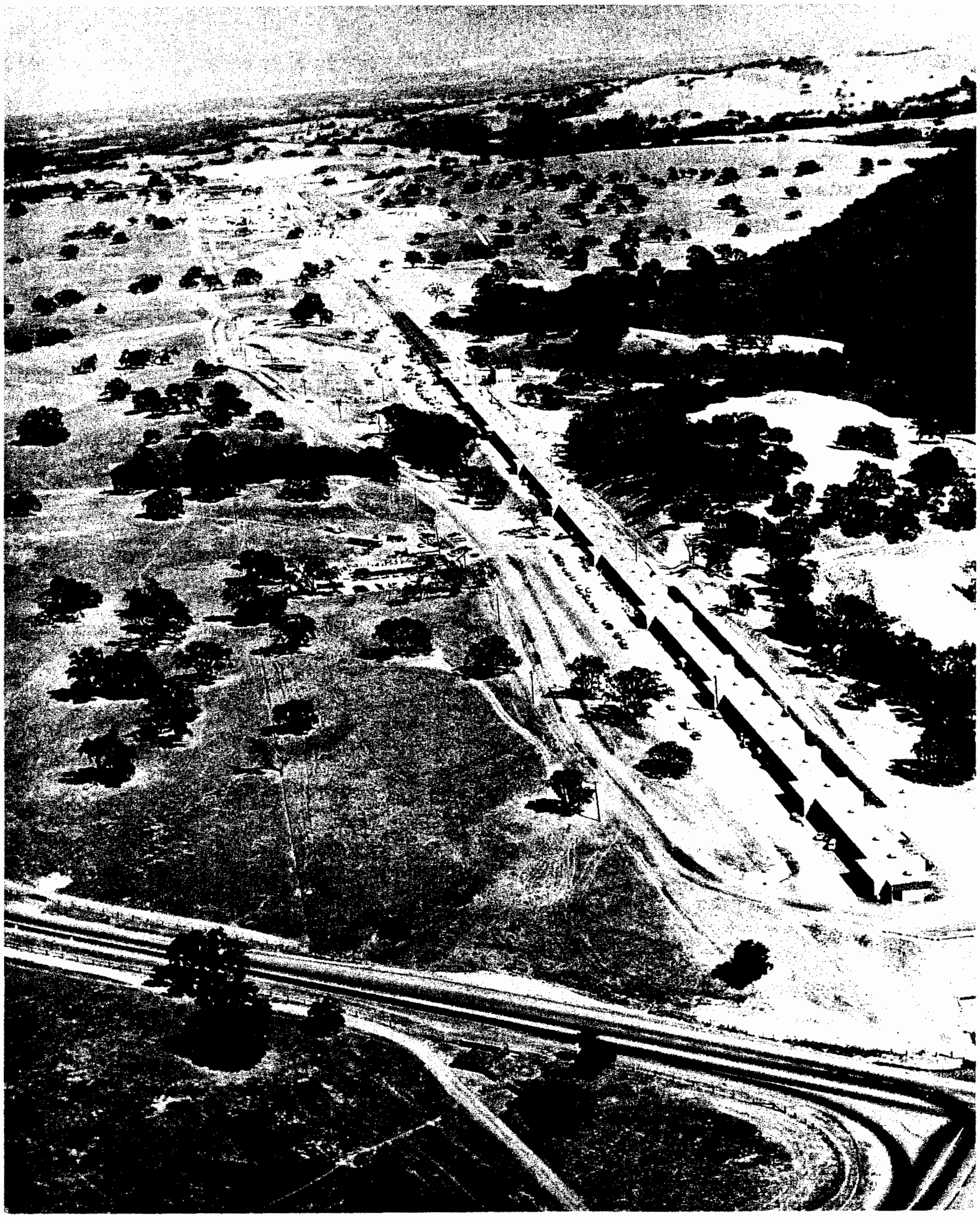

FIG. 4--Aerial view of klystron gallery, looking east.

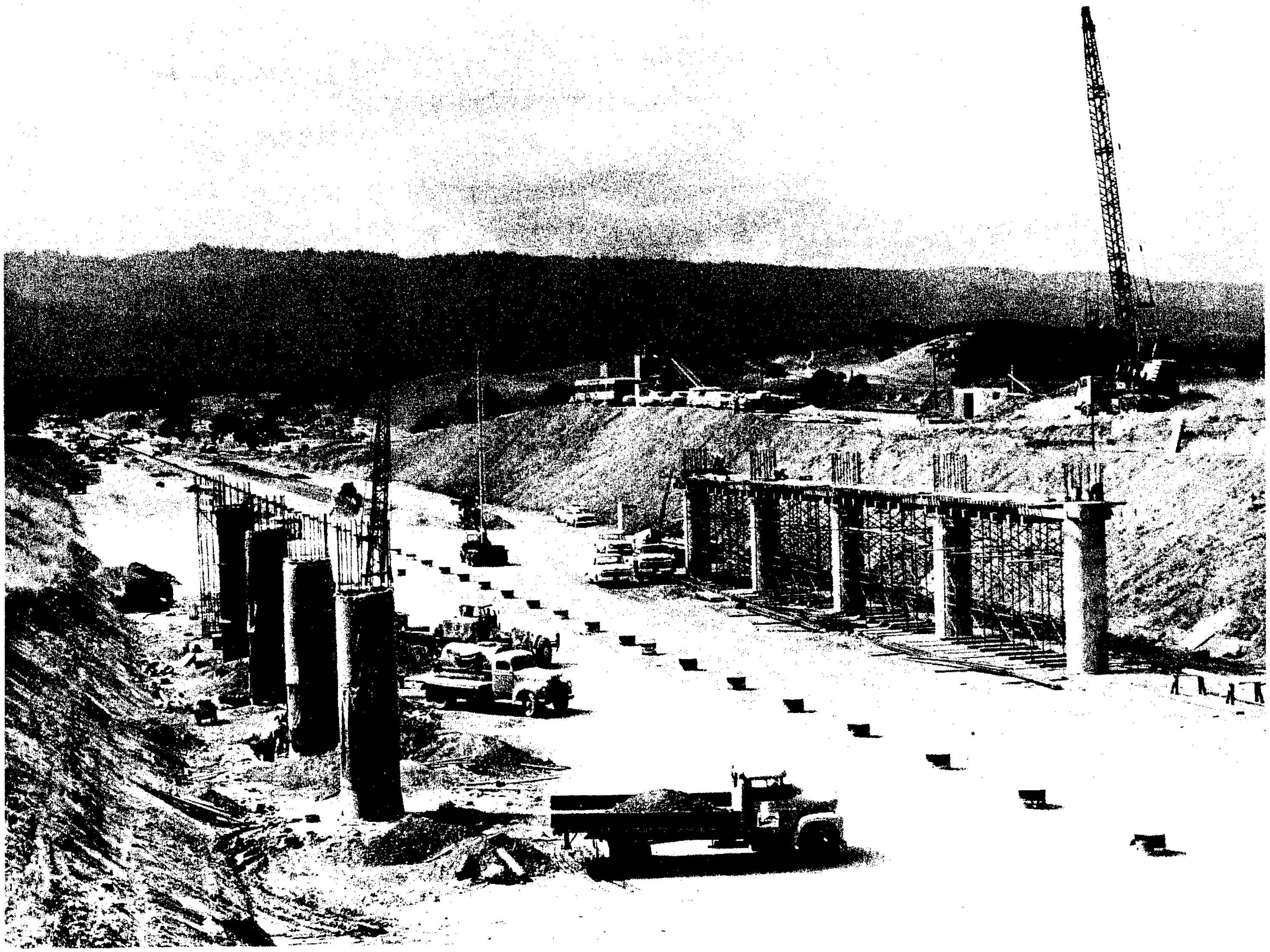

FIG. 5--Freeway bridge substructure under construction.

research area site improvements and utilities (3) are planned as separate contract packages.

Target Area Cranes (5) — Four cranes are planned.

The design of several facilities was completed during the quarter and procurement has been initiated. Bids on the master substation equipment and the switch-house were opened in September and are being evaluated. The specifications for the Data Assembly Building are being printed and will be issued to bidders early in the next quarter. The contract for construction of the beam switchyard has been awarded, and a notice to proceed was issued on September 16, 1964. Design of the materials handling system for this facility is 25% complete.

C. CONSTRUCTION STATUS

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

Facility	Percentage of Completion
Accelerator Housing	98
Heavy Assembly Building	98
Central Laboratory	64
Shops Dining Room	58
Klystron Gallery	35
Landscaping (Increment No. 1)	35
Control Building	30
Klystron Gallery Utilities	
Piping and site improvements (600-Y-1)	35
Electrical (600-Y-2)	1
Cooling Towers (600-Y-3)*	52

*The first of two towers is in operation.

All items of work associated with Sectors 1, 2, 3, 4, and 5 of the Klystron Gallery contract have been completed and turned over to SLAC. Sector No. 6 will be turned over early in the next quarter. Work on succeeding sectors is underway and the work is on schedule.

Work associated with the Accelerator Housing contract is nearly complete. All reinforced concrete and the sub-base and membrane protection for the two-mile underground housing have been completed, as well as the common and stockpile excavation. The access road connecting Alpine Road and the construction site was finished and placed in service.

Four government surplus cranes have been obtained for use in the Heavy Assembly Building, and modification design is underway.

D. PLANT ENGINEERING SERVICES

Alteration of the Electronics Building to provide additional office and laboratory space was completed.

Planning is underway for the move-in of equipment and extension of utilities at the Heavy Assembly Building and Central Laboratory. These two facilities are the next to be occupied, and the work must be coordinated with a phasing out of activities at the temporary buildings on campus.

The Craft Shops are now well established at the Sand Hill site and are providing services for all SLAC departments. The in-house craft force is essentially at its budgeted ceiling strength. Supplementary work performed under a time-and-materials contract for craft services has increased substantially during the past six months.

III. SYSTEMS ENGINEERING AND INSTALLATIONS

A. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. General Accelerator Design

A decision to postpone the installation of the off-axis injector necessitated a review of electrical and cooling water installation drawings to determine the most suitable cut-off point for these services.

The revisions required to incorporate provisions for the baba-abab waveguide configuration ("Operation Flip-Flop") were made to the vacuum system drawings.

As a result of mock-up tests, changes were made in the klystron support frame to alleviate anticipated assembly and seismic problems. Realignment of the frames was completed, and support yokes for klystrons 03 and 06 in Sector 1 of the klystron gallery were installed. Design was initiated of the assembly tooling needed to position the frame with respect to the accelerator centerline and to control dimensional tolerances across the interface between the structural frame and the machined waveguide and klystron components supported thereon.

Four waveguide definitive drawings were issued for project review in August. Two of these involved a shift of the penetration waveguide by 1.505-inches upbeam to provide one-half wavelength shift in phasing and two new drawings showed the baba-abab configuration and the penetration waveguide shift.

The positron source service requirements were made firm so that design of the electrical and cooling water systems can proceed. The vacuum services to be designed and installed depend upon the radiator design; for the time being only the 5-inch vacuum finger will be installed.

The basic dimensional control systems definitive layout was issued for project review. This serves as a convenient repository for information collected from a variety of sources, establishing primary and secondary points of reference in both the klystron gallery and the accelerator housing.

Modifications to the electrical services, cooling water systems installation, vacuum system installation, and klystron support frame procurement subcontracts were completed and submitted.

2. Standards and Specifications

Improvements of the Drafting Instructions are under review. Suggested changes have been prepared for Chemical Film Treatment of Aluminum, Welding Aluminum Vacuum Systems, and Quality Control Workmanship Standards. The sections of the SLAC Standard Parts Catalog relevant to fastening hardware and metals have been drafted and reviewed.

Thirty specifications were written or revised during the quarter in collaboration with the requesting groups.

Assistance on a continuing basis has been supplied to the responsible engineers on the various portions of the support and alignment systems.

3. Model Shop

Activity this quarter included rebuilding the model of a typical 40-foot accelerator module to reflect the latest design of the waveguides and degaussing, plus models of the vacuum field welding study, the mock-up of the 155-mm gun barrels for target area shielding, and the installation of the accelerator (3/8-inch scale) in typical Sector 14. Concrete housings were completed for the beam switchyard model, as were new wooden display bases.

4. Installation Drawings

Work on modification requests for the electrical and cooling water systems continued. For the electronic systems, changes and additions to the Sectors 1 and 2 cable plant were completed, and cross-connect wiring diagrams for Sectors 1 and 2 are in process. Rack layouts and installation drawings for Sectors 3 through 30 were begun. Vacuum system drawings showing the new waveguide configuration were begun, and the Sectors 1 and 2 installation drawings for field use were started.

5. Vacuum

Conductance tests on the 3-inch and 6-inch valve assemblies were completed. The six-inch valves average 1280 liter/second, and the three-inch valves average 355 liters/second. Thermal cycle tests on three-inch and six-inch valves were successful. Two 6-inch valves passed life cycle tests; difficulties were encountered in the three-inch valve life cycle tests.

A leakage current problem exists in two getter ion pumps that were tested; a third pump tested appeared to have acceptable speed. A decision was made to add four anode-cathode pump elements (for a total of 24 such elements) using anodes shortened from 0.790 inch to 0.562 inch. Four pre-production pumps are to be resubmitted.

6. Cooling Water

Final drawings for the positron source cooling water system are being prepared. Flow diagrams were submitted to the positron source review committee.

The corrosion test was shut down and disassembled in July for inspection of pipe internal surfaces. Data was obtained, and the test system was reassembled and put back into operation. The test unit will be moved from the Test Laboratory to the klystron gallery in early October.

A special "low boy" temperature control unit was designed and constructed for use on the testing of a 40-foot module of the accelerator. A temporary make-up water system was installed in Sector 2 in August, and the entire cooling water system is now serviced by cooling tower water. Work is in process on various temporary water service connections necessary for the sector test program.

7. Electrical Services

Substation requirements and changes for the positron source were reviewed. The wide regulation limits that have been established (one percent regulated outputs from 75 to 250 volts dc, combined with currents to 2000 amperes) require special design, and several voltage selection systems were investigated.

Substation VI-A was tested successfully. Load tests and performance evaluations of Substations VI-A and VI-B are not yet possible because a sufficient number of modulator loads are not available.

Tests on Substation VI-B with dc reference voltage were made, and the performance during Sector 1 girder tests was satisfactory.

Installation and testing of the phase monitoring cable are continuing. Both 7/8-inch cable and Prodelin connectors proved satisfactory.

8. Auxiliary Machine Shielding

A mock-up of the penetration with its seal was set up in Sector 3 of the klystron gallery. Various manufacturers of "silastic" compounds were contacted, and a sample sealing diaphragm was used to demonstrate the feasibility of the installation procedure. Procurement is underway to obtain a prototype seal diaphragm having reinforced mesh adequate to support granular radiation shielding material.

9. Electronics

All racks and cables have been installed in Sector 1. Temporary communication facilities have been arranged for Sector Test Team use. Design work was started on the installation package for the instrumentation and control cabling and racks for Sectors 3 through 30.

Forty-three racks were obtained and installed in Sectors 1 and 2 and the main injector alcove during the quarter. This subcontract was expanded to include fabrication of the main injector racks. Design is progressing of racks for Sectors 3 through 30, with emphasis placed on on the completion of fiat racks first.

The first battery charger production unit performed according to specifications, and this design was accepted on the basis of the performance. The first battery was checked out and installed in Sector 1.

A study is being made on various sound and simultaneous multilingual translation systems for use in the auditorium. The study is presently concerned with costs and the performance of wireless vs wired-in translation systems.

B. BEAM SWITCHYARD

1. BSY Housing

Bids for construction of the beam switchyard housing were received in August and work started in September. Several change orders are currently underway, including increasing the diameter of radioactive water system penetrations to the housing, minor relocations of vacuum penetrations, and installation of anchor bolts for SLAC equipment.

2. Data Assembly Building

A review of 90% Title II drawings was completed, and the changes requested were forwarded to the cognizant personnel. This building will be out for bid early in the next quarter.

3. Electrical System

Design of the cable tray system is almost completed. A prototype remotely operable disconnect device has been received and is under test. Three prototype sealed MgO cables have been received. One failed under test; tests on the others are in process. The test facility for processing MgO cable and testing all radiation-resistant cables for effects of humidity is nearing completion. A block diagram of the instrumentation and control system is in the preliminary stage.

4. Cooling Water

Work is in process on the final flow diagrams and layout drawings. Routine progress drawings are being issued for review.

5. Vacuum

The first draft of the specifications for the beam switchyard vacuum pumping system was 80 percent complete at the end of the quarter. Calculations on the pressure distribution in the A beam leg were begun. A prototype of the control unit for the fast pressure sensor will be built. Parts for the fast valve have been fabricated and assembly has been completed; mechanical motion tests indicate all parts operate as designed. Piston retraction, automatic engagement, and the locking cam recoil plate operate with slightly greater performance than anticipated. The initial measured time of gate closure was between one and two milliseconds.

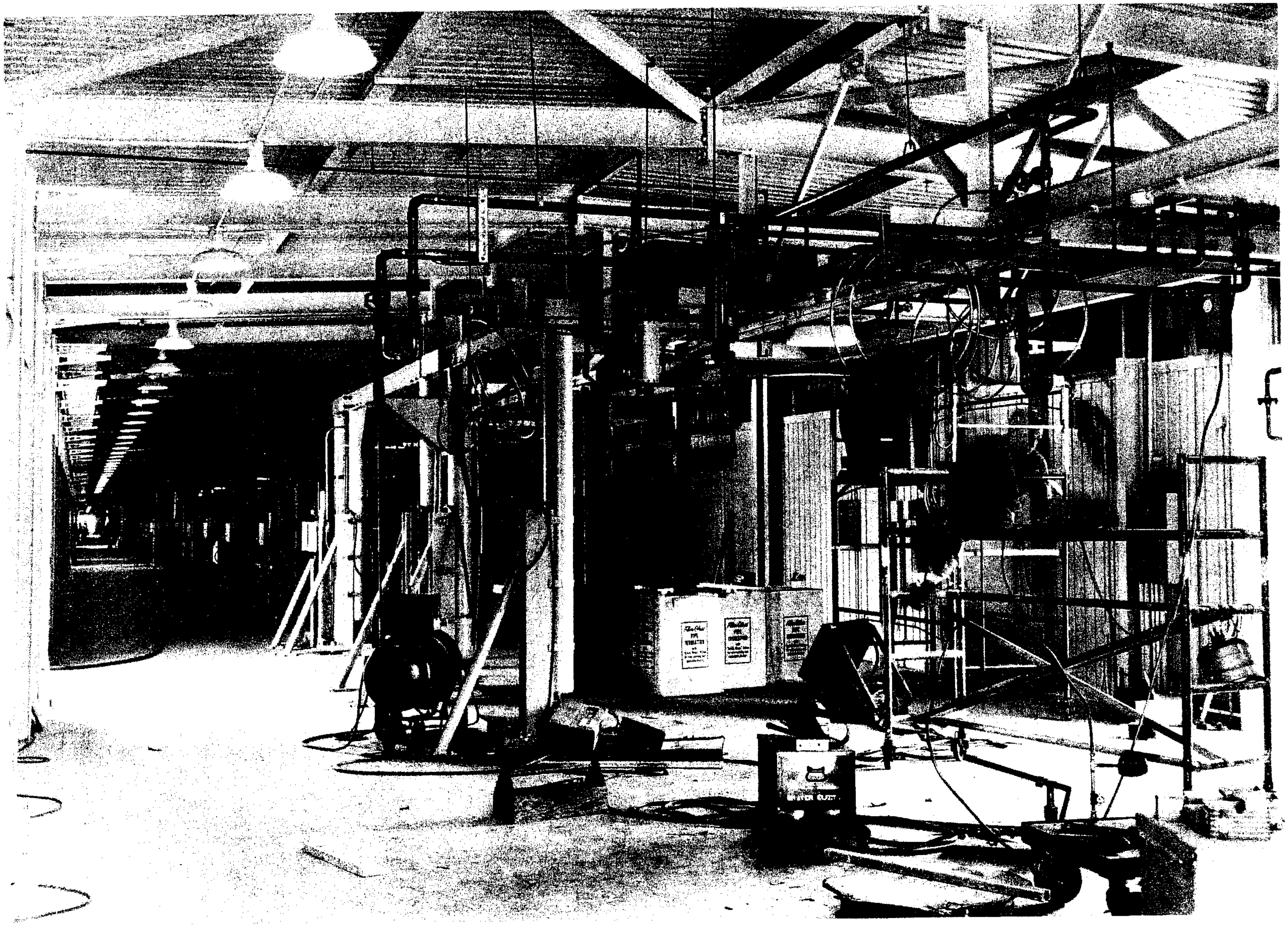

FIG. 6--General view from main injector to Sector 1, klystron gallery.

FIG. 7--Prototype 40-foot accelerator module installed in Sector 1 of the accelerator housing.

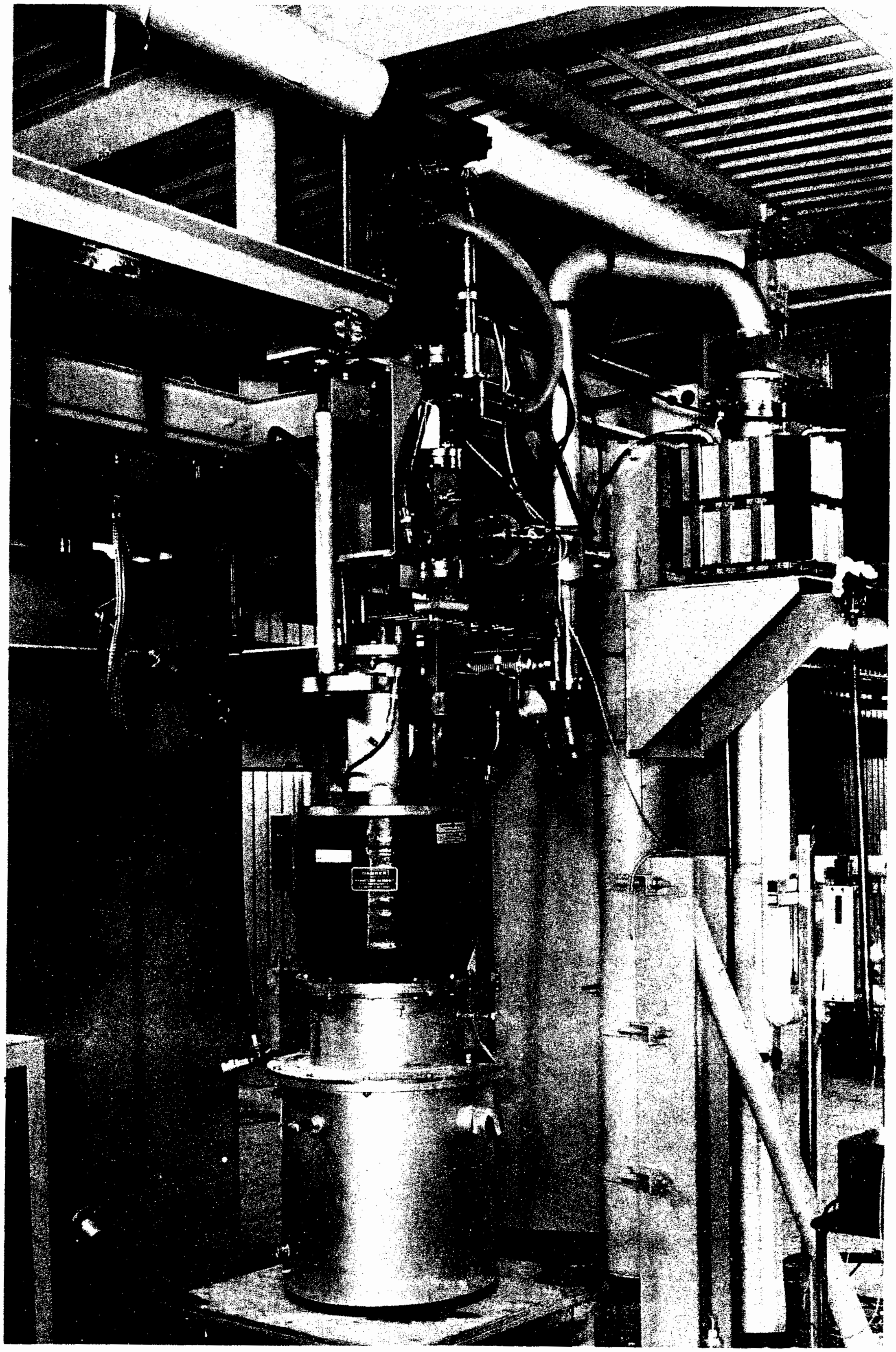

FIG. 8--Klystron tube, vacuum pump, and waveguide installed in klystron gallery for prototype module test.

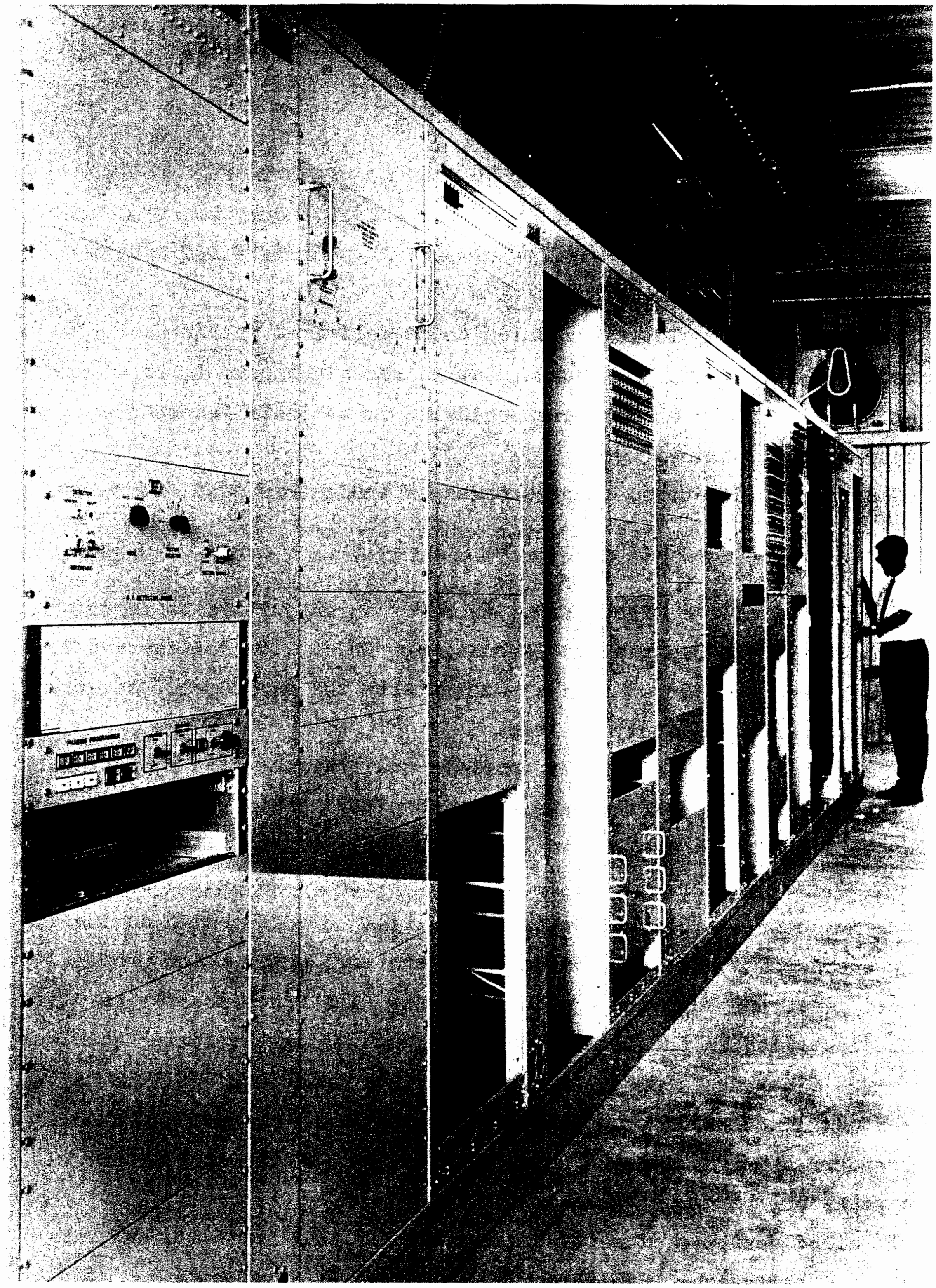

FIG. 9--Control racks in the instrumentation and control alcove, Sector 1.

IV. ACCELERATOR PHYSICS

A. INJECTION

1. Main Injection System

The electrical system, which includes all ac supply sources, cable trays, and penetration hardware, is essentially complete and is presently undergoing final acceptance.

The control console is scheduled to be delivered in November 1964. The internal wiring of the instrumentation racks and console is underway, and all racks and the console are scheduled to be installed in the main injector area by Spring, 1965.

Controls, indicators, color schemes of indicators, and other instrumentation components in the injector system are now standardized to agree with overall project standards.

The design of the high current dc power supply with slow regulation is complete and the bid package is being prepared. The low current dc supplies have been ordered in conjunction with the quadrupole, steering, and degaussing power supply package.

The cooling water system is complete and available for operation.

The bid package for the main vacuum manifold is in process. Vacuum pumps are either in-house or are being procured.

The 0.75c buncher and the ten-foot disk-loaded waveguide section for the injector are being fabricated and will be cold-tested during the coming quarter. Preliminary designs for the collimator, beam profile monitor, lens, and supports are in progress. The bunch monitor cavities will be installed in the Injection Test Stand during the coming quarter before the final design is determined. A prototype focus coil is on order and will be used to conduct heat transfer and electrical tests. The standard steering dipoles have been ordered and the special steering dipoles are being designed.

Detailed design of the waveguide components is underway, and fabrication of parts is scheduled to begin during the next quarter. Design of the supporting structure for the waveguide system will begin next quarter.

2. Off-Axis Injector and Inflector Systems

Following a project policy decision, the construction and installation of the off-axis injector have been postponed. Only those tasks which were near completion at the time of this decision have been completed. A complete set of drawings pertaining to the system is being kept on file.

3. Electron Guns and Modulators

Production of parts necessary to test the bombarder and thermal design of the electron gun, model 4-1, is about 50 percent complete. Development work is continuing in such areas as filament structure and material, joining of molybdenum and tungsten, and other fabrication processes. Computer studies of the bombarder diode electron optics have been used to check the design of the electrode and filament configurations.

Gun model 1-1 was removed from the Mark IV accelerator at the end of the quarter and stored. It will be used for preliminary testing of Sectors 1 and 2. A spare gun has been built by the High Energy Physics Laboratory and will be available in October 1964. Quantatron gun model 2-2 has been operating almost continuously on the Injection Test Stand.

The second Manson modulator, model 4-2, was received this quarter and is undergoing acceptance testing. The improvements in pulse shape obtained in this second model will be incorporated at SLAC in the first model.

4. Injection Test Stand

The Injection Test Stand operated during most of the quarter and was utilized for a variety of experiments, related both to injection work and to requests from other SLAC departments. Experiments included buncher studies, operation of the new water-cooled slits, overall testing of the vacuum system, measurements of the shunt impedance of the rf sweeper, and radiation studies.

5. Beam Knock-Out System

Because the installation of this system has been postponed, final design of the system will not start until the end of the year.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

The main and sub-drive lines for Sectors 1, 2, and 3 are now installed and tested, and delivery on subsequent drive line shipments is expected to be on schedule. Auxiliary switching equipment to connect the main booster amplifier and the sub-booster modulators to their respective drive lines was received and installed. Measurement of the group velocity will be performed over a 700-foot span in the klystron gallery.

2. Varactor Frequency Multipliers

The production go-ahead was given to the vendor for the remainder of the varactor frequency miltipliers. Construction of the twenty-eight units of the production run has been completed, but the vendor is experiencing difficulty in obtaining satisfactory diodes from his supplier. A backup supplier for the diodes is being sought by both the vendor and SLAC.

3. Main Booster Amplifiers

Both main booster amplifiers have been installed in the injection area of the klystron gallery. The transfer switch and dummy load have been installed and both amplifiers have operated simultaneously, one into the main drive line and the other into the dummy load. Operation has been satisfactory; only one or two trip-outs have occurred, which apparently are caused by surges on the main power lines.

4. Sub-Booster Modulators

The sub-booster modulator contract has progressed to the point of final inspection and acceptance of the two pre-production units. Phase stability across the sub-booster klystron was found to be well within specifications and the pulse voltage stability was excellent. At present, the modulator operates with two switch tubes; however, it is believed that the addition of a third switch tube will improve both the operation and the reliability of the unit, and the addition of this extra tube is presently being negotiated.

5. Master Oscillator

The construction of the master oscillator is proceeding on schedule. A demonstration with a prototype brought to SLAC indicated that no major problem should be encountered. Delivery of all three units is expected in late November.

6. RF Drive System Control Circuits

Equipment is being designed to provide for automatic switching of the master oscillator and main booster amplifiers in the event of failure. This equipment will be installed in the master oscillator-frequency counter rack located between the two sub-booster modulators in the injector area.

7. Preliminary Use of the RF Drive System for Sector Tests

The rf drive system, consisting of a temporary master oscillator, a main booster amplifier, a varactor multiplier, a temporary sub-booster modulator, and main and sub-drive lines, has been successfully operated for the majority of sector tests to date.

8. Phase Shifters for Positron Acceleration

For positron acceleration, the drive signals for the first ten sectors of the machine will be switched by 180° using a ferrite switched circulator identical to those used as wobblers in the phasing system. Switching will have to be obtained on a pulse-to-pulse basis, and a driver has been developed for this purpose. Plans for obtaining proper trigger signals from the pattern generator system have been formulated.

9. Drop-Out Cables

Because of a change in connectors, a slight delay has occurred in this contract. However, this delay will not affect the Sectors 1 and 2 tests.

10. RF Drive Power to the End Stations

The method of extending the main drive line into the end station areas has been tentatively chosen. The present plan is to extend the 3-1/8-inch coaxial main drive line into both end stations A and B via the Data Assembly Building. The drive line will be maintained at a constant temperature by means of a temperature-controlled water line and appropriate insulation; this assembly will be routed along with the rest of the cabling to the end stations. After the Data Assembly Building, the drive line will divide into two separate runs to end stations A and B. At each end station, the user will be supplied with the necessary frequency multipliers and amplifiers for his specific requirements.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

Most of the problems on the Isolator-Phase Shifter-Attenuator units have been resolved and quantity production is well underway. The first sixty units are expected to be delivered by November 7, 1964. One issue which remains unresolved concerns the measurement of phase shift versus temperature. The temperature compensating device used by the vendor consists of a short length of RG9 cable with a negative temperature coefficient. At present, measurements made at SLAC on a unit incorporating this device do not agree with measurements reported by the supplier.

The addition of a dual directional coupler to the output of the standard units has been negotiated. A pre-production sample has been tested; the couplers will be fitted to all production units and retrofitted by SLAC to the pre-production run.

Thirty special units with dc control monitors and potentiometer readouts are also being supplied. These units will precede the subboosters and will be adjusted from Central Control. The control phase shifters will also require a length of phase compensating cable.

2. RF Detector Panels

Bids on the rf detector panels have been received, but the subcontract has not yet been let.

3. Programmers and Electronics Units

The contract for these units has been awarded. A special test unit has been designed and built for automatically testing the wiring and functioning of the programmers. It should enable the subcontractor to complete testing of the programmer in about five minutes.

4. Linear Detectors

The design of the thermionic diode detector housing has been further revised. Component and subassembly drawings are nearly complete. A bid package will be prepared for a total of 236 housings, not including spares.

5. Permanent Beam Analyzing Station

Work on fabrication of the permanent beam analyzing station to be installed at the 40-foot point in Sector 1 has been in progress for the past month. The station is expected to be ready by the end of the year. The secondary emission monitor foils and foil box have been redesigned; instrumentation, control, and protection systems are being developed. A mechanical switch will be used to scan the foil signals, and these will be viewed in integrated form for rough beam spectrum adjustment. Protective devices include SEM foils inside and outside the vacuum envelope, thermocouples, and a vacuum gage interlock. In addition, there are interlocks on the cooling water flow, vacuum valve position, and beam dump position. The spectrometer magnet has been delivered, tested, and found to be satisfactory. A commercial power supply suitable for the magnet is being procured.

6. Temporary Beam Analyzing Station for Sector 2

This station has been designed so that it can analyze beams with energies up to 1.5 GeV. The spectrometer magnet will be almost identical in design to the one used in the permanent station but the pole face will not be normal to the incident beam.

Mechanical design is being kept as simple as possible. Because the beam power will be kept low in order to limit radiation levels, the dump will not require water cooling. Only one protection circuit for vacuum failure is planned.

The magnet power supply for the permanent beam analyzing station will also be used on this temporary station, and a second supply obtained from the Mark IV accelerator will be held in reserve.

A prototype fast scanner developed by the Research Division will be used for SEM signal display, with the permanent beam analyzing station available if required.

7. Beam Position Monitors for Drift Sections

Detailed mechanical design of two prototype position cavities and one reference cavity has been completed. Components for one assembly have been made at SLAC and three further sets have been machined by a subcontractor. Cold tests carried out prior to brazing indicated the need for minor dimensional changes; these have been made and tests are proceeding. The design of the coupling assembly is being improved to facilitate setting of the coupling and the loaded Q. The design of the beam position detector panel has been revised. A prototype unit is being assembled, and orders for three sets of rf components have been placed. The revised schematic diagram is shown in Fig.10. As soon as cold tests have been completed on a monitor assembly, beam tests will be carried out on the Injection Test Stand.

8. Beam Position Monitors for the Beam Switchyard

Further tests using the Mark IV accelerator showed that the sensitivity of the resonant ring position monitor was too low with a 3 × 1-3/4-inch beam aperture. Revision of switchyard aperture requirements revealed that a circular aperture 1.8 inches in diameter could be tolerated, although 2 inches would be preferred. It was decided to stop work on the resonant ring, and instead to build TE_{102} resonant cavities similar to the in-line drift section position cavities, by having aperture diameters of 1.6, 1.8 and 2.0 inches. These were tested at the Mark IV accelerator to establish the dependence of sensitivity on aperture diameter. As a result of these tests, it was decided to use cavities with 2-inch-diameter apertures at four stations in the switchyard, with the use of 1.6-inch aperture cavities remaining as an alternative at the two in-line stations in the switchyard. The use of cavities, which are much smaller and easier to fabricate than the resonant rings, makes it possible to include vertical as well as horizontal position monitors at each station. Circuit requirements for beam monitor detector panels to be installed in the upper tunnel alcoves have been ascertained. The need for remote readout and control in the Data Assembly Building has made it necessary to include a solenoid-controlled coaxial switch and

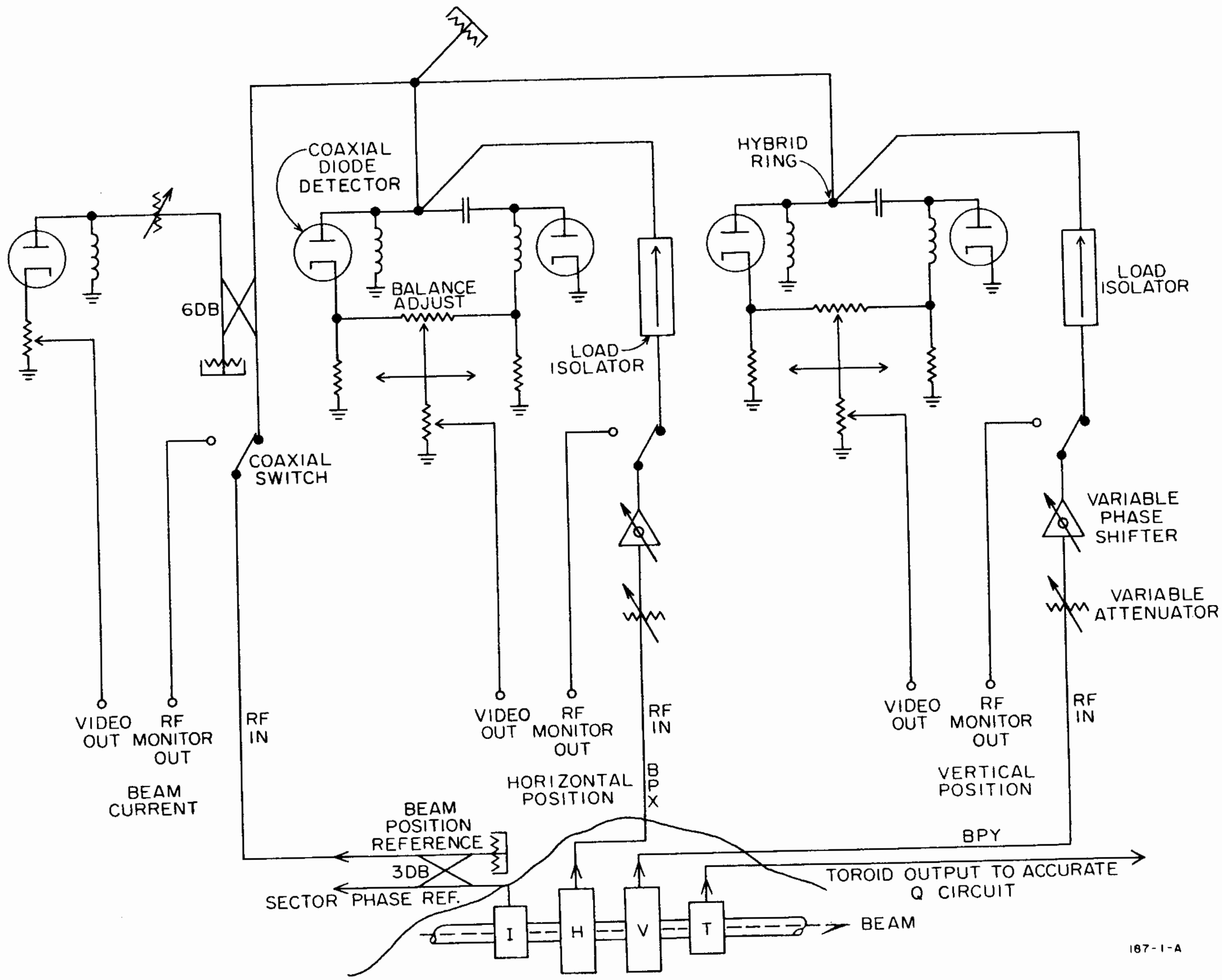

FIG. 10 - REVISED SCHEMATIC FOR IN-LINE DRIFT SECTION BEAM POSITION MONITOR SYSTEM

a monitor-driven phase shifter, as well as cathode follower video amplifiers. Operation and servicing in high radiation environment require careful selection of coaxial cables and the use of quick-disconnect seals and adaptors. The detailed design of each station will be worked out during the next quarter.

D. GENERAL MICROWAVE STUDIES

1. RF Separators

Measurements of the efficiency of the LOLA III deflector ($v_g/c \approx -0.007$) were repeated on the Injection Test Stand and failed to agree with the previous results obtained for the same structure on the Mark IV Accelerator. Whereas the transverse shunt impedance measured on Mark IV was reported as 5.56 MΩ/meter, the new value appears to be 11.25 MΩ/meter. Examination of the couplers used in the Mark IV experiment to measure the incident and output rf power to the separator indicates that their calibration may have been in error. Because the same couplers were used for all three separators on Mark IV, it appears desirable to retest at least one other separator prototype such as LOLA II ($v_g/c = -0.0296$) in order to verify whether this measurement was accurate or not. This test will be performed on the Injection Test Stand in the near future. From the result, it will be decided which design is most efficient and should be selected for use both as an rf separator and as a deflector after the positron radiator, to eliminate electrons when positrons are being accelerated.

2. Coupler Asymmetry

As reported in the last status report,* a number of attempts have been made to correct the phase asymmetry found in the coupler cavity. Slanting the entire endplate of the coupler, thereby making it appear

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 April to 30 June 1964," SLAC Report No. 32, Stanford Linear Accelerator Center, Stanford University, Stanford, California (October 1964).

as if that cavity were misaligned and counteracting the deflecting force due to the transverse phase shift, did not yield the desired result. A number of measurements were made by using two large tuning screws located in the endplate. Several cases were studied as a function of relative insertion of the screws. Another experiment was done by actually machining the entire endplate with a 1° slant.

Another series of experiments is being tried using a symmetrical coupler with two input irises. Two methods are under consideration. In the first method, rf power is fed into the cavity from one side only, and the other iris is connected to a short piece of waveguide which terminates in a moveable short. Amplitude and phase shift in the cavity are studied as a function of iris apertures and short position. In the second method, rf power is fed simultaneously from both sides. It is not believed that these experiments will be of practical use to the two-mile accelerator since "Operation Flip-Flop" has been adopted and will actually accomplish the same result. However, since the complicated experimental setup necessary for these microwave measurements is presently in existence, it seems desirable to find out for other possible uses whether the coupler asymmetry problem can, in fact, be solved inside the cavity itself. Work on this subject is still in progress.

Another verification was made to measure the offsets required to obtain amplitude and symmetry in the input and output couplers of a production 10-foot accelerator section. The required offset for the input coupler is 0.145 inch, and the offset for the output coupler is 0.080 inch.

E. OPTICAL ALIGNMENT SYSTEM

1. Alignment Targets and Frames

The contract for the manufacture of the alignment targets and frames was awarded. The targets will be made by ruling each individual pattern on a tape-controlled ruling machine. The punched paper tapes are generated by converting the magnetic tape output from a Stanford IBM-7090. Both the magnetic tape and the punched paper tape are checked for errors, and a parity convention is carried on both tapes to prevent any errors in reading the tapes. The basic integrity of the targets is guaranteed by the automated character of the manufacturing process; thus only the quality of the work and the accuracy of mounting need be considered in testing. The test will be concerned primarily with the optical properties of the targets. Wherever possible, the test will consist of using the target to focus the beam to an image on the focal plane of a camera with the lens removed. The resulting image will then be studied on a microdensitometer to determine the sharpness and contrast. Standards of performance will be determined by using a special computer program to calculate the intensity of various points on the image. In addition, targets will be checked with an optical comparator.

F. MAGNETIC SHIELDING

A partial delivery of the magnetic shielding order has been received and evaluated. After improving the annealing and handling techniques which were originally used, the material which was delivered gave a satisfactory shielding factor of 20 to 24 for 1 cps.

V. INSTRUMENTATION

A. GENERAL

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

B. DATA HANDLING

1. Status Monitoring

The procurement specification for status monitoring equipment has been issued. Binary status information at each sector will be transmitted to Central Control on a time-shared multiplex system. Each of 100 channels will be sampled in sequence at a rate of 180 channels per second. The sampling is synchronous with the 360-pps repetition rate of the accelerator, and provision has been made for synchronizing the 100 channel frames originating from the transmitters in all of the sectors. The multiplex signal is transmitted to Central Control on an FM frequency shift transmission system. Receivers decode the first 32 channels for each sector for continuous presentation at the Central Control Console.

The three receivers that decode the entire set of 100 signals may be switched to any three sectors. Any channel from any sector may thus be monitored on demand.

2. Equipment Protection System (Beam Shut-Off)

The equipment protection system will consist of two subsystems: a tone generator and receiver, for which procurement is underway; and a set of tone-interrupt units, one at each sector. The design of the tone-interrupt units is complete, and a breadboard is under construction.

3. Beam Monitoring

A technical description of the beam monitoring system has been issued which records in one document the subsystem specifications for sensors, detector electronics, data transmission, and display. 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 three variable-amplitude pulses per beam pulse representing log Q, x, and y for each beam pulse.

In Central Control there is a multiplexer for each set of signals. One samples the 30 FM signals and presents them on an oscilloscope to give a trace which reports the beam intensity as a function of sector number for each pulse. When the operator is dissatisfied with the beam transmission through the accelerator, he may deduce from this display where the beam is being lost. The second multiplexer takes 90 samples from the three baseband inputs from each sector and displays log Q, x, and y on three separate oscilloscopes. From this display the operator can determine the appropriate steering corrections to be made.

The final engineering design report for the baseband transmission system has been issued for review. Bid negotiations for the FM transmission system are underway.

C. BEAM GUIDANCE

Further work was carried out on the electronics for the beam position monitoring system, following a report of the results of tests on the Mark IV accelerator. In particular, the circuits were packaged in a form similar to that which will be used in the accelerator itself.

Video intensity monitors using ferrite cores were permanently mounted in the Mark III and Mark IV accelerators, and the results obtained from these monitors agreed with those obtained from other devices already present. Work on the electronics to give a signal linearly related to the charge in each beam pulse passing such monitors has been continued. A low noise amplifier suitable for this application has been designed and built. Additional tests to study the effectiveness of using a copper tube to totally enclose the cable from a ferrite intensity monitor were performed on the Mark IV accelerator. This was found to help reduce unwanted pick-up of signals which apparently originated at the injector.

A final engineering design report dealing with the baseband telemetry system was issued. This system transmits $\ln Q$ (beam charge), x-, and y-position information to Central Control. A completed breadboard to display this information has been built and tested.

The contract for the constant current supplies to power the quadrupole, dipole, and degaussing coils was awarded. A preliminary engineering design report for the equipment to control these supplies remotely was issued. The design work is essentially complete, and work on the packaging of the units was commenced.

D. TRIGGER SYSTEM

All trigger system components necessary for a complete test in Sectors 1 and 2 are installed and operating satisfactorily. These components are the sequence generator, master trigger generator, rate selector, simplified pattern generator, main trigger line, sector take-off transformers, and Sectors 1 and 2 trigger generators.

The sector trigger generator final prototype is nearing completion and will go out for bids next quarter. Preliminary criteria for the beam switchyard and injector trigger generators were written. Design work is presently underway on the injector trigger generator and the pattern generator. A preliminary injector generator will be ready for Sectors 1 and 2 beam tests.

E. MODULATOR-KLYSTRON PROTECTION SYSTEM

As a result of experience gained in the installation and testing of Sectors 1 and 2, it became apparent that the use of the distribution frame to interconnect the electronic portion of the modulator-klystron protection system and its associated relays was a major source of wiring and checkout difficulty. A redesign was therefore indicated which would integrate the functions of the relay and the electronic circuitry into an integrated package. To expedite this conversion, the plug-in module approach was dropped in the mechanical design, and the tracking features of the electrical circuitry were eliminated in favor of adjustable thresholds. The system will be retested extensively during Sectors 1 and 2 tests and will then undergo a final review.

F. PERSONNEL PROTECTION SYSTEM

An engineering design report was issued for the personnel radiation protection system for the accelerator housing. Criteria for the personnel protection systems in the beam switchyard and end stations are being firmed up as the design of these areas approaches completion. All special components have been designed and prototypes have been fabricated.

G. CENTRAL CONTROL

Mock-up panels in the Central Control Console are being replaced with functional prototypes as the design of each panel is completed.

A back-up console has also been assembled with mock-up panels. Equipment located in this area is for beam setup only or for trouble shooting to relieve congestion on the panels immediately in front of the operator.

H. MACHINE PROTECTION

Two separate types of radiation detectors for the accelerator housing have been proposed: the coaxial cable type of continuous ionization chamber, and a set of discrete ion chambers to detect radiation at each sector. Both systems will be tried out in Sectors 1 and 2 and the results will be used to determine which shall be used for the whole machine. The cable for the long ion chamber has been installed in Sectors 1 and 2. Prototypes of the discrete ion chambers for Sectors 1 and 2 have been constructed and are ready for installation.

VI. HEAVY ELECTRONICS

A. MAIN MODULATOR

1. Modulator Procurement

All 20 pre-production modulators were received before or on schedule.

Two modulators (serial numbers 2 and 3) are on life test in the Test Laboratory with 2304 hours and 1880 hours of high voltage operating time respectively. The rest of the pre-production modulators are installed in the Klystron Gallery in Sectors 1 and 2. Three modulators in Sector 1 are operating into klystron loads, six are on water loads and one is not operating for lack of a load. Most of these modulators have on the order of 10 hours operation on them. The last modulator in Sector 1 has been operated 122 hours in the "Girder 8" test setup, which includes fiat rack, klystron, and rf plumbing in the klystron gallery and a 40-foot accelerator section below in the accelerator housing.

As many as eight of the modulators in Sector 1 have been operated simultaneously on the variable voltage substation. The sector test team is performing various tests on these modulators at the present time.

The modulators in Sector 2 have not been operated except during acceptance tests at Ling.

The main difficulty with the modulators has been the main high voltage rectifiers; five of the units developed arcing between high voltage points within the assembly. The manufacturer subsequently redesigned and rebuilt five of these units, and the rebuilt units appear to operate satisfactorily.

As a result of the tests, about 20 changes have been developed which will both improve the operation of the modulators and minimize component failures.

2. De-Q'ing

Switching devices for the de-Q'ing system continued to be life-tested during this period.

One of the pre-production modulators in the Test Laboratory (serial No. 2) was equipped with a 1100-volt silicon controlled rectifier as a de-Q'ing switch. It failed after about 600 hours of life testing. The gate pulse power was increased in order to break the junction down more rapidly during the fast rise time of the current being switched. In this way, a larger area of the junction carries the switched current, resulting in less instantaneous heating in those parts. (General Electric has found that for low amplitude gate pulses the spreading rate in the silicon chip is of the order of 0.1 millimeter per microsecond.)

A new 1100-volt SCR was installed in Serial No. 2 modulator. With a diode load, as of the end of the quarter, 1200 hours of operation had been logged on this unit.

Serial No. 3 pre-production modulator was equipped with two of the above-mentioned SCR's in series as a parallel experiment to determine if more hold-off voltage capability is required. At the end of the quarter, this system had logged 1100 hours of life.

A third system, using a 50:1 turns ratio in the charging inductor and a single 800-volt SCR, has over 2000 hours life in prototype No. 1 modulator.

3. Switch Tubes

The ZT-7004 hydrogen thyratron developed excessive anode delay time variations after approximately 200 hours of life at full power. The manufacturer felt that this tube was too small to be stable at the SLAC power level without extensive development, and preferred instead to devote development efforts to the larger ZT-7005 tube. At the end of this period a ZT-7005 tube was shipped to us for evaluation. Concurrently, because switch tubes were needed for the pre-production modulators, it was decided that two GL-7890 tubes would be substituted for each ZT-7004 to be delivered under the contract. Ten of the pre-production modulators in Sector 1 were fitted with the GL-7890 tubes. They operated satisfactorily, but single tubes are preferred because they are less expensive to operate and require less maintenance.

Excessive kickouts and poor cold starting characteristics were experienced with the KU-274B and KU-275A tubes. Most of the kickouts occurred during the first few hours of testing a new tube, an "aging period" well known in the industry. The vendor modified some of its test modulators to simulate SLAC load characteristics, and evaluated several of the rejected tubes on these modulators to learn more about the operation of its tubes under our load conditions.

It was decided that an aging period and an increased number of kickouts thereafter (1 per 12 hours at full power) would be allowed for the first 25 tubes delivered under the contract, with the balance of the tubes (25) to be full specification tubes. In tubes received near the end of the quarter, the aging period appeared to have been reduced to about one hour in some tubes, and the tubes appeared to have a low kickout rate thereafter. In addition, because life testing of KU-274B tubes indicated that the life of that tube would not be much over the 1000-hour warranty period, it appeared to be uneconomical to use them in spite of their low initial cost. The contract was therefore modified to allow delivery of the larger KU-275A tube in lieu of each KU-274B tube to be delivered under the original contract. The life of the KU-275A tubes appears to be quite good. Of three tubes operating in test stand modulators into klystron loads, one has over 2600 hours on it and is still operating, and the other two have over 1500 hours of operation.

A third company has developed a new tube, the CH-1191. After a few hours trial run in a SLAC modulator, this tube appeared to be very good, with extremely small anode delay time variation and a very good kickout rate.

One of these tubes was then supplied to SLAC for life testing, and again appeared to be a very good tube. It ran 1675 hours of essentially full power into a diode load. Its failure was probably premature, because there might have been too much current into its pre-trigger electrode during tests with "keep alive" voltage on that electrode.

Continuing efforts to improve SLAC modulators, the use of a dc "keep alive" voltage on the pre-trigger electrode of the thyratrons was explored. The result of this is to maintain a plasma of ions in the vicinity of this electrode so that the tubes might operate more stably. It was found that up to 300 milliamperes of direct current helps to stabilize the anode time delay for all these thyratrons. Anode time delay variations with power and repetition rates can be reduced to a few nanoseconds by use of such a technique without sacrificing other qualities.

4. Pulse Transformer Tank Assembly

Thirteen complete pulse transformer tank assemblies were made during this period. Some were fitted with water loads for life tests of modulators and tanks in the klystron gallery; others were mounted on klystrons. In general, the tanks worked well. Some initial troubles were experienced with the capacitive voltage dividers and with a few of the bypass capacitors on the pulse transformer circuitry.

The search for a better oil expansion tube continued. A metal bellows scheme appeared to be the best solution, so such a system was designed and procurement initiated.

The supplier of the pulse transformer delivered 20 pre-production units. Excessive core losses exhibited have required the supplier to initiate rework now in process.

B. SUB-BOOSTER MODULATOR

The manufacturer of the sub-booster modulator completed the first unit during this quarter.

In SLAC's first sub-booster modulator design two switch tubes (4 PR 1000's) were used. In life testing of sub-booster modulators in the test stands, the switch tubes degenerated in the first few hundred hours. Their peak current capacity would drop to the point where they were not capable of supplying a large enough peak current to charge stray capacitances during the fast rise time on the output pulse (0.2 μsec).

A new sub-booster modulator has been built by SLAC as a backup measure.* Three 4 PR 1000's were used in parallel instead of the usual two. From all indications, three tubes are to be preferred over two because rise time on the output pulse can be met more easily and held within specifications over a longer period of time.

This modulator is installed in Sector 2 and is ready for operation. It has an improved high voltage regulator which will regulate power supply output voltage to 0.01%. It has many other improvements as a result of our experience with the test stand sub-boosters.

For Sector 1 tests, one of the surplus test stand sub-boosters was installed. It appears to operate quite successfully.

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*"Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1964," SLAC Report No. 30, Stanford Linear Accelerator Center, Stanford University, Stanford, California (June 1964).

VII. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

During the reporting period the first 40-foot segment of the accelerator was installed in the accelerator housing at Station 8 of Sector 2. (The installation is temporary because the 40-foot support girder and other components of the 40-foot segment are prototype rather than production items.) The penetration waveguides, the crossbar, the waveguide vacuum valve, and associated components for the segment were also installed. A prototype klystron was installed and power tests were performed.

During the transportation of the assembled 40-foot segment from the assembly area to the accelerator housing, accelerometer checks were made to determine the loadings on the girder. A maximum acceleration of 0.3 g's was measured. Measurements were also made at several stages of the transport and revealed that the alignment of the components on the girder was not perceptively disturbed in transit.

B. ACCELERATOR STRUCTURES

1. Low Power RF Tests

During the period, a total of 47 ten-foot sections of disk-loaded waveguide were tuned, tested, and quality-control checked in the low power test room.

Several modifications in the tuning procedures were begun during the quarter. The most significant change was the making of a removable fixture for the tuning station that allowed the coupler cavities to be tuned while in the machine. The design of a permanent fixture to provide for this coupler tuning was completed, and the fixture should be made and installed by the middle of next quarter.

Other modifications, which add additional features to the tuning station, consisted of adding interlock circuits to monitor temperature, pressure, and possibly rf input frequency at the accelerator section, as well as the water and vacuum systems. This monitoring will provide additional information on these conditions at the operator's tuning console. The interlock arrangement will help to protect an accelerator section from damage or improper tuning by automatically stopping the tuning and providing warning if there is a variation from a specified tolerance in any one area. Presently, the frequency and the two systems are visually monitored. Additional provisions were also being made for monitoring the hydraulic system more closely through the phase meter on the control console.

2. High Power RF Tests

Forty-seven accelerator sections were processed through the high power testing station during the quarter. The time required for the test of a section decreased significantly during the period. This can be attributed to increased experience of operating personnel both in handling the sections and in maintaining the test equipment. Also, the vacuum system worked better with a shorter process time and helped, in turn, to provide for shorter times. By the end of the period, an average of three sections of disk-loaded waveguide were being processed daily.

3. Measurements of Coupler Fields in the Accelerator Structure

The measurements of the phase and amplitude of the axial components of the coupler fields reported during the last period were completed. They indicated that no further corrections for amplitude asymmetry in the couplers had to be made because the effect of the asymmetry was negligible.

In brief, the measurements were performed as follows: Four input couplers with offsets of 0.140, 0.160, 0.165, and 0.180 inch were tested. They were each placed on a test model D input jig and a "sandwich bead" was passed through them in three places parallel to the waveguide axis. These places were near disk No. 1, through the center, and near the end plate of the coupler. A traveling-wave measurement was used and the reflection coefficient of the bead was recorded at regular intervals of bead position. Plots were made of the data and a line was drawn between the points where the curve intersected the edges of the beam aperture. Plots were then made of the slope of the lines of intersection versus offset at the three points where data was recorded for each coupler. Because the slopes of some of the curves were negative and some positive, the point along the zero slope axis where the curves crossed was determined to be the correct offset. This was approximately 0.155 inch.

The same methods were used to determine the output coupler offset. Five couplers were tested with offsets of 0.070, 0.080, 0.090, 0.100, and 0.105 inch. In addition to using the traveling-wave measurement technique, four of the couplers were checked with a standing-wave setup. There was close agreement between the two methods, but the traveling-wave method seemed to offer greater resolution. Both methods of measurement indicated that the 0.080-inch offset was the correct one.

Additional coupler measurements were made by the Accelerator Physics Group as an added check. Their findings essentially agreed with those reported above for the input couplers, but disagreed slightly regarding the optimum size for the output couplers. Because of the ambiguities in the measurement processes and because the difference was not great, it was determined that changes in the coupler size need not be made.

C. STRONGBACK STRUCTURES

As anticipated during the previous quarter, the manufacturer was able to produce production quantities of strongback parts before the end of this reporting period. This meant that the phasing-in of strongback structures to accommodate the six different configurations required by "Operation Flip-Flop" was a relatively smooth transition and schedules were met.

D. FORTY-FOOT SUPPORT GIRDERS

1. General

At the end of the quarter, the subcontractors involved in the production of support girders and associated components were on schedule, and two 40-foot girders had been delivered to SLAC. Installation of accelerator sections, vacuum headers, and other equipment on one of the girders was approximately 50% complete (Fig. 11). All of the girder pipe had been delivered from the pipe fabricator to the accessory subcontractor. All indications are that this second subcontractor will maintain required schedules.

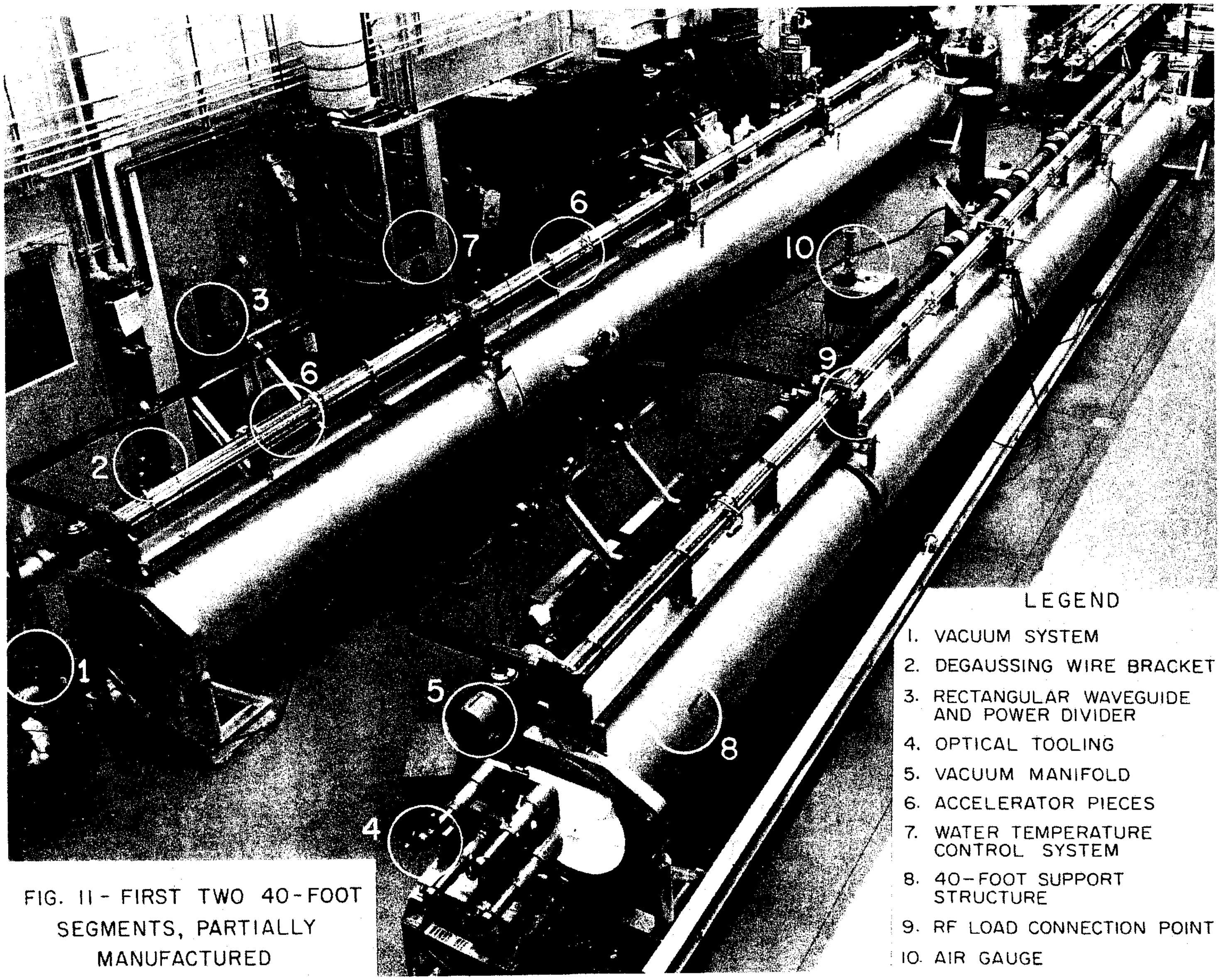


FIG. 11 - FIRST TWO 40-FOOT SEGMENTS, PARTIALLY MANUFACTURED

LEGEND

1. VACUUM SYSTEM
2. DEGAUSSING WIRE BRACKET
3. RECTANGULAR WAVEGUIDE AND POWER DIVIDER
4. OPTICAL TOOLING
5. VACUUM MANIFOLD
6. ACCELERATOR PIECES
7. WATER TEMPERATURE CONTROL SYSTEM
8. 40-FOOT SUPPORT STRUCTURE
9. RF LOAD CONNECTION POINT
10. AIR GAUGE

2. <u>Optical Tooling</u>

Optical tooling for both the placement and alignment of accelerator sections on the support girder and for quality control acceptance inspection of the support girder was received during the period. Both optical tooling setups proved effective for alignment and checking purposes and both were relatively easy to use.

3. <u>Target Actuator and Actuator Boss Seals</u>

Tests were performed on the target actuator assembly, which mounts on an actuator boss on each support girder, and on the flange seals through which the actuator shaft passes.

The target actuator assembly (Fig. 12) consists of a welded, stainless steel metal bellows in a pressure-tight, stainless steel housing. A flange on the housing mounts on the actuator boss of the support girder and the connecting rod attaches to the target hinge mechanism. When approximately 90 psig of air is applied to the bellows, an output force of 240 pounds is applied on the target hinge mechanism. The flexibility of the bellows permits an angular displacement of the connecting rod of nominally two degrees.

Seven actuators made entirely of type 347 stainless steel were tested, and six failed far below the required 6000 actuation cycles. Five of these were returned to the vendor for evaluation and replacement. It was found that the failures were caused by work hardening of the bellows material, and the material was changed to an AM-350 stainless steel. The five replacement actuators were then tested in the same manner as the first seven with no incidence of failure, even when one was cycled over 13,600 times. A technical specification was written for the purchase of this second type of actuator.

A series of tests was run to determine the most reliable and least expensive vacuum seal to be used between the flange on the target actuator and the actuator boss. The test setup shown in Fig. 13 was used. Rubber O-ring seals and hollow O-ring seals were tested initially, but both showed high leak rates. Solid metal seals or crush-type gaskets of indium or gold were considered but not tested because of the expense involved. Instead, plated metal "V" seals (Fig. 14) of both aluminum

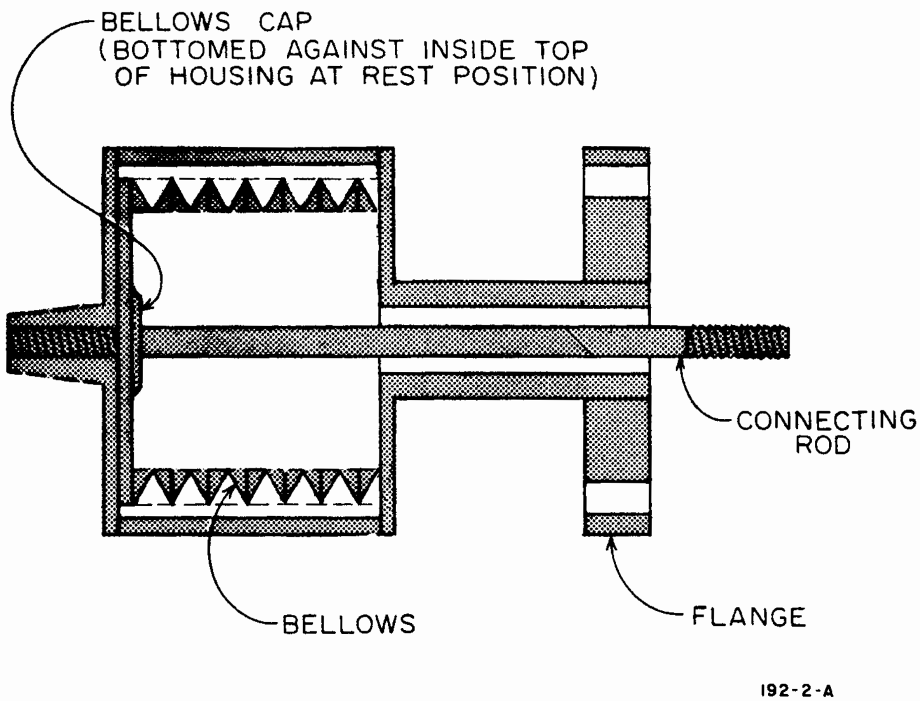


FIG. 12 - TARGET ACTUATOR ASSEMBLY

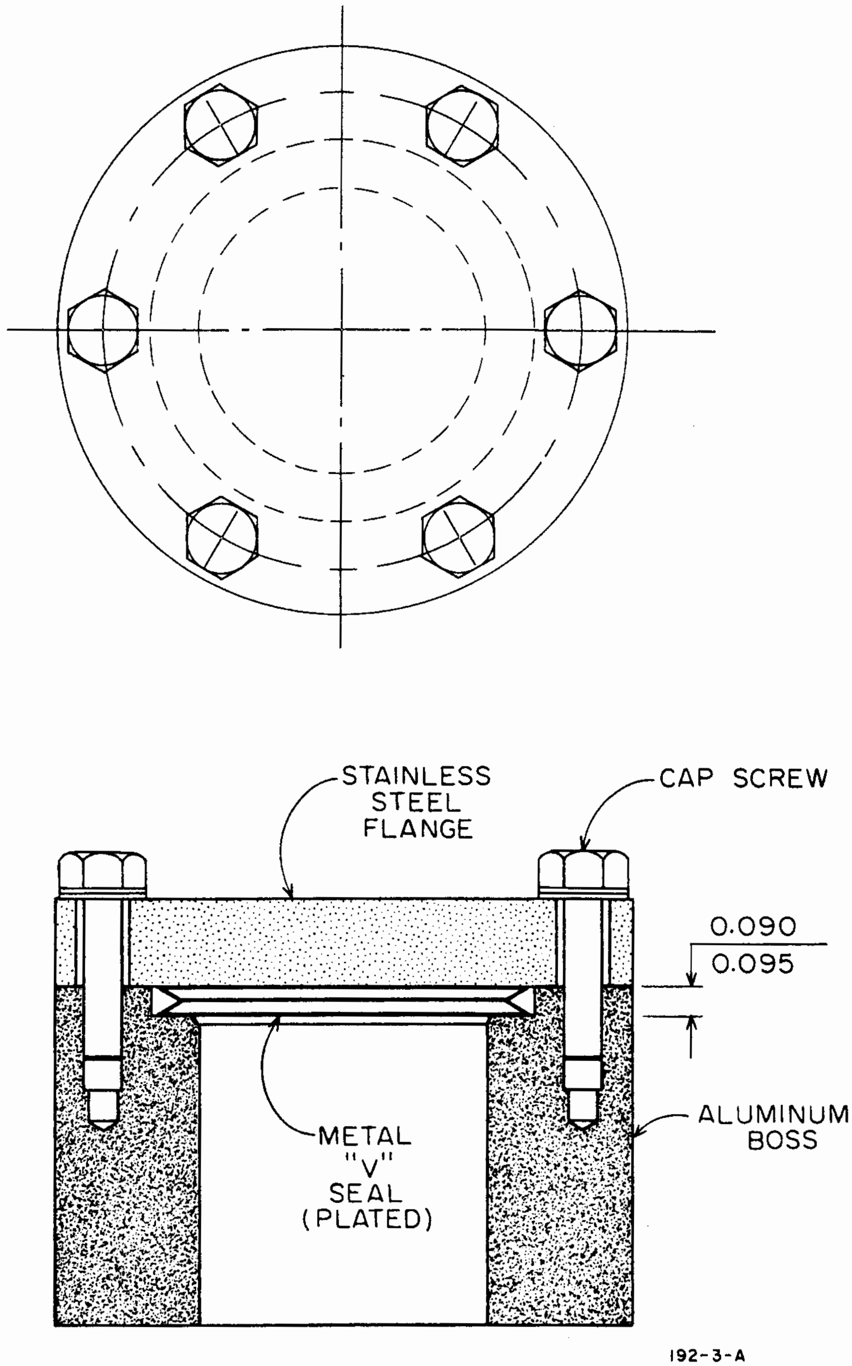
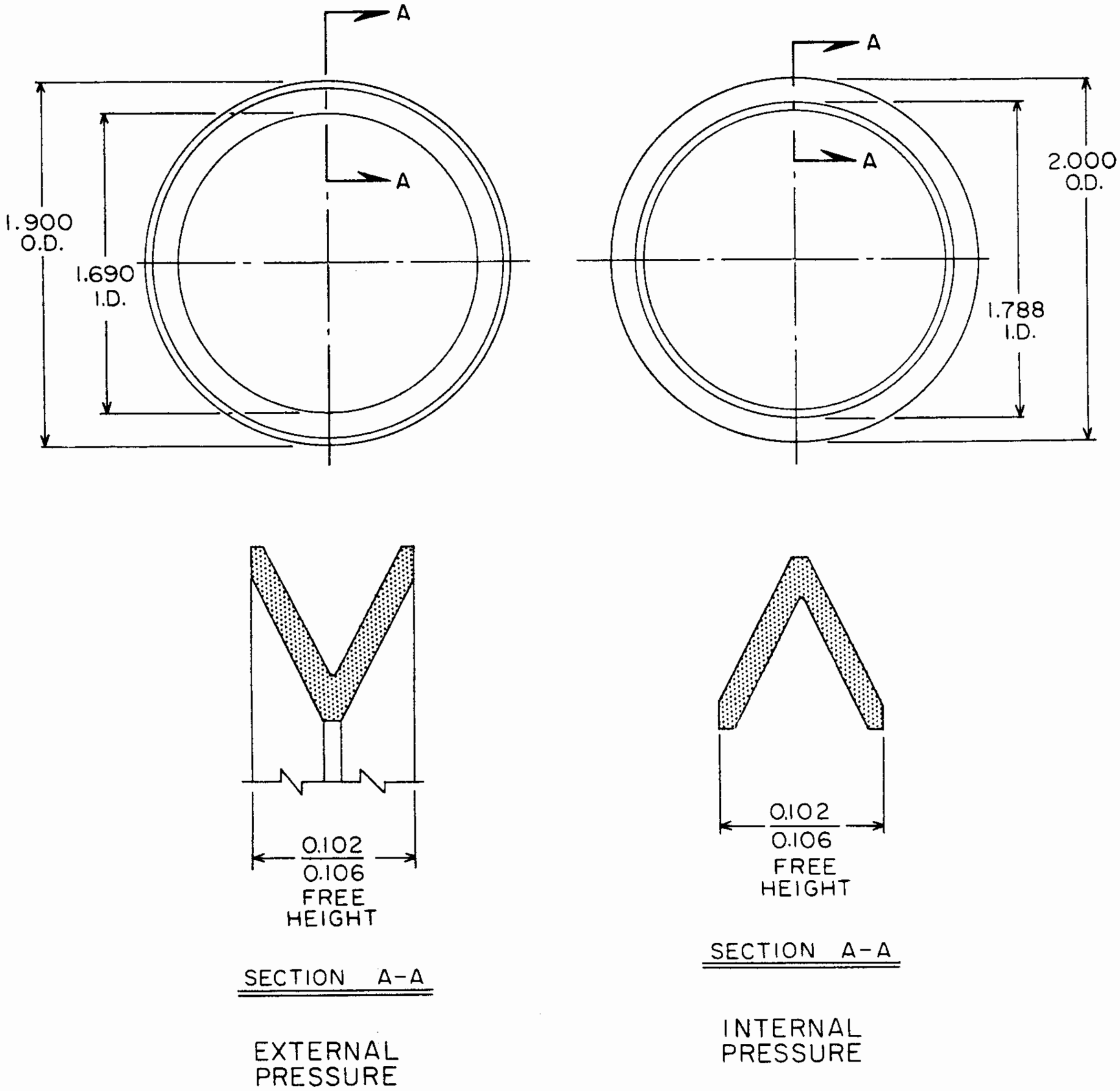


FIG. 13 - ACTUATOR SEAL TEST SETUP



192-4-A

FIG. 14 - METAL "V" ACTUATOR SEALS

and stainless steel with lead or indium coatings were tested, and good results were obtained. Each seal was reused twice and no leaks were detected. It was recommended that a 17-4PH stainless steel, lead-plated seal be used because it has been heat treated to maintain its spring rate over an extended period of time with an expected life of 10 years.

4. Implosion Tests on Simulated Fresnel Targets

Tests were performed to determine the effects of implosion on the Fresnel targets of the optical alignment system. A simulated target (Fig. 15) was constructed and installed in a standard 40-foot support girder to which a 10-foot drift section girder was connected (Fig. 16). For test purposes, a 2-1/2-inch hole with a rubber plug was located normal to the axis of the girder in the side of the drift section, and a six-inch hole with a knock-off plate was located in the end of the support girder. This second hole was parallel to the plane of the target and 40 feet away from the target mount position. Tests were run with the simulated target in both the horizontal (up) position, or out of the path of the shock wave caused by implosion, and in the inserted (down) position, in the path of the shock wave. The Fresnel pattern was simulated by gluing 0.002-inch-thick by 0.032-inch-wide nickel strips over a 3-1/8-inch-square opening in a 0.020-inch-thick copper sheet.

The tests were performed with the two girders pumped down to a vacuum of 100 microns of mercury. Initially, the 2-1/2-inch hole was opened rapidly with the target in the two positions described. No damage was visible when the target was viewed with a telescope 40 feet away. When the 6-inch hole was opened with the girders under vacuum and the target horizontal, again, no damage was visible. However, when implosion through the six-inch hole occurred with the target in the inserted or down position, serious damage occurred to the bottom of the target and its frame, as shown in Fig. 17. The upper portion of the frame was undamaged because it was uniformly supported by the mounting plate of the hinge mechanism. The bottom of the frame was restrained only by two adjustable stops within the girder at the outer edges of the frames. The simulated Fresnel pattern was not damaged because the strips were only glued in place and were able to flex with the implosion shock wave.

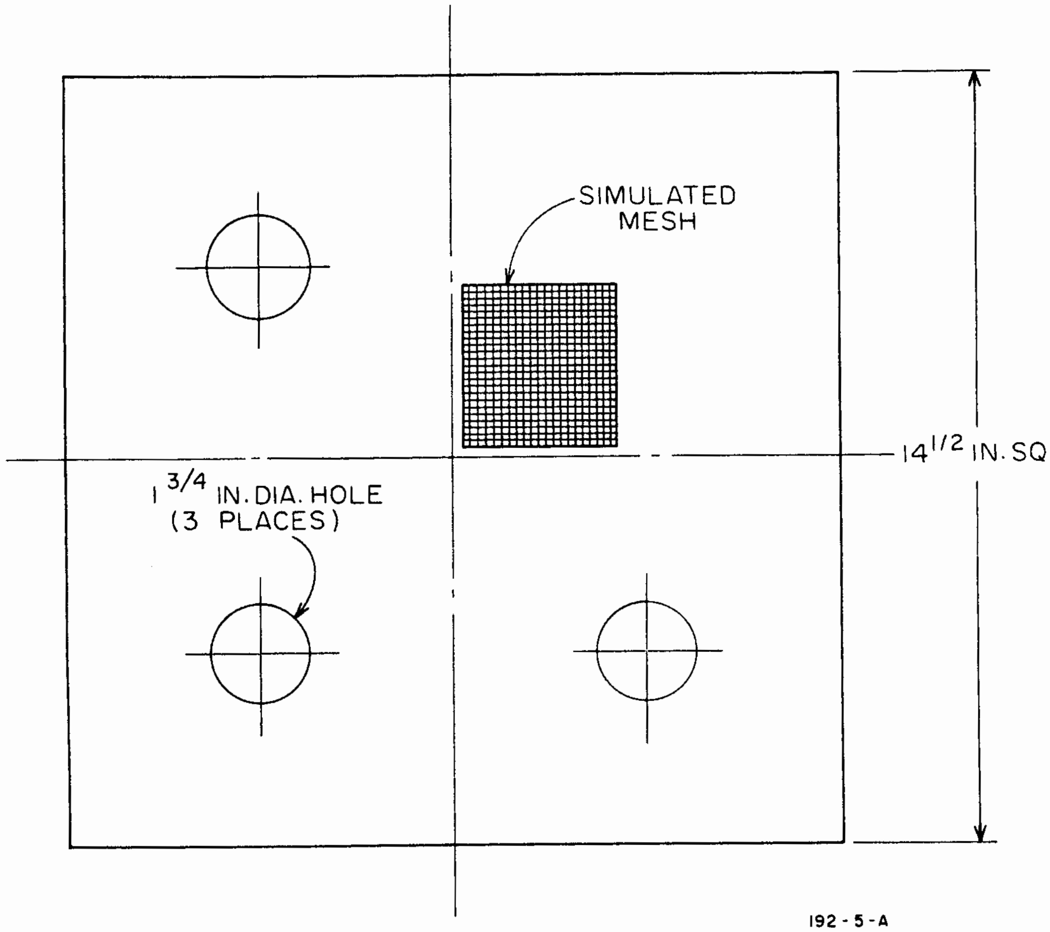


FIG. 15 - SIMULATED TEST TARGET

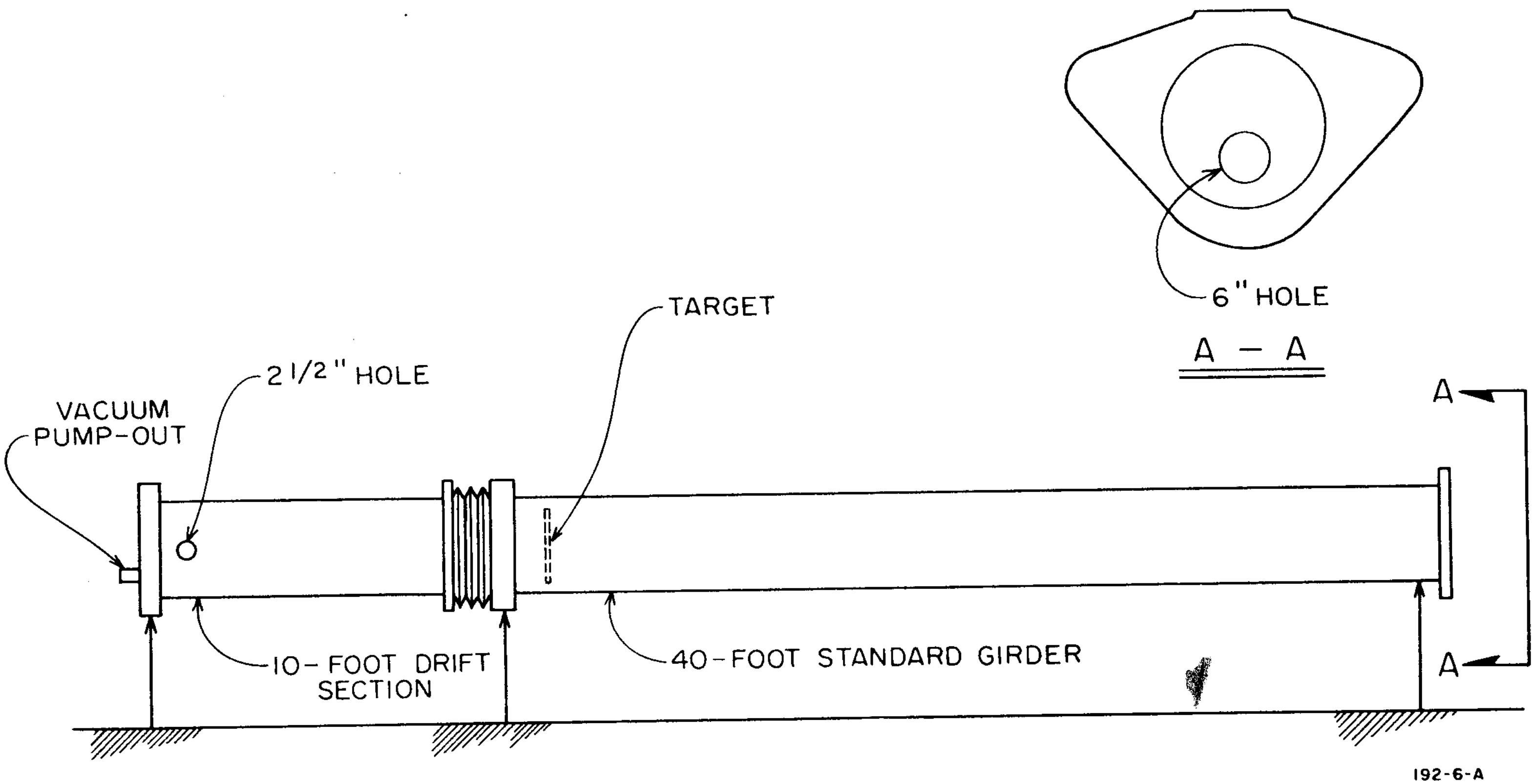


FIG. 16 - IMPLOSION TEST SETUP

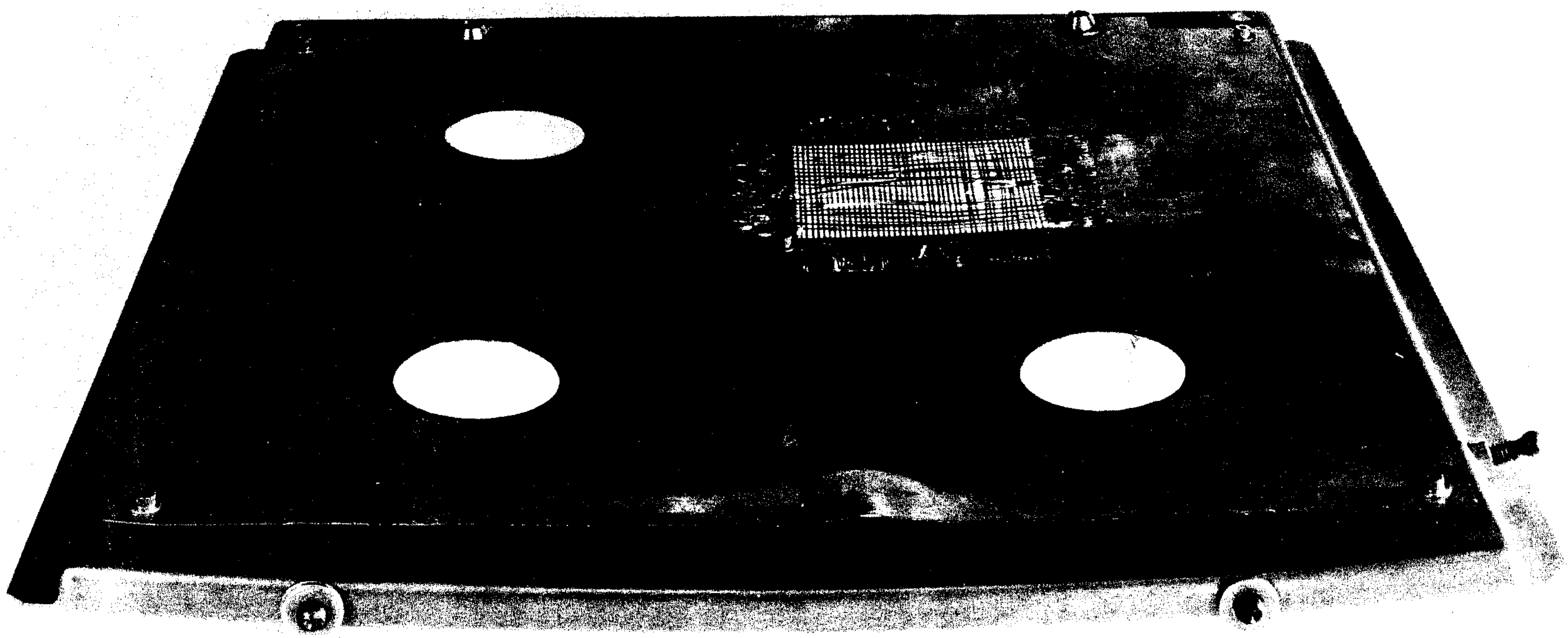


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FIG. 17 - RESULTS OF IMPLOSION ON SIMULATED TEST TARGET

The second test was felt to be more severe than any that might occur during the life of the accelerator. If a failure this severe did occur, it would cause serious damage to the target system only as far as an inserted target, or one normal to the shock wave, was concerned.

E. SUPPORT JACK LEVEL SENSING DEVICE

Studies were made during the period to develop a level sensing device for use with remote actuation of the vertical jacks for each 40-foot support girder. It had been determined that, if one vertical jack was actuated, the maximum allowable angle of tilt on the girder would be 0.001 radian. If this limit were exceeded, possible structural damage could occur to components mounted on the girder.

A developmental contract for this device was awarded; the specification required that the readout device have a resolution of 1/10 of a milliradian (0.0001 radian). This requirement can be met by means of a relatively simple type of instrument and a position sensing system. The instrument or the sensing device itself uses the principle that the thermal variations of a heat sink can be detected and transduced so that they will be indicative of circular misalignment, or angle of tilt, of the accelerator segment to which the device is attached. The sensing device is located on top of the target housing of the support girder. When a vertical support jack is moved, the sensing device provides a reading of the movement to a milliammeter which is calibrated for radian measurement. This milliammeter, or indicator, is located at the jack actuator station in the klystron gallery, where the movement of the jacks can be controlled and misalignment can be corrected.

The elements comprising the indicator have been chosen so that they will be reliable under the temperature and radiation conditions to be found within the accelerator tunnel during the operation of the accelerator.

At this reporting time, it has been decided that the cost of the system for remote actuation of the support girder jacks is too great. Therefore, when a girder is to be aligned, it will be done manually by turning the jack's screws and using a bubble level that is placed over the jack attaching points at the end of a support girder as an indicator. Two prototype girders, however, will be equipped with the remote actuation capability. One of these girders will be equipped with the level sensing device described above, which has demonstrated during extensive tests that it more than meets the specified requirements; the other will have a second type of device yet to be procured. Both systems will be evaluated through observation in this prototype installation.

The capability for remote actuation of all jacks exists in the system and can be provided at a later time, if the need arises, by adding jack actuators and the level sensing devices that would then be required.

F. RECTANGULAR WAVEGUIDE

1. Phase Measurements, General

The phase table* for testing and adjusting klystron gallery crossbars and Sector 1 accelerator housing S-assemblies was assembled and placed in service. When the first crossbar was mounted on the phase table, a need was apparent for a fixture to align the waveguide and flanges of the crossbars before they are mounted in the klystron gallery. Such a fixture was built and has been used successfully. A separate fixture was built to support the crossbar uniformly during handling, and a soft-sprung trailer was built to carry the crossbars to the klystron gallery.

Several independent procedures were used to check the phase relationships in the rectangular waveguide power dividers, crossbars, S-assemblies, and in the phase table waveguide circuits.

A procedure had previously been studied for phase adjustment of the penetration waveguides by measuring their resonant frequencies after they are capped-off and are ready for filling with nitrogen preparatory to storage. The method appears feasible and simpler than previous methods, but will be used only if it later becomes necessary to adjust the penetration waveguides before their installation.

The rectangular waveguide components are now being manufactured with sufficient uniformity so that they may be foamed and installed without prior phase adjustment. The penetration waveguides are installed in the

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 January to 31 March 1964," SLAC Report No. 30, Stanford Linear Accelerator Center, Stanford University, Stanford, California (June 1964); pp. 25-30.

penetration holes, the crossbars are installed in the klystron gallery and are connected to the penetration waveguides, and the two branches of the resulting combination are compared in phase length to detect any abnormally large phase asymmetry. Final phase adjustment is made by squeezing the walls of the S-assemblies and penetration waveguides. A small portion of the length of each penetration waveguide is left thermally uninsulated to provide room for phase adjustment, and provision is made for easy removal of the foam insulation for several feet in case a large phase adjustment is necessary.

The uniformity of the waveguide components also makes unnecessary the magic-T test circuit* which was designed to resolve the half-cycle ambiguity in electrical length of penetration waveguides. The magic-T circuit remains available for use in case of later need.

Several penetration waveguides were checked for reflection before and after phase adjustment, and were found to have reflection coefficients below 0.015 even after severe squeezing.

The modulated-reflection phase tuning and measurement system** had been built and used successfully in final phase measurement and fine adjustment of the rectangular waveguide system after installation.

A reflection modulator is temporarily installed, during girder fabrication, between each accelerator section output port and its rf load. The S-assemblies are installed on the girders in the Fabrication Building, the girders are installed in the accelerator housing, and the S-assemblies on the girders are connected to the penetration waveguides, which are already in place in the accelerator housing. The phase measurement circuit (Fig.18) is rolled on a wheeled cart along the klystron gallery and is connected in turn to the input port of each crossbar assembly in place of the klystron, which will not as yet have been installed. The reflection modulators are switched on one at a

*Ibid, pp. 30-31.

**"Two-Mile Accelerator Project, Quarterly Status Report, 1 April to 30 June 1964," SLAC Report No. 32, Stanford Linear Accelerator Center, Stanford University, Stanford, California (October 1964); pp. 58-61.

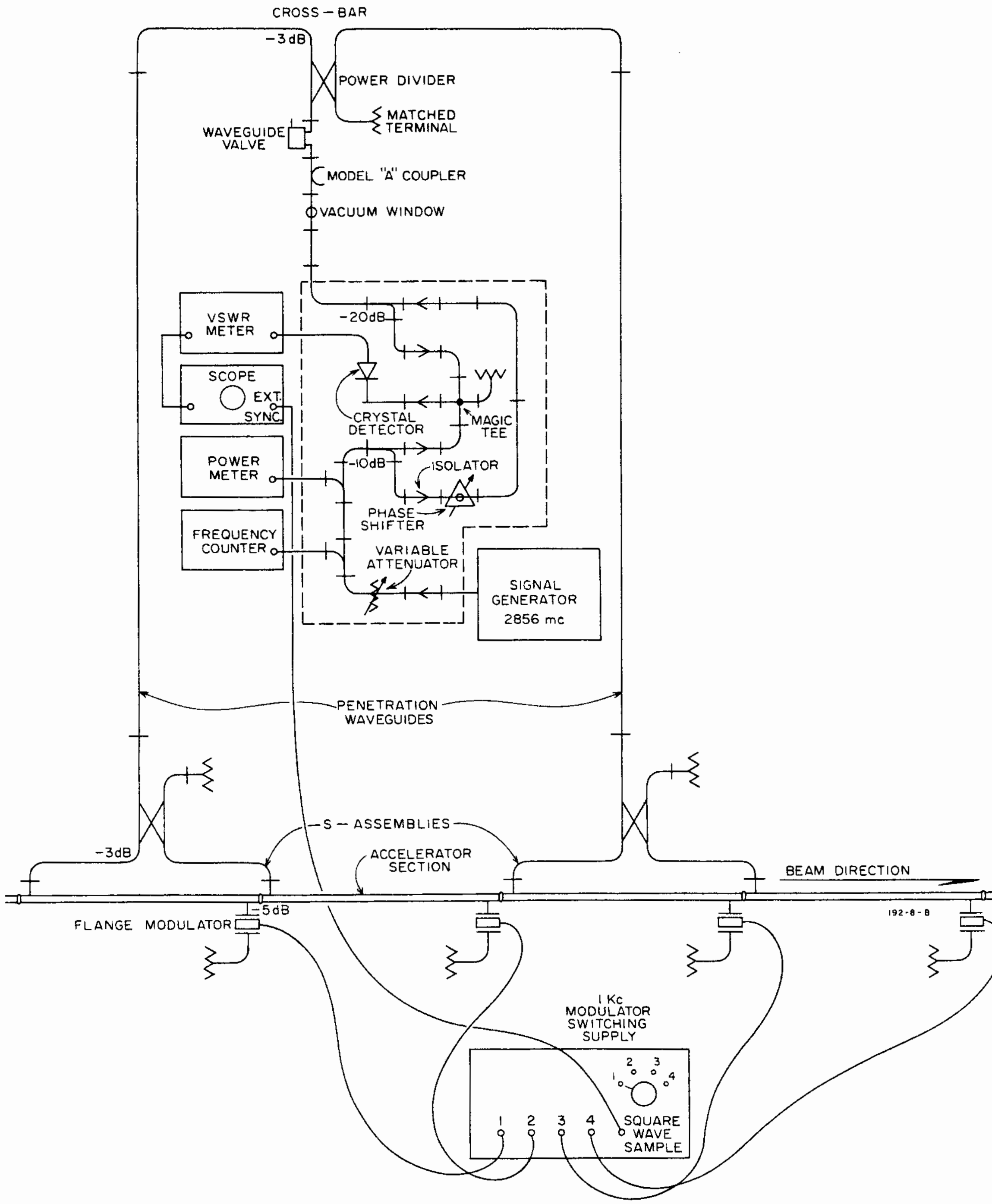

FIG. 18 - MODULATED-REFLECTION PHASE TUNING AND MEASUREMENT SYSTEM

time, and phase length through the waveguide system is read by an operator in the klystron gallery. Adjustment is made on the S-assemblies and ends of the penetration waveguides by an operator in the accelerator housing who is in telephone communication with the operator, in the gallery. The waveguide system for one girder can be phase-adjusted in a few minutes.

A further improvement now under consideration is a remotely-controlled waveguide squeezing tool.* One was designed during the quarter, and a prototype is now under construction. This tool would permit the operator in the klystron gallery to control directly the waveguide squeezing operation.

The modulated-reflection phase measurement system was revised during the quarter to give better sensitivity, and the circuit was analyzed for sources of systematic phase measurement error. No single source was found to give an error greater than a few hundredths of one degree. The circuit is being revised further, both electrically and mechanically, to eliminate temperature-sensitive components (isolators, dielectric-slab phase-changer, and long waveguide pieces), and to reduce the size.

The phase measurement system is checked by measuring large and known phase differences, i.e., by measuring the electrical length of waveguide pieces of known dimensions which are inserted between the reflection modulator flanges and the phase measurement circuit. In normal operation, the phase measurement system is required only to measure a single phase, i.e., each branch of the waveguide system is adjusted to have the same electrical length. Thus the check requires better performance than is required in normal operation. Most possible sources of error would be apparent in such a check.

To achieve this improved performance, several small mismatches were reduced, the directional coupler was tuned for increased directivity, and attention was given to variable phase reflections from the phase-changer.

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*Ibid, p. 61.

2. Modulators for Modulated-Reflection Phase Tuning and Measurement System

a. General

A waveguide-mounted diode switch, using a special L4133 Philco diode, was redesigned for vacuum and fitted into a two-sided (male-female) Skarpaas flange. With a copper gasket on each side of this modulator flange, it is sandwiched in between the high power rf loads and the output of the ten-foot accelerator sections for purposes of measuring the four waveguide feed arms (consisting of one crossbar, two penetration waveguides, and two S-assemblies) and tuning them to equal electrical phase length. This is accomplished by connecting a 2856-Mc signal generator through some waveguide sampling and comparison circuitry (hereafter referred to as the phase measurement circuit) to the crossbar. Null readings on a phase shifter are taken as each modulator is switched on in turn, and thus the down and back phase lengths to each modulator can be compared. Figure 18 shows the modulated reflection system and Fig. 19 is a photograph of a modulator flange. A few of the problems associated with the modulators and the measuring system are discussed in the following paragraphs.

b. Modulator Flange Design

The modulator flange consists of a male Skarpaas flange with a female face machined on the back surface, two tuning screws, and a high speed, point-contact, germanium diode on an insulated post. The screws and the post are mounted in the body of the flange and protrude into the waveguide opening. A teflon O-ring is used to make a vacuum-tight joint around the diode post which connects to a TNC fitting screwed onto the circumference of the flange. A clear HYSOL epoxy was used on the first few models to seal around the tuning screws, but greater versatility was obtained on later models with teflon O-ring seals. The diode post acts as a coaxial capacitance to minimize leakage of the microwaves and feeds a 1-kc square wave, forward and reverse-bias signal to the diode; this causes an equivalent circuit across the waveguide to switch from a transmitting to a reflecting state.

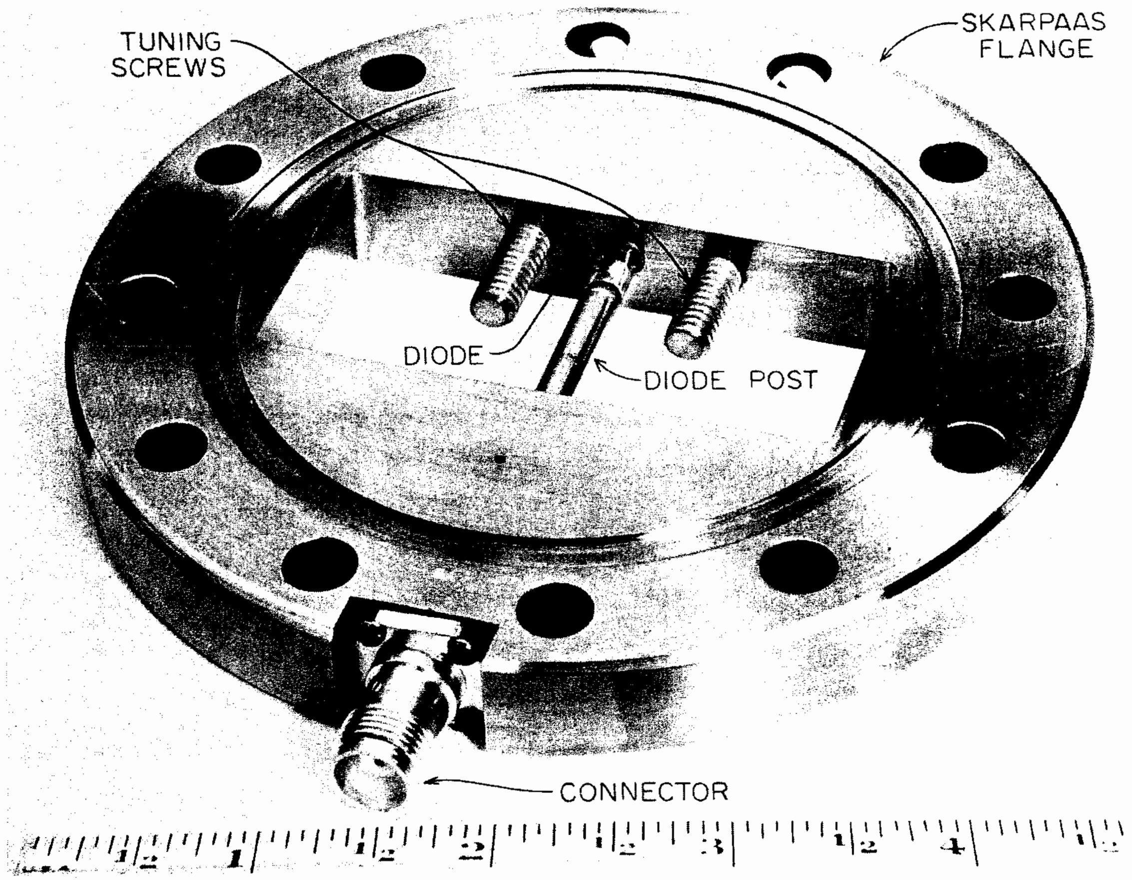

FIG. 19 – MODULATOR FLANGE

c. Modulator Switching Power Supply

A transistorized power supply was built to switch any one of four diodes from a forward-biased state (+ 100 mA) to a reverse-biased state (-20 volts) at a 1-kc rate, while the other three diodes are in a forward-biased (transmitting) state. The design included a 1-kc free-running multivibrator, a buffer amplifier stage, a switching transistor, a stable voltage and current source, and an appropriate diode selector switch.

d. Modulator Calibration

It is necessary to calibrate and tune a set of four modulator flanges relative to each other because of machining tolerances and the presence of a small amount of reflection during the transmitting state. The characteristics of the present modulators are such that, in the reverse-biased state, the voltage reflection coefficient is 94% to 96%, and in the forward-biased state it is 7% to 12%. When the modulator is reflecting, there is an equivalent reflecting plane whose electrical phase distance from any arbitrary reference plane can be measured.

The phase of the small undesired reflection while the modulator is in the transmitting state can be adjusted by the tuning screws without affecting the phase of the desired reflection (reverse-biased state). Therefore, it is usually possible to adjust the position of the resultant reflecting plane so that it is in the same place for each of the four modulators. However, for some sets of modulators the distance measured by the phase measurement circuit has to be compensated by modulator calibration differences.

In an attempt to prevent excessive stress on the female-male Skarpaas flange pair, between which the modulator flange is sandwiched, the slopes on the male and female faces of the modulator flange were altered. As a result, some problems were encountered with regard to torquing the sandwich together and getting consistent modulator calibrations, because the rf joint at the gasket can have a strong perturbing effect on the tuning screw settings. A compromise design has resulted in joints of reproducible phase length if careful torquing methods are used when assembling the modulator sandwich.

e. Checking Phase with the Modulated Reflection System

The phase measurement circuit (see Fig. 18) provides a sensitive means for determining the relative phase lengths from the klystron in the gallery to the four outputs of the accelerator sections mounted on a single girder in the accelerator housing.* Work with the measurement system during the quarter resulted in a null at the crystal detector (see Fig.18) sharp enough to discern phase length differences of less than one-sixth of one degree. In order to get this sensitivity, the input to the phase measurement circuit was a 5-milliwatt, highly stable, 2856-Mc signal, and the 1-kc modulated signal returning from the modulator flanges was down 52 dB from the input signal at the crystal detector. However, noise problems caused by ground loops, dc crystal current and interference, and temperature variations in both the accelerator cooling water and in the phase measurement circuit components cause both short and long term drifts, limiting the accuracy in reproducing any set of four measurements. Some VSWR meters have greater sensitivity when used as a 1-kc tuned amplifier, and the choice of a signal source was found to be very important with respect to its AM and FM noise. Thus, considerable effort is being put into simplifying and improving the measurement system so that the limit for accurate phase tuning of the four accelerator sections on a girder will be established by the degree of temperature control possible.

The crystal multiplier-chains, which we had planned to use, contributed sufficient noise to reduce appreciably the sensitivity of the system. A reflex klystron oscillator, frequency-controlled by a cavity discriminator, has provided a low-noise rf source which is subject to frequency-drift with change in ambient temperature. A signal source is being considered which will synchronize a reflex klystron oscillator with a very stable crystal-controlled oscillator.

A frequency measurement system has been set up to provide a direct indication on an electronic counter by means of a transfer oscillator synchronized with the rf source.

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*Ibid, pp. 58-61.

3. Rectangular Waveguide High Power Tests

The resonant ring was shielded during the reporting period, and it is now possible to go to a peak power of 80 MW without producing excessive radiation. The ring is operated normally at 80 MW peak power and good stability has been achieved with 24 kW average power output. This provides for much more rapid processing of rectangular waveguide components.

With the new stainless steel vacuum station, a pressure of 8 or 9 times 10^{-9} torr can be obtained at the 400-liter-per-second ion pump and 2 or 3 times 10^{-8} torr at the pumpout. It is also possible to process waveguide components in the 10^{-6} torr range and to hold high rf power in the 10^{-7} range after processing.

The high-power calorimeter system previously described* is now being used to check the coupling ratio of the model A directional coupler. A comparison of the readings obtained by this system and those obtained during precision cold tests on the couplers has revealed close agreement, with 0.3 dB as the highest deviation yet observed between the two tests.

4. Flexible Borescope

A flexible fiber-optic device has been obtained for examination of brazed butt-joints in bent sections of rectangular waveguide, where a standard, or rigid borescope cannot reach.

5. Model A Directional Coupler

Production models of this coupler were being made by the end of the quarter. Although only a small number of the couplers have been checked for coupling coefficient, the results were encouraging; the measurements taken indicated that the coefficient was within ± 0.5 dB of the 52 dB desired. As reported under Section F-3 above, the high power tests on the couplers agreed closely with the low power or cold tests.

The four-stud support for the coupler has been replaced by a mounting block and three adjustable bolts (Fig. 20) to provide a more rigid support between the model A coupler and the klystron support yoke. All installed units will have this modified support.

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*Ibid; p. 62.

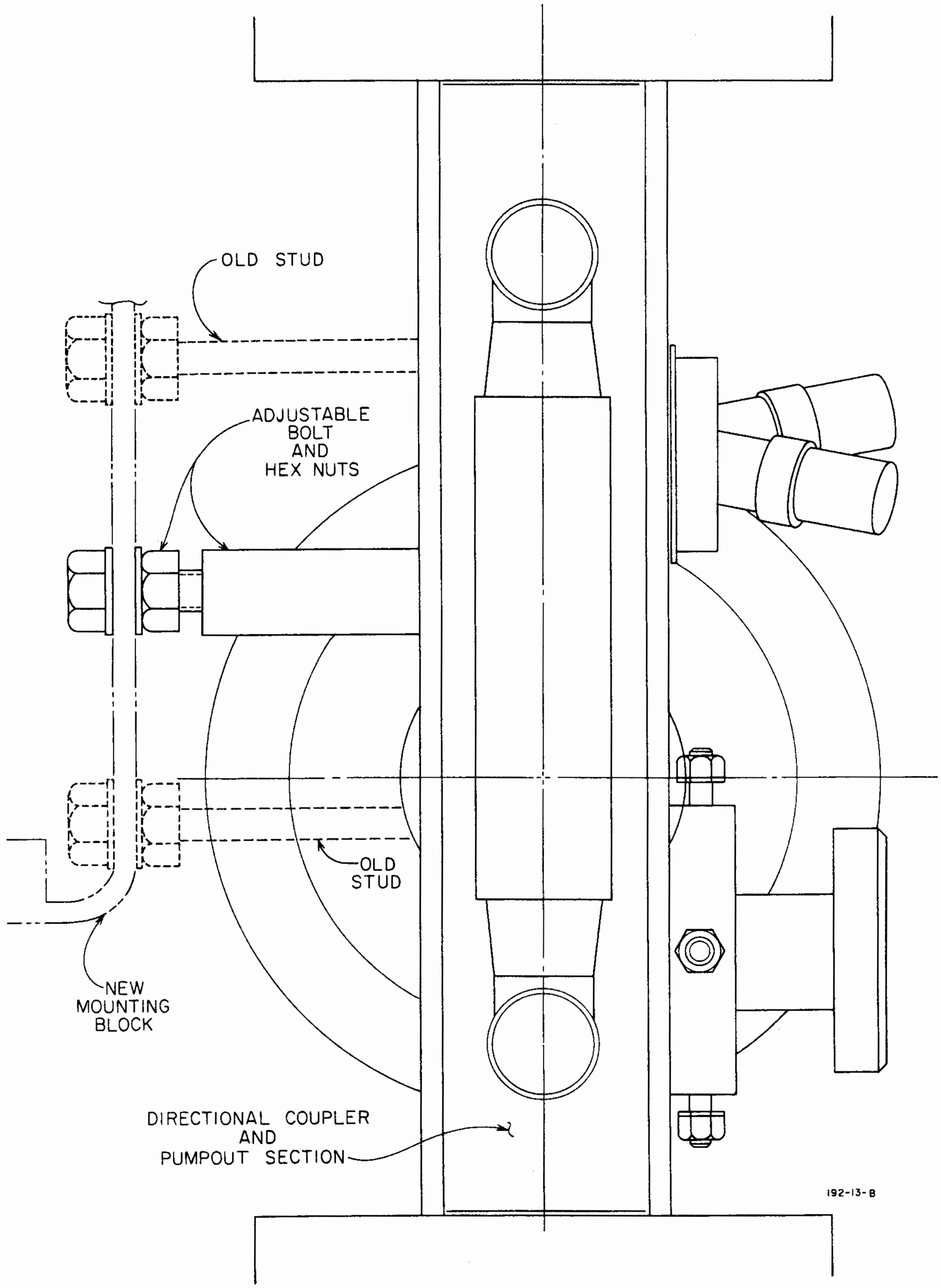

FIG. 20 – MODIFIED MODEL A DIRECTIONAL COUPLER MOUNTING

6. Model B Directional Coupler

Several of the units previously described* have been fabricated and tested. A maximum input power of 12 kW average at 11 MW peak was used. The processing time (i.e., the time required to attain stable operation at 10^{-6} torr at 10 kW average power) varied from 55 to 140 minutes because of outgassing. All units are vacuum baked at 400°C for approximately five hours prior to rf test. These units are tested with the rf phase cable in place and are connected to a matched load as shown in Fig. 21. The use of a waveguide load was necessary because of the output power level in the coaxial line (120 watts average, 110 kW peak). No breakdown in the coax line was detected.

7. RF Loads

The type 304 stainless steel rf loads went into production during the reporting period and a total of 40 were produced and tested. Calculations concerning the corrosion rate of 304 stainless, as compared with the 410 stainless used with the earlier loads, suggests that little difficulty will be experienced with leakage through the welded water jacket seams of the new loads. A typical plot of VSWR vs power level of the loads under high-power test together with the conditions under which the tests were performed are shown in Fig. 22.

8. RF Waveguide Vacuum Valves

a. Pre-Production Valves

All of the eight pre-production valves were completed through brazing, indium processing and assembly. At the end of the quarter all valves had undergone low power rf tests, several had undergone high power tests, and one unit had also been tested in the resonant ring. Table I summarizes the results of the tests made to date and gives the disposition of the valves.

The pre-production units pointed up two areas where modifications were required. The upper weld joint between the bellows and the housing was modified because of the difficulty in making a vacuum-tight weld.

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*Ibid; p. 63.

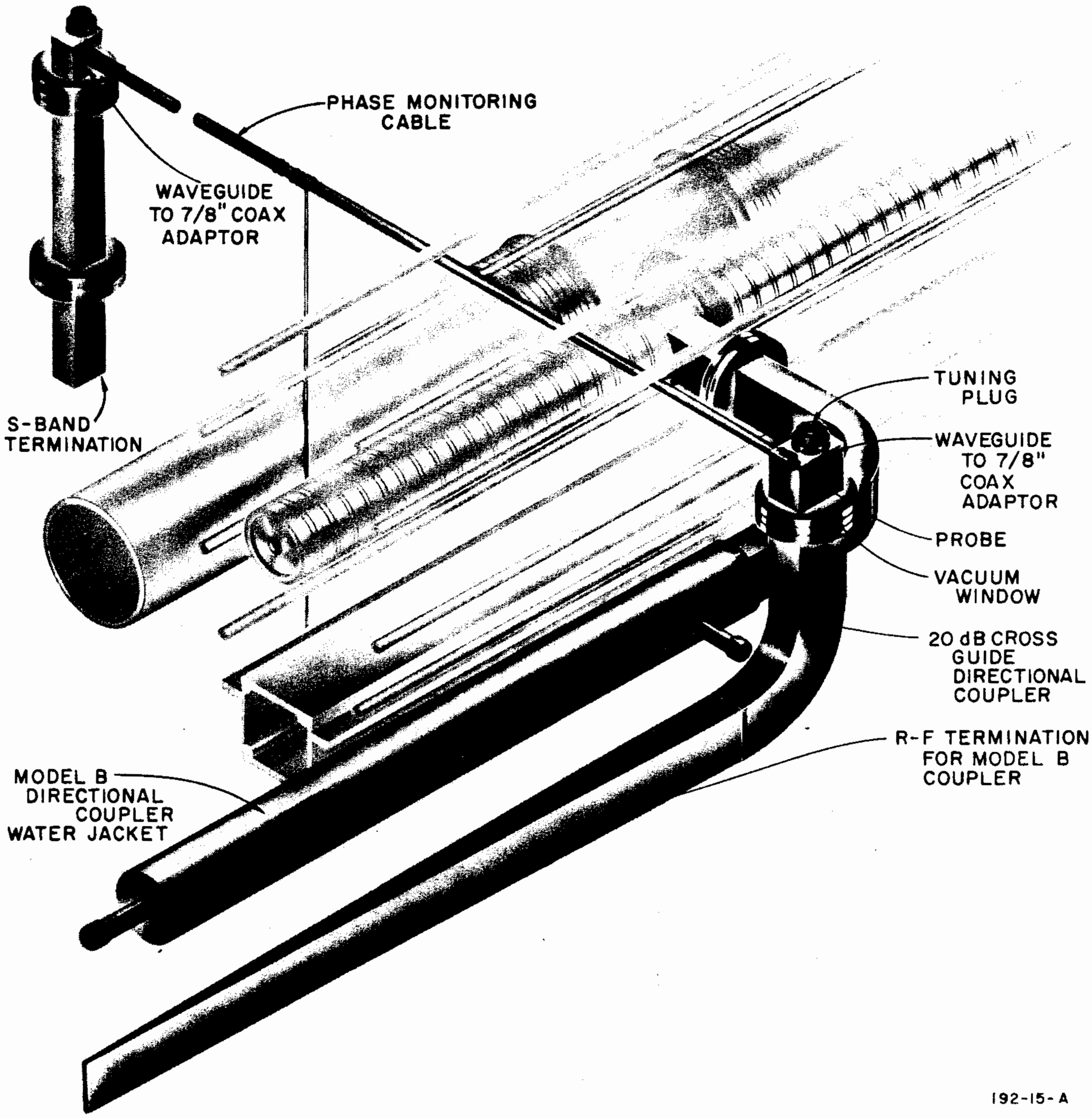


FIG. 21 MODEL B DIRECTIONAL COUPLER, HIGH POWER TEST SETUP

CONDITIONS

PULSE REPETITION FREQUENCY 360 PULSE WIDTH 3.5

H_2O TEMPERATURE 68° F. H_2O PRESSURE 80 lbs.

TIME TO REACH FULL POWER (10 kW) 140 MINUTES

VACUUM AT LOAD

BEFORE TEST 4.0×10^{-6} torr

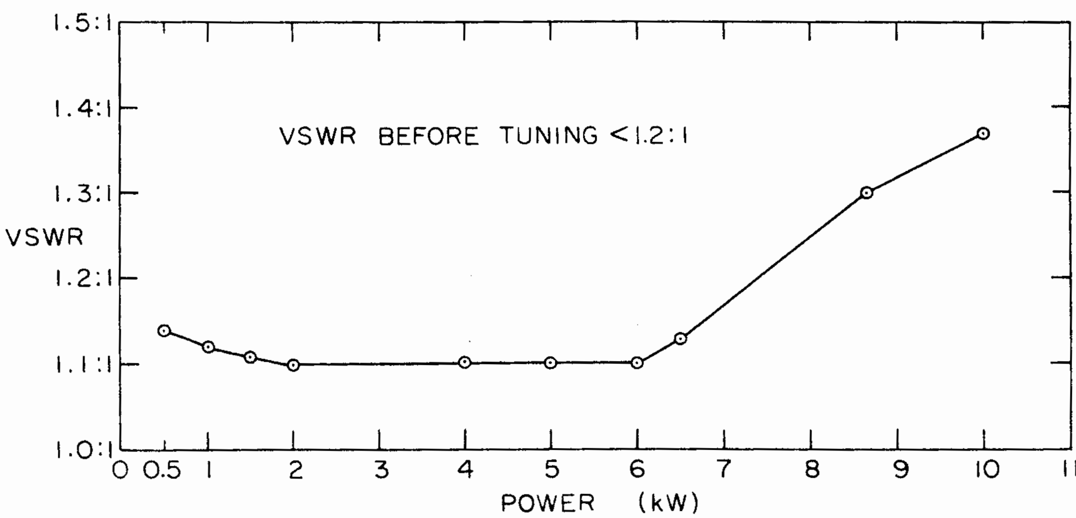
IN TEST AT 10 kW 6.0×10^{-7} torr

AFTER TEST 1.1×10^{-7} torr

ANOMALOUS OUTGASSING AT SPECIFIC POWER LEVELS

LOWER POWER LIMIT 6.60 kW

HIGHER POWER LIMIT 8.65 kW



VSWR vs POWER LEVEL

192-14-A

FIG. 22 - TYPICAL PERFORMANCE PLOT OF RF LOAD IN HIGH-POWER TEST

TABLE I

RF WAVEGUIDE VACUUM VALVE

Valve	Initial VSWR	Final VSWR	High Power Test Average	High Power Test Peak	Remarks, Installation, Other Tests
PP-1	-	1.05	16 kW	13.4 MW	Installed at Station 01-8 on July 30, 1964
PP-2	1.036	1.01	15 kW	11.9 MW	Resonant-Ring tested to 60 MW peak, 30 kW average
PP-3	1.13	1.04	14.2 kW	11.2 MW	Installed at Station 01-3 on Sept. 2, 1964
PP-4	-	1.02	15.6 kW	12.4 MW	Installed in Test Stand No. 1 Sept. 3, 1964; 134 closings - max. leak rate 27×10^{-8} std. cc He/sec; Remelted; 18 closings to Sept. 30, 1964
PP-5	1.083	1.05	-	-	
PP-6	1.06	1.02	-	-	
PP-7	1.083	1.05	-	-	
PP-8	-	1.05	-	-	

C-2 Operating in Test Stand No. 3; 69 closings as of Sept. 30, 1964

C-5 Installed in klystron mock-up.

C-6 Removed from Test Stand No. 1 because of water load fracture; valve had 35 closings.

The knife edge for the copper gasket vacuum seal was changed to reflect the same type of vacuum seal made by the rf flanges. Both modifications have been made in the production parts as well as on the pre-production valves.

As can be seen from Table I, little or no rf tuning was required to obtain an input VSWR ≤ 1.05. This is an important result, because previously fabricated units (Types A and C) required considerable tuning. The controlled fabrication and assembly procedures used for these eight units indicate that excellent repeatability between units of the production run can be expected. Although high power tests on all units are not complete, the levels attained in test stand operation are comparable to those anticipated in actual operation and no evidence of difficulty is present. In addition, the unit which has undergone resonant-ring test performed satisfactorily at power levels of 60 MW peak and 30 kW average. The determination of the peak power level will be reviewed and other valves will be resonant-ring tested next quarter.

Cycle tests on the indium seal were also made, on the order of 100 closings obtained with a maximum leak rate of 15×10^{-8} std. cc He/sec. One valve was closed 225 times with a maximum leak rate of 25×10^{-8} std. cc He/sec. These tests will be repeated on a sample basis to verify the data and to obtain a value for the maximum acceptable leak rate.

b. Production Valves

At the end of the quarter eight production valve bodies had been assembled through the first braze and were awaiting a final machining. It is anticipated that 20 units will be completed by the end of the next quarter.

c. Actuator

The actuator described in the previous status report* was tested and used in the cycle tests mentioned above. However, a simpler and less expensive version is being fabricated.

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*Ibid; p. 69.

d. Other Valves

Table I includes follow-up data on other waveguide valves described previously.*

G. DRIFT SECTION

The design of the drift sections was changed and finalized during the reporting period. The changes were made primarily to improve the ease with which the sections could be assembled. Also, it was decided that the sections would be fabricated in a manner that made them both removable and interchangeable.

The profile monitor parts and all other components for three standard drift sections were placed on order. It is estimated that the parts will be on hand late in the next quarter and that two sections will be assembled and ready for sector test by the end of that quarter.

One design change for the sections was made for alignment purposes. A hole was drilled in each of the section's component mounting brackets. Precision optical tooling was then provided so that each component on a drift section could be aligned with better accuracy than the earlier design had provided.

H. BEAM ANALYZING STATIONS AND TEMPORARY BEAM TEST ANALYZING STATION

The design of the beam analyzing stations and the temporary analyzing station for Sectors 1 and 2 beam tests is approximately 60% complete. Twenty-five percent of the parts for the stations, or all those that were considered to require longer procurement lead time, went out for bid during the quarter. The test station should be assembled and ready for use by December 1964.

The magnet with rotated pole faces suggested for use in the temporary station** was rejected in favor of using the same magnet that will be used in the beam analyzing stations.

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*Ibid.

**Ibid; p. 24.

VIII. KLYSTRON STUDIES

A. SUMMARY

During the quarter, RCA delivered eight klystrons, two of which were not acceptable. Sperry delivered six klystrons, five of which were not acceptable. Eimac and Litton Industries appear to be making satisfactory progress in the initial phases of their subcontracts.

The Stanford klystron development program has resulted in the design of tubes showing significant improvement of performance when operating in permanent magnets. Four tubes tested during the quarter in permanent magnets achieved peak powers in excess of 22 MW at 250 kV.

Two RCA klystrons ended life test because of window failure, one after 1100 hours and the other after 2100 hours of operation. One Sperry klystron is now on life test with a total accumulated time to date of 275 hours.

Window failures during processing of tubes have been reduced to the vanishing point by pre-testing all coated windows on the resonant ring. In addition, SLAC is collaborating with the klystron vendors to help them in coating windows for their tubes.

Tests on the klystron gallery mock-up have indicated the desirability of some changes in the protection system. The six windows in life test are still operating satisfactorily at levels of approximately 15 MW, 15 KW, after 3000 hours of operation.

The sub-booster klystron shelf life problem is not fully resolved, but operational data on these tubes is excellent. Four tubes are still operating satisfactorily after 2500, 3900, 4600, and 9000 hours of operation, respectively.

B. SUBCONTRACTS

Of the eight klystrons received from RCA, one is on test; two have been rejected, one because of a window failure during the 20-hour high power run, the other because of a leak which developed in the heater seal upon installation of the socket adaptor. The remaining tubes were accepted, as was the tube received at the end of last quarter.

RCA has gradually shifted from engineering to production tubes during the quarter. In general, the power output measured from their tubes is between 19 and 21 MW, and indications are that the full specifications will be met soon by gradually increasing the tube perveance from the present value (1.8 to 1.9) to 2, and by continuing to improve the quality of the permanent magnets.

The window problems with the RCA tubes (overheating and cracking) appear to have been resolved. The compression band was redesigned because it was found that reliable vacuum integrity could be obtained with much less pressure than initially anticipated. Accordingly, the value of the mechanical strength of the window material is no longer as critical as it once appeared to be. Another advantage of this pressure reduction is that RCA is now able to effect satisfactory, reliable window seals using alumina or beryllia supplied from any of their three suppliers.

Initially it had appeared that the Frenchtown material did not multipactor in the RCA tube design. However, evidence of multipactoring was later discovered, and a coating program has been instituted at RCA. Stanford has contributed to this program by testing some of the windows coated by RCA, and in turn coating some ceramics supplied by RCA with our own techniques for comparison purposes.

Of the six klystrons received from Sperry during the quarter, only one was acceptable under the end-of-life acceptance test conditions. One was received with poor vacuum and could not be tested, three exhibited heavy internal arcing, and one suffered a leak in the window area during the 20-hour acceptance test run.

The main problems at Sperry at the present time appear to be related to production quality control. Although Sperry processes at least 10 tube bodies per month, the yield is extremely low, and failures can be attributed to poor cathode emission, sparking, leaks, window troubles, and similar types of mechanical difficulties.

Litton Industries started testing the first tube of six to be built under their subcontract. The tube exhibited heavy gun oscillations in spite of the fact that the electrical design is identical to Stanford's;

it is suspected that mechanical changes in construction of the anode housing and the cathode support caused the oscillations. However, by operating in the vicinity of 250 kV, above the oscillation region, they were able to observe between 19 and 20 MW peak power. The tube was later lost by cathode seal puncture during initial tests in permanent magnets.

Eimac is in the process of final assembly of their first test vehicle, which should be baked and ready for tests early in the next quarter.

C. FACILITIES

The procurement of all facilities for installing klystrons in the klystron gallery is not yet completed. The majority of the items needed are on order, but some have not been received yet, and the installation of equipment on electric carts and trailers has not yet been completed. The truck for moving klystrons to the gallery was received late in the quarter, and adequate platform and hauling devices are now being designed for use with the truck.

The klystron support yoke has been modified to increase the stiffness of the waveguide support bracket, and tests on the mock-up test stand indicated the necessity for adding a stabilizer between the klystron and the klystron support frame. The required changes in the klystron support frame are being made, and procurement of the stabilizer has been initiated. It is expected that all klystron support yokes will be received within approximately six months.

In spite of the shortcomings of existing equipment, three klystrons were installed in the klystron gallery without difficulties for initial tests of Sector 1.

The fabricating area problems (water, air conditioning, and power) are gradually being resolved. The procurement of a high temperature ceramic metalizing furnace has been completed and delivery has been scheduled for approximately October 20. Installation and test runs of this furnace should be completed by the end of October.

A low voltage X-ray machine is now on order and is scheduled for delivery by November 25. The existing cobalt source has been used primarily to inspect a large quantity of aluminum castings and weldments for the Mechanical Design and Fabrication Department. Although the results have been good, they will be vastly improved by the use of the low-voltage machine which is currently on order.

D. KLYSTRON MOCK-UP TEST STAND

The klystron mock-up has now been operated many hours at 18.7 MW, the maximum available power from the klystron at 250 kV. Operation is into a water load at present. As soon as possible, other portions of the accelerator waveguide system and sections of accelerator will be installed on the system.

During this quarter the klystron mock-up test stand has been used to make a number of electrical and mechanical tests, which are described below.

1. Electrical

Considerable time was spent testing the fiat racks, particularly the modulator-klystron (M-K) protection unit. This unit operated correctly except that difficulty was experienced in tracking the protective klystron circuits and power output with the reference voltage for the de-Q'ing circuit. The M-K package was modified to obtain correct tracking on the mock-up, but other tests in the accelerator and a study of the effect of perveance and modulator variations indicated that it would be very difficult to adjust this unit on the accelerator. Accordingly, the M-K unit has been redesigned to eliminate the tracking feature and the first unit has been installed on the mock-up for test. Because the redesign also involved moving most of the relays into the M-K unit from the fiat rack relay panel, considerable wiring changes were required in the fiat rack. The terminals in the fiat rack have been moved from the rear to the front of the rack to make wiring and servicing easier. The first new M-K unit now operates as designed after some vacuum circuitry was changed and noise was eliminated from the forward power monitor by a filter. Other models will be tested as they are built. The modulator has operated well except for troubles in the de-Q'ing circuit, where the SCR and voltage divider were replaced.

2. Mechanical

Tests were performed on the modification of the klystron support to increase its stiffness. Changes were made on the stiffener until the resonant frequency of the system was raised to 4 cps. The initial installation resonated at about 1 cps.

The Hovair works satisfactorily if the pads are conditioned properly and the floor has no humps on which the frame could bind. The new fork lift has been modified to allow better control of lowering than was possible in the original foot-operated system. There is still some problem in aligning the waveguide flanges during installation, and a jig will have to be devised to simplify this procedure.

The laboratory cryopumping system has worked well, pumping to a pressure at which the main system can be connected in 2 to 5 minutes. The truck mounted system is now under construction. The waveguide valve has been operated six times without trouble. Failure of the discharge vacuum gauge to start was caused by a defect in the control unit. A new control unit has operated satisfactorily.

E. KLYSTRON FABRICATION AND DEVELOPMENT

Fifteen new tubes were built, and eight tubes and two diodes were reworked during the quarter. In addition, six new water loads and six load-to-tube adaptors were completed.

Three tubes could not reach full test because of low perveance and generally poor vacuum. In addition, there were two high voltage seal failures, both caused by inadequate purging of the area between the seal and the permanent magnet during final permanent magnet acceptance tests.

During this period, tubes incorporating the initial gun design (Piquendar), the Merdinian gun design MS-1, and the Merdinian gun design MS-2 have been built and tested. As a result of the tests, it has been decided to standardize hereafter on Merdinian gun design MS-2 as giving the most reliable performance. A comparison of the stability of the tubes built with Piquendar or Merdinian (MS-2) gun indicates a much greater tendency for oscillations with the Piquendar gun. Although it is usually possible to eliminate the gun oscillations by careful adjustment of heater power and the body oscillations by careful adjustment of the focusing, the Piquendar gun tubes are not as a rule stable over the whole voltage range with fixed focusing. By comparison, tubes with the MS-2 gun have shown great stability, although some minor instabilities have still been observed in a few of the tubes tested. In addition, some changes in the klystron interaction space were introduced, which resulted in apparently improved operation. The tubes built during the next few months will be of the same design as those which have given the best performance during this quarter.

The nine tubes using the MS-2 gun design have given power output in excess of 19 MW at 250 kV in permanent magnets. Seven permanent magnets were received during the quarter, and the tubes are interchangeable in the magnets with very little variation in performance from magnet to magnet. The average degradation of power output with the tube operated in permanent magnet compared to the best focusing obtainable with electromagnet is less than 3%. Four of these tubes, including the two tubes designed with a modified interaction space region, have given power output in excess of 22 MW. By comparison, the three tubes using the Piquendar gun had power outputs between 16.7 and 20.4 MW at 250 kV, and showed a degradation of power output between electromagnet and permanent magnet of approximately 8% on the average.

Figure 23 shows typical magnetic field plots under which SLAC 2422 klystrons have been tested. PM-8 was an experimental magnet, and tube performance in this field is not as good as in the field of PM-9. All permanent magnets obtained during the past three months produce fields which are within a few percent of PM-9, and we have been able to duplicate performance from tube to tube and magnet to magnet.

Figures 24 and 25 show the comparison in performance obtained in a given tube under different focusing conditions. Figure 26 compares the performance obtained with two tubes of similar design in different permanent magnets of the PM-9 field. These tubes have drift distances of approximately 3.5 inches between cavities. Except for a slight difference in gain, the performance of the two tubes is identical within the accuracy of the measurements. All tubes built with the Merdinian gun and tested in PM-9 have produced in excess of 19 MW at 250 kV.

Two tubes have also been built where the drift distances were increased to approximately 4-3/4 inches and 3-3/4 inches respectively

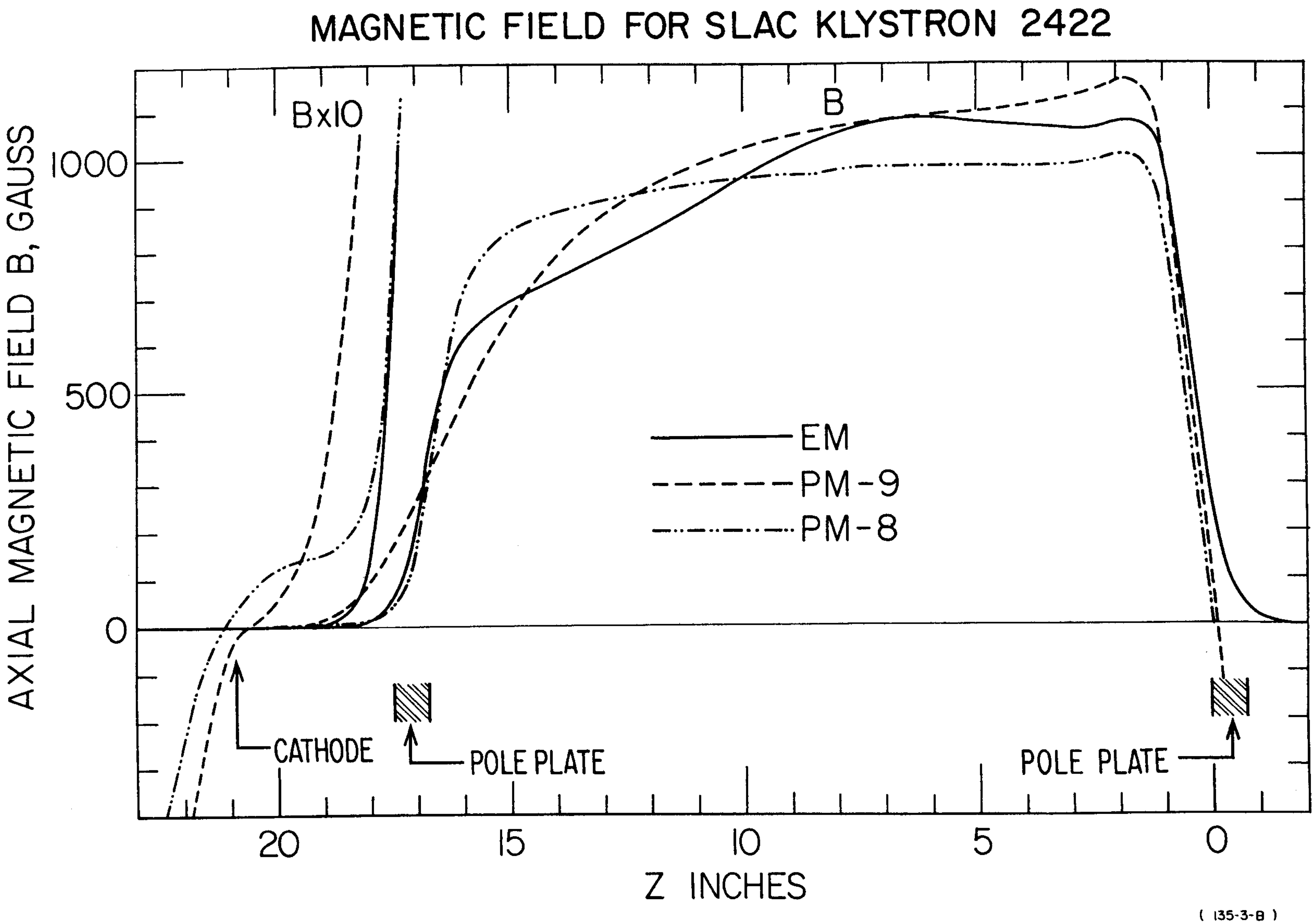

FIG. 23--Magnetic fields, used on SLAC Klystron 2422.

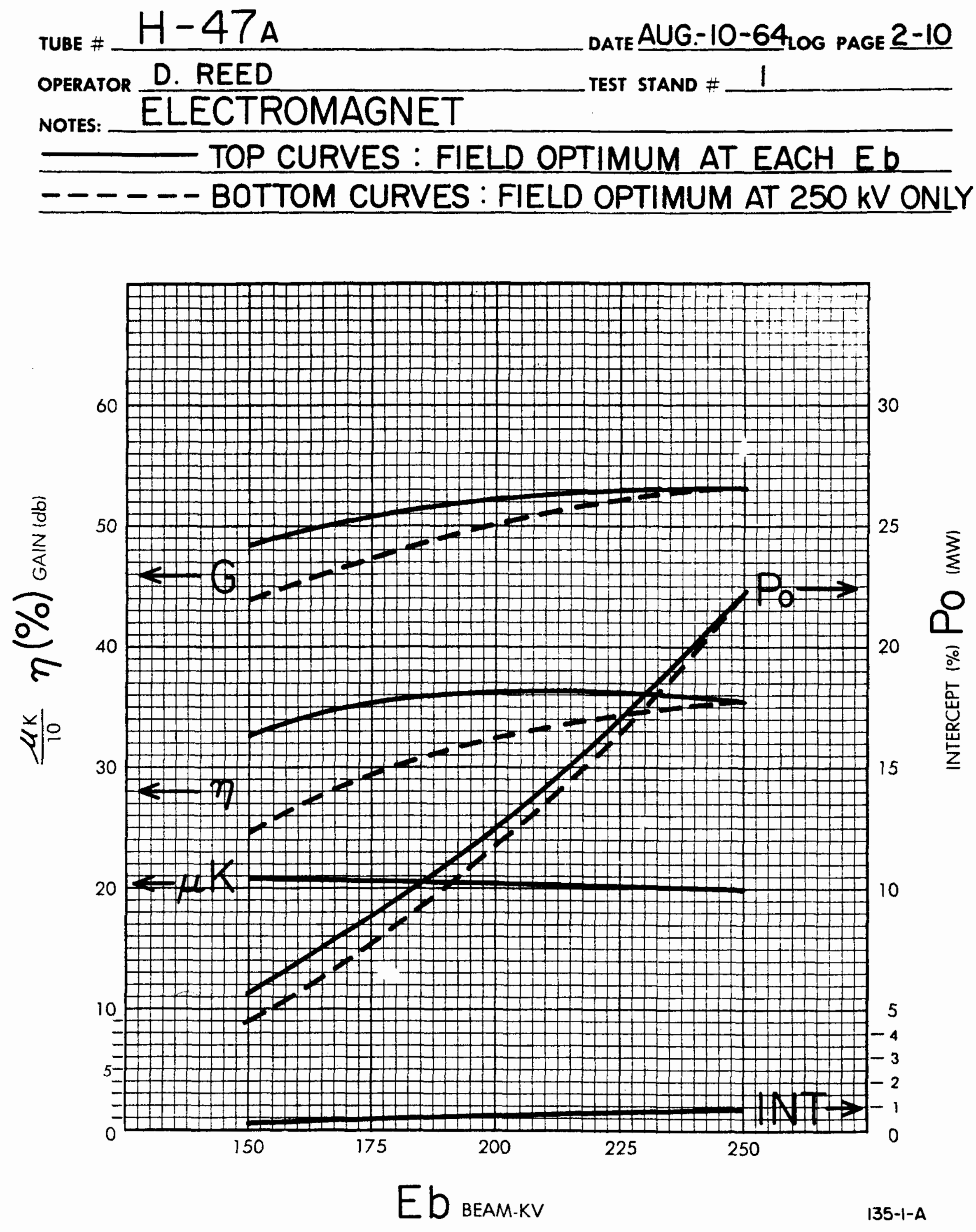

FIG. 24--SLAC Klystron 2422 performance with optimum focusing and fixed electromagnetic field.

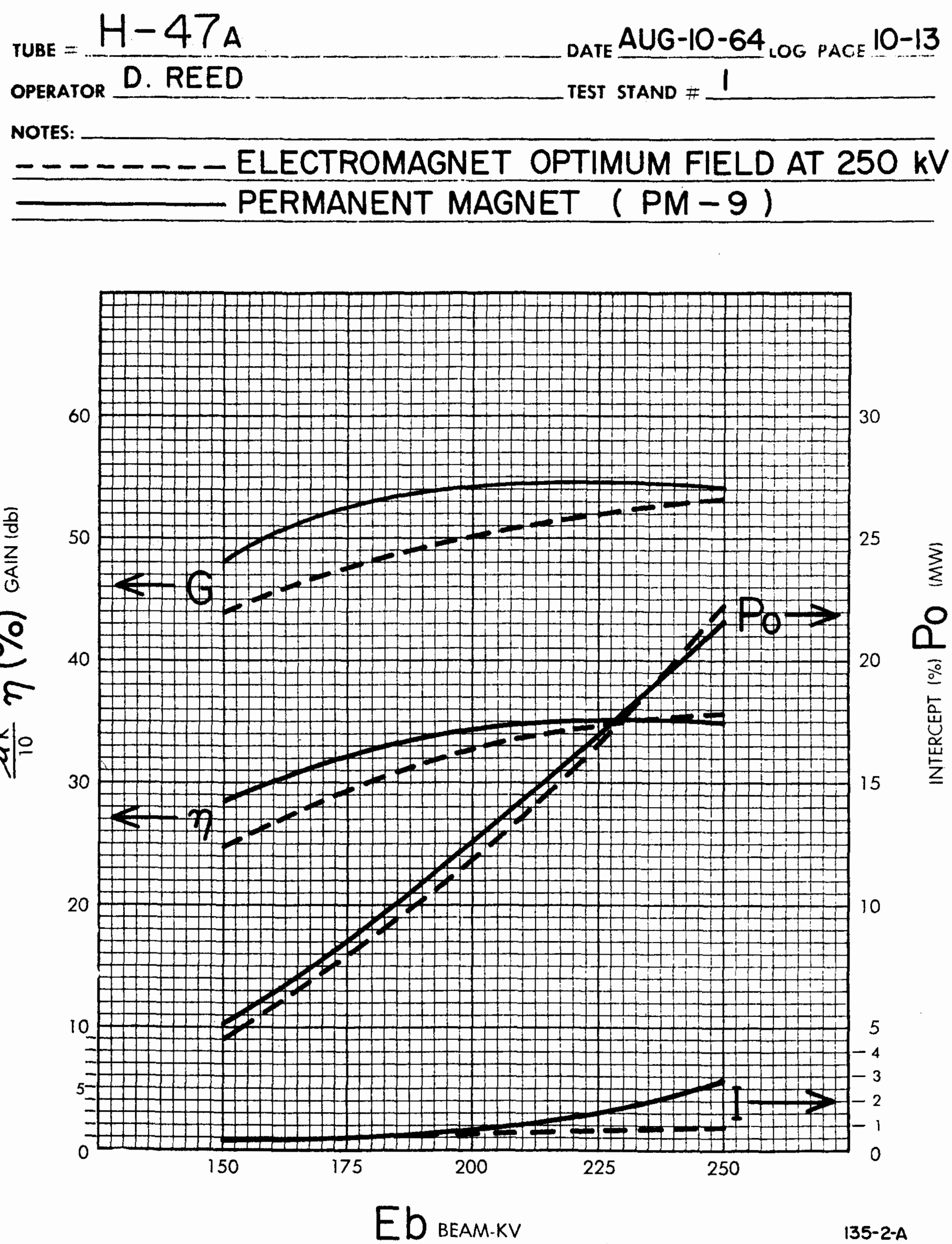

FIG. 25--SLAC Klystron 2422 performance comparison with fixed field, electromagnet and permanent magnet structures.

TUBE # H-47A and H-57A DATE ______ LOG PAGE ______

OPERATOR ______ TEST STAND # ______

NOTES: PM-9 and PM-13 μK between 1.9 and 2

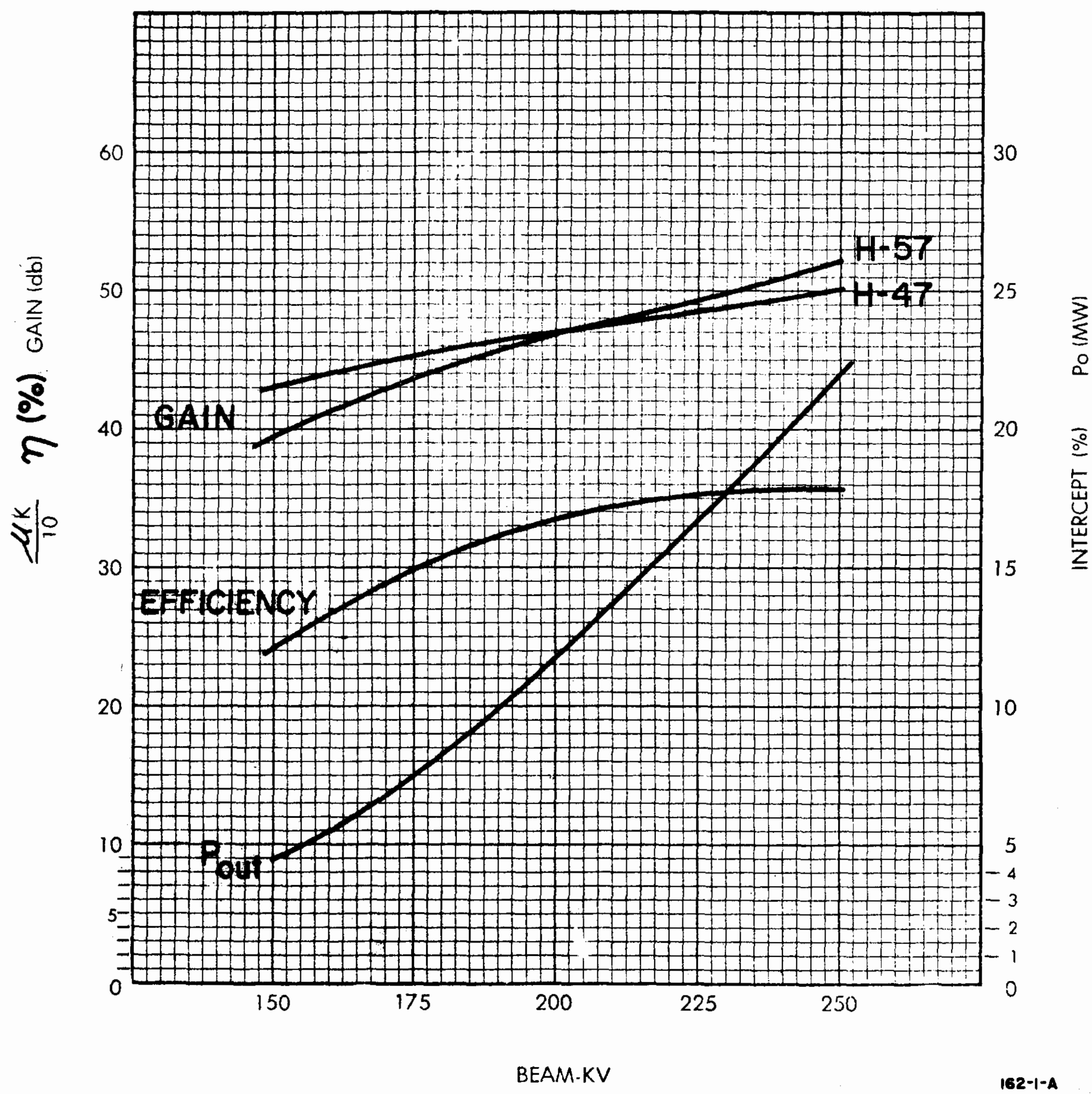

FIG. 26--Comparison of performance of SLAC 2422 Klystrons of similar interaction space design.

between the 3rd and 4th and 4th and 5th cavities. Complete data in permanent magnet has been obtained for only one of these tubes, and is shown in Fig. 27. The other tube exhibited a small amount of oscillations at voltages in excess of 200 kV. By careful tuning of the permanent magnet, it was possible to eliminate the oscillations, and the power output measured at 250 kV was in excess of 22.5 MW.

The difference between the efficiency of the tubes, Figs. 26 and 27, is startling, particularly in the 200 kV operating region. At present the reasons for the differences are not fully understood.

In addition, a comparison of the above data with Fig. 28 of the previous quarterly report* indicates the improvement in klystron performance which has been achieved during the past quarter.

Six Stanford tubes failed during the quarter after total operating times ranging from 13 to 1223 hours. One of the diodes used by the Modulator Group is now temperature limited, but is still operating after 6500 hours. With the termination of the Mark IV operation, the two tubes which had been on the Mark IV accelerator are being removed after 760 and 1950 hours of operation, respectively.

F. KLYSTRON INSTALLATION AND MAINTENANCE

In addition to determining the equipment necessary for installation and maintenance of the klystrons on the two-mile accelerator, a careful study of the requirements during machine operation has been instigated. One of the main problems is to achieve a klystron handling and control program which will be reasonably simple, yet will permit the determination at any time of the position and operating conditions of the tubes in-house.

A klystron control program has been outlined and procedures written. This program will cover handling of all klystrons from the time of receipt of the tube to the time it is to be dispatched to the line. Basically it provides a registration of all klystrons received for potential

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*"Two-mile accelerator project, Quarterly Status Report, 1 April - 30 June 1964," SLAC Report No. 32, Stanford Linear Accelerator Center, Stanford University, Stanford, California (October 1964); p. 75.

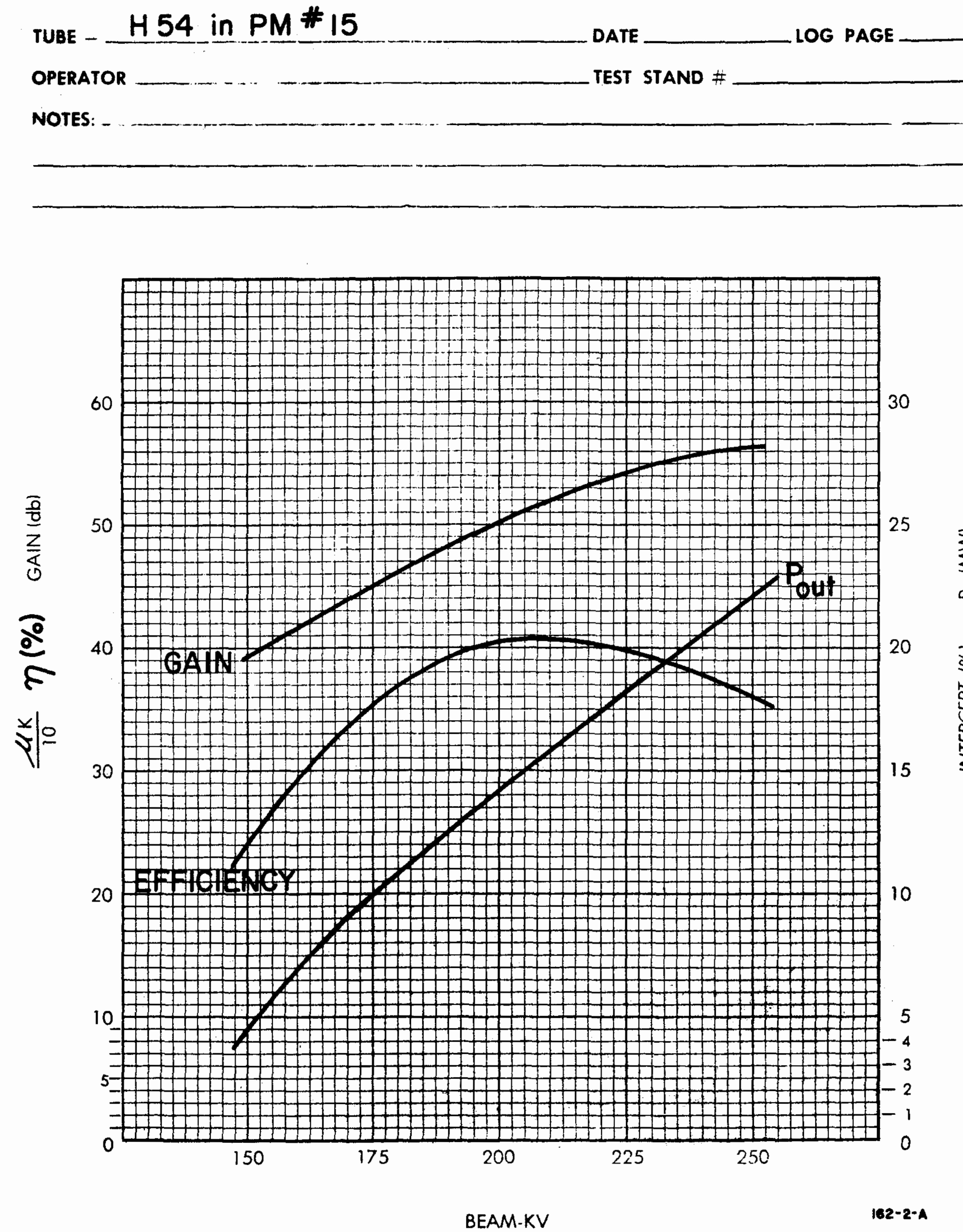

FIG. 27--Performance of SLAC 2422 Klystron of latest interaction space design.

use on the line. Records will be kept by both location and tube serial number. Pertinent data on klystron performance will also be entered in these records. In addition to the klystron registration card, a station card has been prepared that will identify station activity as opposed to individual tube activity. Klystron tags are being prepared to be attached to each tube.

Currently being planned are the method for gathering klystron performance data on a daily basis, the establishment of operating criteria in relation to the possible removal of a tube from the line, and the method of transmitting information on a timely basis to the klystron dispatcher for his action. Before the time of the next quarterly report this program should be well defined.

G. HIGH POWER KLYSTRON WINDOWS

1. Resonant Ring Tests

a. Klystron Window Pre-Testing

Routine pre-tests of all Merdinian klystron windows have continued throughout this quarter. After being coated, each window was tested in the high vacuum resonant ring at powers up to 36 MW (33 kW). During the reporting period, 26 windows were tested prior to installation on Stanford klystrons. Only three windows heated to temperatures in excess of 140° at the 36 MW level, and two of these windows were those which had been excessively coated during the previous quarter. Repeated wet-blast cleanings were necessary before the coatings on these windows were removed sufficiently to allow them to operate normally. The other overheated window also displayed symptoms of multipactor during operation. This particular window appeared not to have been coated sufficiently due to a variation in the coating technique. Subsequent cleaning and recoating resulted in normal, multipactor-free operation of this window.

b. Frenchtown Window Tests

A fourth Frenchtown window was tested in the low power ring, completing the test series begun last quarter. This window suffered multipactor similar to that observed on two of the other three Frenchtown windows tested, and failed during peak power operation at 33 MW (5 kW). Failure of three of the four windows tested in this series showed that Frenchtown 4462 is as susceptible to multipactor and thermal failure as is AL-300 ceramic.

Additional tests of Frenchtown 4462 windows were performed in the high vacuum ring using the same material and the same geometry as that employed in the RCA klystron window. Four windows were tested, all but one of which displayed multipactor symptoms and suffered consequent overheating. After the application of sputtered titanium coatings, the three "hot" windows operated without multipactor or overheating. The results of these tests corroborated the results of the Frenchtown test performed in the low power ring and indicated clearly the advisability of titanium coating on Frenchtown 4462 as well as on AL-300 ceramics.

c. RCA Coated Windows

Several samples of AL-300 ceramic coated with titanium (by evaporation) at RCA are now being subjected to ring tests in order to evaluate the effectiveness of the RCA coating technique. Results to date have been encouraging, as the two windows tested thus far have both operated without overheating despite visual indications of slight multipactor. Both windows overheated in subsequent tests after the RCA coating had been removed by wet-blasting.

d. AL-300 Window Tests

Four AL-300 windows were tested in the low power ring during the quarter as part of a continuing investigation of the relation between material properties and window performance. All of these windows were of the standard AL-300 body, but had been subject to slight variations in the firing-cooling cycle. Three of the windows failed (with initial failure probably internal) despite the fact that no multipactor symptoms were observed during any of the four tests. Total failure occurred at 45 kW (50 MW) in each case, although slight damage had been observed at 30 MW (4.7 kW) and 45 MW (7 kW) during previous operation. Interpretation of test results in the latter two cases was complicated by the possible contributions to the window damage of breakdown due to poor flange contact. Further tests are planned in continuation of this investigation.

e. Boron Nitride Windows

Four more samples of hot-pressed boron nitride were tested during the period, including three of a type of BN which is virtually free of oxygen and therefore considerably less hygroscopic than the other types which were tested. The oxygen-free product was more susceptible to high peak power failure, however; apparently the lower density increased the probability of internal failure. One further test remains in the test program on this material; that test is to be performed on a recently received sample of the pyrolitic form of boron nitride.

2. Other Window Work

a. Material Study

The emphasis on investigating physical properties of the window material is being continued. Study of material properties is more or less divided into experimental and analytical phases. The experimental work consists of resonant ring tests of the effects of variations in the window material. The analytical phase is concerned with the study of particular properties of the material, such as secondary emission, thermal conductivity, microstructure as revealed by electron microscopy, etc.

Experimental study to date has primarily been concerned with the effect of variations in the firing-cooling cycle on the behavior of the ceramic in window service. Samples for this purpose have been provided by Western Gold and Platinum. Wesgo has also provided samples of a variant of the standard AL-300 ceramic in which a smaller grain size is intended to provide greater strength. Dielectric constant measurements will be made on this material in addition to the resonant ring tests.

As part of the analytical study, secondary emission measurements on various window materials will be performed. The secondary emission measuring apparatus has been assembled, wired, and installed in a bell-jar vacuum envelope and will soon be in operation.

Work was completed during the quarter on a measurement technique capable of comparing the thermal conductivity of various windows. The technique has proved capable of resolving differences of thermal conductivity of the order of 15 to 25 percent on the basis of measurements made on AL-300, AL-995, and AD-96 materials. The purpose of this measurement is to provide comparative thermal conductivity data on windows of a given material which have or have not suffered multipactor and overheating. At present, however, no intact samples of overheated window disks are available for comparison with those windows which operated without multipactor.

b. Window Observation Ports

Viewport windows have been fabricated into several of the waveguide bends to be located between klystron and water load during tube test. One such assembly has already been installed on the acceptance test stand so that direct evidence is now available in the event of window misbehavior during tube test.

c. X-rays for Window Diagnosis

Attempts were made to determine the presence of internal window damage by means of X-ray photography. Low energy X-rays ($\approx$ 50 kV) were found to be most effective for examining alumina windows. Voids of significant size ($\approx$ 0.005 inch or larger) were made visible by X-rays, but the technique was not sufficiently sensitive to resolve density changes due to internal damage.

d. Resistivity of Coated Windows

Routine measurements of the resistivity of titanium coated windows are still being made as a precaution against excessive window coating. Two windows with excess coatings were caught by the measurement during the past quarter, thus avoiding the waste of time which would have been involved in ring-testing such a window. There is still no simple means of determining insufficient coating, but one such window was discovered during ring pre-test.

e. Coating of RCA Tube Windows

Several RCA tube window assemblies have been sputter-coated with titanium in the SLAC window coating facility during the past month.

RCA has thus been able to fit several klystrons with coated windows during the interval in which their own coating facility has been under construction. Several of these windows have been installed in RCA klystrons and have performed well in tests both at RCA and at Stanford.

H. SUB-BOOSTER KLYSTRONS

During the quarter, 12 sub-booster klystrons were received and three have been rejected for either pulse droop or pulse breakup. In addition, two tubes were returned for replacement out of four tubes tested during regular checks of shelf life. The program to discover the cause of the shelf life failures has continued, but the corrective measures to be introduced in the fabrication techniques have not yet been determined. The cause is probably to be found in the cathode region, not in the body, but which material or technique improvement will solve the problem is not yet known.

Eleven sub-booster tubes are now in operation, with the longest life on record at the present time slightly in excess of 9000 hours.

IX. MARK IV PROGRAM

A. OPERATION

The Mark IV accelerator continued to operate two shifts per day, five days per week, as it had during the previous quarter. The experimental schedule was so heavy that quite frequently two shifts were required on Saturdays, as well.

There was very little time lost from experimental runs due to machine equipment failures.

The supplementary heat exchanger, referred to in the preceding quarterly report, was received and installed. It was very effective in improving the water system temperature control stability during a considerable amount of hot weather which occurred this final quarter.

The klystron in socket No. 1, which had been there since early January 1964, was replaced on July 22. This tube supplied adequate output power, but was difficult to operate because of its low gain, poor rf pulse shape, and requirement of high power for its heater.

The thyratron switch tubes continued to operate throughout the entire quarter. The total accumulated running time of these tubes as of the morning of October 1, 1964, was as follows.

Modulator	Heater Hours	Anode Hours
1	5352	2290
2	5282	2282

B. TERMINATION OF ACTIVITIES

A project management decision was made to terminate the Mark IV program at the end of the current quarter. Mark IV operations ceased on September 30, 1964, and the machine was slated for dismantling during the first part of the next quarter.

X. BEAM SWITCHYARD

A. GENERAL

The design effort approached a peak during this quarter, as preparations began for major procurements. The housing construction contract was awarded and work begun. The Data Assembly Building bid package was finished and reviewed. The electrical, water, and vacuum system packages were underway.

B. INSTRUMENTATION AND CONTROL

1. Beam Monitors

In selecting proper hole sizes for the protection collimators, the need for a beam position monitor with a 3-inch by 1.8-inch beam opening has been eliminated. A cavity type position monitor with a circular beam opening of 2 inches has been chosen.

Prototypes have been built of the two alternative solutions for the beam profile monitor: the Cerenkov cell (Fig.28) and the zinc-sulfide screen changer (Fig.29). Both prototypes work satisfactorily.

For reasons of economy, the number of synchrotron light observation stations has been reduced. Television viewing has been eliminated for the present. A direct observation through a mirror system will be developed for one accelerator station.

2. Protection System

A proposal for an equipment protection system was submitted and approved. A prototype ionization chamber has been tested satisfactorily. The design of the electronics for the protection system is well underway.

3. Computer

A small digital computer will be used in the Switchyard for data handling for the scanning of status and interlock signals and to a very limited extent for digital control (primarily analog settings, e.g., magnet currents).

C. MAGNETS

The prototype 3° bending magnet was received and measurements were made. The mechanical tolerances were met with the exception of the pole face flatness.

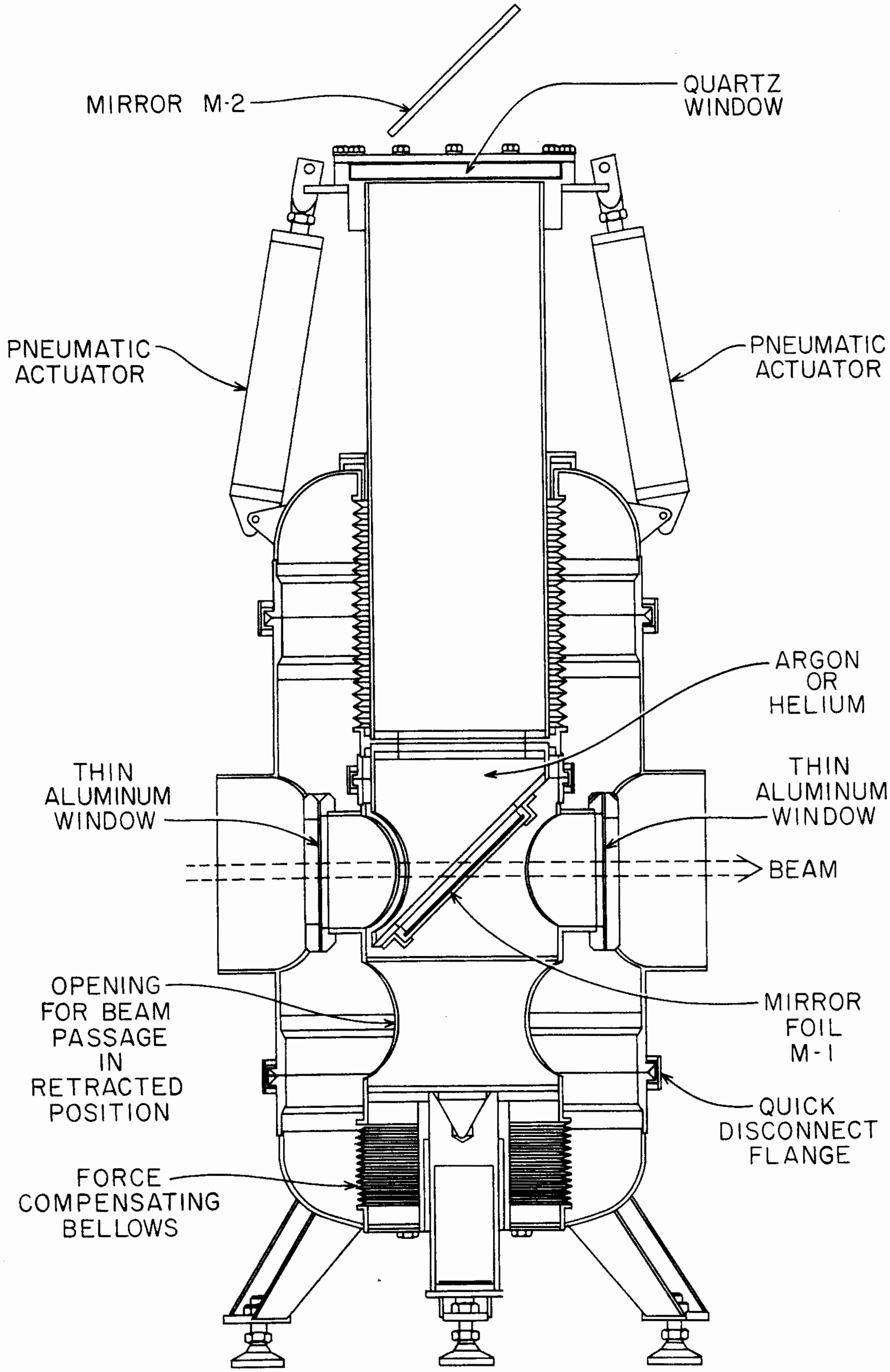

FIG. 28 CERENKOV CELL

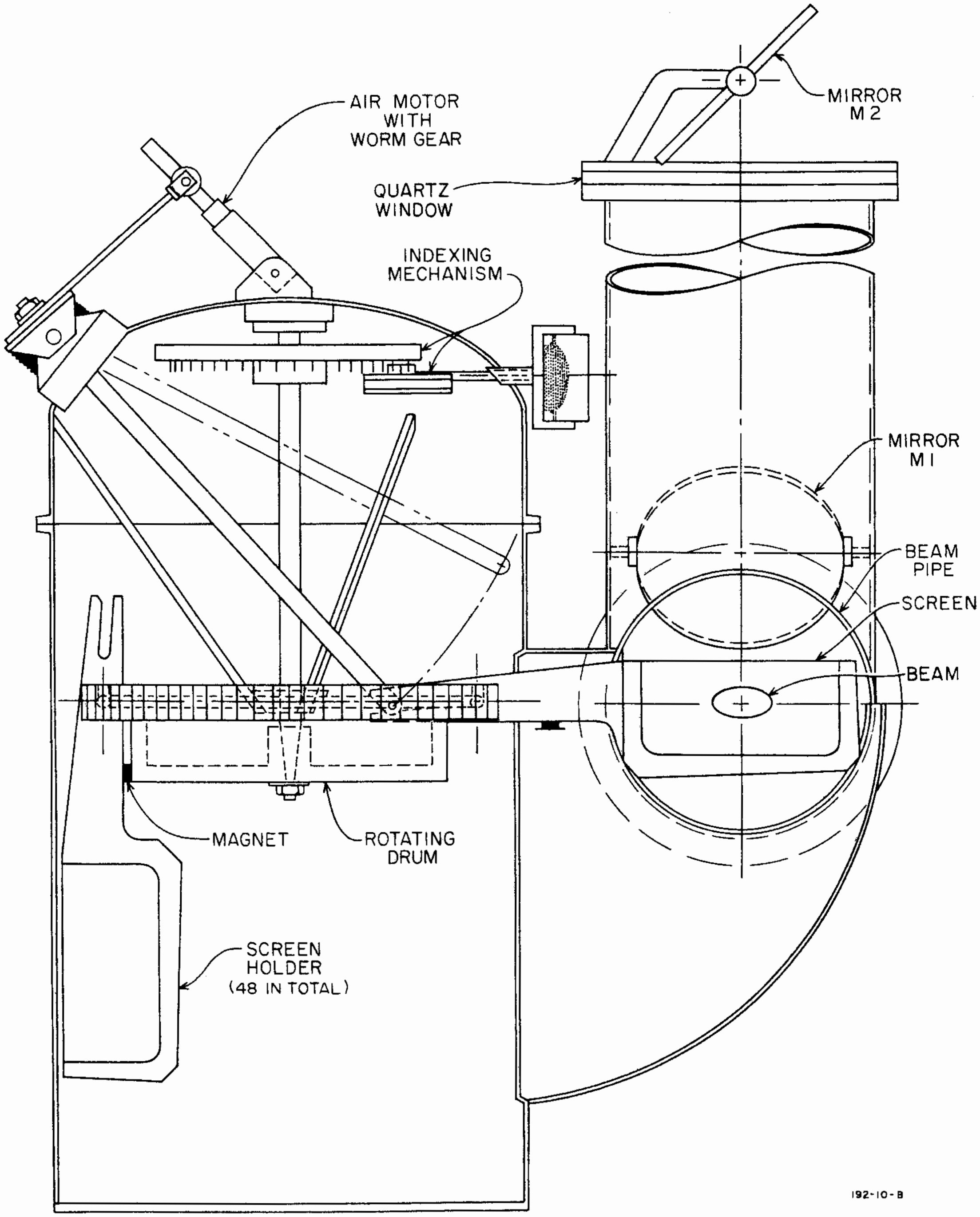

FIG. 29 ZINC SULPHIDE SCREEN PROFILE MONITOR

The magnetic measurements showed the $\int B d\ell$ to be uniform within 0.01% over a total width of 3-1/4 inches at 12.5 kG. The absolute homegeneity was within 0.01% over a width of 6 inches at the center of the magnet at 12.5 kG.

The drawings and specifications for the 3° bending magnets were completed and are being reviewed prior to request for bids.

The prototype 8-cm quadrupole magnet was received and magnetic measurements were made. The field gradient was found to be 452 gauss/cm at 500 amps. The effective length was found to be 78.41 inches (vs. 78.74 inches calculated). The straightness of the magnetic center was found to be within 0.001 inch over the entire length. The gradient was found to be linear with current within 1% up to 800 amps.

The prototype 0.1° pulsed bending magnet was received and measurements were made. The magnet gap was found to be far out of flatness tolerance. The magnetic measurements showed the field variation to be outside acceptable limits. The magnet was run at full repetition rate and at high currents for long periods and showed no sign of deterioration. It is believed that with more careful control of fabrication processes on the switchyard pulsed magnets, the field tolerances will be met.

Bids were requested for 50,000 pounds of hollow-square copper coil conductor. This is about 98% of the copper required for the dc magnets to be used in the beam switchyard. SLAC will thus be able to supply copper to the coil fabricators.

D. POWER SUPPLIES

1. DC Power Supplies

The series transistor regulators used to regulate the 64-kW dc power to within ±0.005% for the prototype 3° bending magnets have proved satisfactory. The ac voltage vs. field characteristics of the prototype 3° bending magnet and the 8-cm quadrupole magnet were studied during this period. The specifications for the power supplies required by these magnets are being prepared and are to be issued early in the next quarter.

Precision 1000-amp shunts, which are used to measure the magnet currents to within 0.01%, were received and are being evaluated.

2. Pulsed Magnet Power Supplies

Life tests of the prototype pulsers were run using the pulsed magnets, and runs were made to determine optimum operating parameters for the ignitrons. Tests were conducted on the heating of various types of beam chambers in the field of the pulsed magnet. A satisfactory chamber design has not yet been found; thus, the final design parameters of the pulsed magnet power supply have not been set.

The specifications for the procurement of the power supplies have been written and are being reviewed.

Tests are being conducted to ascertain the best method of degaussing the pulsed magnet. It appears that one method is to feed a full sine wave of current through the magnet each pulse.

E. VACUUM CHAMBER SYSTEM

1. Remote Disconnect Couplings

On the basis of comparative tests, it was decided to use an indium sealed coupling design in the vacuum system. In three sets of tests, the 6-inch prototype was opened and closed 80, 50, and 65 times respectively without exceeding a leak rate of 10^{-5} torr-liters/sec.

A prototype of a proposed 10-msec closing fast valve was fabricated and testing began. First tests with weak springs were encouraging. Prototypes of remotely operable water and electrical disconnects were made and evaluation is in process.

F. SLITS AND COLLIMATORS

Studies are progressing concerning the energy-absorbing module of the slits and collimators. Various designs and fabrication techniques are under consideration.

G. ALIGNMENT

1. Light Pipe System

The following is an outline of the alignment method proposed for the switchyard equipment (see Fig. 30):

The main reference line in the beam switchyard will be defined by the extension of the accelerator alignment technique (laser beam, Fresnel lenses) for about 750 feet from the end of the accelerator. The laser light source

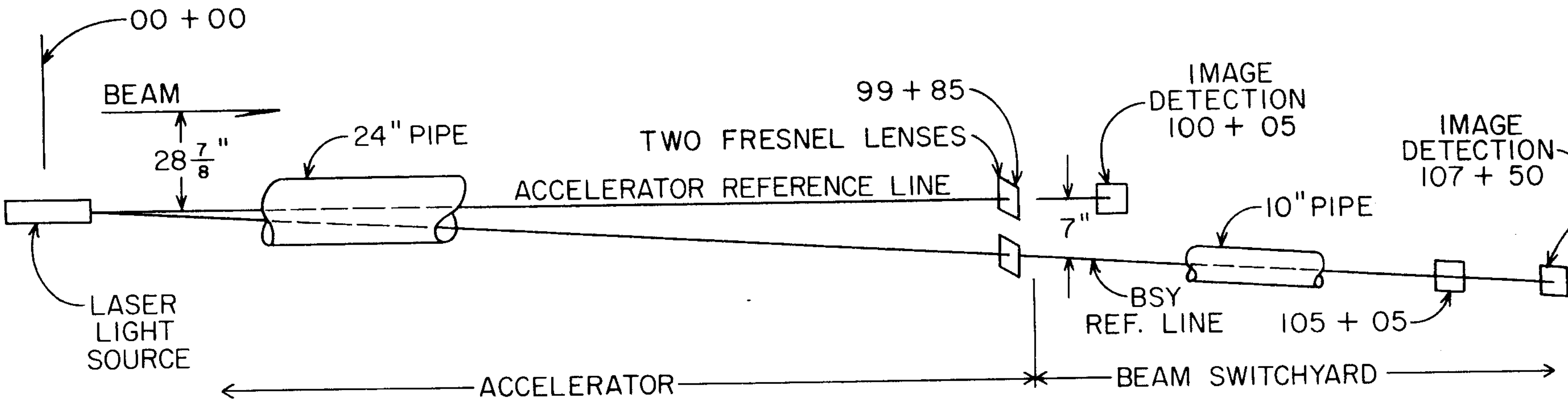

FIG. 30 - ALIGNMENT SYSTEM FOR THE BEAM SWITCHYARD

at the beginning of the accelerator (Station 00 + 00) and one of two Fresnel lenses at the end of the accelerator (Station 99 + 85) will form the accelerator reference line. The other Fresnel lens at Station 99 + 85 and one Fresnel lens in the beam switchyard at Station 105 + 08 will determine the beam switchyard reference line. The double lens system at Station 99 + 85 is necessitated by the fact that (1) the 24-inch accelerator light pipe must neck down to a 10-inch pipe, and (2) the centerline of the 10-inch pipe must be 7 inches below the 24-inch accelerator pipe for equipment to clear in the beam switchyard.

The image detection station for the accelerator reference line will be at Station 100 + 05. The image detection station for the beam switchyard will be located at Station 107 + 50.

The 24-inch accelerator support (light pipe) will continue into the beam switchyard for about 100 feet to support BSY equipment. After this first 100 feet, the 24-inch pipe will neck down to a 10-inch alignment pipe. The 10-inch alignment pipe will be connected directly to the collimators and to the pulsed magnet stand to facilitate their alignment directly by the laser system. After the pulsed magnet group, a system of external targets on the 10-inch light pipe references the internal Fresnel lenses and will be used to transfer measurements to the beam transport equipment in the A and B beams.

The 8-cm quadrupole doublets and the energy-defining slits will be referenced directly to the laser system but will not be aligned directly by it.

2. Alignment Targets for Beam Transport Equipment

A mock-up of the 8-cm quadrupole was set up in a positioning jig to test procedures and methods of positioning the magnetic axis and the magnetic center. Also, procedures and methods of referencing the magnetic axis for alignment purposes in the beam switchyard were studied. Two reference systems are required because the magnetic axes are not orthogonal to the gravity axis due to the fact that the beam both slopes and banks in the A and B beams.

A tower was set up over the mock-up to test second-story alignment procedures and to discover problems that may exist in the precision alignment of the beam switchyard.

3. Alignment Equipment

Alignment telescopes, jig transits, theodolites, collimators, and many accessories needed to develop alignment techniques and targetry for the beam switchyard were purchased and received. A collimating test stand was set up for the calibration and testing of the alignment equipment.

H. VACUUM PUMPING SYSTEM

Two research projects were completed in this period. The first one deals with the oil trapping efficiency of the 10-foot accelerator section to be used as an oil barrier in the BSY differential pumping system. Tests show that a refrigerated 10-foot accelerator section is a satisfactory baffle for preventing oil migration to the accelerator. The second project was the development of an all-metal vacuum gauge which would trigger the fast BSY valves. This gauge (McClure switch) is a very simple cold cathode device. The three gauges tested demonstrated very good reliability and repeatability.

I. BSY HOUSING

The contract for construction of the BSY housing structure, penetrations, retaining walls, backfill, and equipment pads was awarded. Notice to proceed was given on September 16. The schedule calls for completion of all structures and connection of power and lighting systems to the Data Assembly Building by May 30, 1965. Total completion is scheduled for September 1, 1965.

Design of the Material Handling System is on schedule and is expected to be completed by January 15, 1965. The completed system, installed and checked out, is scheduled for July 30, 1965.

J. BEAM DUMP

The basic design of the beam dump was completed. The main features of the design are shown in Fig. 31.

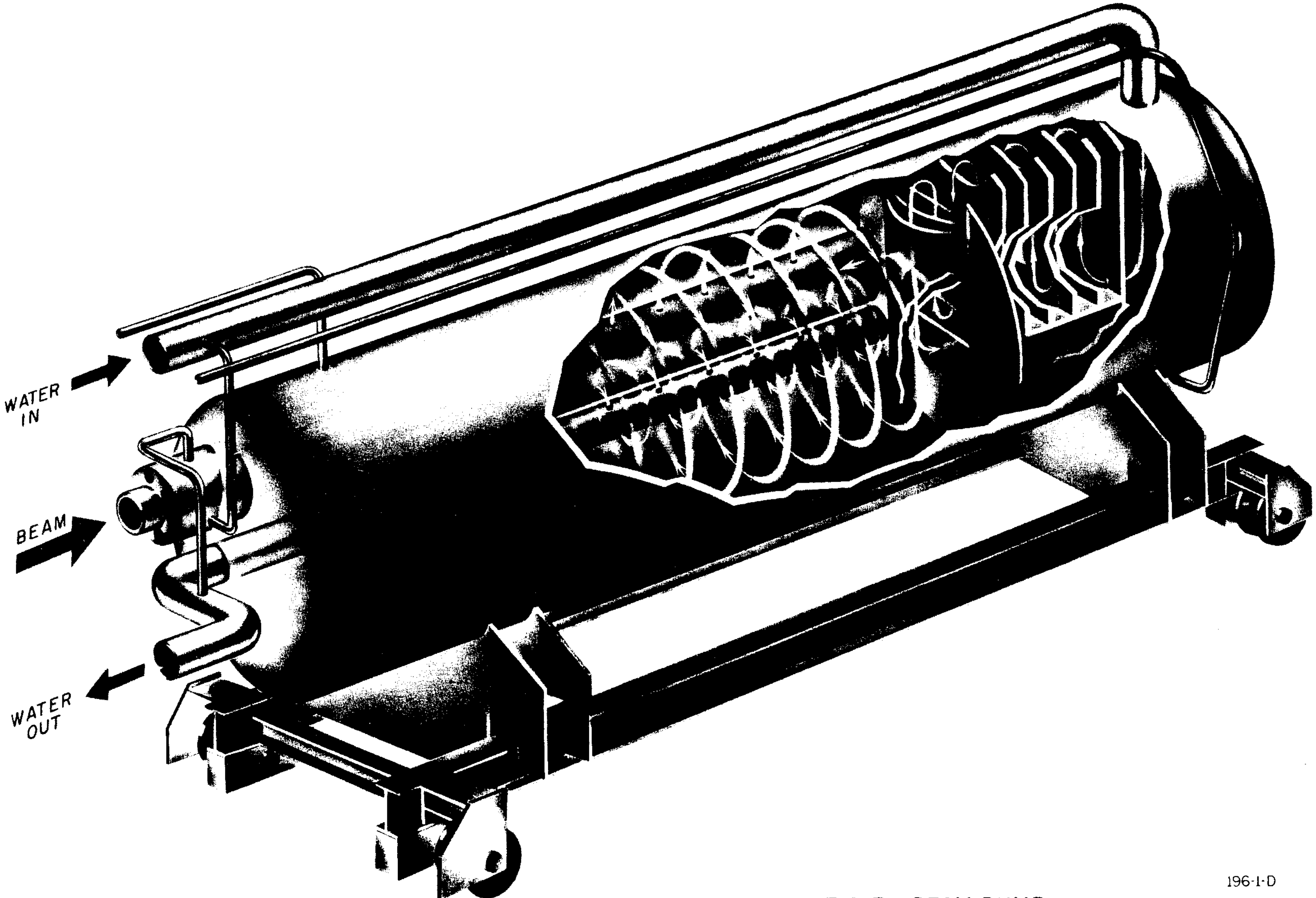

FIG. 31 BEAM DUMP

XI. TARGET AREA DEVELOPMENT

During this quarter two Title II submittals of End Station A were received. The 50% submittal was received on July 27, 1964, and the 90% submittal on September 28, 1964. No major changes in criteria for End Station A were made during this quarter.

The 50% submittal of Title II work for End Station B was presented to SLAC on August 17, 1964. No major changes in End Station B were made.

During this quarter considerable work was done on the Utility Tunnels in End Stations A and B. For reasons of economy, the cross-sectional area of the tunnels was reduced, and corrugated-metal "cattle passes" were used to communicate between the Research Area Power Substation and the End Stations. In addition, the number of lateral tunnels in End Station B was reduced from three to two.

Aside from the changes mentioned above, the only other important change in the utility tunnels was the inclusion of electrical power control centers: one in the utility housing south of End Station A and one north of End Station B. Power emanates from the Research Area Power Substation to these control centers for subsequent distribution through the utility tunnels. By having the control centers here (rather than inside the end station buildings), it is possible to avoid running power into the building and then immediately out again for distribution via the utility tunnels.

During this quarter a decision was made to include both end stations and the utility tunnels in one construction package.

XII. PRE-OPERATIONS RESEARCH AND DEVELOPMENT
[Contract AT(04-3)-515]

A. EXPERIMENTAL GROUP A

Most of the quarter was spent in the preparation of a proposal* for the construction of spectrometer facilities for electron scattering and photoproduction in End Station A. After consideration of the various physical problems likely to be investigated in the interval following turn-on, two instruments with the following parameters were included in the proposal.

p_{max}	20 BeV/c	8 BeV/c
Solid angle	10^{-4} steradian	10^{-3} steradian
Momentum resolution	$\pm$ 0.05%	$\pm$ 0.05%
Momentum acceptance	$\pm$ 2%	$\pm$ 3 - 4%
Angular resolution (production angle)	0.3×10^{-3} radian	0.3×10^{-3} radian
Acceptable target length	$\approx$ 10 cm	$\approx$ 10 cm
Minimum angle at which beam will miss instrument	0.6°	$\approx$ 15°

Considerable investigation was necessary to establish the various parameters. In particular, the requirement of distinguishing between processes which differ only by the production of one pion leads to the stated requirements for energy and angular resolutions.

Magnetic systems to meet these criteria were studied. The proposed low-energy spectrometer is a conventional arrangement of quadrupoles and bending magnets with momentum analysis in the vertical plane. This results in a detector position approximately 20 feet above the beam line. The forward-angle high-energy spectrometer is a unique design stemming from a desire to analyze momentum in a horizontal plane, and at the same time preserve angular resolution within the angular acceptance of the spectrometer.

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*This proposal was a joint effort involving (in addition to Group A) Group C at SLAC, a group from California Institute of Technology, and a group from Massachusetts Institute of Technology.

Further calculations including second-order optics will be undertaken in the next quarter and may require changes in the proposed spectrometers.

Possible detection equipment and data-handling systems were also considered. The desirability of collecting data simultaneously over regions of angle and momentum much larger than the required resolution has led to the proposal of two-dimensional hodoscopes in the focal planes of each spectrometer. In addition, very preliminary studies of particle identification equipment were undertaken. Data handling will require a medium sized on-line computer.

In addition to the preparation of the proposal, work continued on the positron source, for which new radiator concepts were developed, and on End Station A and Target Utilities.

B. EXPERIMENTAL GROUP B

1. Pion Beta Decay

R. R. Larsen (in collaboration with R. Bacastow, C. Ghesquiere and C. Wiegand, Lawrence Radiation Laboratory)

This experiment has been successfully completed and is now being written up. The result (a 20% measurement) is in agreement with CVC. Details will be published in The Physical Review.

2. $\pi^- p$ Interactions at 3.9 BeV/c

Z. Guiragossián (in collaboration with R. Birge, R. Ely and T. Schumann, Lawrence Radiation Laboratory, and M. Whitehead, California State College, Hayward, California)

Two-prong and four-prong interactions have been measured in the LRL 72-inch hydrogen bubble chamber using the Flying Spot Digitizer. With 60% of this exposure scanned and measured, the following reactions have been identified:

1.	$\pi^- p \rightarrow \pi^- \pi^+ n$	1340 events
2.	$\rightarrow \pi^- \pi^0 p$	855 events
3.	$\rightarrow \pi^- p \chi_0$	1000 events, χ_0 = 2 or more π^0's
4.	$\rightarrow \pi^+ \pi^- \pi^- p$	610 events
5.	$\rightarrow \pi^+ \pi^- \pi^- \pi^0 p$	970 events
6.	$\rightarrow \pi^+ \pi^- \pi^+ \pi^- n$	480 events

Results on Reactions 1 and 2 have been submitted for publication in the

Proceedings of the 1964 International Conference on High-Energy Physics at Dubna.

Preliminary evidence obtained from Reaction 3 shows that the A_2 resonance ($A_2 \rightarrow \rho^- \pi^0$) is copiously produced whereas no evidence was found for the A_1 (1100) $\rho\pi$ enhancement.

3. $\pi^- p$ Interactions at 4.2 BeV/c

Z. Guiragossián (in collaboration with S. Chung, D. Miller and R. Birge, Lawrence Radiation Laboratory)

About 15,000 four-prong interactions in the LRL 72-inch hydrogen bubble chamber have been measured, and three times as many events of Reactions 4, 5, and 6 above were obtained. A study of the multipion resonances A_1, A_2 and B, and of the N^* formation is in process, using the combined data at 3.9 and 4.2 BeV/c.

4. $K^- D$ Interactions at 2.7 BeV/c

Z. Guiragossián, C. Ghesquiere and F. Martin

Scanning and measuring the events of interest in the 2.7 BeV/c $K^- D$ exposure are being performed at SLAC; this exposure was obtained by a separated K^- beam at the Bevatron using the LRL 72-inch hydrogen bubble chamber.

The interactions of interest are the final states of Λ^0 + one π and $\Sigma^{\pm} + n\pi$, where $n = 1, 2, 3,$ and 4. The purpose of the experiment is to test charge independence at high energies and to investigate various $Y^* \rightarrow \Sigma\pi(\pi)$ resonances.

5. Almost Monochromatic Photon Beams

J. Ballam and Z. Guiragossián

The study on the production of almost monochromatic photon beams at SLAC has been completed. The results of this study have been submitted for publication in the Proceedings of the 1964 International Conference on High-Energy Physics at Dubna.

C. EXPERIMENTAL GROUP C

1. Vacuum

As part of a program for establishing vacuum system design parameters for the proposed 3-BeV storage ring, investigation of gas desorption by low-energy electrons has been underway.

The experimental program is oriented toward measuring the amount and type of gases desorbed by low-energy electrons. Desorption rates as influenced by angle of incidence, surface preparation, and in-vacuum treatments are being measured for various candidate metals.

The metals under study are: stainless steel (austenitic), tungsten, tantalum, titanium, copper, molybdenum, niobium, zirconium, and gold. The metals are being subjected to the following surface preparations: chemical etching, electropolishing, electroplating, evaporated coatings, and inadvertent contamination (fingerprints). In-vacuum treatments that are being performed alone or in combination are: vacuum baking, heating in hydrogen, heating in oxygen, glow discharge bombardment, and electron bombardment (1-10 kV).

Two experimental setups are being used to obtain electron desorption data. The first apparatus (the movable target system) permits bombardment of a small area of each facet of a hexagon-shaped target. Desorption measurements can be made on six different materials, identically processed in vacuum, at normal and grazing incidence by moving the various target facets into the line of the beam. The materials are brazed to the faces of the hexagon. Operating pressures in this system are in the 10^{-9} to 10^{-10} torr range.

The second apparatus (a simple coaxial diode) was built to supplement the data obtained with the movable target system. The diode is very simple to assemble and dismantle and permits operation at much lower pressures (10^{-11} torr range). With the diode, a larger area is under bombardment and the surface is more nearly identical to that of materials used in construction than is the case with the brazed foils in the other apparatus. It is planned to give a grazing component to the electrons emitted from the coaxial filament by surrounding the cylinder wall with an electromagnet. To change surface pretreatments, the tube can be removed, treated and reexamined, or treated in place, under vacuum. In order to change materials, either the tubes are changed or foil liners are inserted.

The results to date are given below. Most of the following information has been obtained with the movable target system; however, the diode system is now in operation and beginning to provide data.

a. Desorption rates

Total desorption rates varied from 2×10^{-4} molecules/electron for clean unbaked surfaces to $\approx 5 \times 10^{-7}$ molecules/electron for baked and bombarded surfaces.

b. Energy dependence

The desorption rate for most surfaces appears to increase parabolically for electron energies between 20 and 500 volts. Measurements will be extended to higher energies as part of the in-vacuum treatment program.

c. Normal vs grazing incidence

Grazing incidence bombardment yielded approximately twice as much gas as normal incidence.

d. Material differences

Targets of niobium, molybdenum, tantalum and stainless steel yielded similar amounts and types of gases when bombarded (within a factor of two).

e. Gases desorbed

Increases in CO and H_2 were dominant during electron bombardment although small amounts of CO_2 and CH_4 were observed during the early stages of bombardment. Normally, the H_2 increase was greater than the CO increase by factors ranging between 2 and 20 to 1. However, as Lichtman* has indicated, some of the H_2 may result from CO-H_2 exchange on the walls. It is probable that atomic oxygen is desorbed, which then forms and releases CO by surface contact reactions.

f. Contamination effects

One of the stainless steel targets gave desorption rates consistently higher by a factor of five than the other stainless steel targets. These high desorption rates persisted during and following bakeout above 325°C. Subsequent examination of this target showed a clear fingerprint located in the area that had been under bombardment by electrons.

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*D. Lichtman, "Adsorption-desorption of residual gases in high vacuum," Eleventh Vacuum Symposium, Chicago, Illinois, October 2, 1964.

2. Detector

Work during this quarter has been concentrated on development of the streamer chamber. The isotropy of this type of chamber, its ability to show vertices, and its multiple track efficiency make it the most suitable type for the colliding beam project. However, two drawbacks of this type of chamber are that its light output is poor and the streamers can be undesirably long.

Work at SLAC and the results from Russian workers* show that it is not possible to increase the light output appreciably; gas mixing and choice of film do not gain us more than a factor of 2 or 3 whereas we need a factor of 25. The use of image intensifiers is being investigated.

It would be desirable to keep the length of streamers less than 2 mm without decreasing their light output. The factors that govern streamer length are not well understood. Indications are that the length remains approximately constant for pulse widths less than 50 nsec and that relatively low voltage tails of pulses that exceed 50 nsec spread the streamers quickly. Therefore, we have concentrated on producing square pulses with clean, sharp falls and good rise times. The pulse width should be variable within the range 5 to 50 nsec. A Marx generator with a triggered pressurized shorting gap remains the most promising method for generating such pulses. With such an arrangement (which is nearly completed) we propose to study the following:

1. The dependence of streamer length on pulse width and height and methods of improving the ionization measurements which are being conducted at Stanford's High Energy Physics Laboratory; and

2. The effect of pulse width on the improvement of the isotropy of conventional wide-gap chambers. The equipment for this experiment has been completed.

Some preliminary analysis of the tracks of various monoenergetic particles in the 25-cm-square by 10-cm-deep streamer chamber (neon at 1 atm-pressure) indicates that dE/dx can be determined by measuring the blob density. The true blob density in a track was obtained by measuring

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*G. E. Chikovani, *et al.*, "Investigation of the mechanism of operation of track spark chambers," JETP 19 (No. 4), 833 (1964); and "Track spark chamber with isotropic properties as a device to study high-energy nuclear reactions," Institute of the Academy of Sciences of the GSSR preprint (1964).

the distribution of the gap lengths between blobs from 24-cm-long tracks. Blobs which occur closely together merge so that gap lengths less than about 2.5 mm were not seen.

From the exponential slope of the distribution for large gap lengths, the blob density for minimum ionizing (I_{min}) pions was found to be 2.8/cm while for 2.3 I_{min} protons it was 5.5/cm. The ratio 1.95 is in reasonable agreement with the expected ionization ratio of 2.3, considering the preliminary nature of the results. It is important that recording and developing conditions be the same for all the tracks in these measurements.

Studies are also starting on the attainable momentum precision which is possible in a streamer chamber. Curvature measurements are now being made on tracks which are not in a magnetic field. Later, a magnetic field will be used.

D. EXPERIMENTAL GROUP D

Group D is primarily concerned with a program of photoproduction studies. In such studies one must analyze many-body final states, and this leads to the need of an analyzing system capable of handling almost 4π.

Studies have been made of the problems of using wide-gap spark chambers in a large magnetic field volume with a configuration similar to that of a hydrogen bubble chamber. This has led to the preliminary design of a large magnet (cylindrical magnetic field volume 2 meters in diameter and 1 meter deep). It is planned to place a hydrogen target (either liquid or gas) at the front of the magnetic field volume. It is hoped that the development of streamer chambers will allow their use in the region surrounding the hydrogen target. In the area downstream ordinary wide-gap chambers can be readily used, if desired, because the high-momentum particles occur in relatively restricted angles. To eliminate the background of electron-positron pairs, the central plane of this configuration will be desensitized by the use of a gas of different sensitivity. (This technique has been successfully used by J. Walker at Harvard.) If the forward central plane is desensitized, the principal background will be Compton electrons. Studies of these backgrounds indicate that beam intensities of between 100 and 1000 equivalent quanta per pulse with 10 cm of liquid hydrogen may be possible. This would lead to data rates of about six events per minute at a cross section of one microbarn.

This configuration can be supplemented by the use of external forward-angle spark chambers, Cerenkov detectors, and shower counters. Simple trigger systems can be devised utilizing scintillation detectors in the forward angles. Studies indicate that with a spark resolution of ±0.5 mm a momentum resolution of ±2% will be obtained at 5 BeV if only the two-meter region inside the magnet is used. If external spark chambers are used it should be possible to improve this to ±0.5%. It is also hoped that spark consistency of better than the ±0.5 mm will be obtained. It is most important that a good energy resolution be obtained if one is to use only kinematic identification of events.

It is not clear what experiments will be performed first, but the most obvious will be to undertake studies of reactions with all charged final states, such as

$$\gamma + p \rightarrow p + \pi^+ + \pi^-$$
$$p + 2\pi^+ + 2\pi^- .$$

Such experiments can be completely determined without the need for external devices such as Cerenkov detectors and shower counters if sufficient momentum resolution is obtained.

It should be possible to use this device with minor changes in electro- and muo-production experiments. The use of monochromatic photons from positron annihilation or tagging may be possible, but the preliminary experiments postulate only the use of a hardened bremsstrahlung beam.

Preliminary studies have been made of the following problems: possible experiments; wide gap spark chamber operation; magnet design; optics problems; data analysis; momentum resolutions; backgrounds; production of a clean photon beam; auxiliary equipment (Cerenkov detector, heavy spark chambers); electro- and muo-production.

Work is continuing on these problems, with emphasis on final magnet design, design of components for the photon beam, testing of spark chambers at the Mark III accelerator, and the creation of a computer program for simulating events.

E. EXPERIMENTAL GROUP E

1. Experimental Work — M. Kreisler, F. Martin, M. L. Perl, T. H. Tan

Two experiments were completed at the Cosmotron. One experiment, $p + p \rightarrow d + \pi^+$, has already been reported.* The second experiment was a

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*O. E. Overseth, et al., Phys. Rev. Letters 13, 59 (1964).

study of the deuteron angle and momentum spectra in the reaction $p + p \rightarrow d$ + two more additional particles. The purpose of this experiment was to investigate the general behavior of the deuteron production mechanism in p + p collisions and to look for resonances in the additional particles. The data collection has been completed and analysis is underway.

The doctoral thesis of M. Kreisler consists of the first measurement of diffraction and large-angle elastic scattering of neutrons on protons above 1 GeV. This experiment is being carried out using the external beam of the Bevatron and is in collaboration with M. Longo and S. Powell of the University of Michigan. This team was used to set up the experiment and to begin data taking. The experimental equipment is of large size and of medium complexity. Most of it was designed and made at SLAC.

A bubble chamber measurement of large-angle $\pi^- + p$ elastic scattering at 3.63 GeV/c was completed and a paper is being prepared.

Work on analysis of a K^- - d bubble chamber exposure was continued.

Design work was continued on a very high energy bubble chamber beam at Brookhaven National Laboratory for use with the BNL 80-inch chamber.

Design work was begun on the first experiments (a survey experiment and a muon experiment) we would like to do at SLAC.

2. Electronic Development - A. Barna and D. Horelick

A high-voltage, mercury-relay-type pulse generator delivering 2.5 kilovolts into 50 ohms with a risetime of 0.3 nanoseconds has been built.

A digital data scanner-recorder is being designed and constructed. The unit accepts data from up to fourteen 10-Mc commercial counters and prints the information on paper tape.

A high-speed, direct-coupled amplifier for use as a zero-crossing detector in conjunction with coincidence circuits is being developed.

3. Data Reduction Equipment - D. Porat

One machine for digitizing bubble chamber tracks was available during this period. The electronic circuits and components were systematically improved during the period in order to achieve better reliability.

Design of the electronic system for the measuring projector (four-digit accuracy) was started. Two such projectors are now being constructed and will serve for digitizing spark chamber tracks. The general system, layout, and choice of the major components was fixed.

Detailed circuit design was started on the electronics for the SP-V scanning machines. New circuit developments are described below.

A velocity servo loop was developed to transport film. The time-modulated power-amplifier stage uses silicon-controlled rectifiers controlled by a novel circuit. Stable operation over a wide range of environmental conditions as well as higher circuit reliability are achieved using fewer components, owing to the high power gain of SCR's as compared with transistors.

A "window amplifier" was designed to actuate an inhibiting signal whenever the film is moving above a certain (low) speed. The circuit is bi-directional, enabling it to generate the signal independent of the direction of motion of the motor driving the film.

Negative feedback to control acceleration was added to the servo loop (in addition to the commonly used velocity feedback). The acceleration control enables the film transport to have a fast response but restricts the forces acting on the film to predetermined values in order to prevent film damage.

A set of functions was developed to permit second- or higher-order zero-pole corrections using a single operational amplifier. Results were applied to the shaping of the frequency-response curve of the feedback loop.

F. THEORETICAL PHYSICS

1. Publications

The following articles or reports have been completed since the last listing:

(1) R. J. Adler and S. D. Drell, "Meson exchange effects in elastic e-d scattering," Phys. Rev. Letters 13, 348 (1964)(SLAC-PUB-33).

(2) S. D. Drell (with A. C. Finn and A. C. Hearn), "Bounds on propagators, coupling constants, and vertex functions," SLAC-PUB-39; ITP-125 (submitted to Phys. Rev.).

(3) Y-S. Tsai, "High energy gamma ray source from electron-positron pair annihilation," SLAC-PUB-45 (submitted to Phys. Rev.).

(4) M. Thiebaux, "Drell model pion photoproduction programs," SLAC Internal Report, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1964).

(5) U. Maor, "Estimates of high energy photo-pion production at 0^o," Phys. Rev. 135, B1205, (1964) (SLAC-PUB-30).

(6) S. M. Berman and U. Maor, "Effects of the ρ-N vertex on pion photoproduction in the forward direction," SLAC-PUB-38 (submitted to Nuovo Cimento).

(7) M. Thiebaux, "Off-shell correction in pion photoproduction," Phys. Rev. Letters 13, 29 (1964) (SLAC-PUB-34).

(8) S. D. Drell, "Asymmetric μ-pair photoproduction at small angles," Phys. Rev. Letters 13, 257 (1964) (SLAC-PUB-35).

(9) S. M. Berman (with M. Veltman), "Baryon resonance production by neutrinos," CERN 9276/TH. 455 (to be published).

(10) S. M. Berman (with M. Veltman), "Transverse muon polarization in neutrino-induced interactions as a test for time reversal violation," CERN (to be published).

(11) J. S. Bell, "Nuclear optical model for virtual pions," Phys. Rev. Letters 13, 29 (1964) (SLAC-PUB-32).

(12) C-H. Woo, "High energy elastic scattering at large angles and the statistical model," SLAC-PUB-42 (submitted to Phys. Rev.).

(13) J. S. Bell and J. K. Perring, "2π decay of the K_2^o meson," Phys. Rev. Letters 13, 348 (1964) (SLAC-PUB-43).

(14) D. Speiser (with R. J. Oakes), "SU_4 mass formula," Phys. Rev. Letters 13, 579 (1964).

(15) D. Speiser, "Fundamental representations of Lie Groups" (to be published).

(16) M. Bander, "Iterative solution of the N/D equations" (submitted to J. of Math. Phys.) (SLAC-PUB-31).

(17) M. Bander (with G. L. Shaw), "Threshold and asymptotic behavior of the N/D equations" (submitted to Ann. Phys.) (SLAC-PUB-60; ITP-122).

(18) J. S. Bell, "On the problem of hidden variables in quantum mechanics," SLAC-PUB-44 (submitted to Rev. Mod. Phys.).

(19) C-H. Woo, "Test for the Peierls' mechanism and the A_1 resonance" (to be published).

Items 1-3 have been described previously.* A code for computing the pion photoproduction cross section has been developed and written up.[4] Subsidiary codes for computing pion-nucleons total cross sections and codes for making corrections due to the use of thick targets are also described. Similar writeups are in preparation for the following codes: (a) Muon or electron pair photoproduction; both pair coincidence cross section and

*"Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1964," SLAC Report No. 30, Stanford Linear Accelerator Center, Stanford University, Stanford, California (June 1964).

singles cross section are coded. Proton form factors are built into the codes but may be easily changed. (b) Compton scattering; differential cross sections for either photon or electron observation are included. Subsidiary codes include bremsstrahlung fold-in procedures. (c) Electron or positron scattering; the Rosenbluth, Møller, and Bhabha cross sections are coded. Another procedure combines these, folds in the pair energy-spectrum from thin target bremsstrahlung, and thereby computes single scattering rates for electrons and positrons in a target.

2. Particle Production Studies

a. Photopions

The problem of forward pion photoproduction has been studied in terms of the ρ-exchange mechanism.[5] It was found that by reggeizing the ρ it is possible to understand the forward angle photoproduction data from the Cambridge Electron Accelerator, but quantitative predictions are very uncertain because of lack of knowledge of the ρ parameters. It is shown that these parameters could be evaluated and a clean test of the theory made by experiments in a deuterium bubble chamber. The contribution to this process which comes from the inclusion of the ρ-N total cross section is shown[6] to be an order of magnitude smaller, and to have a different energy dependence; this could be verified by studying one-prong forward events in a hydrogen bubble chamber. Although the Drell mechanism is inadequate to explain the forward cross section just discussed, agreement with experiment at larger angles can be improved by including a Ferrari-Selleri type correction.[7]

b. Photomuons

The information that can be extracted from the study of very asymmetric mu-pairs has been explored.[8] Although the experiments will be difficult to carry out, it is shown that this technique could be used at SLAC both to give new sensitive tests of quantum electrodynamics, and to obtain fundamental and qualitatively new information about the vector meson resonances.

c. Neutrinos

Calculation of the inelastic neutrino process leading to the pion-nucleon 33 resonant state[9] indicates that this process will exhibit an energy dependence to the elastic interaction, but that the absolute magnitude of the cross section is an order of magnitude larger. It has also been shown[10] that study of the transverse polarization of the muon in neutrino-induced reactions can provide a test of time reversal invariance. Although neutrino cross sections for nuclei are often estimated by adding up the cross sections for individual nucleons, this procedure ignores the reabsorption of the produced pions within the nucleus. This effect has been calculated[11] and shown to reduce drastically the cross section to be expected at small momentum transfer.

d. Weak Vector Bosons

The rates for the production of the observable final particles in an electron-positron colliding beam experiment are being computed under the assumption that the intermediate step is the production of a pair of weak vector bosons. This calculation includes a detailed study of the backgrounds due to the processes $e^+ + e^- \rightarrow 3\gamma$, $e^+ + e^- \rightarrow e^+ + e^- + \gamma$, $e^+ + p \rightarrow e^+ + p + \gamma$.

3. Two- and Three-Nucleon Problems

A more detailed investigation of the relation between the n-p $^1S_0$ effective range and charge independence reveals that all but two experiments are consistent with the hypothesis of charge independence, when due account is taken of known small effects. These two n-p total cross section experiments have less than a 4% chance of being consistent with the hypothesis, and if accepted would require 30% or greater charge-dependent modifications of the strong interactions in this state. Because this is in apparent conflict with a recent analysis showing charge-dependent effects to be less than 1% for this state in light nuclei, let alone evidence from elementary particle physics, it is clear that new precision measurements of the n-p total cross section below 5 MeV should be attempted in order to test this basic symmetry principle.

Investigation of recent calculations of the process $n + p \rightarrow \gamma + d$ near threshold reveals that a recently proposed dispersion-theoretic approximation is unreliable, and hence that there is an 8-10% discrepancy between the non-relativistic prediction and experiment. Calculations of mesonic effects presented to date amount to only 2-3% effects. It is suggested that the mechanism recently invoked by Adler and Drell[1] may be responsible for at least part of the residual discrepancy.

A complete calculation of the three-nucleon bound state has been carried through for a model in which it is assumed that only singlet and triplet nucleon-nucleon S waves are important, and that these interactions are separable. The bound state has somewhat more binding than is observed, which is reasonable as effects left out will reduce the binding, but it is found that a physically inadmissible "ghost state" close to zero energy is also predicted. The separable potential approximation is a very reasonable way to go "off the energy shell" from a dispersion-theoretic point of view, but this result shows that it leads to results dramatically different from those obtained using a local potential with identical properties for two-nucleon scattering. Hence the three-nucleon system does provide qualitatively new information about the strong interactions which is not obtainable from two-nucleon scattering experiments. The more difficult calculation using local potentials will now be attempted.

4. Elementary Particle Physics

A possible way out of the apparent CP violation in K_2^0 decay has been shown to be the assumption of a new long range force proportional to hypercharge.[13] Because of the local (in a galactic sense) preponderance of matter over anti-matter, this could readily account for the experimental result. Such a theory also predicts a local inequality of gravitational and inertial mass, but the interaction strength required to explain the K_2^0 experiment is small enough to be within experimental uncertainties for the other effect.

Existing schemes based on SU_3 attempt to introduce order into the elementary particle picture by relating particles of different isospin and hypercharge but the same spin and parity. One way to generalize this scheme still further is to SU_4 and hence relate particles with different spin as well; the mass formula for such a scheme has been worked out.[14]

Wigner's calculus of weight diagrams is extended to orthogonal and symplectic groups. A straightforward method for decomposing direct products is presented. The results are proved within the theory of characters. Finally, it is shown that some important invariants can be expressed through a complex monomial.[15]

5. Other Theoretical Physics

A new and elegant scheme for solving the N/D equations encountered in many dispersion-theoretic calculations has been developed.[16] The method is very efficient for constructing low-order approximations, and converges to the exact solution if iterated. Asymptotic and threshold behavior of N/D solutions have been investigated in detail, and the dangers inherent in many currently popular approximation schemes were demonstrated.[17]

One of the perennial problems about quantum mechanics is the question whether a scheme without its inherent statistical character could be constructed without doing violence to known or knowable experimental facts. Investigation of the Von Neumann "proof" that such schemes are impossible reveals that it relies on smuggling an essentially quantum mechanical postulate, which is by no means a necessity of thought, into the construction of alternative schemes.[18] More recent "proofs" suffer from similar defects, and a new axiom is proposed as worthy of study.

G. PHYSICAL ELECTRONICS

Development work on high-gain, low-density KCl transmission electron multipliers for use in a variety of very fast electronic detection systems was continued during the quarter. A fabrication technique for producing a suitable substrate for the KCl dynode has been developed. Density and gain measurements have been performed on the dynodes.

The substrate consists of an Al_2O_3 window, 1000 Å thick and 1 inch in diameter, upon which is evaporated 500 Å of Al. The Al_2O_3 window is formed in a 2-inch-diameter × 0.125-inch-thick machined Al preform by chemical polishing, anodization, and selective etching of Al in a technique similar to that of Hauser and Kerler.* The Al is deposited by vacuum evaporation over the Al_2O_3 window, to make electrical connection to the KCl dynode. Using this method the substrates are "pin-hole" free, reasonably strong, and are produced with about 80% yield. Work is being continued to obtain a smoother Al surface before anodizing, to produce more tightly stretched dynodes, and to scale up the process so that more dynodes can be produced simultaneously.

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*U. Hauser and W. Kerler, Rev. Sci. Instr. 29, 380 (1958).

The KCl dynode is prepared using the method described by Goetze, et al.*
As reported, a low density form of KCl is essential for high gain and long lifetime of the dynode. Densities of 1-2% of the bulk density are required. Density measurements have been carried out using glass and Al foil substrates but are strongly hampered by water vapor in the atmosphere. Also, the appearance of the films is markedly dependent on the type of substrate used. For these reasons, density measurements are planned for the coming quarter using a controlled dry atmosphere and the substrates discussed above.

Limited gain measurements on the dynodes have been completed for KCl deposited on self-supported nitrocellulose films covered with 500 Å of evaporated Al and for the Al_2O_3 plus substrates discussed above. These measurements were made using an electron gun in the energy range 0-20 keV and were carried out immediately after deposition without exposing the dynode to the atmosphere. Gains of 30 to 60 have been obtained, in good agreement with those reported.** The gain has been found to decay exponentially with time after deposition with a time constant of approximately 100 minutes. Goetze also observed an irreversible deterioration of the gain in unbaked vacuum systems.† In all the above work an unbaked diffusion pumped vacuum system was used. A bakeable ion pumped system is presently being constructed in which gain and lifetime measurements will be carried out in a cleaner environment. The bakeable system is so designed as to allow measurements of the secondary yield for either low energy (0-20 kV electrons) or minimum ionizing electrons from the Mark III accelerator. In the coming quarter we hope to confirm the expected high yield of two secondary electrons per incident minimum ionizing electron.

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

**Ibid.

†Ibid.