SLAC-71
UC-28, Particle Accelerators
and High-Voltage Machines

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 July to 30 September 1966

March 1967

Technical Report

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I. INTRODUCTION

This is the eighteenth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the twelfth Quarterly Status Report of work under AEC Contract AT(04-3)-515, both held by Stanford University. Contract AT(04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that has as its chief instrument a two-mile-long linear electron accelerator. Construction of the Center began in July 1962. 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 electron beam was first activated in May 1966. In June 1966, a beam energy of 18.4 BeV was achieved. Beam currents of up to 15 microamperes have been obtained. 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 retained the services, under subcontract, of the firm Aetron-Blume-Atkinson, a joint venture. In these reports this architect-engineer-management firm is often referred to as "ABA."

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

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

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

II. PHYSICAL PLANT

A. GENERAL

Prior to July 1, 1966, the primary functions of the Plant Engineering Department were liaison between SLAC and Aetron-Blume-Atkinson (ABA), the architect-engineer-manager for design and construction of buildings and utilities, and, through the Crafts Shop, to make skilled tradesmen available to requesting groups for purposes of minor construction as well as to operate completed portions of the electric power and cooling tower water systems.

Prior to July 1, 1966, the primary functions of the Systems Engineering and Installations Department were to coordinate design of the installations of the accelerator, prepare drawings and specifications for the installation of equipment, vacuum systems, low conductivity water cooling systems, electrical power services, and electronic cable plant and equipment rack programs by construction firms under subcontract to SLAC, to manage the installation work and, through the Design Drafting Shop, to make designers and draftsmen available to requesting groups.

During the first six months of 1966 the two departments were operated under a combined management arrangement and during that period the ABA construction and Systems Engineering installations were substantially completed. During the present quarter the two departments were combined into a single Plant Engineering Department and its functions altered to meet the requirements of the present operational status of SLAC. Present functions include:

1. Operation and maintenance of electrical and mechanical services for the accelerator, the Beam Switchyard, the End Station area, and the main campus offices, laboratories and shops except for heating, ventilation, and air conditioning equipment and systems.

2. Carry-on work for final completion items of the ABA construction work and the Systems Engineering subcontracts for the accelerator and Beam Switchyard.

3. Management of new construction work, general plant projects, and the minor modifications program for SLAC facilities.

4. Provision of architectural, civil, structural, electrical, and mechanical services engineering support to requesting SLAC groups.

5. Provision of skilled tradesmen through the Crafts Shop and designers and draftsmen through the Design Drafting Shop.

Figures 1 - 5 show the status of the laboratory at the end of the quarter.

B. OPERATIONS AND MAINTENANCE

1. Accelerator

Emphasis was placed on variable voltage substation control modifications, improving safety shut-down interlocks for the klystron, waveguide, drive line and accelerator LCW cooling water loops, investigating alternate possibilities for improving performance of LCW cooling water systems serving the main injector and Sector 1, and improving low-flow alarm switches.

2. Beam Switchyard

Added electrical and LCW cooling water systems were put into operation during the quarter. Emphasis was placed on subcontractor punch lists and debugging operations.

3. End Stations

During the quarter all portions of the research area electrical distribution and LCW cooling water systems were put into operation. Emphasis was placed on improving reliability of these systems so that continuous operation could be achieved.

4. SLAC Utilities

All remaining substations and cooling towers became operational during the quarter. Emphasis was placed on review of load trends to determine optimum billing arrangements for electrical power and investigation of noise levels of cooling towers, particularly those serving the accelerator. In addition, final corrective measures by substation equipment vendors were expedited to insure compliance within a reasonable time with state industrial safety orders.

C. CARRY-ON WORK

1. ABA Construction

The only things remaining to be done are punch list items and the settlement of change orders and claims. Some progress was made in settling change orders, but until the claims are settled, the construction subcontracts cannot be completed.

FIG.1-WEST (MAIN INJECTOR) END OF THE ACCELERATOR

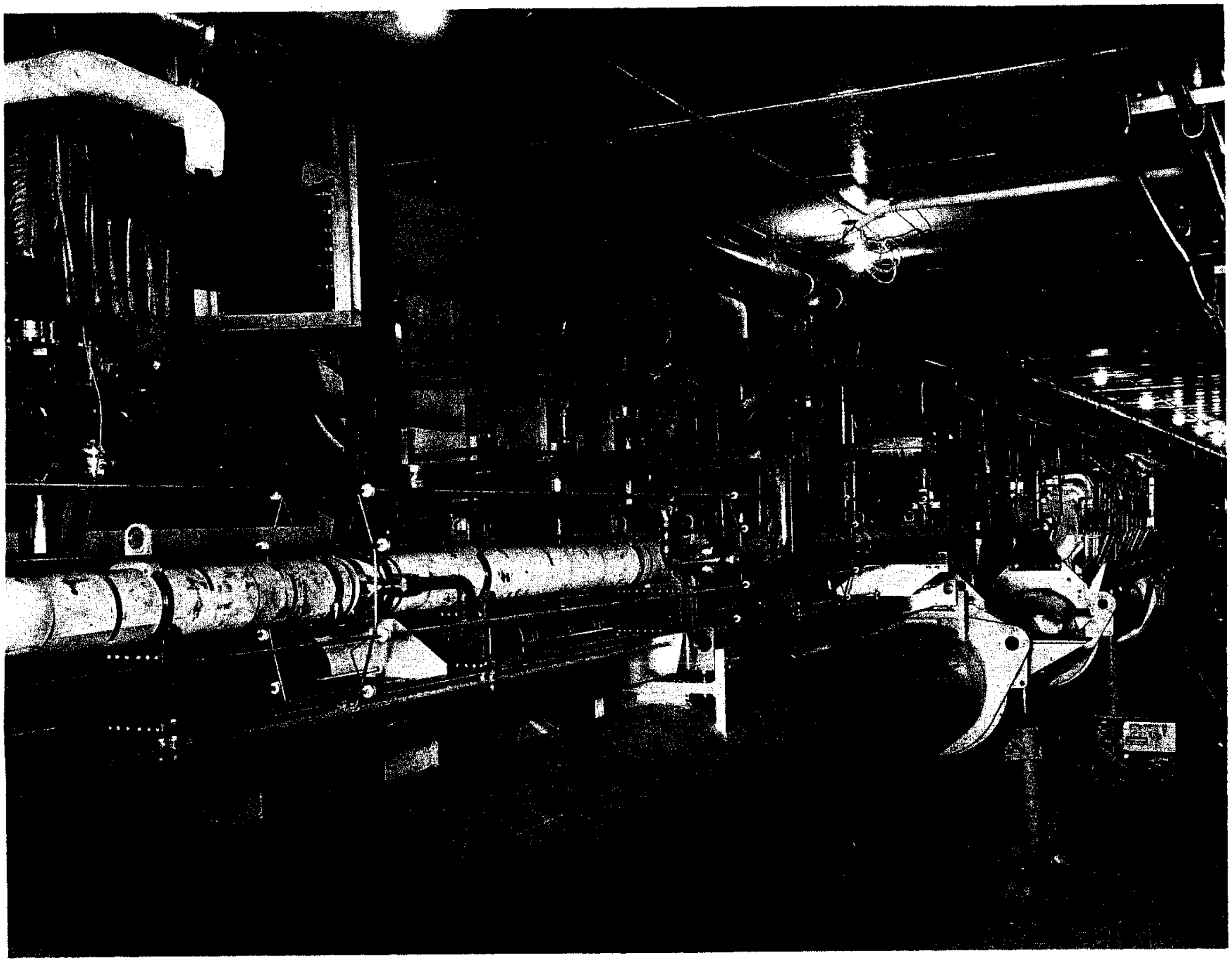


FIG. 2-POSITRON SOURCE AT SECTOR 11, SHOWING SOLENOID POWER CABLE RUNS

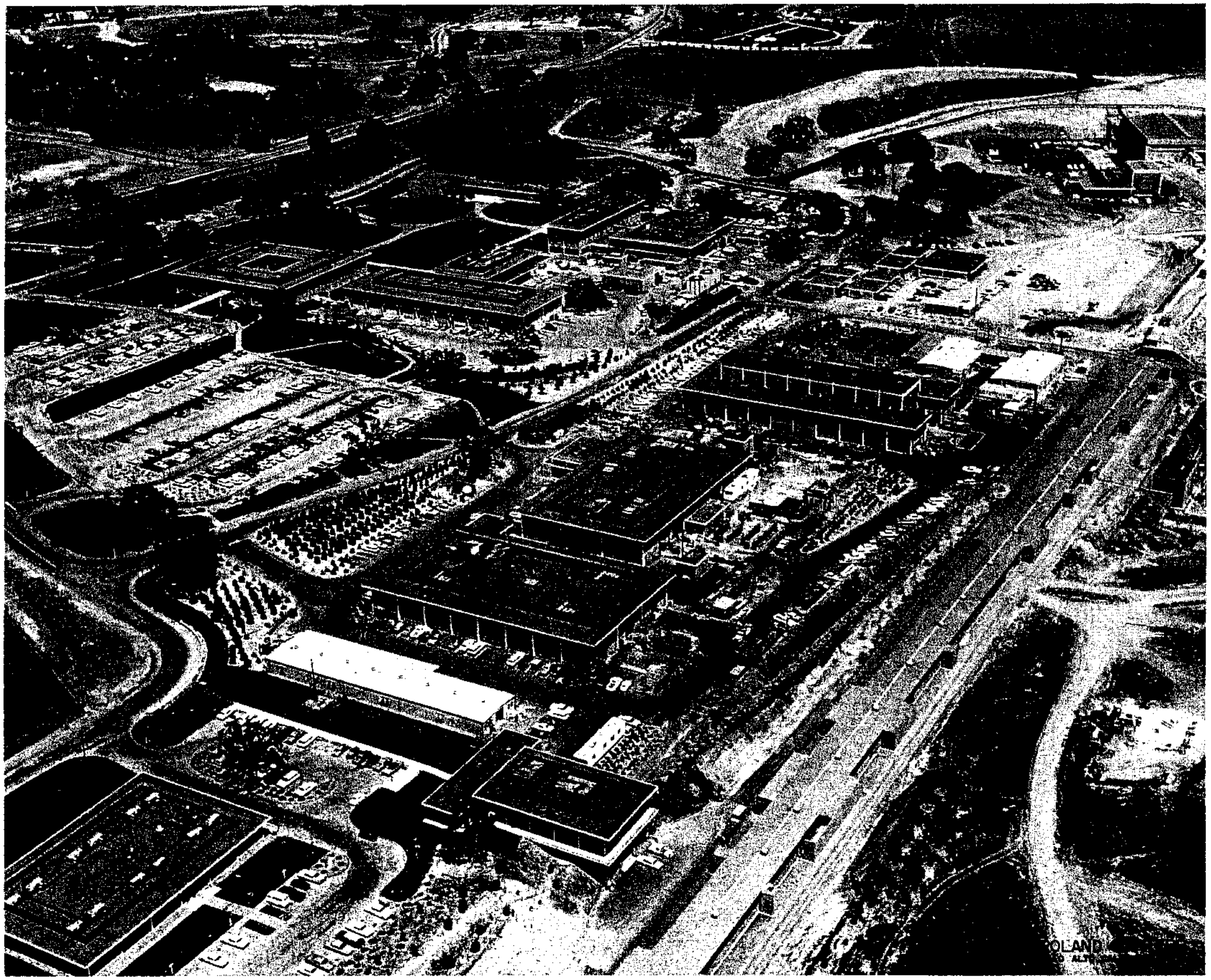


FIG.3-SLAC BUILDINGS AND SHOPS, LOOKING NORTHEAST

FIG. 4-BEAM SWITCHYARD, LOOKING NORTHEAST

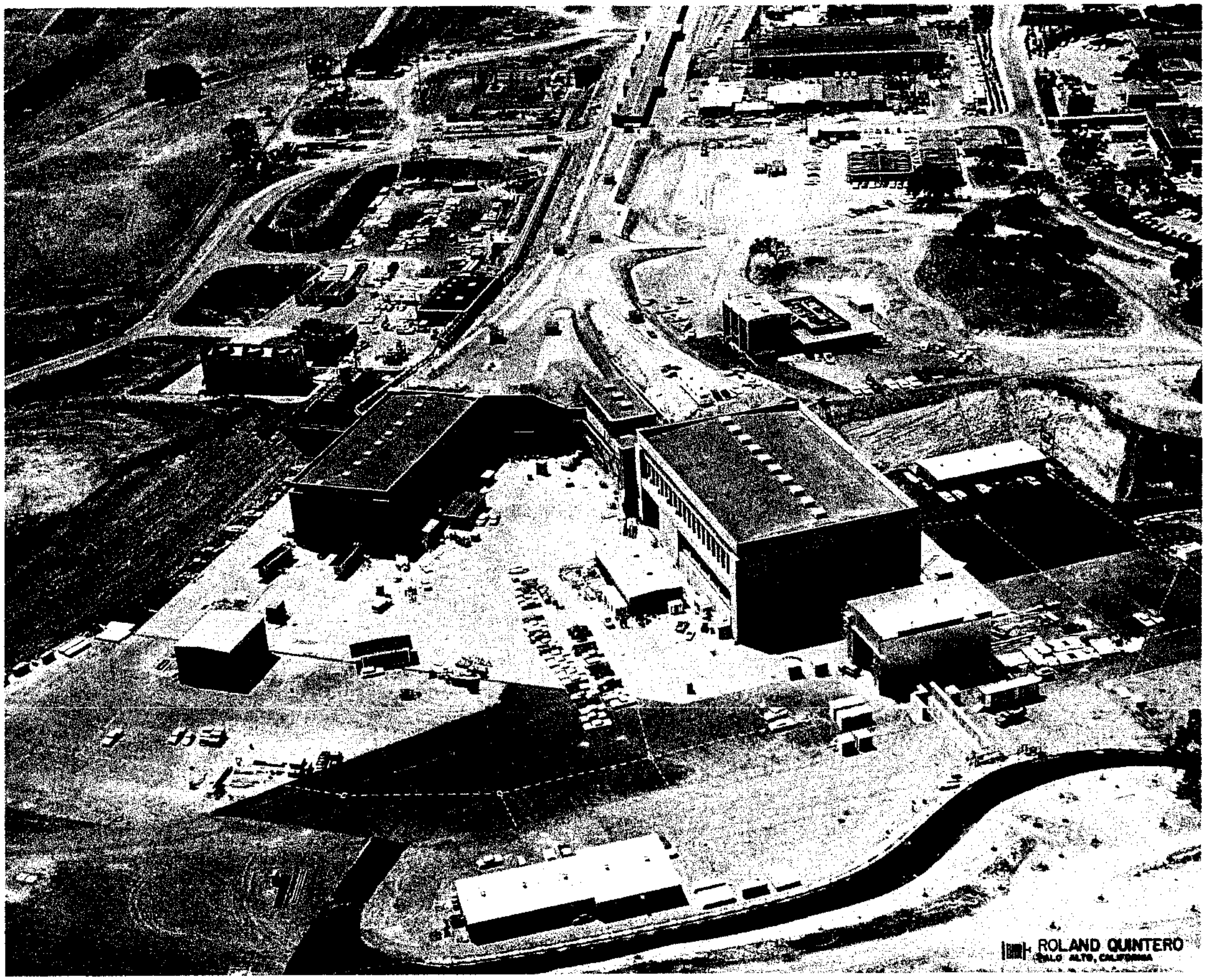


FIG. 5-END STATIONS AND RESEARCH YARD, LOOKING WEST

Meetings were held with ABA management to decide how to proceed with closeout of construction subcontracts.

The 220-kV tie line was completed and activated during this quarter.

2. Accelerator

Final completion of subcontract work on electrical and LCW cooling water services to the positron source was achieved except for final punch lists and debugging.

3. Beam Switchyard

Installation of BSY equipment was completed except for a few items scheduled for delivery during the next quarter. Electrical/electronic installation was complete except for final punch list items. LCW cooling water was completed, but a number of change orders and claims remain unresolved.

D. NEW CONSTRUCTION WORK

A number of new construction items were underway during the quarter, as listed below:

Facility	Status
A/E Building Medical Facility	In design
Central Laboratory Extension	Architect-engineer firms being reviewed
Data Assembly Building expansion	Construction subcontract awarded
Klystron store room	Out for bids
General Services Building	In design
Fire Station	In design
Construction Office Building conversion	In design
Project sign and gate house	Just starting
Radiation monitoring wells	In construction
Paving of north yard road	Completed
Gallery visitors alcove	Completed
Gallery stairs at Sector 4	In design
End Station A heating	Procuring equipment
Electric power factor correction	Just starting
Electric power remote indicators	In procurement
Research Yard sewer extension	In design

Facility	Status
Research Yard exterior lighting	In design
Research Yard 12-kV breakers	In procurement
Fabrication Building CDA modifications	In design
BSY fire detection system	Completed
40-inch bubble chamber enclosure	Completed
82-inch bubble chamber utilities	In design
82-inch bubble chamber building	In design
End Station A power supply enclosure	Completed
2-meter spark chamber enclosure	In construction

E. PLANT ENGINEERING SUPPORT

A number of long-term assignments and specific projects for other groups were underway during this quarter. The power supply enclosures and target cooling water for End Station B were completed. The liquid hydrogen storage facility is under construction. Projects in process include electrical work in the Data Assembly Building and End Stations, electrical assistance provided for Group A, and mechanical assistance provided for Groups B and C. Assigned but not begun yet are services for the central and K beams.

For the project as a whole, space use planning continues to be performed. Also, a site master plan was issued for review.

III. ACCELERATOR PHYSICS

During the summer quarter of 1966, a large fraction of the effort of this department was devoted to accelerator performance and beam experiments. In the present format of the Quarterly Status Report, it is difficult to give a complete account of these experiments while reporting on individual accelerator systems. Starting next quarter, the format of the Quarterly Status Report will be modified. For this quarter, on topics concerned with overall accelerator performance, the reader is referred to separate papers. Some titles and authors are listed below.

1. G. A. Loew, "Report on the Stanford Linear Accelerator Center," Proceedings of the 1966 International Conference on Instrumentation for High Energy Physics, Stanford Linear Accelerator Center, September 9 - 10, 1966; p. 365 (SLAC-PUB-235).

2. R. H. Helm, "Computer Study of Wave Propagation, Beam Loading and Beam Blowup in the SLAC Accelerator," Proceedings of the 1966 Linear Accelerator Conference, Los Alamos, New Mexico, October 1966; p. 254 (SLAC-PUB-218).

3. O. H. Altenmueller, E. V. Farinholt, Z. D. Farkas, W. B. Herrmannsfeldt, H. A. Hogg, R. F. Koontz, C. J. Kruse, G. A. Loew, and R. H. Miller, "Beam Break-Up Experiments at SLAC," Ibid., p. 267 (SLAC-PUB-224).

4. W. B. Herrmannsfeldt, "SLAC Alignment System," Ibid., p. 163 (SLAC-PUB-222).

5. R. H. Miller, "Measurements of the SLAC Injector Emittance," Ibid., p. 65 (SLAC-PUB-223).

6. K. B. Mallory, "Some Effects of (Not Having) Computer Control for the Stanford Linear Accelerator," Ibid., p. 479 (SLAC-PUB-221).

7. R. B. Neal, "Initial Operating Experience and Performance of the SLAC Accelerator," Ibid., p. 4 (SLAC-PUB-219).

Concerning individual systems, this report is presented in the same format as in the past.

A. INJECTION

1. Main Injector System

The injector has been operating satisfactorily during the past period and has exhibited no major failures. Injector documentation is virtually complete, and routine maintenance responsibility for most systems has been turned over to the regular maintenance group.

2. Electron Guns

The final design of the SLAC gun (designated Gun 4-2), incorporating improved internal corona shielding and the Litton ceramic envelope, was operated satisfactorily with a bombardment heated thoriated tungsten cathode. Construction of a second model 4-2 gun was begun.

At the end of the quarter, the gun on the injector had been in position for one year. The cathode had been at operating temperature in excess of 2600 hours and high voltage had been applied to the gun in excess of 2500 hours. No indications of aging were observed. This gun is a model 4-1 gun and has a conventional oxide cathode. The maximum cathode to anode voltage is limited to about 60 kV by internal arcs. The cathode is maintained at a temperature such that its temperature-limited emission from the cathode is about 1.3 A.

The automatic scanning feature of the gun optics analyzer was made operational during the quarter. The analyzer now can be programmed to measure the current density in the beam from a gun in a pattern very similar to the raster of a TV tube. Optics data have been obtained for both the SLAC model 4-1 and 4-2 guns. During the coming quarter, the analyzer will be used to measure the optics of the gun currently in use on the Mark III linear accelerator to determine its suitability for use on the superconducting accelerator prototype.

3. Gun Modulators

The present Manson modulator has been further modified to provide pulse height analog signals to CCR (Central Control Room) and finer control of the pulse height function.

The new gun modulator cabinet has been designed and is out for price quotation. The important parts of the new modulator consist of a bias switching chassis, a pulser chassis, a filament and bombarder control chassis, and a chassis which brings analog, status and control signals across the 100-kV deck. The bias switching chassis is completely designed and well into the fabrication stage. The new transistor circuitry associated with this chassis is built on cards and has been operating continuously during this past month for reliability tests. Recent experiments on the machine have shown that the gun has good cutoff characteristics down to approximately 10^3 electrons per pulse ($\sim 10^{-10}$ A), and an attempt is being made to tighten the stability of this bias so that currents over the full range (10^{-10} to 10^{-2} A) may be stably programmed on a pulse-to-pulse basis. A breadboard of the pulser chassis has been constructed and tested. A 1-kV pulse into 150 ohms has been achieved at the output, but not with the required flat top or rise time. Recent tests on the gun have demonstrated that a pulse of only about 600 volts will be adequate. Hence, the pulser breadboard is being modified to operate into a 75-ohm impedance which will permit it to be mounted in the Klystron Gallery, rather than in the Accelerator Housing. The pulse will be transmitted downstairs on a 75-ohm cable.

4. Beam Knockout System

The beam knockout 50-kW amplifier is constructed and undergoing tests in the Modulator Group. The knockout plates which were previously installed on the machine have been tested by applying a dc voltage to them. While the deflection is approximately as calculated, the plates seem to collect a large number of secondary electrons produced when the primary electron beam is intercepted by the scraper plate. This phenomenon could cause severe loading of the rf resonant circuit, and it is hoped that it can be cured by coating the scraper plate with some material of low secondary emissivity such as carbon or titanium. This problem will be further investigated. The resonator circuit will also be constructed and tested.

B. DRIVE SYSTEM

1. Main and Sub-Drive Lines

The installation of the main and sub-drive lines is complete and both lines have been operating satisfactorily. The extension of the main drive line through the Beam Switchyard and to the End Stations has been completed and tested. Tests on a short length of cable directly buried underground showed that the cable had been deformed during installation and back-filling, and, consequently, the entire underground run was placed in metallic and nonmetallic conduit. Subsequent tests have shown that the technique of cable pulling through the conduit was entirely satisfactory.

2. Varactor Frequency Multipliers

During the past quarter, the operation of the varactor frequency multipliers has been satisfactory. A few diode failures were reported, but their exact causes are not known. It is possible that output power changes from the main booster amplifiers may have contributed to these failures.

3. Main Booster Amplifiers

Main booster amplifier No. 1 has been overhauled and is presently in service. The equipment to update Unit No. 2 will be prepared in the laboratory so that the downtime of this amplifier will be minimized. The klystron in Unit No. 1 failed during the quarter after approximately 3000 hours. In Unit No. 2, the main drive line transfer switch was reinstalled after repair. A spare interchangeable transfer switch is now also available. The major improvement in both these switches is the use of ceramic material for the center conductor insulators which should improve the resistance to overheating.

4. Positron Phase Shifters

A test was performed to ascertain that the "gating-in" of the 180° phase shift does not produce any effect on the beam when all accelerating sectors are switched at the same time. It appears that no energy change, spectrum change, or beam position change could be detected as long as the phase shifters were inserted at a rate less than 300 times per second. However, at 360 pps the gate operated improperly. It appears that it can be made to operate at 360 pps if the gate width is reduced to approximately 1 millisecond. This increases the minimum amplitude signal to the phase shifter driver from its present 1 volt to 2.5 volts.

The positron phase shifters were modified by the inclusion of two manual switches. An "electronic driver, by-pass" connects the circulator to 24 volts in series with a current-limiting resistor. Another switch reverses the terminals of the circulator coil. This switch is used to facilitate the setting of the short and to manually insert the 180° phase shift for positron operation.

5. RF Drive System Control Unit

Manpower considerations again have prevented the completion of the remote control and switching functions in the master oscillator rack. Local and/or manual controls have been available. All units but one were installed and ready for test. During the next quarter, the remainder will be completed.

6. Sub-Booster Modulators

The sub-booster modulator failure rate has continued to decrease to about seven failures per month. The most frequent failure seems to be due to the failure of one of the precision power supplies which fortunately can easily be replaced by a spare unit when needed.

7. Sub-Booster Klystrons

Eimac has three more new klystrons to deliver on the original contract. In addition, several tubes are due on repair under the existing warranty. The new procurement from Litton Industries is progressing. Receipt of the first tubes is scheduled in February 1967. The activity is being monitored on a weekly to bi-weekly basis to insure compliance with the contract.

C. PHASING SYSTEM

1. Isolator-Phase Shifter-Attenuator Units

These units have been operating without trouble, apart from an occasional failure of the attenuator coupling roll-pin. This defect is corrected as described in the previous report. It has also been discovered that switching transients generated in the phase-shifter motors have been responsible for isolated instances of fast valves closing and phasing programmers skipping steps. Suppressors will be fitted across the terminals of all motors.

2. RF Detector Panels

These units are operating very well and require no adjustment apart from the thermionic diodes, which have to be rebalanced occasionally or, in some instances, replaced.

3. Programmers and Electronics Units

Work is continuing on the diagnosis and correction of faults. Servo loop instability due to crossover distortion in the gated voltmeters has been eliminated by additional decoupling. This necessitated partial rewiring of the electronics card cages, to form a negative ground system.

Bypass capacitors across the diode bridge batteries were replaced, to reduce leakage and prolong battery life.

There have been some mechanical failures of potentiometers used in the servo amplifiers and gated voltmeters. These are being examined periodically and replaced when necessary. The value of the potentiometer controlling the gate timing will be reduced to improve setting stability.

To reduce sensitivity to thermionic diode unbalance, the pre-amplifiers in some gated voltmeters were bypassed. The overall gain was re-established by increasing the servo amplifier gain. Unfortunately, this idea had to be abandoned because it reduced the system signal-to-noise ratio.

Removal of crossover distortion in the gated voltmeters reduced their gain. This was also temporarily corrected by increasing servo amplifier gain. We are now in the process of improving and standardizing the performance of every gated voltmeter. Gate widths are being adjusted to 0.2 microsecond. The diodes in the gating bridge were found to be very poorly matched, which resulted in a badly distorted output waveform. All diodes are being replaced by matched sets, which also have lower forward resistance, giving higher gain.

A redesigned programmer timing generator worked well in the laboratory, but failed in Klystron Gallery tests. It is now certain that the failure was due to the motor transients mentioned in paragraph C.1. The new timing generator will be tried again when all motor terminals are fitted with suppressors.

4. Overall Performance of the Phasing System

While the phasing system works well when properly adjusted, it has not yet achieved the standard of reliability which permits CCR to start the Programmers in Sectors 3 through 30 in quick succession, with high probability of achieving an almost optimally phased machine in less than 5 minutes. That this is so is not entirely the fault of the phasing system: phase instability in the beam or any sub-booster or klystron will stop the phasing sequence, if the instability is greater than 4 degrees. Instances of such instabilities are not infrequent.

When the modifications outlined in paragraph C.3. are complete, and switched attenuators are fitted in all rf detector panels, the reliability of the phasing system will be greatly improved. If the video output of each rf detector panel is made available in CCR, it will be possible to follow each phasing operation and immediately note all failures. All 243 stations can be phased in succession from a random start in 30 minutes.

The problem of back-phasing is being pursued. When investigated, most cases reported as back-phasing turn out to be mis-phasing. For this reason, priority is still being given to elimination of all faults discussed above.

5. Linear Detectors

Drift in the differential balance of thermionic diode pairs is a problem in the beam position monitor detector panels, as well as in the phasing system. The possibility of remotely balancing the position monitor diodes from CCR is being considered. An adequate number of replacement diodes, assembled and tested, are on hand.

D. BEAM POSITION MONITORS

1. In-Line Beam Position Monitors

The monitor system has performed adequately during the quarter. The CCR zeroing switch enables the operator to note the sectors in which the thermionic diodes need to be rebalanced. This is done routinely, as required, normally a few sectors per week.

All other faults in the position monitoring system occur in the sector electronics or in the CCR display.

2. Beam Switchyard Beam Position Monitors

All six monitor assemblies were installed in the Beam Switchyard. It has been reported that there are discrepancies of up to 2 mm between the electrical axes of the position monitor cavities and the beam axis as defined by adjacent quadrupoles and profile monitors. Mechanical alignment errors are suspected. The problem will be investigated as soon as Switchyard beam time is available for calibration of the monitors.

3. End Station A Beam Position Monitors

The microwave beam position monitor for End Station A was tested on the Injection Test Stand (6 MeV) accelerator. Figure 6 shows the microwave hardware and the beam coupler installed horizontally in the test stand. The remotely-driven table in the foreground carries a toroid and a differential secondary emission monitor for measuring beam current and position, respectively. Using the receiver shown in Fig. 8 of SLAC Report No. 65*, the sensitivity was 31 mV/mm

*"Two-Mile Accelerator Project, Quarterly Status Report, 1 January to 31 March 1966," SLAC Report No. 65, Stanford Linear Accelerator Center, Stanford, California (1966), p. 20.

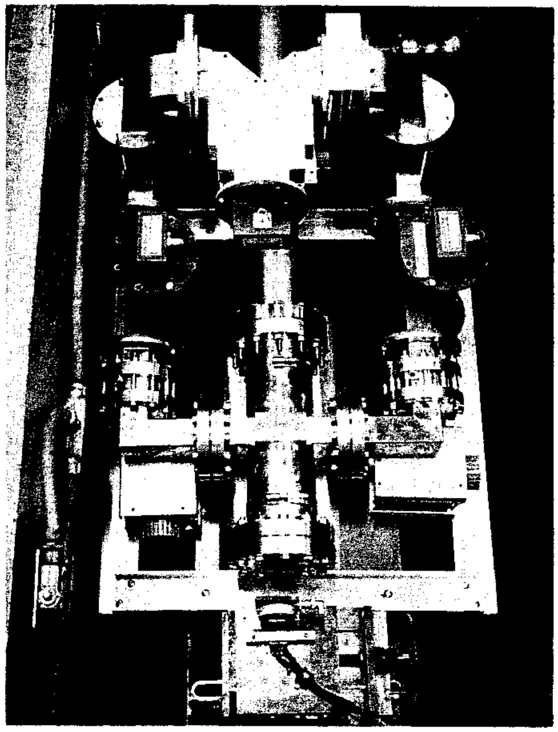


Fig. 6 - MICROWAVE HARDWARE AND BEAM COUPLER INSTALLED ON TEST STAND

of beam displacement at peak beam currents of 25 μA to 1 mA. The limit of position resolution is overshoot in the video response of the logarithmic amplifiers. At 20-Mc/sec video bandwidth, this corresponds to a beam position uncertainty of 0.3 mm.

The monitor is being installed in End Station A.

E. BEAM ANALYZING STATIONS

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

F. GENERAL MICROWAVE INVESTIGATIONS

As reported in the last QSR, a large variety of microwave experiments were started and are being continued to investigate the beam break-up problem. A comprehensive up-to-date summary of all these experiments can be found in the report by O. H. Altenmueller, et al., listed in the introduction to this section.

G. OPTICAL ALIGNMENT SYSTEM

During this quarter, the Beam Switchyard extension of the laser system was adjusted and aligned. Beam Switchyard target No. 14, which is used to locate the main vertex points for both A and B beams, is also being used as one of the main reference points for both the accelerator and the Beam Switchyard. The other fixed point is the westernmost target behind the injector. The junction between the accelerator and the Beam Switchyard is made by aligning girder No. 30-9 to the Beam Switchyard line using the lower half of the double target. Then, the upper half of this double target defines the accelerator line.

The first realignment of the accelerator is illustrated in Figs. 7 and 8. The displacements shown are equal in magnitude and opposite in direction to the corrections which were actually made. A small vertical displacement of the accelerator end points (about 0.010 inch) was made at the time that the Beam Switchyard line was adopted as a primary reference.

A general report on results obtained with the alignment system is contained in the paper by W. B. Herrmannsfeldt listed in the introduction to this section.

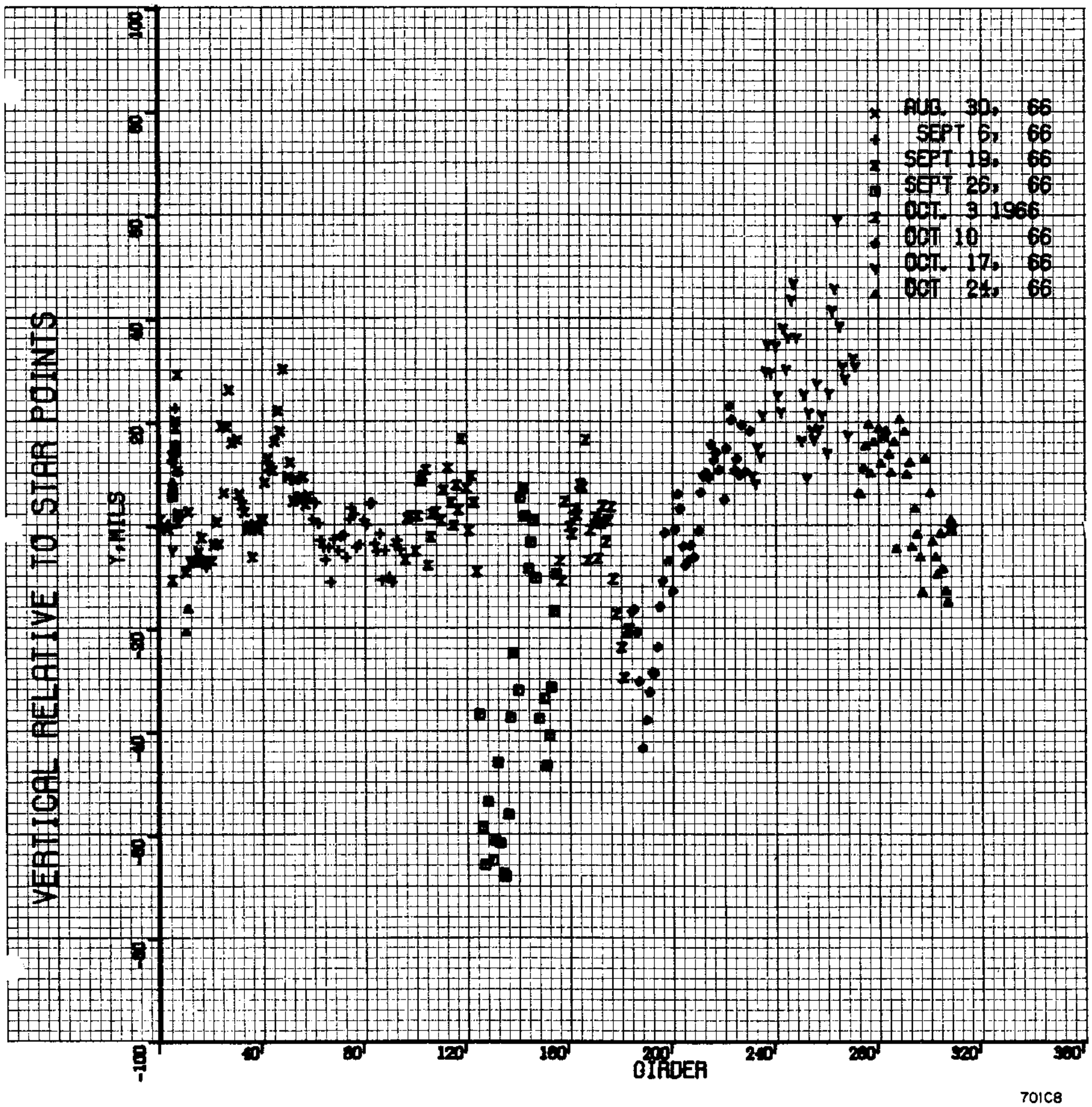


FIG. 7 - VERTICAL REALIGNMENT OF ACCELERATOR

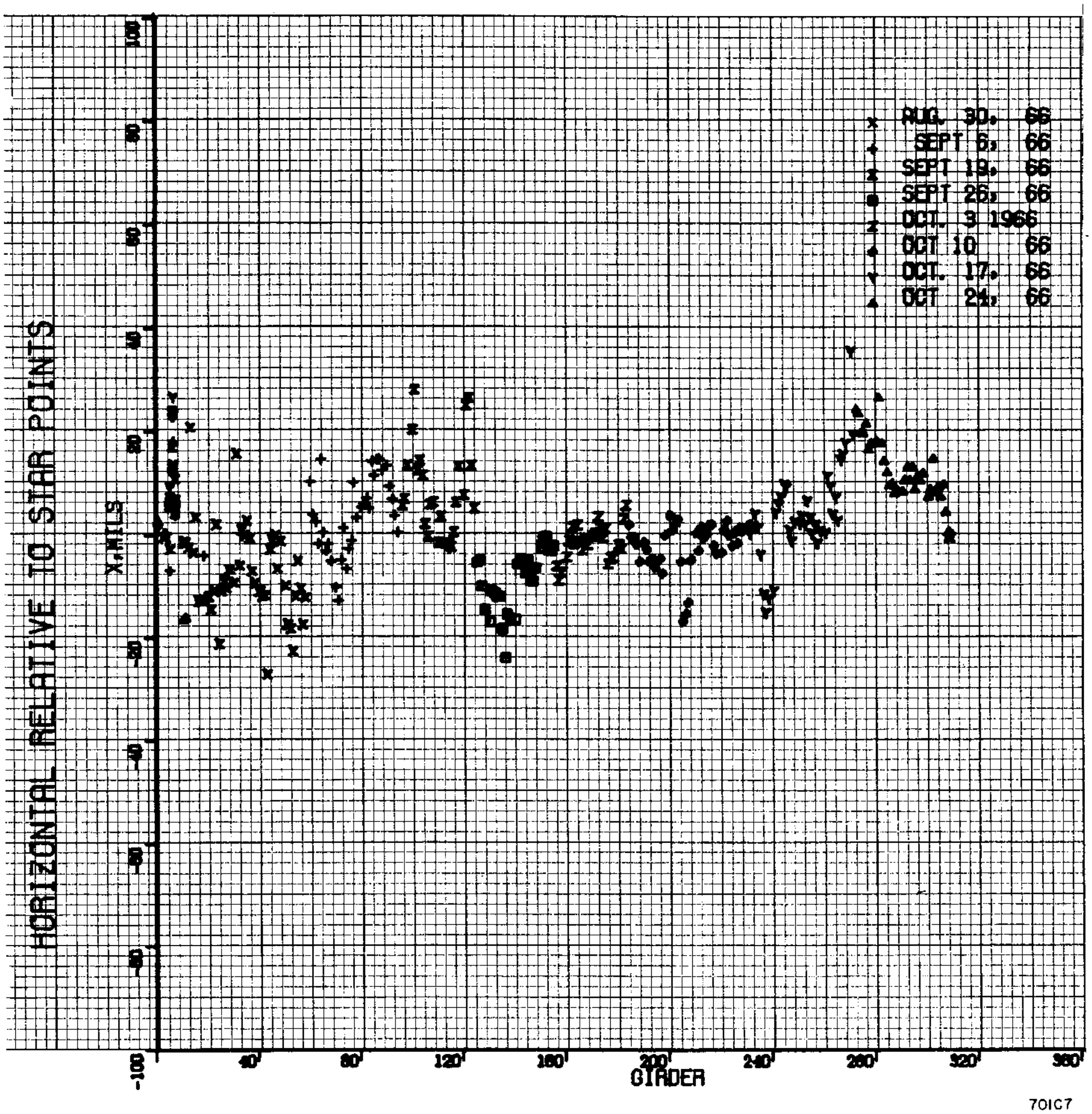


FIG. 8 - HORIZONTAL REALIGNMENT OF ACCELERATOR

H. THEORETICAL AND SPECIAL PROJECTS

Ever since the discovery of the multisection type of beam break-up at SLAC, much of the theoretical work which is being undertaken has been geared toward understanding the effect and proposing a corrective program. An up-to-date comprehensive report on this work is summarized in R. H. Helm's paper listed at the beginning of this section.

I. MAGNETIC MEASUREMENTS

Magnetic measurements and the corresponding data analysis were performed during the past quarter on the following magnets:

1. Five 8-cm Beam Switchyard quadrupoles.
2. Five 0.1° pulsed magnets.
3. Beam Switchyard magnet B-38.
4. Quadrupoles Q-81 and Q-82 for the 8-GeV spectrometer.
5. Seven 18D72 magnets.
6. One 18D36 magnet, measured at Brookhaven National Laboratory using our rapid magnet mapper.

IV. INSTRUMENTATION AND CONTROL

A. GENERAL

The major activities during the past quarter have been (1) making Central Control complete enough to operate the entire machine, (2) design of Positron Source instrumentation, (3) completing the BSY portion of the personnel protection system and (4) starting a major program of updating schematics and as-built drawings of the control system.

B. CENTRAL CONTROL

All three switched sector panels have been in regular use for several months. The design of the sector status monitoring system was originally based on the notion that all sectors would be alike. This turned out to be not quite true. For example, electrical substations exist only in even-numbered sectors. As a consequence, some of the status lamps would normally show an alarm condition whenever a switched sector panel was connected to certain sectors. This made the discovery of real faults unnecessarily difficult. Most of these so-called goofy lights have been fixed, either by strapping the transmitting relay contacts into the "normal" state, or by electrical suppression of erroneous information in CCR.

All of the initially planned equipment for control of the injector has been installed in CCR and is in daily operation. A few signals require connection at the Injector.

The interface between CCR and the Data Assembly Building in the research area (DAB) is still incomplete. All analog meters, status readouts and remote control switches have been installed and checked out in CCR. A number of these still have to be connected in the DAB. Temporary oscilloscopes are being used for display of spectrum signals pending installation of SLAC oscilloscopes and logic packages. Two TV monitors have been installed to allow display of BSY profile monitor signals in CCR.

Other work in CCR during the past quarter has included installation of a TV gate monitor and key-switch system to permit CCR operators to control access at the radiation fence near CCR, installation of an FM radio panel for communications with SLAC personnel and vehicles, and personnel and machine protection system modifications to allow alternative Beam Analyzing Station (BAS II)/Beam Switchyard (BSY) operation, as described below.

C. POSITRON SOURCE

The positron source will have two targets: an oscillating "wand" which crosses the beam axis and can be used for one or two pulses per second interlaced with normal electron beam pulses, and a rotating "wheel" which can be used for continuous positron beam pulses. Design of the wheel and wand control circuits has been completed. The wheel control panels are built and installed. The interconnections are checked out and the system is ready for the final test with the wheel. A minor modification had to be made on the wand control panels to allow for holding the wand in the beam position. The "wand driver and interlock" chassis has been breadboarded and the design has been finalized. The complete package is under construction.

The positron source system also includes special beam optics equipment (solenoids, quadrupoles, etc.) and an rf separator. The control and interlock circuits for the uniform-field solenoid power supplies were tested with the uniform-field solenoid in operation. The separator consists of an rf portion which bends accelerated electrons and positrons in the same direction and a magnet which straightens out the positrons while further deflecting the electrons. In order to allow interlaced electron and positron beams, the magnet must be pulsed. Its supply is a prototype for any pulsed steering which may be required along the accelerator. The engineering model, which will be used at the positron source, is being built and final tests will be completed by the early part of October.

D. PERSONNEL PROTECTION SYSTEM

One of the chief elements of the personnel protection system is the machine shutoff system, which shuts off all high voltage to the klystron modulators when a person enters a portion of the Accelerator Housing, Switchyard or End Station accessible to the beam. The system is now essentially complete. The main protection circuits consist of two tone loops which run the length of the Klystron Gallery. During the past quarter the loops have been rewired to provide a properly balanced circuit. The signal now drops 40 dB when the loop is broken, in contrast to the 20 dB reported last quarter.

A transfer switch has been added to allow severing the accelerator from the Switchyard itself. It is now possible to operate the beam to the BAS at Sector 20 with the BSY open, if three beam stoppers are in place and the BAS magnet is on. Since the mechanical protection is adequate, the equipment protection interlocks in the Switchyard are also disconnected. This allows all BSY circuits to be worked on while operational adjustments and experiments can be carried out on most of the accelerator itself.

The change between BSY and BAS operation requires that the accelerator be completely off, since the Accelerator Housing must be entered to insert or remove the beam stoppers. When the stoppers are modified to allow actuation from the Gallery or CCR, the transfer logic will be rewired to require that conditions be safe for the new mode of operation before the interlock circuits can be switched. The latter logic is already used to allow work in End Station A or B while the beam is in the other End Station or bottled up in the BSY.

Originally, the pulse magnet was to be interlocked off, a beam stopper in place, and the slit closed in order to allow entry to an End Station during operation. It now appears that the pulse magnet controls are too flexible to allow secure interlocking and the mechanical drive system for the slit is not up to the frequent operation that would be required. Additional beam stoppers must therefore be installed to provide a triple barrier between personnel and beam.

To date, no radiation monitors have been used as direct inputs to the machine shutoff system. The reason was that radiation monitors are generally not fail-safe devices and neither (1) provide the absolute protection desired for personnel in primary beam areas nor (2) can be trusted not to shut down the machine unnecessarily. In some secondary beam areas, however, radiation monitors must be used to protect personnel during experiments. It is now proposed that these monitors automatically close the beam stoppers mentioned above.

E. MACHINE PROTECTION SYSTEM

The Machine Protection Long Ion Chamber System was modified. The positron gate circuit was installed; it is now used to desensitize the PLIC during the large pulse which is produced when the beam is stopped at BAS II. A warning level discriminator was provided to alert the operator to drift of beam steering or focusing. A ×10 amplifier was added to the oscilloscope signal channel. The expanded sweep circuit for the modular oscilloscope was finished. This circuit makes it possible to locate a beam steering fault by adjusting a potentiometer to center the pulse rise and reading the sector number on the dial.

PLIC sensitivity was measured as a function of the direction of missteering, up, down, left, right, etc. Asymmetry was found to be ± 15% at most.

F. CONTROL SYSTEMS

Some special hardware has been planned for CCR and Sectors 27 and 28 to facilitate multiple-beam fine energy spectrum controls. This system will not be completed for some time, so the resulting problems were discussed with experimenters. An agreement was reached on energy spectrum requirements and operating procedures, as follows:

1. Only one high quality beam will be run at a time. It may, of course, be switched between different experiments.
2. The energy of other beams will be controlled to within "± one klystron's worth."
3. Experimenters will tolerate down time corresponding to that expected due to recycling klystrons - 3 to 5% of the time.
4. For the high quality beam, spectrum control will rely upon klystron pulse voltage control in one (or two adjacent) sector(s), and sub-booster phase control in one sector.
5. For other beams, energy adjustments will be made by switching klystrons between "accelerate" and "standby."
6. The arrangement will sometimes involve some loss of maximum energy when two or more experiments operate simultaneously. This will be regarded as a scheduling problem.

V. ELECTRONICS

During this quarter, the Light Electronics Group was merged with the Heavy Electronics Group to form the Electronics Engineering Group. Also, the modulator and other heavy electronics equipment maintenance was shifted to the Electronics Assembly and Maintenance Group.

A. MAIN MODULATOR

The main modulators continued to work well this quarter. Most of the troubles occurred in the pulse capacitors and small parts. There were about 150 bad capacitors during the quarter. A few of the main rectifier transformers and charging chokes developed oil leaks around their bushings but these were repaired by the manufacturer.

The problem of the main rectifiers occasionally burning up appears to be solved. As mentioned in the previous quarterly report, we suspected that the rectifiers were subjected to short circuit current for too long a time when the contactor hung up due to eroded contacts. The circuit breakers were adjusted to cut out on their thermal trips to prevent damage to the rectifiers. These circuit breakers have magnetic and thermal trips. The magnetic trips cut out in two cycles of the ac waveform. The thermals cut out in about ten seconds (for our short circuit current) which is too long for these rectifiers. Near the end of last quarter we set all the magnetic trips on sensitive to take advantage of their fast tripping action. Since then no more rectifiers have burned up. However, while this has solved the rectifier problem, it has resulted in the circuit breakers tripping during every switch tube fault, because the magnetic trips are faster than the normal action of the contactor and the circuit feeding its coil. Fortunately, switch tube faults are few, but nevertheless, it has resulted in extra work for the accelerator operators who must reset the circuit breakers when they trip out.

In order to alleviate this problem, we have taken steps to reduce the number of operations of the contactors. We have observed that most faults in the system happen external to the modulators. These faults trip the contactor each time they occur, which has resulted in the rather rapid erosion of the contactor contacts. In order to reduce wear and tear on the contactors, the modulator interlock system and the modulator-klystron protection unit were modified in such a manner that external faults only interrupt the trigger to the modulator. This was done in Sectors 5 and 6 first so that the system may be further evaluated.

The circuit breaker tripping problem will be solved by the installation of shunt trip coils in the circuit breakers which will operate slower than the magnetic trips but still fast enough to protect the rectifiers in case of contactor hang-up. These coils will be fed a slightly time-delayed signal from a sensing resistor in the ground side of the high voltage power supply. The magnetic trips, of course, will be set on a less sensitive position so that they will not trip out on normal switch tube faults.

The problem with the SCR switching units in the de-Q'ing system, as mentioned in the previous quarterly report, is being solved by the manufacturer on a routine basis, using our spares in order not to interrupt our operating schedule.

1. Switch Tubes

In operations to date on the accelerator we lost 25 tubes, of which 17 were large, single tubes and 8 were dual tubes. Many of these tubes were early failures and will be replaced under warranty.

In all operations to date, including the two-mile accelerator, Mark IV accelerator, and test stands, we have lost 60 tubes. The average life thus far has been about 1,800 hours on I.T.T. tubes and 1,400 hours on Tung-Sol tubes. Since many of these tubes are early failures, average life numbers are expected to increase considerably above these numbers.

About 28 small trigger thyratrons have been lost in all our operations to date on the machine. During the quarter, a new contract for these tubes was awarded.

2. Pulse Transformer Tank Assemblies

Another 19 pulse transformer tank assemblies were completed during the quarter, giving us a total of 290 complete units. We were about 20 assemblies ahead of klystron requirements, so we shut down the assembly line temporarily.

B. CAPACITOR CHARGER POWER SUPPLY

This project, consisting of two power supplies each capable of charging a 0.75-microfarad capacitor to 50 kilovolts in 80 milliseconds, after allowing a

20-millisecond dead period, is for use on a spark chamber in the Research Division. We have built two units and done preliminary testing on one. So far the tests look satisfactory.

C. BEAM KNOCKOUT MODULATOR

This modulator, a pulsed radio frequency amplifier at 39 megacycles, is used at the end of the accelerator to break up the beam into a series of extremely narrow pulses for certain physics experiments. It is in the testing phase.

D. MODIFICATION OF MAIN BOOSTER No. 1

The amplifier for the high voltage regulator was reworked for easier maintenance and better regulation. Other parts of the main booster were shifted around for easier maintenance. At the end of the quarter, this unit had been operating about one week while main booster no. 2 was being repaired.

E. MAGNET POWER SUPPLIES

1. <u>360-kW B-Beam Transport Power Supplies</u>

All of these power supplies were checked out and made operational. However, when two or more were operated on a common power source, we experienced an interaction problem. At certain output currents from one power supply the current would be unstable, while another power supply's output current was adjusted.

The problem was solved by performing a rather minor modification. By the end of the quarter we were in the process of making these modifications on all power supplies.

2. <u>1590-kW Power Supplies for Spectrometers, Group A</u>

These power supplies were delivered during the quarter. Shortly after delivery and installation, their water-cooled transformers developed water leaks.

Four out of eight transformers had leaks, which was sufficient reason to look into the possibility of obtaining better transformers and mounting them outside the building. Investigation is now proceeding.

3. <u>567-kW Power Supply for Spectrometers, Group A</u>

Three out of six power supplies were delivered this quarter. At the end of the quarter one was checked out and ready for load tests.

4. <u>3.4-MW Power Supply for the Bubble Chamber</u>

Construction of this power supply continued. The main problem was in the water-cooled transformers. The first attempt failed due to too high leakage inductance. The manufacturer was building from a new design at the end of the quarter.

5. <u>5.8-MW Power Supply for the Spark Chamber Magnet</u>

This power supply was almost finished at the end of the quarter. The problem with the transformers in the 1.59-megawatt power supply was thought to come up in these transformers because they are of the same design as those for the 3.4-MW supply. It was decided to switch to oil in place of water in the cooling tubes and use an oil-to-water heat exchanger to remove the heat.

F. OTHER ELECTRONICS

1. <u>Positron Source Electronics</u>

Engineering work was done in connection with the positron target. The pattern generator design was modified for operation with the positron wand source.

2. <u>Trigger Generators</u>

New trigger generators were designed for the counting house, pulsed steering magnets, and End Stations A and B.

3. <u>Gated Oscillator for the Research Area Department</u>

This circuit, which translates beam pulse information from analog to digital form for use in physics experiments, was out of the design phase and into the electronic assembly shop.

4. <u>Liquid Hydrogen Target Control System</u>

A system for determining the liquid hydrogen level in a target was designed and released to the assembly shop. Assistance was provided the research people in conducting rupture tests on the target vessel.

5. <u>Fast Valve Controllers</u>

The design of the fast valve controllers was improved to make them more reliable in their operation. Nine units were modified on the machine.

6. <u>Pulsed Dipole Power Supply</u>

This power supply was designed and released for fabrication to the electronic assembly shop.

7. <u>End Station Beam Position Monitor</u>

The design of this unit was almost finished at the end of the quarter.

VI. MECHANICAL DESIGN AND FABRICATION

A. GENERAL

By the end of the reporting period the solenoid A unit with edge-cooled double pancake solenoids making up coils 0, 1 and 2 had been completed and mounted on the radiator strongback of the positron source. Installation of the balance of the strongback components was in progress.

Machining and assembly of the major components of the wheel target drive was in progress. Preparations were being made for load tests of the crank arms. Tests during the period indicated the desirability of a double instead of a single bellows to insure the integrity of the vital crank arm, water-vacuum interface. Bids were out for procurement of the bellows.

The wand target for the positron source was completed except for the installation of the target and one cooling water connection.

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

B. MAGNET ENGINEERING

The magnet engineering group completed the installation and testing of components for the BSY A-line during the quarter and were preparing for B-line work. All quadrupole magnets had not been received by the end of the period and the group was pressing their procurement.

1. Three-Degree Bending Magnets

Magnetic measurements were completed on all three-degree bending magnets for the B-line; designations were made and installation of the magnets began.

2. Pulse Magnets

Coil cracks that had appeared with the pulse magnets were repaired, and all magnets were reassembled and readied for vacuum chamber installation and placement in the BSY. This should be completed next quarter.

3. Quadrupole Magnets

Magnetic measurements were completed on the A-line quadrupoles and they were installed. Both of the 18.6-cm magnets for the B-line were received, magnetically measured and readied for installation. The 8-cm magnets were received and will be ready for installation during the next quarter.

4. <u>Photon Beam Stripping and Bending Magnets</u>

Magnets A-8, A-12 and B-28 were installed and measured during the quarter. Beam stripping magnet B-29 installation was delayed, however, awaiting the installation of the dump magnets.

5. <u>Dump Magnets</u>

All four dump magnets had to be disassembled during the period because of coil cracks. These were repaired and the magnets reassembled, and they were ready for installation by the end of the period.

6. <u>Beam Dump East Steering Magnets</u>

These magnets were completed, installed and tested during the quarter.

VII. KLYSTRONS

A. SUMMARY

During the quarter the operation of klystrons on the machine resulted in a total accumulation of 127,000 tube hours, giving a cumulative figure of 283,000 total klystron hours. The endurance run was completed after approximately 130,000 operating hours. Ten klystron failures occurred during the endurance run (some of which were recorded during the previous quarter). The total number of klystron failures for the quarter was 15, giving a cumulative number of 54 klystron failures in operating sockets since the first activation of the machine.

Deliveries from vendors continued at a satisfactory rate, and our tube inventory is steadily growing. The development effort at SLAC has been emphasized since fewer tubes had to be built to fill up sockets on the line. We have been able to obtain 27.5 MW in permanent magnet from two experimental tubes.

There have been four driver amplifier failures in operation in the Klystron Gallery during the quarter, and at the end of the quarter the number of spares available for use remained 14. Design work on the Litton version of the driver amplifier is progressing.

The vacuum system maintenance does not present any real difficulties with the possible exception of occasional thin valve leaks. As a result, several sectors were let up to nitrogen during work in adjacent drift sections, and had to be rough-pumped and restarted.

B. KLYSTRON PROCUREMENT

1. Sperry Subcontract

Sperry is still experiencing production difficulties which are apparently not yet fully understood but which result in a low yield. The majority of the problems are still associated with tube gassiness, resulting in excessive processing time. The changes in processing techniques reported previously have apparently not yet resolved the difficulties.

On the other hand, there appear to be very few window failures at present in Sperry tubes (only one during the past quarter).

2. RCA Subcontract

Although the yield at RCA is not as high as desirable, the causes for a poor yield are quite different from those at Sperry. A majority of the failures in RCA tests were window failures. In spite of the apparent improvement in coating techniques, the secondary emission studies indicated that the load side of the window suffers from degradation during the bakeout process; hence, some windows still fail from multipactoring.

In addition, there appear to have been a number of windows which have failed due to arcing at the window, which again results in destruction of the window. This arcing may be caused by extraneous modes existing in the waveguide, by some excessive filets of brazing alloy in the vicinity of the window, or by a small gap around the compression seal over part of the window length.

Other problems in production involve leaks; enough of these were at the rf input seal to justify a redesign of the seal. Cathode seal punctures have also caused some losses. It appears that the RCA cathode seal may be marginal; at least the incidence of cathode seal punctures appears to be higher for RCA tubes than for the other tubes.

RCA is still experiencing difficulties in obtaining a high yield of the tubes to be repaired for Stanford. No reasons for the difficulties encountered have been ascertained yet.

3. Litton Subcontract

During the quarter Litton experienced some difficulties in processing their tubes due to arcing and/or oscillations. As a result, their yield has been lower than previously, but they were able to continue deliveries at an acceptable rate.

The reasons for the production problems are not yet fully understood, but it is suspected that they are associated with deposition of emitting material on the focusing electrode. So far, techniques to suppress such emission have proven unsatisfactory, but changes in assembly, cleaning, baking, and processing techniques have been found which could explain the sudden decrease in yield.

In general, the Litton tubes appear to perform satisfactorily, although we have occasionally measured window temperatures higher during acceptance tests than the temperature measured at Litton.

4. Driver Amplifier Klystrons

Eimac has almost completed initial deliveries of tubes against the contract, and a few replacement tubes for plate and shelf life failures are still to be delivered. Adding the number of tubes on hand to the number of warranty replacements due gives an adequate number of spares until deliveries are expected from Litton Industries.

The progress at Litton on design of the driver amplifier has been slower than anticipated, resulting in slippage of the scheduled test for the first tube. Litton now expects to test the first tube early in October. Litton is also experiencing difficulties in receiving magnets on schedule from the permanent magnet vendor. At last report the first magnet had been built but was not acceptable because of excessive transverse fields.

C. KLYSTRON RESEARCH AND DEVELOPMENT

The main emphasis of the SLAC klystron fabrication activity has been directed toward improvement of the performance of the present "standard" klystrons. Specifically, we have completed the construction and tests of an experimental klystron with two output cavities and double output waveguide; we have built and tested two tubes with increased drift tube diameters near the output cavity; and we have built and tested a one-third-scale beam tester.

The results of the double output cavity tubes are shown in Fig. 9. Each waveguide contains stub tuners with which the output cavity coupling can be adjusted for optimum performance. It was found that the maximum power output was obtained when the tuners of the first cavity were optimized. Under these conditions the power output from the first cavity was approximately 6.5 to 26.5 MW at voltages from 150 to 250 kV. The salvaged power in the second output cavity remained substantially constant at approximately 1 MW.

The main result obtained from this tube is a much less critical variation of power output either as a function of load mismatch or as a function of drive. The reason is that the salvaged power from the second cavity increases if the first output cavity is not tuned for optimum. These results confirm the findings of the successful extended interaction output cavity tube built, where the saturation curve was extremely broad and the sensitivity-to-load mismatch was extremely low. On the other hand, it does not appear promising at the present time to pursue the extended interaction cavity approach for efficiency improvement since the tests indicate that the increase in efficiency will probably be marginal at best.

Two experimental tubes (XM-12) were built with the third and fourth drift tube diameters increased from 1-1/8 inches to 1-1/4 inches, but with all other

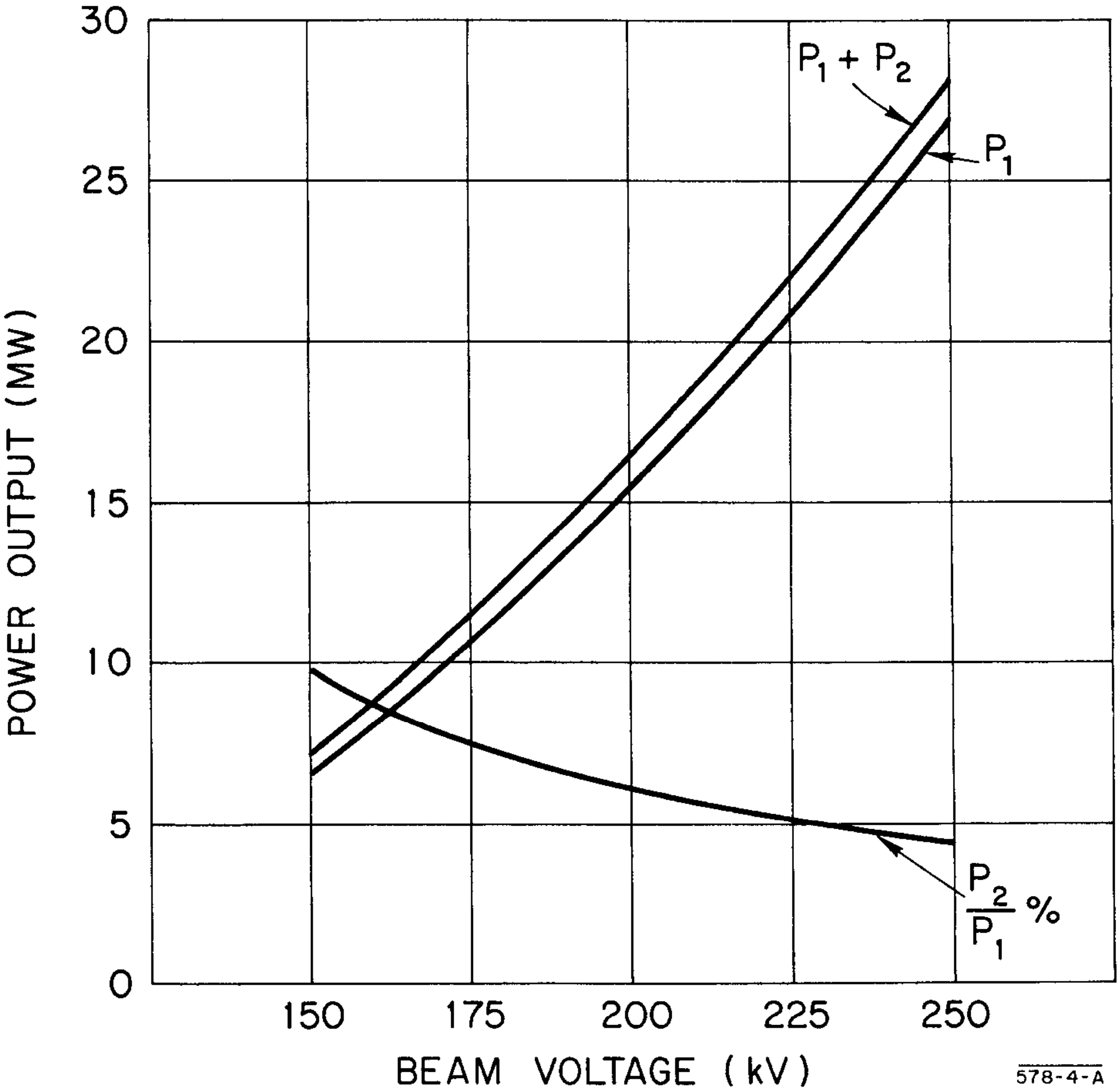


FIG. 9 --EXPERIMENTAL DOUBLE OUTPUT KLYSTRON PERFORMANCE

dimensions equal to those of the XM-7 ("standard") tube. Upon test in electromagnets, both tubes exhibited performance essentially equal to that of the best XM-7 tubes, but the magnetic field requirements had been drastically reduced from the optimum electromagnet field for XM-7 tubes, as seen by comparing curves 2 and 3 of Fig. 10. These tubes were then tested in permanent magnets which had been demagnetized from their standard value by approximately 100 gauss. The actual magnetic field plot is given by curve 4 of Fig. 10, and the average performance in permanent magnet of the two XM-12 experimental tubes is shown in Fig. 11. Their performance in permanent magnets is substantially the same as in electromagnets, and it can be seen that the performance improvement over the average XM-7 tube in permanent magnet is 10 to 20% at voltages from 200 to 250 kV.

In an attempt to further improve the performance of these tubes, an additional experimental tube was built with the same drift tube diameter but with the output gap length reduced by approximately 10%. This tube will be tested next quarter. We are also planning to build a few additional tubes of the XM-12 design in hopes of verifying the good performance of the first two experimental tubes built.

A diode beam tester was built to one-third scale to check the gun performance and entrance conditions in electromagnet at beam voltages of approximately 25 kV. Beam interception in the drift tube was obtained by thermal measurements, which confirmed the fact that the magnetic entrance conditions for the beam are not completely optimized in our present design; there appears to be some scalloping which probably results in interception near the second cavity in the standard tube. Additional work will be done with this beam tester in an attempt to improve the entrance conditions or the gun design.

D. KLYSTRON TEST AND MEASUREMENT

During the quarter, 33 tests were performed on Stanford tubes, including tests on special design tubes, such as the XM-12. In addition, 220 individual tests were performed for acceptance of vendor tubes and retest of tubes removed from the Gallery (61 new tubes and 34 Gallery returns). The average time per test was approximately 30 hours for Stanford tubes, 11 hours for acceptance and retests. The total high voltage running time was approximately 3800 hours.

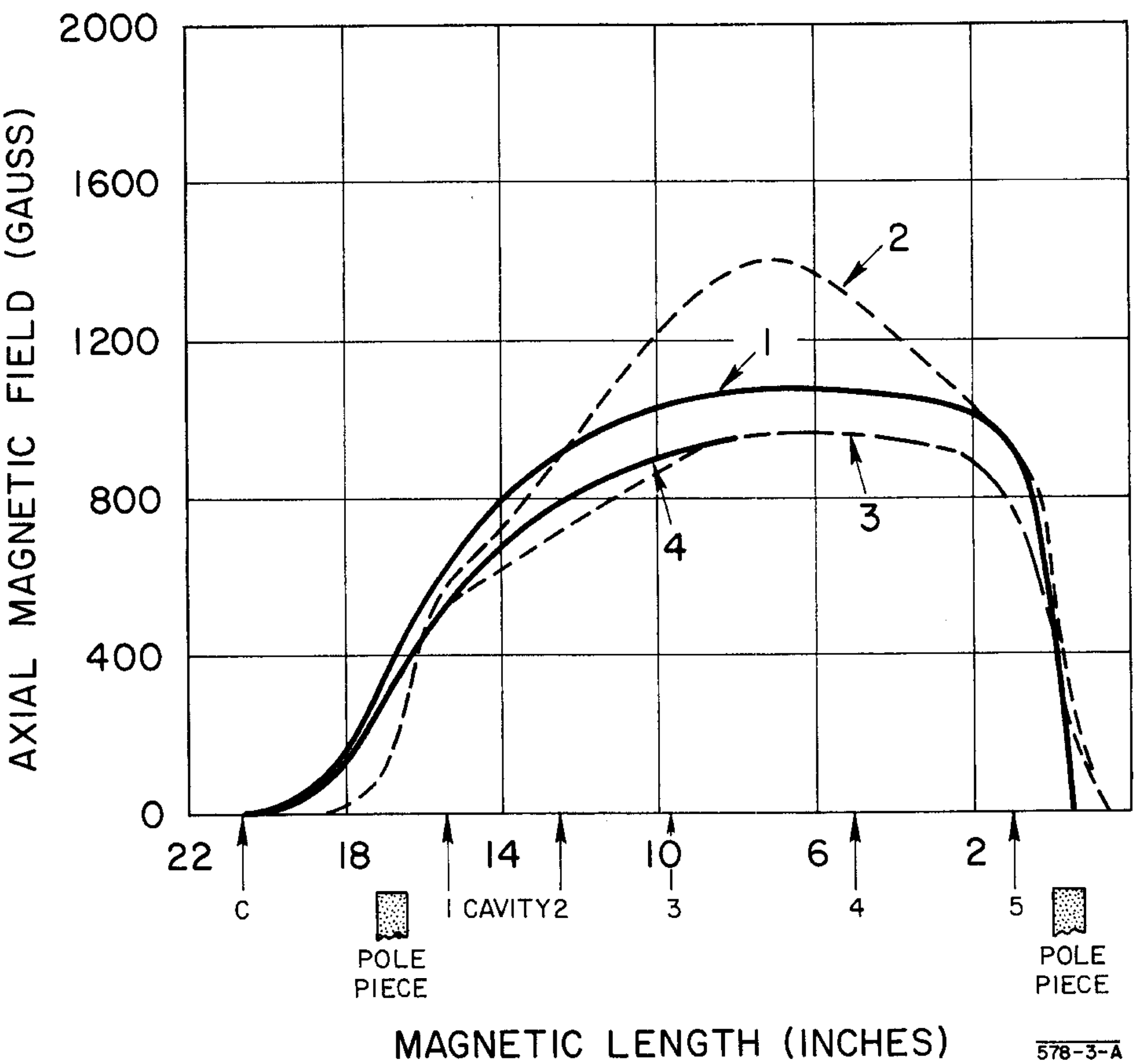


FIG.10--AXIAL MAGNETIC FIELDS FOR STANFORD KLYSTRONS
1-"STANDARD" PERMANENT MAGNET FIELD
2-ELECTROMAGNET FIELD FOR XM-7 AT 250 kV
3-ELECTROMAGNET FIELD FOR XM-12 AT 250 kV
4-PERMANENT MAGNET FIELD FOR XM-12

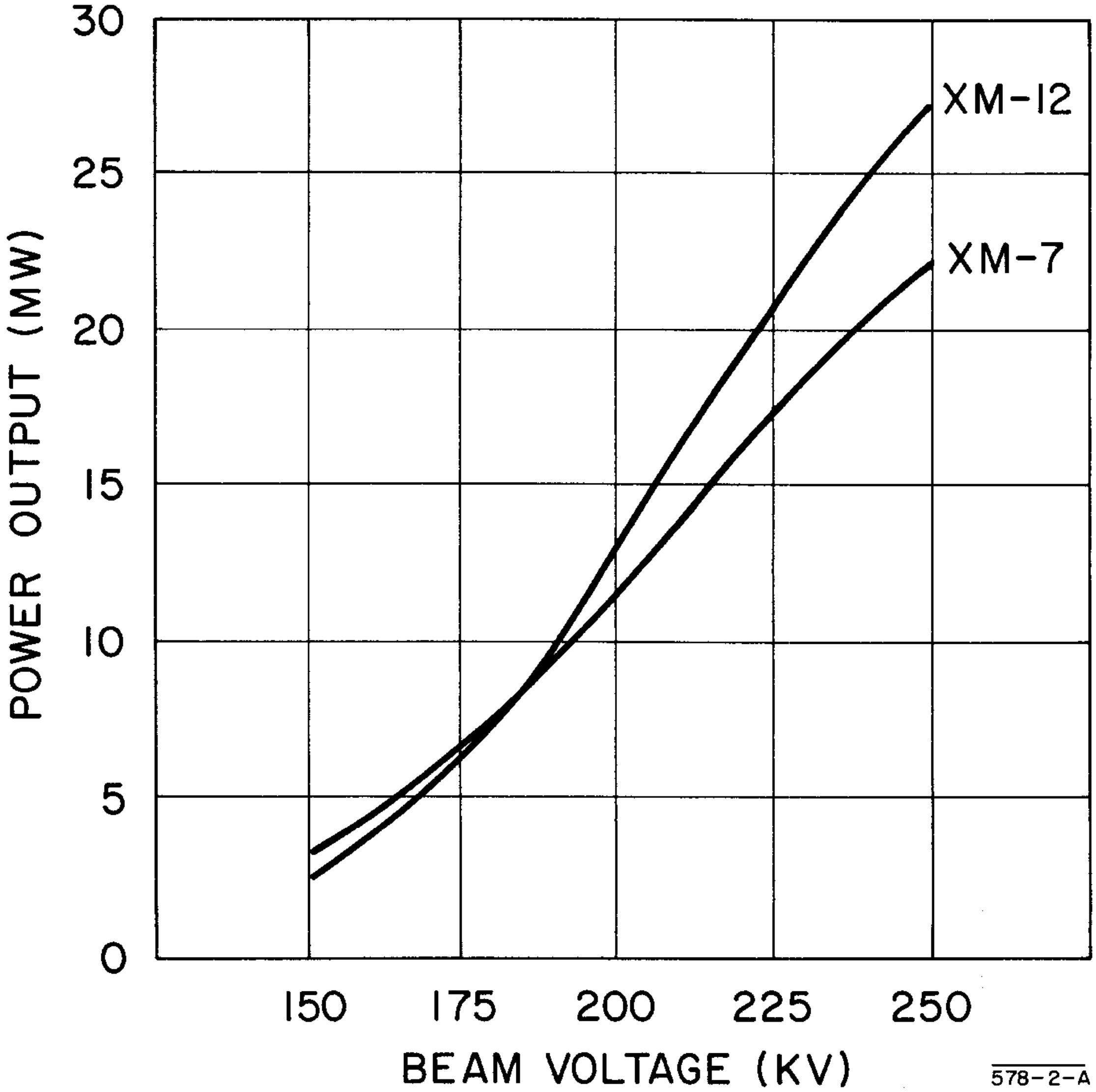


FIG. 11 -- STANFORD KLYSTRON PERFORMANCE IN PERMANENT MAGNETS

The number of test hours is still decreasing from the previous quarter's and we are now running on a two-shift basis. In addition, we are attempting to concentrate all tests in fewer test stands to allow us to eventually de-activate one or two test stands if necessary.

The test stand maintenance continued to be essential to the operation of the klystron tests. Major component failures resulted in approximately 390 hours of non-availability time during the quarter due to major component failures. These included three input ac circuit breakers, one primary Variac, and one charging choke. The sub-booster modulator performance was better, with only five switch tubes replaced. We believe this improvement is mostly the result of replacement of the 4PR1000 by the PL279 switch tube. In addition, three sub-booster voltage regulator failures were observed.

E. GALLERY OPERATION

1. High Power Klystron Operating Experience

The high power klystron operating experience can be evaluated best in the following table.

TABLE I

Tube Usage and Failures

Date	Operating Hours		Quarter		Cumulative	
	Quarter	Cumulative	Number Failed	Av. Life at Failure	Number Failed	Av. Life at Failure
To 12/31/65		27,000			10	297
To 3/31/66	11,000	38,000	13	252	23	272
To 6/30/66	118,000	156,000	16	234	39	256
To 9/30/66	127,000	283,000	15	594	54	350

As can be seen from the table, there were 15 klystron failures this quarter, but 34 klystrons were removed from the Gallery. In addition to the tubes removed for actual failure, tubes were removed because of suspected problems such as high perveance, arcing in the pulse transformer tank, modulator mismatch, water leaks and oil leaks.

The causes of the failures can be tabulated as follows:

Number of Failures	Cause
6	window
5	tube gassiness
2	pulse breakup (probably gas-induced)
1	open heater
1	arcing cathode

The endurance run begun in April was concluded on August 15. Approximately 1200 hours per socket were accumulated on 112 stations in the accelerator. The operating levels, average operating hours per socket, and information relative to failures during the run are given in the following table.

TABLE II

Endurance Run

Sector Pair	Operating Level				Average Operating Hrs./Socket	Cumulative Klystron Failure	Av. Life at Failure
	Ref. V	Klystron Beam V	Klystron P_{out} pk	PRF			
3/4	115	240-250	19-22	60	1175	1	690
5/6	115	240-250	19-22	360	1050	6	270
7/8	105	220-230	16-18	60	1200		
9/10	105	220-230	16-18	180	1140*		
13/14	105	220-230	16-18	360	1135	2	920
15/16	90	195-205	11-14	60	1200	1	595
17/18	90	195-205	11-14	360	1190		

*This pair of sectors began the run approximately 60 hours after the others.

One of the objectives of the endurance run was to determine a relationship between operating levels and tube mean time to failure. Unfortunately, the total number of failures was insufficient to produce meaningful statistical information which could lead to such a relationship. On the other hand, a statistical analysis of the failures observed indicates that the average tube life, averaged under all conditions of the endurance run, is probably 3000 hours with an uncertainty of ± 1000 hours.

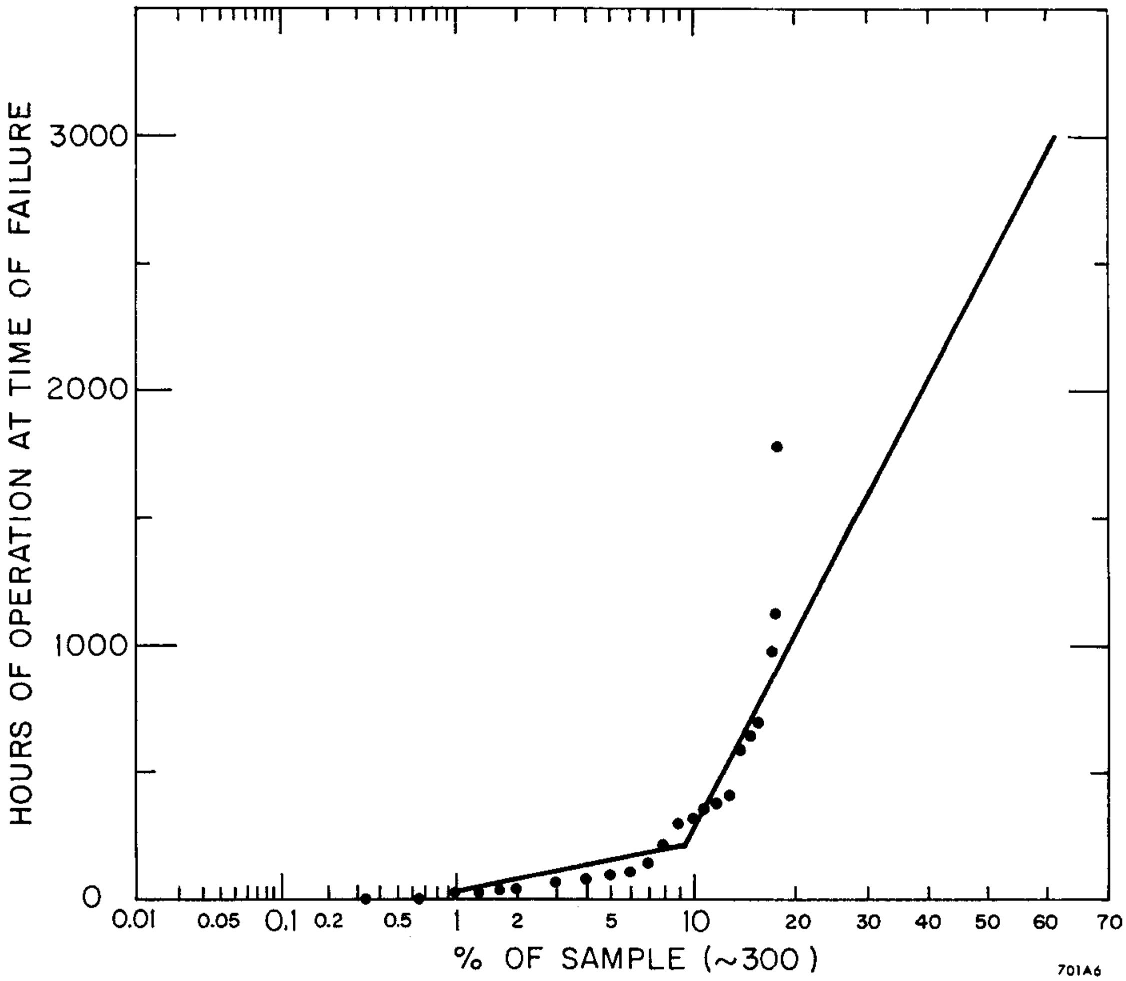
One of the important results of the endurance run was to point to the necessity for a better understanding of the operating problems at high peak and average power. It can be seen from the table that the actual average operating hours per socket decreases from 1200 for sectors operating at low levels to as low as 1050 for the pair of sectors operating at the maximum power and repetition rate.

One would hope that with a total of 283,000 accumulated socket hours (including nearly 130,000 for the endurance run), one could predict the klystron MTTF reasonably accurately. This unfortunately is not yet possible. Using statistical methods and plotting the actual failures on probability paper (Fig. 12), there appears to be a definite break in the failure rate, which is an indication that a majority of the failures observed to date are of the infant mortality type. Extrapolating the average line through the points corresponding to more than 10% of the sample, a MTTF of 2500 hours would be predicted. Obviously, this assumes that there will not be a major cause of failure, which has not yet been observed since the longest life tube is only slightly over 3000 hours.

One can also plot, as in Fig. 13, the age distribution of the tubes installed in the Gallery. At the end of the quarter, the mean age of all tubes in the Gallery was 1087 hours and the median age 1225 hours. The large peak in the distribution at around 1500 hours is caused mostly by the tubes in those sectors which were subjected to the endurance run. In fact, the mean age of all tubes in the first 18 sectors is close to 1400 hours, while for those in the last 12 sectors, it is about 600 hours. Figure 14 gives the average life at failure for all failures per quarter, the number of tube replacements and tube failures per quarter, and the average operating hours per tube (including those which were replaced or failed) since the initial operation of the machine.

2. <u>High Power Klystron Maintenance</u>

The klystron maintenance activity is divided into preventive maintenance and investigation of trouble reports coming from either the Accelerator Operations Group or other groups. The preventive maintenance has not yet reached the full efficiency which will be needed to make it really effective. Part of the problem is of course the question of available manpower, which on occasion has to be diverted from preventive maintenance to investigating trouble reports; efficiency was also decreased by the difficulty of scheduling uninterrupted maintenance during the initial operation of the machine. No major problems were



ALL KLYSTRONS – FAILURES DISTRIBUTION ON 10/1/66

FIG.12

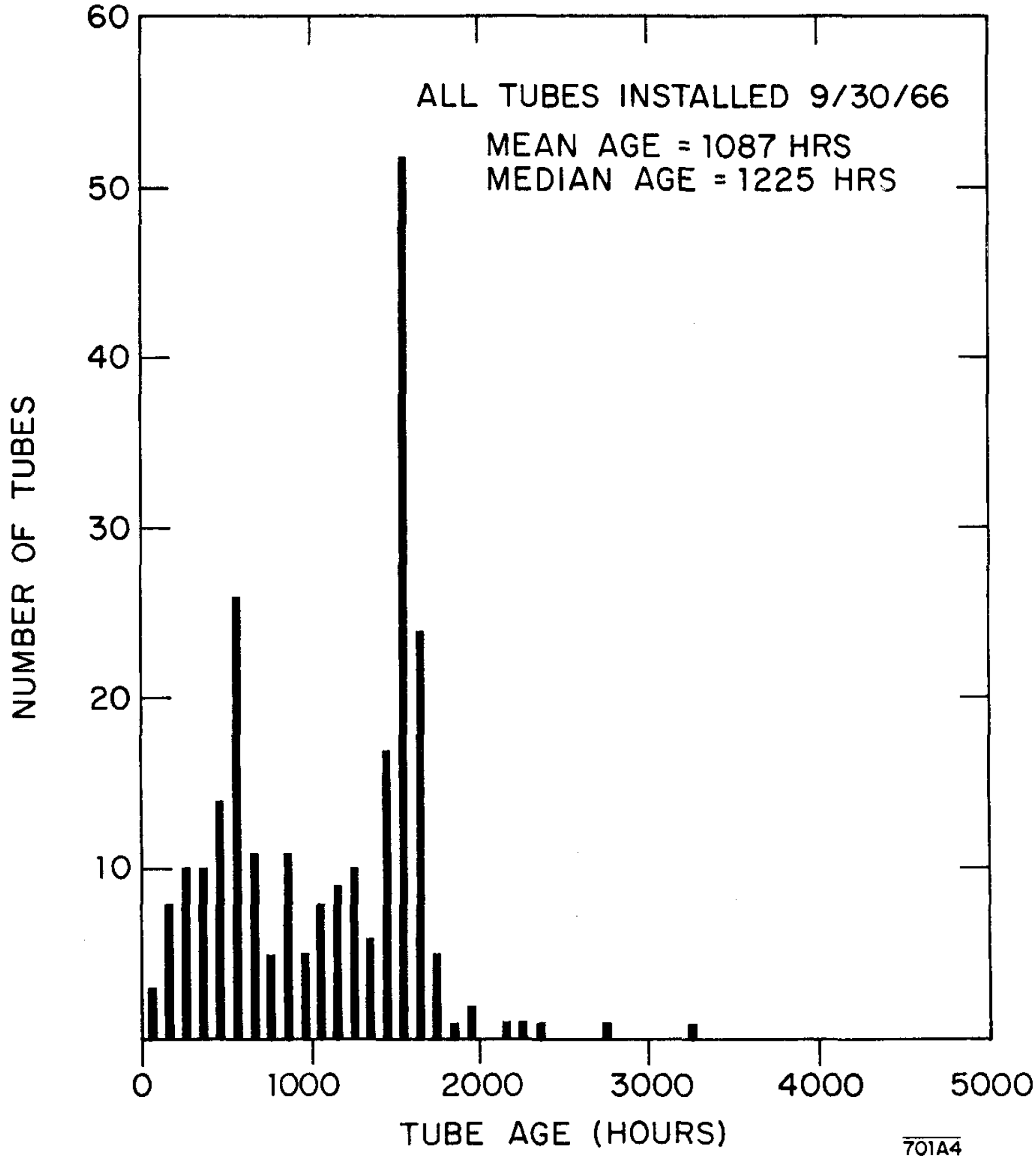


FIG. 13 - KLYSTRON AGE DISTRIBUTION (100-HOUR INCREMENTS)

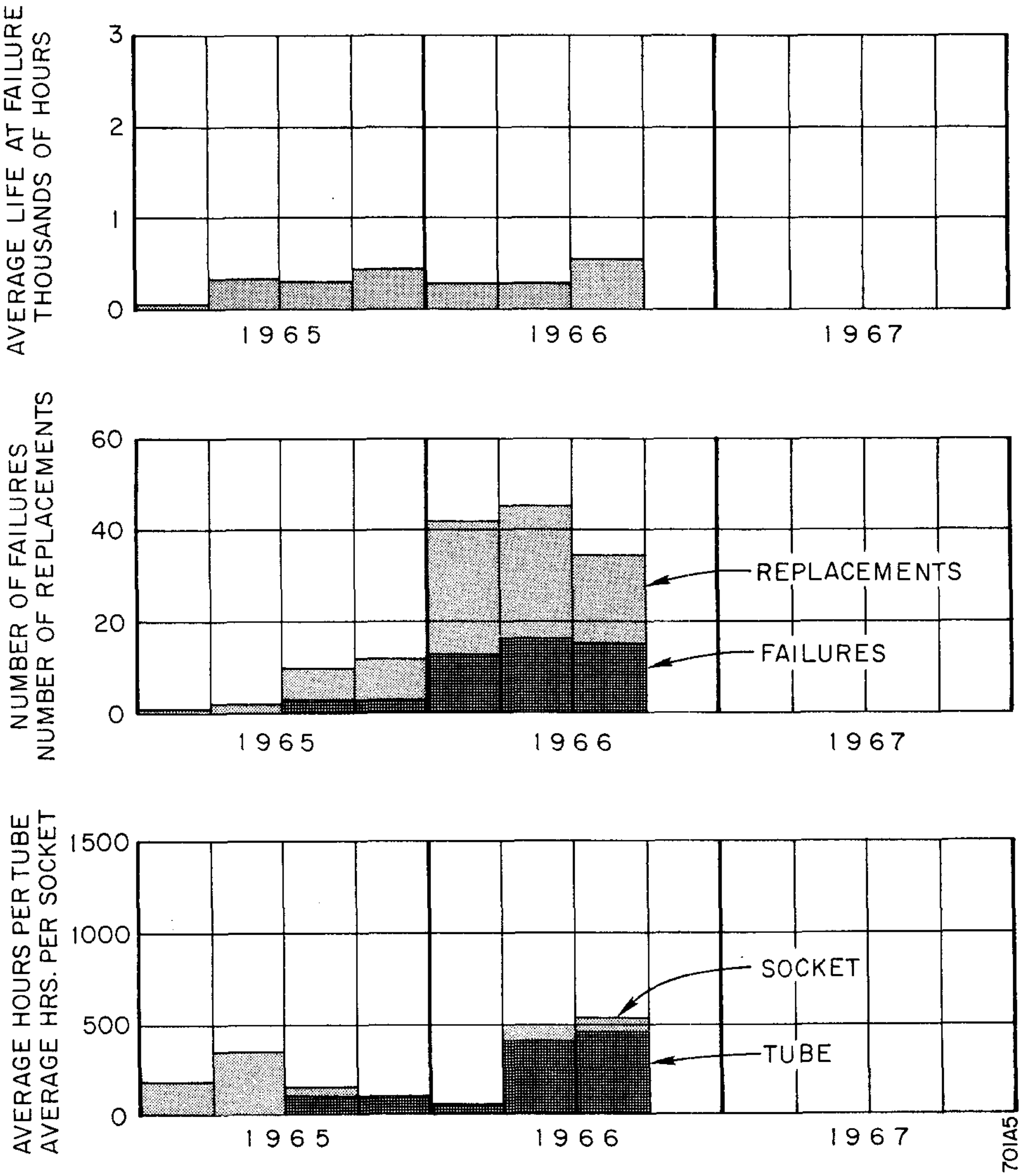


Fig. 14--KLYSTRON QUARTERLY OPERATING EXPERIENCE, ALL HIGH POWER KLYSTRON VENDORS

uncovered by preventive maintenance during the quarter.

Approximately 250 trouble reports were investigated during the quarter as well as 50 repeat checks (recheck of a station if another system on the station has required repairs).

Thirty-four klystrons were removed from the Gallery, and their replacements had to be "run up" to ascertain the proper operation of the tube just installed. Of the 34 klystrons so replaced, only 15 were failures; 8 other replacement tubes were suspected failures but turned out to be still within specifications after check in the Test Lab; 2 tubes were also removed for special modulator tests, 2 for suspected tank failure, 3 for oil leaks, and 4 for water leaks.

3. Driver Amplifier Klystrons

During the quarter approximately 27,000 high voltage hours were accumulated on the sub-boosters in use in the Gallery, and 5000 hours in the Test Lab. Although nine tubes were replaced in Gallery sockets, only four were tube failures, with an average life at failure of 3320 hours. No failures occurred in the Test Lab sockets. All failures observed this quarter were caused by output pulse droop, which is probably an indication of tube gassiness. One tube also failed on shelf life.

In general, there were serious problems on only a few of the Gallery stations, as evidenced by the number of tube failures. However, most stations indicate an out-of-specification phase shift during the first 500 to 700 nanoseconds during the flat second of the pulse. A team of Accelerator Physics, Heavy Electronics and Klystron Group personnel is attempting to determine the cause for this phase shift and apply the necessary corrections.

4. Main Booster Klystrons

Three main booster klystrons were used in the two sockets; with only one station available for use during most of the quarter, the operating hours dropped to less than half that of the second quarter--1617 hours. One tube failed out of warranty, apparently the victim of gas.

Equipment and circuit problems at both main booster stations are reflected in klystron problems; faulty power supply regulation and defective body current metering probably contributed to the failure of tube A5-14. The failure of the interlock circuit which permitted the tube to run under any condition short of a circuit breaker trip probably permitted the melting of the input cavity gap of tube V5-21-B. The defective drive line transfer switch has been replaced but is not yet operating.

Engineering modifications are continuing at both stations and hopefully will overcome these problems. Other problems require attention, such as the lack of a minimum water flow interlock on the rf dummy load, lack of an arc detector in the rf output circuit, and body current instability which appears to be a result of focus current drift. Efforts are being made to determine the cause and extent of the drift.

5. Vacuum System Maintenance

The second cryosorption vacuum roughing pump was received, tested and accepted. Performance was far better than that of the first unit. A pressure of 5×10^{-4} torr was reached in 82 minutes (which includes initial cooling time) and a pressure of 5.5×10^{-5} torr was reached in 150 minutes. Liquid nitrogen consumption to 5×10^{-4} torr was less than 200 liters.

Drift section let-ups continued through the quarter so that modifications could be made. The 10-foot drift tube at Sector 20 was reinstalled and all temporary beam stoppers were removed.

Thin valve problems seem to be getting worse. Many fast valves, closed during let-ups, leaked enough to lose vacuum in the adjacent sector. Many manual valves are also causing problems.

An all stainless-ceramic thermocouple gauge has been installed at the refrigerated baffle in Sector 30. This allows the pressure to be checked when the section is isolated from both the accelerator and Beam Switchyard vacuum systems.

Six manifold gauge assemblies with the addition of all stainless-ceramic thermocouple gauges have been built and will be installed next quarter on a trial basis. The thermocouples will help determine sector pressure for starting ion pumps and in cases of accidental let-ups.

All accelerator system vacuum gauge and pump pressures are being recorded once a week, usually on Friday. In general, the vacuum gauges have performed very satisfactorily. A few gauges seem to have a tendency to extinguish when the indicated pressure approaches 10^{-9}, although these gauges are supposed to be operable down to the 10^{-13} torr region. In general, we have been able to restart them without further difficulties by changing magnets.

One 3-inch isolation valve in a 5-inch manifold required a bellows assembly change.

Leak detecting is being done as the workload allows on a once-a-week basis. About 15 stations (out of 245) have small tolerable leaks ($1 - 4 \times 10^{-7}$ base pressure), and an effort is being made to locate and repair them.

F. HIGH POWER KLYSTRON WINDOWS

1. Stanford Klystron Windows

One more SLAC klystron window failed during the quarter and two other hot windows were noted, which seems to indicate a trend toward increased window heating. While no definite cause has yet been identified, two possibilities are presently under study: (1) the altered vacuum-bake cycle in use since April, and (2) inconsistencies in the coating control system.

2. Resonant Ring Tests

Klystron window pretesting continued at the reduced rate required by current tube production. 50% of the windows pretested were rejected on the basis of ring test temperature data.

Double-window testing continued with tests being completed on the third and fourth double-window assemblies and begun on a fifth assembly. To date, no final conclusions have been reached concerning the comparative stability of the standard coating, of an oxygen enriched coating, or of a tungsten carbide coating.

As part of the effort to avoid the stability problems involved in the use of coated windows, the use of grooved windows as an alternative method of suppressing multipactor on the tube side of the window is being tested further. This work will include investigation of the effect of magnetic fields on the multipactor prevention capability of the grooved window surface.

The test program on RCA windows concluded with tests of RCA ceramics coated in a poorer vacuum with the intention of achieving increased coating stability. On the basis of ring tests before and after exposure to a simulated RCA braze cycle, both specimens of the latest RCA coating were clearly superior to coatings tested earlier in the program. At present, failure by window puncture appears to be a problem at RCA. Arc discharges from the window surface to the adjacent waveguide transition could be a cause of puncturing, but attempts to induce this type of event in ring tests have not been successful.

3. Window Life Test

The window life stand was operated for an additional 350 hours during the quarter, bringing the total operating time to approximately 10,000 hours. Operating power levels up to 25 MW were attained during the final weeks of operation, with no window failures resulting from the increased input. The extended run was then terminated, and tests of the effect of vacuum bake were begun on the life test window circuit.

A portable oven capable of baking individual windows to 550° C has been constructed, and four of the life test windows have been baked to date. Significant increases of window operating temperature followed bake of three of the four windows. One of the three windows failed thermally at the relatively low power level of 10 MW. The single instance where window performance did not respond to baking was probably due to the lower bake temperature (475° C as compared to 530° - 550° C) on this particular window because of the failure of one of the oven heating elements.

Results of these tests seem to indicate that vacuum baking of windows in the life test configuration can be a useful alternative to the double-window test technique of evaluating window coating stability.

4. Window Coating Activity

Aside from the preparation of tube windows for SLAC and Mark III klystrons, the major portion of window coating work this quarter was devoted to experimentation with coating in a 2% oxygen-98% argon atmosphere and two attempts to calibrate the crystal monitor measurements of relative thickness against an absolute measurement of the actual coating thickness.

Heavy emphasis has been placed upon investigation of the effect of oxygen added to the coating vessel atmosphere. The object of increasing the oxygen content of the coating as it is deposited is to improve the stability of the coating through its exposure to vacuum bake. The only specimen of this coating to go through bake and test on a klystron has performed well.

One of the difficulties of analyzing the oxygen-enriched coating arises from noticeable variations in coating deposition rate and crystal monitor response as compared to coating in the standard argon atmosphere. Apart from the perturbing effect of the oxygen mixture, it has become apparent during the past several months that crystal monitors are subject to wide behavioral variations when they are infrequently used, doubtless because of the additional opportunity for surface films to accumulate. Both of these problems point to the continuing need to calibrate our crystal monitor data in terms of actual coating thickness. Unfortunately, none of our attempts at coating calibration has met with success. Work is continuing on interferometer measurement of the film thickness as the most promising of the possible calibration methods.

VIII. ACCELERATOR OPERATIONS

A. SUMMARY

The accelerator operated on a fixed schedule throughout this report period. It was manned for fifteen 8-hour shifts a week, starting at 8:00 a.m. Monday, and ending at 8:00 a.m. Saturday. One or two of these fifteen shifts were scheduled shutdown periods for maintenance and for preparation for Positron Source installation in Sector 11.

Throughout most of the period, accelerator on-time featured operation to BAS II (the analyzing magnet and beam dump in Sector 20). Considerable machine physics work was accomplished as well as operator training and equipment shakedown. The rf "endurance run" to obtain klystron life statistics, originally planned to accumulate an average of 2000 hours life on each klystron station, was terminated on August 13, after an approximately 1200-hour average had been reached.

On September 12, work in the BSY (Beam Switchyard) had progressed to the point where it was possible to run beam in the A-beam line. Beam to D-10, the Tune-Up Dump, was achieved September 13; to D-11, the A-Beam Dump, September 16; and through ESA (End Station A) to D-400, Beam Dump East, on September 20. From September 13 on, beam was run to the BSY nightly (Monday through Friday).

The long period of essentially continuous operation has unveiled problems and equipment troubles. These have been tackled as they appeared, and have been, or are being cleared up; as a result, operation is steadily improving.

B. OPERATION - GENERAL

The accelerator is manned from 8:00 a.m. Monday morning, to 8:00 a.m. Saturday morning. Through September 7, the accelerator was off, and, in general, the housing was open from 8:00 a.m. to 4:00 p.m. on Monday and Tuesday to allow installation of wiring, plumbing and equipment in preparation for installation of the Positron Source on Girder 3 in Sector 11. This work was essentially completed by September 7. Throughout these shutdown periods, of course, maintenance, equipment modification, and preparation for machine physics experiments also took place. Since September 7, the day shift each Monday has been scheduled for maintenance and machine changes.

A good portion of the continuing modulator and klystron maintenance cannot take place during these scheduled maintenance periods, as it requires operation of the equipment. This work is normally taken care of during regular operation, as it is always possible to operate stations--or sectors--on the "standby" pulse, letting the beam drift through the affected part of the accelerator.

Prior to September 12, machine operation consisted of running beam to BAS II* (Beam Analyzing Station II) on the first girder in Sector 20. The analyzing magnet at BAS II can determine beam energy up to 3 GeV. The beam line following the magnet was broken and a water-cooled dump installed, so that, in addition, higher energy, unanalyzed beam could be run. Appropriate shielding was also installed, so that beam could be run to BAS II with no radiation hazard to workers in the BSY.

Prior to beam operation to BSY and ESA commencing September 12, the beam line following the BAS II magnet was re-established, and insertable beam stoppers were installed at 20-1 (Sector 20, Girder 1), 20-9 and 28-9. These stoppers and the BAS II magnet current have been interlocked into the Personnel Protection System, allowing operation to BAS II in the daytime while work is going on in the BSY, yet affording easy changeover to full accelerator beam during the night. Since September 12, a regular pattern of operation has been followed. The period from 8:00 a.m. to 4:00 p.m. on Monday is used for accelerator changes and maintenance; there is no operation, rf or beam. Throughout the same 8:00 a.m. to 4:00 p.m. period on Tuesday through Friday, beam can be run to BAS II for machine physics experiments and operating experience. Changeover to BSY operation commences each evening, Monday through Friday, at 4:00 p.m., and operation in the BSY mode continues until 6:00 or 6:30 a.m. The accelerator is then converted to the BAS II mode while a radiation survey is made of the BSY and ESA, so that construction can proceed during the day.

The endurance run, which started April 25, 1966, was originally planned to accumulate either an average of 2000 hours per station klystron on-time, or to continue until twelve klystrons had been lost in the sectors selected for the test. At the beginning of the report period, about 700 hours had been accumulated. The need to prepare for operation to the BSY with beam terminated the run on

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*BAS I is located on the first 40-foot girder in Sector 1, and is used for injector tune-up.

August 13, after an average of approximately 1200 hours had been reached and six klystrons were lost. More information on this subject will be found in Section VII of this report.

C. BEAM OPERATION - BAS II

Thirteen shifts per week, prior to September 12, were scheduled for running beam to BAS II. When operation to the BSY commenced, four shifts per week were retained for BAS II operation. Machine physics, equipment checkout and improvement, and operator training took place during these periods.

1. Machine Physics

A large portion of the operating time was devoted to machine physics. The major areas of concern will be mentioned here; the work and its results are described in more detail in Section III of this report.

a. Beam Break-Up (BBU)

It has been established that it will be possible to obtain the full design energy of 20 GeV, but it has also been determined that the current output of the accelerator is limited to about half of the design value of 50 mA peak. (This limitation applies to the full pulse width of 1.6 μsec; for shorter pulses, higher currents are possible up to a maximum of about 80 mA at pulses of 100 nanosec or shorter.) This current limitation, referred to as "beam break-up" or BBU, is a radial oscillation of the beam, with a frequency of 4140 Mc, which builds up rapidly as the current is increased above the onset value.

A large portion of the work done during beam operation into BAS II has dealt with this problem. The only promising results so far were achieved by the use of stronger focusing. A program has been instituted to rearrange the quadrupole magnets and add power supplies; the stronger focusing thus attained should increase the maximum current available by about 50%.

b. Multiple Beam Operation

In preparation for future operation into the various research areas, where it is planned that interlaced beams of different energies and currents can be supplied to two or more experiments, several multiple beam runs were initiated. It was found that two or more beams of quite different energies and currents can be set up quite rapidly, and that steering and focusing, although more tricky than for a single beam, do not offer serious problems.

c. Positron Operation

A proposed experiment requires positrons of energy of the order of 20 GeV. (The energy of positrons from the Positron Source at Sector 11 is limited to 12 - 13 GeV.) An experiment was run with a simple target inserted in the beam at the end of Sector 1 to determine the yield that could be obtained if positrons were to be generated and accelerated from that position. The experiment was successful; positrons of 1.9 GeV (accelerated by three sectors) were detected at BAS II. The current was about 10^5 positrons per pulse, and the yield was roughly 3×10^{-6} e^+/e^-.

d. Beam Monochromatization

A simple measurement of the energy spectrum can be misleading in that it shows the energy distribution of all the electrons in the pulse. Several spectra, taken at different times during the pulse, will probably be found to be quite different. For example, the electrons at the beginning of the pulse will tend to have the highest energy--particularly at higher current operation--because the early electrons experience the effect of higher accelerating fields before beam loading has taken effect. (A method of beam loading compensation has been included in the design to aid in counteracting this effect.)

There are some research experiments using the beam for which a non-uniform energy distribution throughout the pulse is highly undesirable. Consequently, several experiments have been run to determine the energy distribution, the efficacy of the beam loading compensation that has been provided, and the operating conditions under which the energy distribution is optimum.

e. MIT Accelerator Experiment

MIT is considering the construction of an electron linear accelerator using accelerator sections identical to those in the SLAC accelerator. The MIT accelerator is to have a relatively very high duty cycle; consequently, it would be run at much lower peak power and, therefore, much lower gradient than the SLAC machine. Several days were spent running Sectors 1 and 2 under the MIT parameters (except, of course, for the duty cycle), with particular attention being paid to the effect on BBU.

f. Low Currents and Dark Current Work

A low beam current study has been in progress with two basic aims. One has been to study the "dark current" in the accelerator to determine its sources and, hopefully, to reduce it. The other has been to provide a low current monitor to aid in the development of the injector control in the low current region.

2. Equipment Checkout and Improvement

An important advantage of the ability to operate with beam during the completion of the BSY and research areas has been the opportunity afforded to check out the components and make changes were necessary.

a. Phasing System

The automatic phasing system sequentially adjusts the phase of the rf output of the eight klystrons in a sector. From the very first beam runs, the system has operated well. However, continuing beam operation has uncovered nagging problems. At times entire sectors will not phase, or one or several klystrons in a sector will be found to give low or negative energy contribution. The problem cannot always be laid to the phasing system; instabilities in the beam, drive system, or modulator/klystron system will affect its proper operation.

The problems with the phasing system are being studied under operating conditions and several noticeable improvements have been introduced. Improvements in the operation are continuing.

b. $V = f(P)$

The rf in an accelerator section must have the proper phase in order for the beam to gain the maximum possible energy as it passes through that section. Although the phase of the rf supplied to each girder is easily adjusted by a phase controller in the drive to each klystron, there is no such easy adjustment of the relative phase of each of the four sections on a girder. As each girder and its associated waveguides were installed, the four sections were phase-tuned by mechanically altering the waveguide dimensions at appropriate places along the feed line. Beam operation to BAS II allowed a check of the quality of this phase-tuning for all girders in Sectors 1 through 19. (A similar check will be run on the remaining eleven sectors as time is available during operation into the BSY.)

The relation between klystron output power and energy gain per sector is $V = k\sqrt{P}$, where V = the energy in MeV and P = megawatts of peak rf power at the klystron output. The value of k determined was 20.0. One section on Girder 8-4 was found to be 180° out of phase; this will be retuned during the shutdown for the Positron Source installation.

c. Positron Source Steering Effect

Though the Positron Source itself has not yet been installed, the special rf sections following the source have been in place for some time. These sections are surrounded by a large solenoid for axial focusing. If properly constructed and aligned, the solenoid should have no steering effect on the beam.

The solenoid was found to indeed have a steering effect; several experiments have followed to determine a method of alignment to minimize this effect.

D. BEAM OPERATION - BSY

Beam to the BSY, into D-2, the Temporary Central Beam Dump, and D-10, the Tune-Up Dump, was attempted September 12, and was achieved September 13. Beam operation into the BSY has continued nightly since that date.

Beam was first achieved to the A-beam line and D-11, the A-Beam Dump, on September 16, and to Beam Dump East on September 20.

From September 13 to September 30, BSY operation has consisted largely of checkout of BSY equipment and controls and instrumentation, and, largely coincident , operator training. Several radiation runs were made to determine area radioactivity levels and the effectiveness of the shielding, and to examine the radiation in the cooling water systems.

There has been no great emphasis on "pushing" the accelerator during this period; consequently, operation has generally been with beam energies in the 5 to 15 GeV range. The highest energy achieved during the period was 15.6 GeV.

IX. RESEARCH AREA

A. SUMMARY

During the reporting period Research Area Operations Group was absorbed and combined with Research Area Physics and the Beam Switchyard Instrumentation and Control Group to form the Research Area Department. The new department reached its full manpower staffing in August 1966. Departmental effort was channeled toward completing End Stations A and B, the Beam Switchyard, and adjacent support facilities. Included in our work are:

1. End Station A and associated beam line
2. Beam Dump East
3. Beam experiment equipment installation, including electronics
    a. Mu beam
    b. Annihilation beam
    c. Photon beam
    d. K-meson survey beam
4. Liquid Hydrogen System
5. Yard communications and instrumentation and control
6. End Station B
7. Magnet power supply houses
8. Experimenters' trailer
9. Beam Switchyard

End Station A was successfully turned on and received the first beam on 20 September 1966.

End Station B installation has been progressing rapidly and is approaching completion. The facility is expected to receive the K-meson survey beam on 1 November 1966.

B. END STATION A AND FACILITIES

Beam Equipment installation and check-out were completed by mid-September in preparation for receiving the first beam to the End Station.

Major installation included:

1. Beam pipe system terminating at Beam Dump East.
2. Magnet system with power supplies.
3. Personnel protection system.
4. Beam instrumentation, including zinc sulfide monitors, current intensity monitors, collimators and TV monitors.
5. Control cabling from the End Station to the Data Assembly Building.
6. Ion gas supply system.
7. Concrete shielding.

Work did not include items being performed by Group A personnel; however, support to that group was given where required.

The beam successfully reached End Station A on 20 September 1966, with parameters of 2.0 mA peak, 20 pps, 1.5 μsec at 10 GeV. Three hours later, the beam extended to Beam Dump East.*

Following the success of the first beam, experiments were performed during the remainder of the reporting period, with intermittent shut-down for maintenance or installation of additional equipment. Experiments included:

1. Photon Beam
2. Quantameter calibration and measurements
3. BSY beam transport study
4. BSY beam optics study

Experimental beams were also effectively used for calibration and testing of beam instrumentation.**

C. BEAM EXPERIMENTS

1. Mu Beam

Essentially, the beam line has reached 80% completion and extends from the port funnel to the NE corner (End Station B). The port funnel section was completed but was disassembled to allow installation of a Be target. Following placement of the target, the section was reassembled.

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*Daily Report 19/20 September 1966; Research Area Operations. Available upon request from RAD.

**Ibid.

Installation of the quadrupole magnets progressed during this reporting period with the completion of eight 8Q48 magnets and attendant stands and power supplies. Water connections to six magnets will be completed by late October.

Precision alignment of the beam system is expected to take place and be completed by the end of October.

Difficulty in obtaining adequate magnet power supply cable on schedule was encountered. However, additional sources of supply were found and cables are expected to be installed by late October.

2. Annihilation Beam

Initial beam design and layout drawings are expected to be completed and released by October. Presently, these drawings are 90% complete. Following release of design drawings, effort will be placed on installation documents and material requirements.

3. K-Meson Survey Beam

The survey beam is composed of two beam lines separated by an angle of 3°. These beams are the electron beam and the K-meson or secondary beam. The installation is approximately 75% complete, with operation expected by 1 November.

The Beam Target room equipment has been placed, including:

a. Shielding
b. Be target housing
c. Instrumentation
d. Drift pipe sections

Remaining equipment, such as a divergent chamber assembly and additional beam instrumentation, will be installed in October.

The electron beam line is partially complete, with the dump, concrete shielding and instrumentation in place. Completion is scheduled in October. One 8Q48 and one 18D72 magnet have been positioned in the K-meson beam line. Drift pipe sections and another 8Q48 magnet system are expected to be installed by October. It appears that the remaining magnet system installation will take place toward the end of the year. However, to avoid delaying beam turn-on, alternates are being investigated.

D. LIQUID HYDROGEN SYSTEM

The system, consisting of a storage facility and control panels, is 75% complete. The storage facility requires completion of paving, placement of the LH_2 manifold, and fencing. These items are scheduled for completion by mid-October. The target control panel and chassis are fabricated and are awaiting installation into racks. This effort will be completed by October.

E. INSTRUMENTATION AND CONTROL

Installation of control panels for Building 209 has reached 95% completion. Only one panel remains to be finished. Expected date of completion is the end of October. However, cross-connects in Building 209 have been progressing slowly and are only 35% complete. The pace has been attributed to inadequate manpower, and without increased staffing, anticipated completion is mid-November. There is, however, a concerted effort to avoid schedule delay.

F. GENERAL FACILITY WIRING

Trunk lines are 80% installed. Other cable requirements are expected to be complete by late October. Work includes control wiring to the Experimenters' Trailer.

G. PERSONNEL PROTECTION SYSTEM (END STATION B)

Two access control modules have been placed and hook-up is now in process.

Four tunnel gates are being installed beneath the End Station. The system is expected to be operational by 15 October 1966.

H. BEAM SWITCHYARD

Beam Switchyard operation was suspended July 1 for installation of equipment in the A and B lanes. Installation of A lane equipment was nearing completion by the end of September.

1. Alignment

a. Beam Switchyard

The final alignment of the Beam Switchyard transport system was completed during this quarter, with the exception of three pulsed magnets which were not available for installation.

The slits and collimators in the C-Beam were set using both the laser and optical tooling alignment methods.

The energy-defining slits in the A- and B-Beams were aligned using the vertex points and the stretched wire technique. Instrument stands supporting vacuum pumping stations were realigned under vacuum load.

Shop alignment of all BSY equipment was completed.

b. End Station A

A drift line was established from the Switchyard through the End Station to Beam Dump East. From this line the pivot was set and the position of the dump was defined.

The instrument stands for the test of the electron and photon beams were set in the End Station alcove. Special techniques were developed for the alignment and position monitoring of the Beam Dump East instrument stands.

c. End Station B

A drift line from the Switchyard extended into the End Station redefined the base line for the 10-foot grid pattern for the secondary particle transport system.

The secondary beam magnets were targeted and aligned in the field to the redefined base line. The base line was scribed on the End Station floor and into the yard for future beam equipment layout.

d. Position Verification

No problems due to misalignment of the BSY equipment have occurred. The position of the quadrupole magnets and various instruments on the A-, B-, and C-Beams have been tested with the electron beam and appear to be within the assigned tolerance zone.

2. Power Absorbers

a. High Power Collimator and A-Beam Slit

Through July, efforts were devoted to completion of the shop assembly and alignment of high power slit SL-10 and the vertical slit of high power collimator C-1. Manufacture of parts for the drive and actuation systems was completed. During August, the equipment was installed in the final location in the Beam Switchyard. The horizontal slit of the high power collimator C-1 and the high-Z collimator C-O as installed in the Beam Switchyard are shown in Fig. 15 .

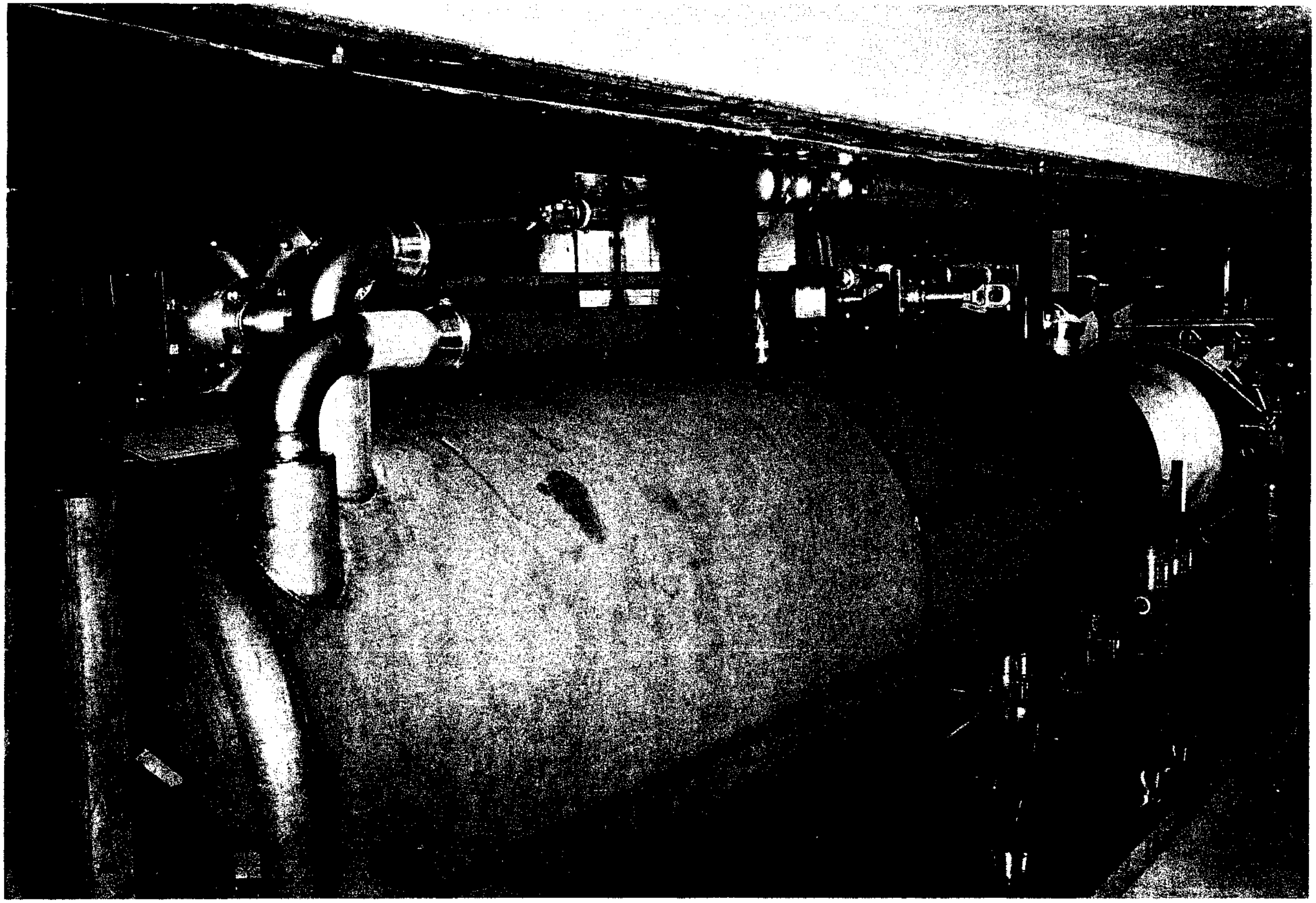

FIG. 15 - HORIZONTAL SLIT OF HIGH POWER COLLIMATOR C-1 AND HIGH-Z COLLIMATOR C-0 INSTALLED IN BEAM SWITCHYARD

Through September, the systems were calibrated with the remote readout and control systems in the Data Assembly Building.

All systems lived up to accuracy expectations and requirements. For example, slit SL-10 gap opening and centerline reproducibility are better than ± 0.3 mm.

b. High-Z Collimators and Slits

The High-Z collimator C-10 and the High-Z slit SL-11 were installed in the Beam Switchyard and connected to the drive and actuation systems during July. During August, these units were calibrated to the remote readout and control systems in the Data Assembly Building. The photon beam collimator C-10 and High-Z slit SL-11 were installed through August and calibrated in September. Calibration results were good.

c. High Power Beam Dumps

The A-Beam dump and Beam Dump East were vacuum checked and installed in their final locations. Assembly of the remote window removal system was completed and permanent parts of the guidance system were installed. Proper functioning of the window removal system was demonstrated with the successful remote removal and installation of a window.

d. Operations

All collimators, slits and beam dumps have had successful first exposure to the electron beam at relatively low power.

3. Beam Switchyard Instrumentation

a. Magnetic Measurements

The installation of the remanent field measuring equipment has been completed; associated probe installation is also 100% complete.

b. Electronic Control

Beam current monitoring system amplifiers for End Station and BSY toroids I-400, I-401, I-10, I-13, I-30, I-33 and I-15 were installed and calibrated during this reporting period. Prevalent toroid noise problems consisting of 1-MHz oscillations were solved with the exception of noise associated with toroids I-15 and I-400. Noise generated by the trigger system is currently under investigation.

Position system monitors P-10 and P-12 were tested and are satisfactory.

A multiplexer and analog-to-digital converter unit for the BSY control computer has been delivered and the required interface built. The subsequent checkout is expected to be performed during the next reporting period. The remainder of the BSY Control Computer has been completed and the system is operational; the system is being used for control of A-Beam magnets and has proved successful. Further tests of the system are being performed and the writing of a program for more sophisticated loop control for the magnets is in progress.

The entire slit and collimator control system has been installed in the DAB Control Room. However, the system is being used in manual control mode, pending completion of computer control programming.

The interlock and status signal scanner still has apparent noise problems. The unit has been modified to improve noise rejection. However, redesign of the computer interface is necessary to completely eliminate existing noise problems. Changes are expected to be done early in 1967.

The base band transmission link required for sending spectrum information to CCR was modified. However, additional work is necessary to improve the frequency response of the link. Construction of the 0.1% resolution spectrum analyzer electronics has been completed. System checkout has reached 90% completion. The integrating electronics has been tested satisfactorily.

The performance of the video electronics is poor, which has been attributed to high noise levels in the DAB. The possible sources of noise and corrective measures to be taken are now being studied.

All channels of the secondary emission monitor interlock system (SEM) were installed and checked out.

The four quadrant SEM's on the A-Beam Dump and Beam Dump East were checked out and performance was satisfactory. However, the poor performance of the secondary conduction monitors installed in front of collimators C-1H and C-1V has posed problems. The causes are yet undetermined and possible solutions are being investigated.

The interlock and status system wiring was checked out and system testing performed at the close of the reporting period. The system was found to be functional during beam operations. Completion, extension and improvement of the system continued.

X. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

A. EXPERIMENTAL GROUP A

1. 1.6-GeV Spectrometer

The spectrometer structure has been erected and mounted on its wheels. The drive-motor/gear-reducer unit was installed and tested and showed good speed and position control ability. The magnet core and coils are about 75% completed: The coils are ready to impregnate with epoxy, and concrete shielding forms have been completed and are ready to be filled with concrete. Two lead and paraffin filled 8-ton steel doors are in fabrication, as is the vacuum chamber. An angular position monitor was installed and used to test the drive motor response. It was found that the spectrometer could be easily positioned to an indicated 0.001 degree. It is anticipated that at the current rate of progress, all mechanical equipment now in preparation will be operational by mid-February 1967 as planned.

2. Spectrometer Installation

During this period the magnet frames for all three spectrometers and the shield structures for the 8-GeV and 20-GeV spectrometers were assembled. The drives and running gear were checked out mechanically.

Magnet coil production proceeded slowly, and at the end of this period the coils of the 20-GeV bending magnets were still not delivered. Magnet assembly and measurement moved as quickly as coils became available, and two completed quadrupoles were mounted on the 8-GeV spectrometer.

Water piping on the spectrometers and in the tunnels is about 75% complete. Electrical work on the 8-GeV spectrometer was about half finished, but had not been started for the 20-GeV.

The two 1.50-megawatt power supplies were installed, but several of the power transformers developed water leaks before they could be put into operation. As a result these power supplies were returned to the vendor; it was decided to purchase standard distribution transformers and, because of their size, to install them externally in a separate enclosure. Work was then started on the installation of the 567-kW supplies, with the intention of using two of them in series to measure the large bending magnets.

The power supplies are now the pacing item, since they are delaying the measurement and installation of the bending magnets.

3. 42-foot Section

The End Station A primary beam instrumentation is now fully installed. Early tests with the electron beam have led to some improvements on this equipment. The beam intensity and position monitors are working reasonably well, although more tests are needed before accurate calibrations can be performed.

The counting house is completely wired for status and remote control of the beam line equipment. Only a part of the proposed link with the Data Assembly Building is so far complete. Instrumentation of the spectrometers is in progress.

4. Counting House Racks-MIT Chronetics Order

The delivery and installation of all equipment racks and control consoles was completed during this quarter. The installation and checkout of the beam control associated electronic equipment is 75% complete. The fast experimental electronics, e.g., Chronetics 100-Mc Logic, was completely delivered and checkout was completed. Final installation of fast electronics is 50% complete. Installation of fast electronic coaxial signal cables from the counting house to the spectrometers has begun. Computer interface to beam control associated electronics and fast electronics is 75% complete in installation, 50% complete in checkout.

5. 9300 Computer

An additional 16K of memory installed on the SDS 9300 now provides the maximum 32K words for this computer. The computer has been moved into the End Station A Counting House. A sufficient amount of front end hardware has been completed and installed to enable reading scalers, pulse height analyzers, digital inputs, and a clock into the computer. At present, four multiplexer units are stationed at various locations of the counting house. Each multiplexer is capable of accepting data from 31 different devices (24 bits/device). The ability to manually select and display on indicator lights the contents of the selected device has proved to be useful during hardware debugging. Status indicators on the interrupts to the 9300 (the "arming" and "waiting" flip-flops) are also valuable for debugging software programs.

Sufficient software has been written to read and log data, to analyze data and display it on-line. Both the SPECTRE system, which allows loading of programs, and a standard SDS Real Time Fortran IV system are in use. Data may also be analyzed off-line by changing only the main executive program.

B. EXPERIMENTAL GROUP B

The analysis of four-prong events from our 16-GeV/c π^- run in the Brookhaven 80-inch hydrogen bubble chamber has reached about the half-way point. We were able to make a contribution to the Berkeley High Energy Conference in September on the preliminary results. At present we are evaluating how well the two-prong events can be analysed and expect shortly to begin serious measurements.

The ASI 6020 has been delivered, and engineering design and programming have progressed satisfactorily. We expect to simulate the entire measuring process shortly, although actual measurements cannot begin until December when the NRI digitized projector will be fully serviceable.

The analysis of the 2.65-GeV/c K^- interactions in the LRL 72-inch DBC should be complete in December. These events have served as a critical test of the TVGP system of analysis programs which are now in running order. We expect to be able to report on I = 2 hyperon production and some neutral three-body decays of excited hyperons.

Work on instrumentation and detectors for testing the monochromatic e^+ annihilation beam is progressing well and should easily meet the February run date.

Preparation for the rho photoproduction experiment, in collaboration with Group C, is going ahead as planned. The on-line computer system should be ready by February, when the apparatus will be used to help test out the monochromatic γ-ray beam. The experiment will be run around early summer.

An exposure of about 63,000 photographs of 16-GeV/c π^+ mesons in the 80-inch HBC has been made at Brookhaven. We expect to complete the run with about 20,000 more photographs shortly. This work will complement the analysis of 16-GeV/c π^- interactions. We hope to measure this film with the new ASI 6020 on-line system.

The group has also started to build a Spiral Reader measuring machine in collaboration with the Conventional Data Analysis Group and the Graphic Data Study Group. The project involves a strong collaboration with the Alvarez Group at LRL, Berkeley. It is hoped to have the machine in operation by late 1967, at which time it will increase the measuring power of the group by approximately 500,000 events per year.

A systematic study of inelastic pion scattering has been undertaken in collaboration with the Alvarez Group at LRL, Berkeley. The experiment has measured about 70,000 two-prong events of $\pi^- p$ in the region 900 - 1300 MeV/c and the analysis is progressing well. The extension of the analysis to higher and lower momenta will be continued through the next six months. The analysis should throw light on the investigation of the many inelastic N* resonances.

C. EXPERIMENTAL GROUP C

The work of this group will be reported on at the end of the next quarter.

D. EXPERIMENTAL GROUP D

1. Large Streamer Chamber

Tracks have been obtained in the lower half of the $2 \times 1.50 \times 0.6$-meter streamer chamber.

Work is now being done to improve the shape of the pulse delivered from the Blumlein pulser.

2. Two-Meter Magnet

The final coil delivery is now scheduled for early in December.

Installation of the water lines and manifolds is virtually complete.

3. 5.8-Megawatt Power Supply

Delivery is now scheduled for early in November.

E. EXPERIMENTAL GROUP E

The following experiments are being analyzed:

1. More pictures in the 1- to 6-GeV neutron-proton elastic scattering experiment are being measured to increase the statistics over our previously published results and to look more carefully for a second diffraction maximum (J. Cox, F. Martin, M. Perl).

2. In the 6-GeV/c proton-proton interaction experiment carried out in the 72-inch Lawrence Radiation Laboratory hydrogen bubble chamber, our results on strange-particle events are now being assembled for publication. The non-strange-particle events are now being measured with emphasis on a study of the 1410-MeV nuclear resonance (F. Martin, M. Perl, T. H. Tan). This is a collaboration with the Lawrence Radiation Laboratory.

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

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

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

Design and construction continued on the following:

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

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

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

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

F. EXPERIMENTAL GROUP F

We expect to assemble the 1.6-GeV/c spectrometer in January. The hodoscope is now complete and other counters that are planned are beginning to be fabricated. Work is in progress to construct a large mirror for a Cerenkov counter. A back-up hydrogen target for End Station A in case the SLAC target is not ready in time is complete and tested.

G. 40-INCH HYDROGEN BUBBLE CHAMBER

The SLAC 40-inch hydrogen bubble chamber construction program is entering a new phase; since design and procurement are largely complete, the emphasis is now on fabrication and testing of components.

1. Vacuum Tank and Chamber Parts

Fabrication and machining of the stainless steel vacuum tank has been completed by the SLAC Heavy Machine Shop and the tank is now being fitted to the magnet iron for pressure tests. See Fig. 16.

The major parts which make up the bubble chamber body have also been machined at SLAC. This pressure vessel was tested to 225 psi, and is now being prepared for a preliminary vacuum test. The support ring which supports and

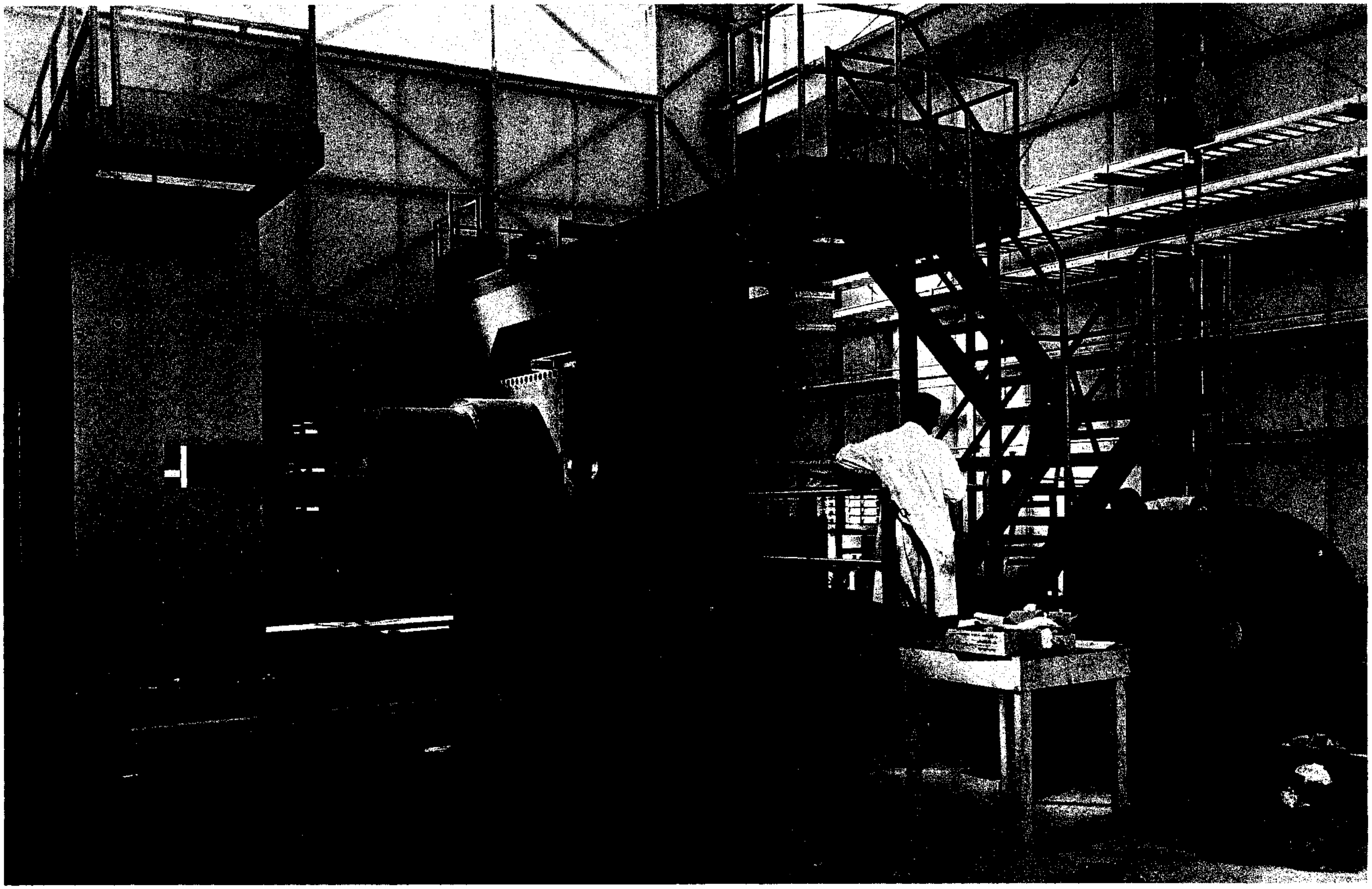

FIG. 16-STAINLESS STEEL VACUUM TANK FOR 40-INCH HYDROGEN BUBBLE CHAMBER

locates the chamber in the vacuum tank is the only major chamber part which is not completed. When this part is completed early next quarter, a chamber to vacuum tank "check fit" will take place.

The chamber will use hollow stainless steel "O" rings plated with 2.5 mils of indium to assure vacuum integrity of the chamber filled with liquid hydrogen. The rings, which are approximately 44 inches in diameter, will be plated at SLAC by a machine made especially for the job.

2. The Magnet System

All components of the 240-ton magnet yoke have been fabricated, inspected, assembled, and finish painted.

All platforms and stairways have been fabricated. The upper level platform, one lower level platform, and the stairways have been installed and the remaining lower platform will be set on the iron as soon as the magnet cooling water lines and electrical conductors have been assembled. All components of the magnet support and separation system have been fabricated, inspected and installed. The system has undergone several "check-out" cycles without any apparent difficulty.

The twelve HBC magnet coils are being fabricated by the vendor. Each coil is a double pancake, 16 turns per layer of 1-3/4 inch-square copper conductor, epoxy impregnated. Coil winding commenced in June; six coils were wound as of September 30, 1966. The first coil is scheduled for epoxy vacuum impregnation early in the next quarter, with impregnation of one coil every eight days thereafter. The anticipated contract completion date is February 1967, with four coils to be delivered by December 1966. The SLAC engineer in charge is in one-half time residence at the vendor, coordinating and monitoring fabrication and providing engineering support.

3. Refrigeration System

Before the move in June to the Cryogenics Building, components were either made or purchased for the valve vessel lid and the two control panels. On taking occupancy of the Cryogenics Building, work began simultaneously on the control valve vessel and the two control panels.

The valve vessel required two heat exchangers not commercially available. SLAC-designed and built exchangers were completed in late September, allowing assembly to proceed. It is estimated that by the middle of November it will be complete.

Running parallel to the lid, the work on the two control panels progressed without any delays. The control room panel is complete. The platform control panel will be completed by the end of October, when it will be mounted in its final position on the upper platform of the magnet.

The 15,000-gallon bulk liquid hydrogen storage vessel for the laboratory was delivered and installed at the end of September. Painting and site work are expected to last until mid-October, whereupon a three weeks' performance test is scheduled. The two 2,000-liter LH_2 trailer vessels have been delivered. They will be tested simultaneously with or immediately after the acceptance test of the 15,000-gallon tank.

4. Expansion System

A prototype of the expansion piston complete with a dummy chamber and piston was tested. Commercial valves were not available to control oil flow fast enough for a proper expansion stroke so a one-inch, 3000-psi air pilot operated valve was designed. While our own design of valve was being made, about 60,000 cycles were run on the expansion system with a modified commercial pilot operated valve. During this trial period many annoying problems such as mounting of auxiliaries and packing clearances were solved.

By the end of June, the SLAC expansion valve had been tested to the extent that the prototype chamber expansion system had run more than 500,000 strokes, with a cycle time of 0.025 to 0.030 second.

After considerable testing and selection of materials, the expansion system ran 210,000 cycles without maintenance. With a few small repair parts, 40,000 expansions per shift were typical during the last third of the endurance run of approximately 2 million strokes. Since our primary objective of proving the internal mechanical parts was achieved, testing was suspended while refinements of the external system are being made.

5. Electronics

The control console has been installed in the control room building and the inter-rack wiring is underway.

The electronics for the expansion and magnet transport systems have been built and tested.

The final camera film drive, flash tube controls, and high voltage power supplies have been tested satisfactorialy with a camera interlock breadboard.

The alarm system has been received, but the circuit cards are being returned to the vendor for rework. However, the chassis and rack wiring will proceed concurrently.

The chamber building electrical utilities and motor control center have been installed. The vendor is experiencing some trouble with the 3.4 MW power supply. The transformer is being rewound because the first transformer had too much leakage inductance.

6. Optics

Nearly all phases of the bubble chamber optics have moved from the development stages into final assembly. The camera is being assembled in its final configuration after extensive development on the camera mock-up yielded quite satisfactory operation. The data board components are presently being fabricated.

The 43-inch-diameter glass window has been received in its final form, complete with fiducials. This window has a maximum ray deviation of ± 1-1/2 seconds over the usable surface and seems to be excellent in all respects. The window will not be coated.

A rather extensive study of the optical and technical properties of several retrodirectors (Scotchlite) has been completed. This study included observing bubbles in liquid hydrogen against several Scotchlites and concluded that the final lot of SPR 704 (Lot 32A) will work adequately in our chamber. An ample supply of this Scotchlite is on hand, as are the fiber glass piston liners to which it will be attached.

Work on the camera control electronics is proceeding smoothly. The basic control concepts have been tried and found satisfactory. Some work remains on the details of the camera interlock logic and control panel layout before final assembly is started.

The present schedule calls for a completely wired, assembled and working camera to be ready in February.

7. Enclosure and Crane

The enclosure (Butler type building) for the bubble chamber was completed and equipped with a 7-1/2-ton crane. In order to test the enclosure's mobility, the building was lowered on the pneumatic tires and rolled for 50 feet (see Fig. 17).

A test of the pressure relief panels which comprise 50% of the enclosure wall and roof area was witnessed. The panels relieved at the design load of 30 psf.

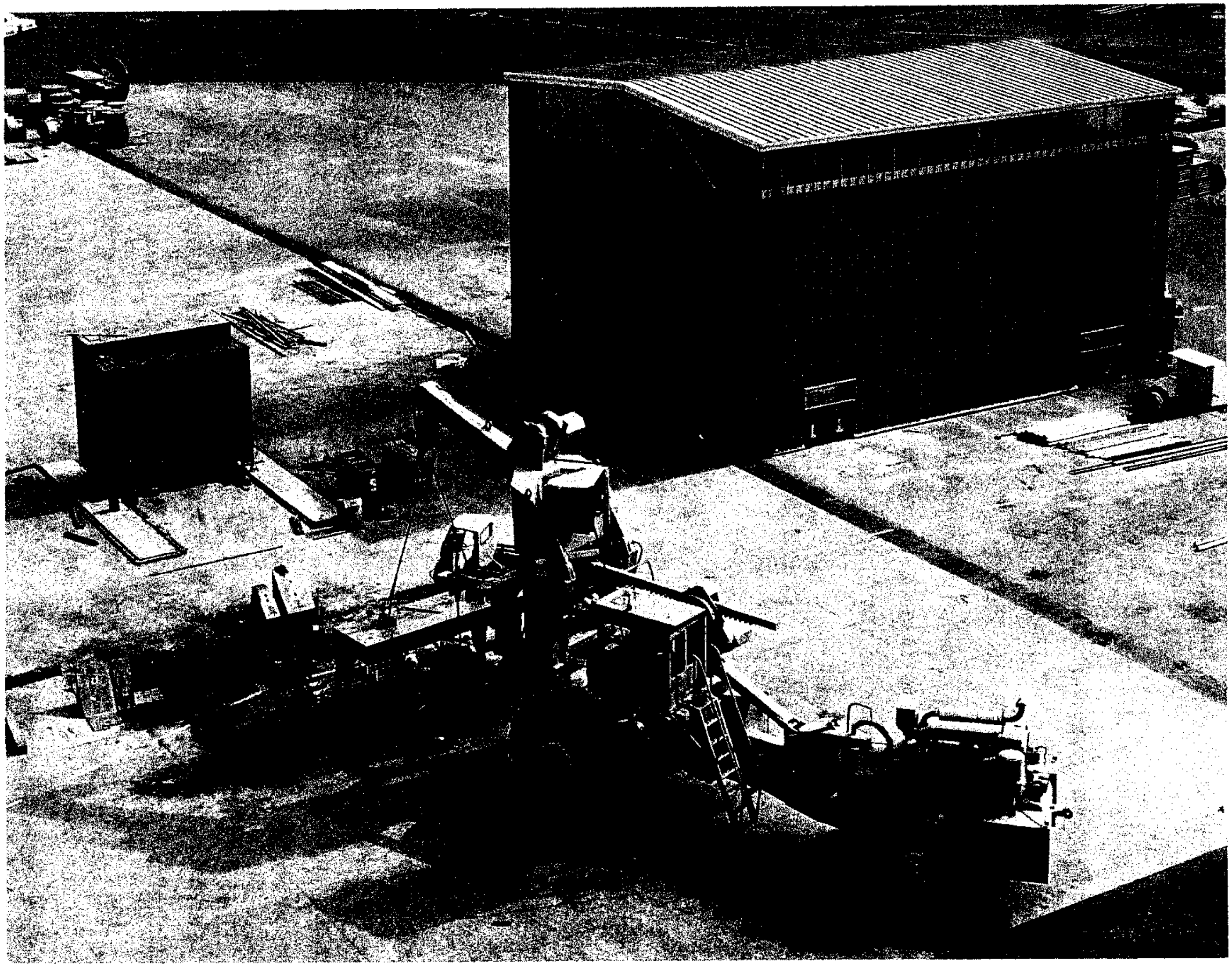

FIG. 17 - ENCLOSURE AND CRANE FOR 40-INCH HYDROGEN BUBBLE CHAMBER

8. Publications

The Bubble Chamber Group has prepared three papers; two were presented at the High Energy Physics Instrumentation Conference at SLAC, September 9-10, 1966.

1. J. Ballam, R. Blumberg, J. Mark, K. Skarpaas, S. St. Lorant, "Selected Problems and Solutions in the Design of the SLAC 40-Inch Hydrogen Bubble Chamber," SLAC-PUB-229.

2. B. Sukiennicki and H. Barney, "Tests on Scotchlite Placed in a Simulated Hydrogen Chamber," SLAC-PUB-230.

The third paper prepared by the group was the laboratory hydrogen safety code, which was presented to the Hazardous Experimental Equipment Committee for review and publication.

H. PHYSICAL ELECTRONICS

1. Relativistic-Rise Detector Study (Division of Research)

The following paper was presented at the APS Meeting in Mexico City: "Secondary Electron Energies in Field-Enhanced Secondary Emission," by Edward L. Garwin and J. Edgecumbe. This paper summarized the data which we have obtained on the subject--some of which has been reported in the two previous reports. The most probable secondary electron energy, E_{PK}, for several dynodes is shown in Fig. 18 as a function of V_{G1}, which is equivalent to the collector potential in the standard gain measurements. The value of E_{PK} present in this figure represents the most probable kinetic energy of a secondary electron as measured at the collector electrode. Peculiar to all low-density "smokes" investigated under dc bombardment is a value of V_{G1} (to be denoted V_m) above which E_{PK} increases linearly with V_{G1} and with a slope of one. For $V_{G1} \leq V_m$, E_{PK} is constant at ~ 2 eV. This is interpreted to mean that the exit surface potential of the dynode, V_E, is equal to V_{G1} for $V_{G1} < V_m$ and that V_E is limited at V_m for $V_{G1} > V_m$. That is, the large values of E_{PK} observed for $V_{G1} > V_m$ result from a low energy (~ 2 eV for all V_{G1}) secondary leaving the dynode and being accelerated through the potential difference between $V_E = V_m$ and V_{G1}.

Also shown in Fig. 18 are data obtained on bulk-density KCl with a dc primary beam and a low-density KCl with a pulsed primary beam (the primary beam being pulsed on 100 μsec before the measurement of E_{PK}, which allows insufficient

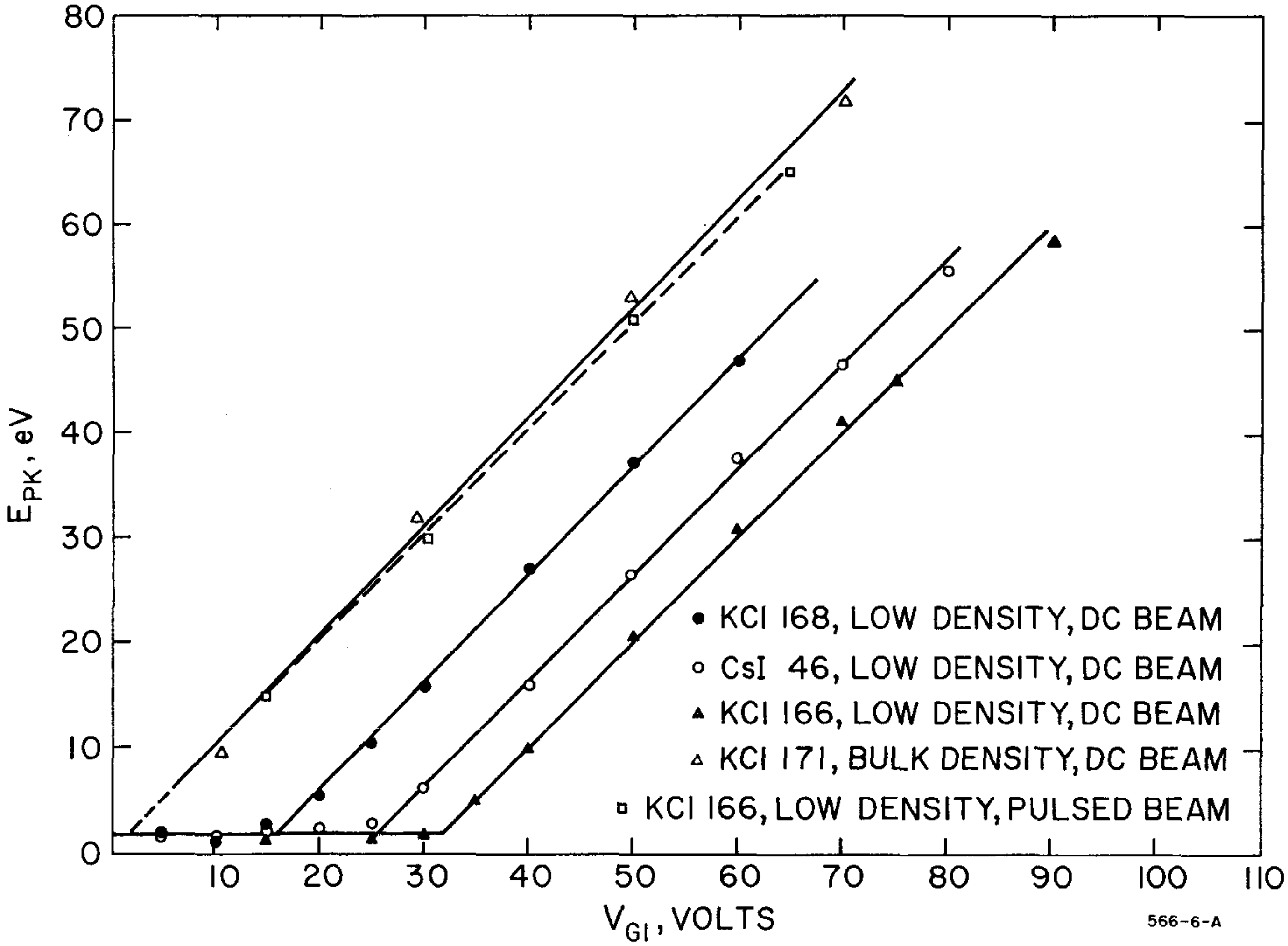

Fig. 18 - MOST PROBABLE SECONDARY ELECTRON ENERGY, E_{PK} (measured at G_1) vs. THE FIRST GRID POTENTIAL FOR LOW DENSITY AND BULK DENSITY DYNODES

time for the exit surface to charge). Both of these curves are representative of a low-energy secondary leaving the dynode and being accelerated between an uncharged exit surface and the collector.

Figure 19 illustrates the location of V_m on the gain (δ) versus collector potential (V_c) characteristic. It is interesting to note that there is a large increase in δ for $V_c > V_m$. If, as suggested above, V_E is limited at V_m for $V_c > V_m$, then the large increase in δ above $V_c = V_m$ must be due to action of the external electric field leading to enhancement of the secondary emission process. This could take place, for example, by extraction of secondaries released deep in the pores of the emitter. Initially, it was felt that the above was not inconsistent with internal "avalanche-like" multiplication as a result of the exit surface potential. Internal multiplication would increase the number of electrons available at the surface (including surface areas deep in pores) of the dynode, which would increase the total gain obtainable with external field enhancement. However, if internal multiplication were taking place, then at collector potentials below the ionization potential ($\simeq$ 10 eV for KCl) one would expect E_{PK} to increase with increasing V_c. This was not observed.

As reported in the previous report, some difficulties were encountered in the preparation of low-density CsI dynodes with high gain. This has been related to bakeout of the dynodes as part of the normal processing of the vacuum system used for measurement. Apparently at temperatures $\gtrsim 200°$ C there is sufficient mobility of the molecules composing the film to collapse the low-density structure into a structure approaching bulk density. As part of these measurements, V_m and δ were measured as function of temperature (T). As shown in Fig. 20, an interesting maximum was observed in a plot of V_m vs T. Low-density CsI also exhibited a maximum in the V_m vs T curve which occurred at a much lower temperature, $\sim 50°$ C. For T $\gtrsim$ 150° C, V_m was reduced to zero--that is, the exit surface of the low-density CsI dynode did not charge. At present, the behavior of V_m vs T is not understood. From a practical point of view, the above indicates that the bakeout temperature of the low-density CsI dynodes must be limited. Low-density CsI dynodes have survived 150° C for 24 hours and 200° C for 12 hours.

Toward the construction of a four- or five-stage multiplier tube, we have fabricated 600-Å Al substrates with 96% open area grid backing them for support.

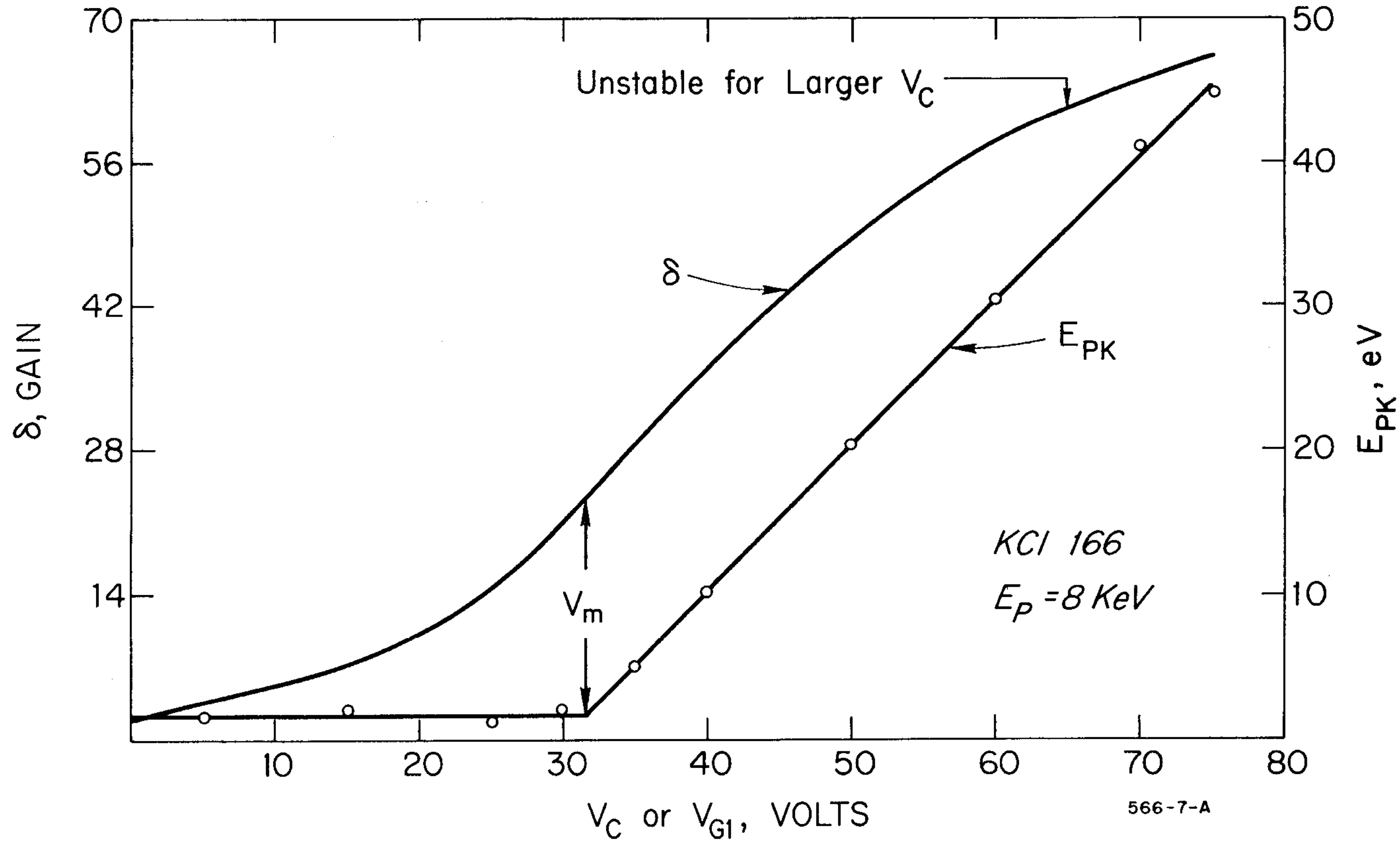

Fig. 19-ILLUSTRATING THE LOCATION OF V_m ON THE δ vs V_C CHARACTERISTIC FOR THE LOW DENSITY DYNODES

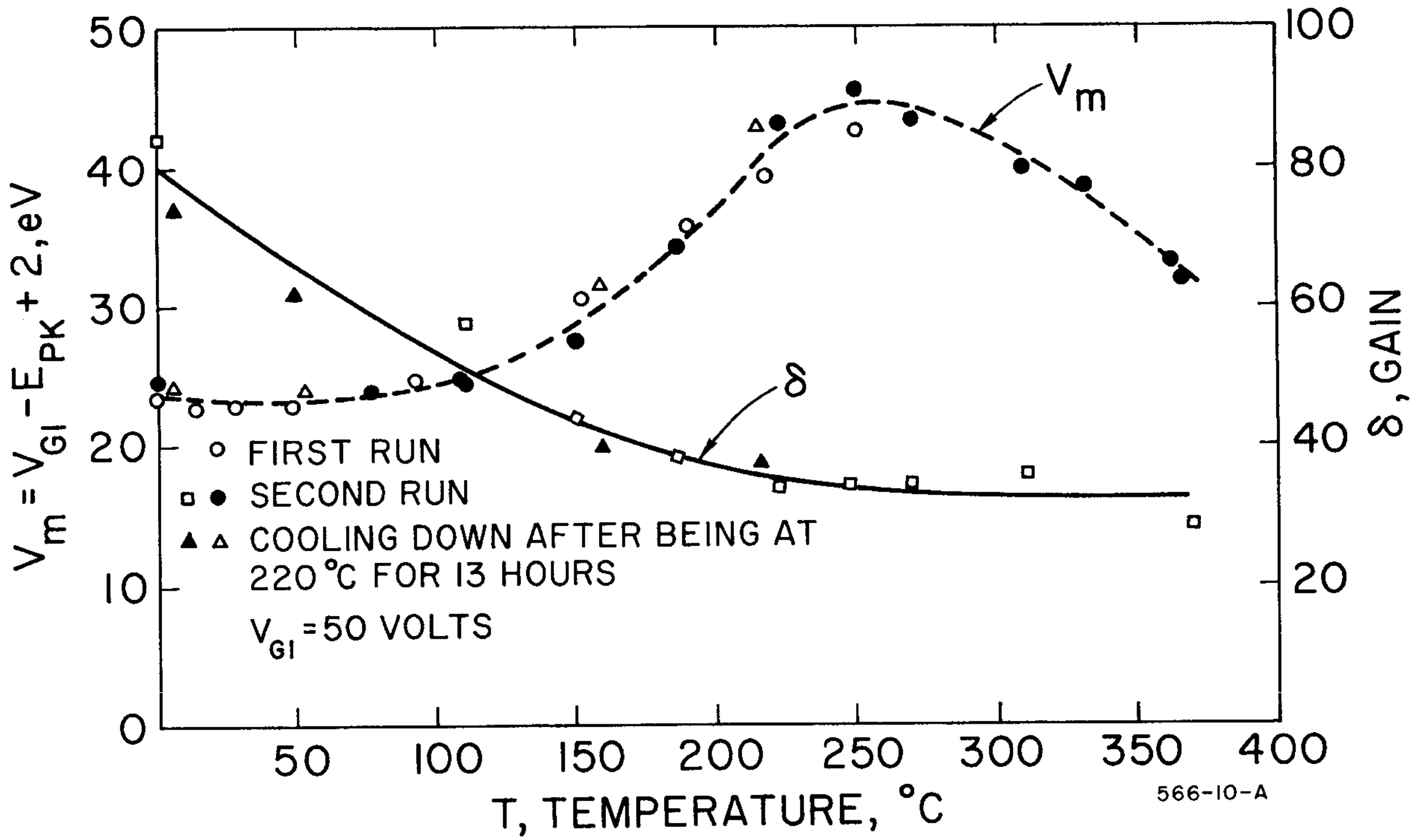

Fig. 20 - LIMITING EXIT SURFACE POTENTIAL (V_m) AND GAIN (δ) AS A FUNCTION OF TEMPERATURE FOR A LOW DENSITY KCl DYNODE

These substrates have been prepared by evaporating Al on a KCl coated glass slide, dissolving the KCl in water on which the Al film floats, and then picking up the Al film on the grid. Low-density KCl dynodes on these substrates show maximum gain for primary energies of 6 to 7 keV and thus should be usable at interstage voltages of ~ 5 kV. Another interesting form of dynode was also tried during this quarter in an attempt to achieve high gain at low primary energy. It consisted of a grid, with an inter-wire spacing of about 50 μ upon which was evaporated the alkali halide. The grid spacing corresponded to approximately twice the normal low-density dynode thickness. High gain was observed at high primary energy, because the film was too thick. However, the evaporation of the alkali halide was not optimized. This technique will be looked into further, and may provide quite large, mechanically strong dynodes.

A tube structure for measuring the statistics of secondary emission from low-density dynodes in the 10-keV range, as well as the multi-MeV primary energy range, was completed. The method consists of accelerating the secondaries leaving the dynode to 25 - 30 keV and having them impinge on a semiconductor detector capable of measuring the energy deposited by individual electrons. Of major importance in this technique is near-perfect transmission of the secondary electrons through the electron optical system used to accelerate the electrons. To date, measured values for the transmission range from 70 - 85% and appear to be time dependent. This is believed to be attributable to charging of the high-alumina ceramics used to isolate the high potentials. Work is continuing to improve the system.

2. Study of Detailed Mechanism of Secondary Emission in Low-Density Transmission Dynodes (Division of Research)

The study of the elementary processes that take place in a low-density dynode during secondary emission has been started. On the experimental level, a vibrating probe measurement system to determine directly the dynode exit surface potential has been developed. The operating frequency of the probe can be above 6 - 7 kc, and through the use of a low noise preamplifier, it will be possible to measure the rise time (expected to be greater than tenths of seconds) of the surface potential after a primary beam is turned on. Equipment will allow illumination of the dynode with monochromatic light from 6000 Å to the vacuum ultraviolet while the secondary emission characteristics are being monitored.

These measurements should promote understanding of the charge-trapping processes in the dynode.

From a theoretical point of view, the loss of energy by kilovolt primary electrons in the dynode has been investigated. From published experimental results of scattering of keV electrons by thin foils, it has been possible to obtain $\frac{dE}{dx}$ vs E or vs x in low-density films. These functions, when used in conjunction with a simple diffusion theory of escape of secondaries, result in realistic secondary yields for uncharged dynodes.

A simple trap model for the transport and trapping of charge in a dynode is being studied. Preliminary results for dynodes charged to high fields (thus neglecting diffusion) indicate the plausibility of such a model in the steady state. A more careful study of the transport problem is being carried out to see whether the simplifications of the above model are acceptable.

3. Development of a "Gridless" Multiplier Structure (Division of Biology and Medicine)

Initial attempts to overlay a low-density dynode with a thin layer of metal to act as a grid have resulted in a non-conducting deposit. The film appeared black, which is understandable because of the roughness of the low-density deposit. We are in the process of trying to fabricate the overlayed dynodes differently. The method consists of fabricating the low-density dynode in the usual manner and preparing the thin overlayer ($\sim$ 50 Å) separately on a nitrocellulose film. Then the two structures are mechanically clamped together and the nitrocellulose is baked away. We have succeeded in clamping the two structures together but have not yet baked the nitrocellulose nor measured the gain.

The reason for grids following dynodes is to maintain the exit surface potential below that which gives breakdown and instability in the gain. Another method for stabilizing the exit potential is by increasing the conductivity of the alkali-halide deposit. Studies of ionic conductivity indicate that addition of divalent impurities performs this function in crystalline alkali-halides. Therefore, low-density dynodes were prepared from mixtures of $CaCl_2$ and KCl, which have nearly the same vapor pressures at evaporation temperatures. The range of $CaCl_2$ concentration was from 0.13% to 100% (mole fractions). No gross change in charging time was evident, and the gain was typically about 15, rather low to be interesting at this time.

In order to understand better the structure of the low-density dynodes we have had some electron micrographs taken. Examples of the photographs obtained are shown in Figs. 21 and 22. These pictures are cross sections of the deposit obtained where the thin (~ 50 Å) Al_2O_3 substrate cracked and rolled over, exposing an edge view of the dynode. The surface roughness discussed above is apparent in the photographs. The particles making up the film are ~ 300 Å, which is smaller than previously thought. Electron diffraction indicates that the small particles are single crystals. For the production of multiplier structures, the alkali-halide will be deposited simultaneously on several dynodes. These electron micrographs will provide confirmation that the film structure has not been altered by the multiple-depositions process.

I. MAGNET RESEARCH

1. Water-Cooled Magnets

All positron source magnets are installed. The magnets for the homogeneous field section and some of the high field solenoids have been tested to full current and behaved according to calculation. The high field magnet (design current, 4000 amps) was tested up to 3000 amps for approximately four minutes. Due to difficulties with the power supply regulation, the test had to be interrupted and will continue as soon as power supplies are repaired.

The 2.5-meter magnetic slit, the first of its kind in the world, was measured and is now installed in the B-beam area. The field distributions measured are according to calculation.

In order to deal with problems concerning shimmed pole edges and shaped ferromagnetic paths, the NUTCRACKER program was extended to operate with variable mesh size. The mesh size was chosen to achieve higher data accuracy without increasing the number of nodes in order to accommodate the storage capacity of the available computers. The new modification has been tested for magnets with rectangular coordinates and is being further developed for cylindrical coordinates.

2. Superconducting Magnet Research

The winding insulation for the 12-inch, 70-75 kG split coil magnet proved to be exceedingly complicated. The insulation, consisting of insulated high resistance flat strip, did not meet the abrasion requirements during insulation

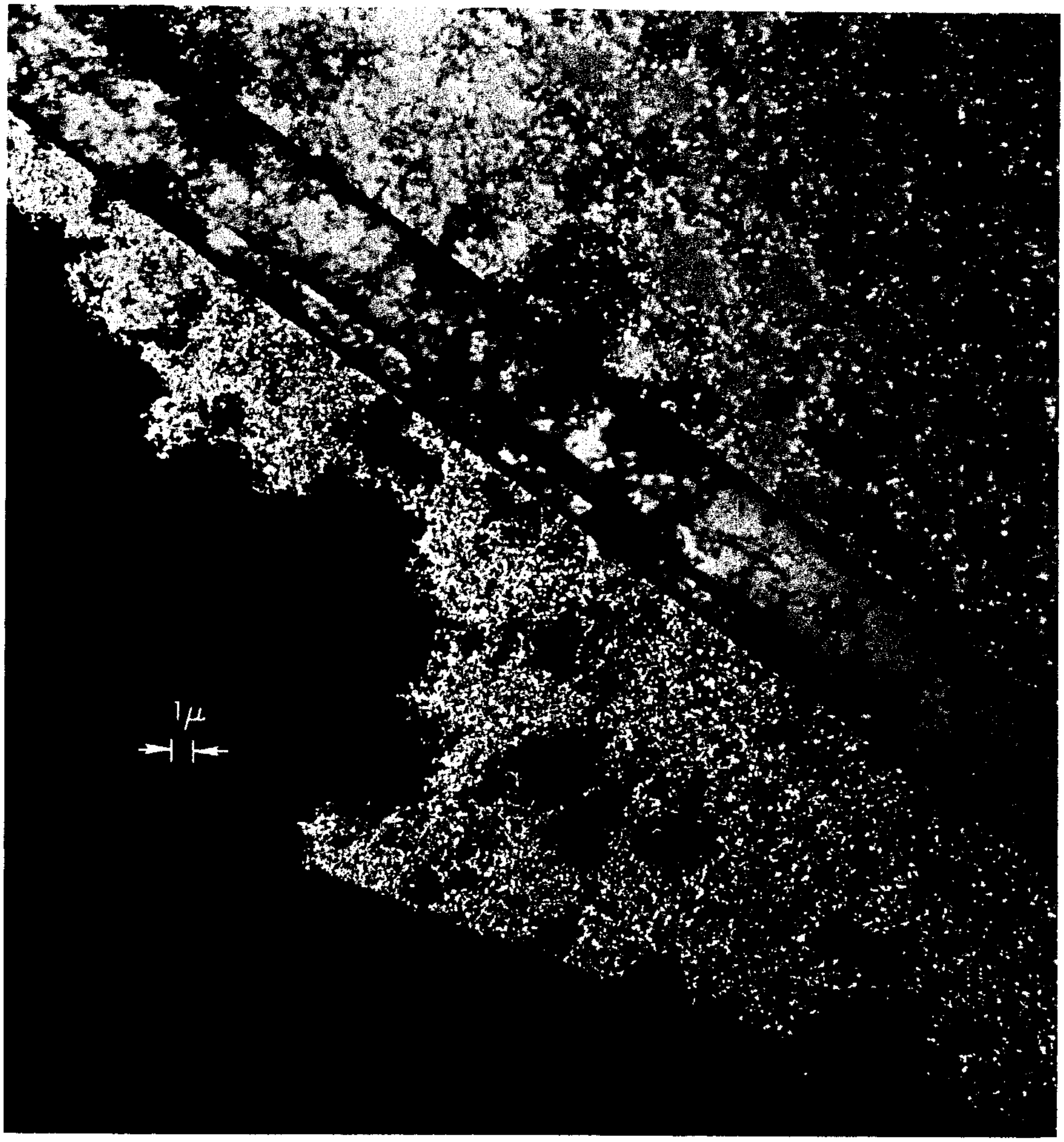

FIG.21 -- CROSS SECTION OF A LOW DENSITY KCl DYNODE TAKEN ON AN ELECTRON MICROSCOPE AT 4,000 X.

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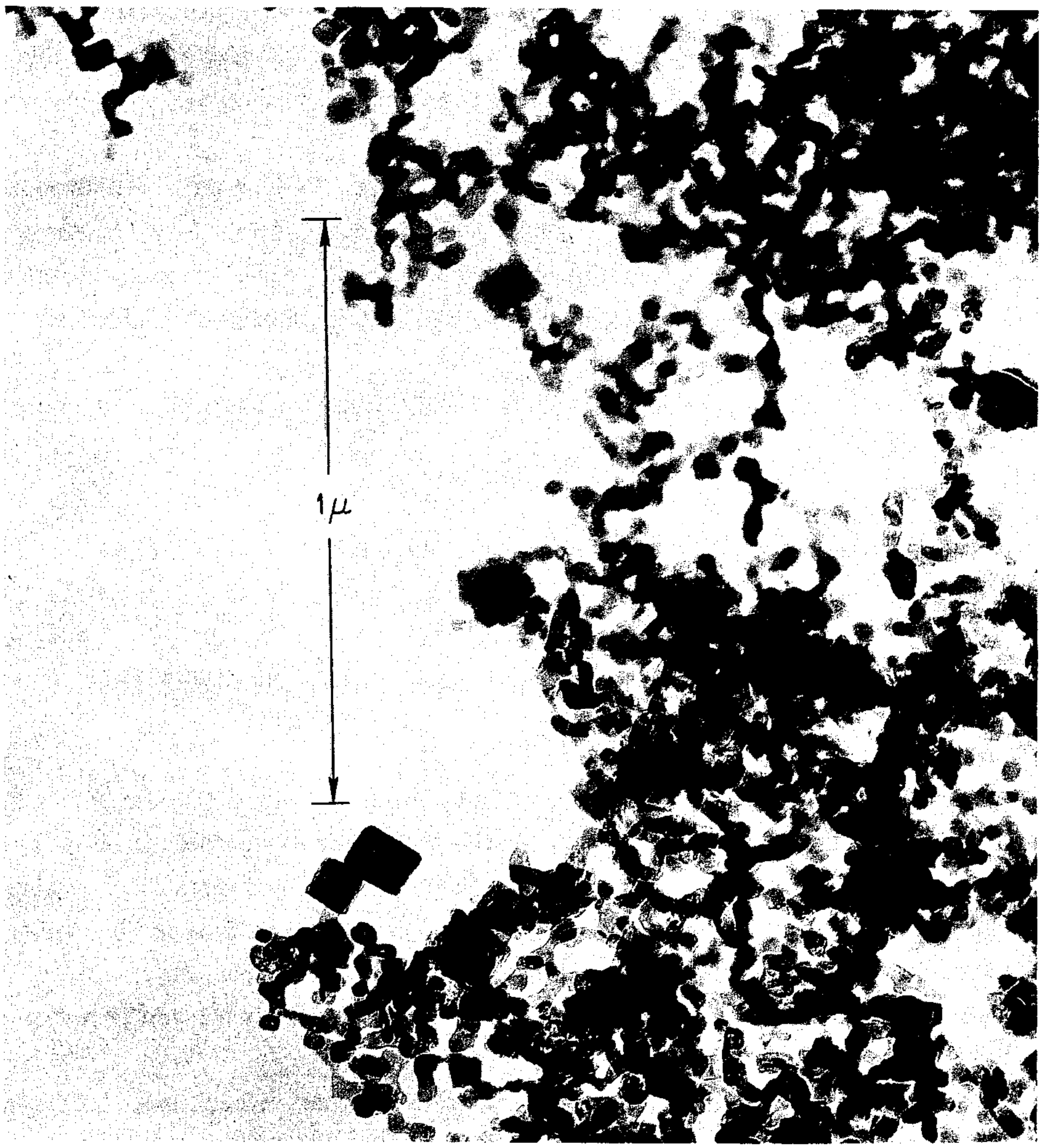

FIG. 22 -- CROSS SECTION OF A LOW DENSITY KCl DYNODE TAKEN ON AN ELECTRON MICROSCOPE AT 100,000 X.

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winding and punctured due to the high magnetic forces. Even epoxy structures used in rockets failed when exposed to the conditions expected in high field magnets. It is not feasible to insulate the superconductor with glass fibers, or any other organic materials which will undermine the heat transfer and show cold flow effects. New ways of improving the conductor insulation are currently being studied.

During the period of developing the cable for the 12-inch coil, it was found that Nb(Ti) did not show any size effect, predicted earlier for Nb_3Zr by several authors. The phenomena, tested for wires up to 0.05-inch diameter, will enable the building of cabled magnets with lower coils and much higher mechanical strength and improved space factor.

The installation of the new Cryogenics Laboratory is completed and is in full operation.

3. Reports

1. H. Brechna, et al., "Size Effect and Critical Transport Current in Titanium (22 at % Niobium," to be published in J. Appl. Phys. (SLAC-PUB-220).

2. H. Brechna, "Eddy Current Losses in the SLAC One-Meter Liquid Hydrogen Bubble Chamber Piston," SLAC Internal Report 66-44 (1966).

J. AUTOMATIC DATA ANALYSIS

During the past three months, a BPS program to run the Hummingbird CRT film digitizer on-line to the IBM 360/50 computer was completed. It outputs on printer, magnetic tape, or display scope the raw digitizings from the scanner. With the availability of this program, the digitizer has been used mainly for two purposes: (1) to study hysteresis effects when randomly accessing the scan pattern, and (2) to study the digitizing quality of bubble chamber and prototype spark chamber film.

Work on the analysis program for the colliding beam experiment (CBX) proceeded as far as possible in the absence of real film, which has not as yet arrived. In the meantime, work has started on an analysis program for a neutron-proton (n-p) scattering experiment to be performed by Experimental Group E, in collaboration with others, at Brookhaven this November. The analysis program for this spark chamber experiment is patterned closely after the CBX program.

The major difference between the CBX and n-p experiments is that the latter involves some very difficult pattern recognition problems. Instead of trying to solve these with software only, we plan to make extensive use of human intervention using the display scope and its associated light pen and typewriter keyboard. Much effort in the past three months has been spent in trying to circumvent the shortcomings, both in the IBM hardware and the operating system, encountered in attempting to construct a practical, usable, man-computer interface.

K. THEORETICAL PHYSICS

1. A. Dufner, S. Swanson and Y. Tsai, "Tables of γ Spectra from e^+ Hydrogen Atom Collisions," SLAC Report No. 67 (August 1966).
2. J. D. Bjorken and M. C. Chen, "High Energy Trident Production with Definite Helicities," submitted to The Physical Review (SLAC-PUB-200).
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Work has been completed on the γ spectra from positron-hydrogen atom collisions. These are presented in tabular form for use in designing the quasi-monochromatic photon beam.[1] Methods used to compute pion fluxes as presented in the Users Handbook are compatible with CEA data, while it was shown that the phenomenological methods of Cocconi, Koester and Perkins (UCRL-10022) give cross sections which are too small by a factor of 250. Secondary particle fluxes for some of the early SLAC experiments have been calculated, using the methods outlined in the Users Handbook.

High energy trident production of electrons has been computed.[2] Work is continuing on the trident production of muons, for use in experiments at SLAC, BNL, and cosmic ray experiments at the University of Utah. Production of muon pairs in a nuclear field is a significant test of both quantum electrodynamics and of muon statistics. Accurate computer codes have been developed to calculate the differential cross section and a Monte-Carlo integration method for total cross sections which is reasonable in terms of computer time. Calculations for specific experimental configurations remain to be done, but preliminary results indicate that at 10 GeV the muon trident cross section integrated over a small angle forward cone would increase typically by a factor of two if the muon obeyed Bose statistics.

Work started elsewhere on radiative corrections to wide-angle electron pair production is being completed. The differential cross section for pair production plus one "hard" photon was integrated numerically over the phase space of the undetected photon. This result was matched to the Bjorken, Drell, Frautschi result for the virtual plus "soft" photon contribution to yield the total radiative correction. This method makes no assumptions about the phase space of the undetected photon. Results have been computed for the DESY-Columbia wide-angle pair experiment. These results can be successfully compared with various approximate formulae. In particular, to high accuracy the exact result is simply a factor of two times the Bethe-Heitler and pair plus 1 photon differential cross sections for the corresponding spin zero calculations. Radiative corrections have also been studied for the Browman-Grossetete-Yount experiment on e^+-e^- scattering. The question of the "exponentiation" of the radiative corrections is now fairly well understood for this experiment. While the work is not complete, it is believed that the radiative corrections will be calculable to a fraction of a percent of the cross section.

The process $e^+ + e^- \rightarrow \rho^\circ + \rho^\circ$ has been investigated as a possible test of C-noninvariance in electromagnetic interactions. Both one- and two-photon exchange contributions have been calculated. It appears that the use of a high energy beam would favor the detection of the effect, if it exists. Detailed formulae will be presented elsewhere. The specific model of electromagnetic C violation in which the electric charge operator for the hadrons is $Q = Q_{GN} + Q_K$ has been investigated. Here Q_{GN} is the charge as given by the Gell-Mann Nishijima formula, whereas Q_K is even under C and invariant under SU_3 transformations. It is then natural to look for a symmetry group which combines the SU_3 generators and Q_K in a non-trivial fashion. It was shown that none of the simple rank three groups permits one to assign two of the generators to the C-odd quantities T_3 and Y, and a third commuting generator to the C-even Q_K. This work was terminated because of the discouraging experimental results on η-decay; the theorem was discovered and published independently.

Work started elsewhere on the reformulation of renormalization theory was continued. The general objective was to find a prescription which is simpler than, but equivalent to, the usual subtraction of counter terms. This is accomplished by a carefully arranged sequence of operations on the original Feynman integral. Many clarifications of exposition were achieved and a possible further simplification of the approach was discovered.

A systematic investigation is being made of the effects of weak interactions on systems described by quantum electrodynamics, - Lamb shift, hyperfine splitting, etc. The relativistic Cottingham to the proton structure corrections in the hyperfine splitting in hydrogen is being further investigated by adapting it to the calculation of the deuteron structure corrections in deuterium hyperfine splitting. Deuterium structure is quite well understood from a nonrelativistic approach and thus provides a test of the more ambitious relativistic Cottingham approach. Previous work on this problem has been submitted for publication.[3] Work on the high q^2 limit of form factors for bound systems of two or three particles, previously reported, has been prepared for publication.[4] A review of electrodynamic interactions has been presented.[5] Work is in progress on extending the calculation of the anomalous magnetic moment of the electron via dispersion theory. Work was completed on an inelastic model for the n-p mass difference.[6]

Work started elsewhere on the structure of the Bethe-Salpeter equation in momentum space is being extended to study renormalization effects and inelastic unitarity. The connections between current algebra, the conserved vector current hypothesis, and the pion-dominated divergence of the axial current have been explored and clarified.[7]

Several problems, mainly of principle, concerning the PCT symmetries have been formulated in terms of Lie algebra theory, and some of them treated.[8] Technical details concerning earlier work on those parts of group representation theory that are useful in quantum mechanics have been presented.[9]

A computer code for calculating all particle channels allowed by energy, charge, hypercharge, and baryon number conservation in a high energy reaction has been constructed. It is found that for the higher resonances, the number of open channels is too large to be informative, and is not greatly simplified by the assumption of I-spin conservation. The problem of including higher symmetries in such a way as to lead to comprehensible results, but allowing recovery of more complete descriptions as these assumptions are relaxed, is under study.

New experimental results make it desirable to reinvestigate the determination of the low-energy proton-proton scattering parameters. It is found that the nuclear physics assumptions needed to lead to definite results are justifiable experimentally, but that there is still some difficulty with electromagnetic corrections both to the differential cross sections and to the energy-dependence of the phase shifts. The current data are in contradiction with the vacuum-polarization effect predicted by quantum electrodynamics, if analysed in a conventional way. It is suspected that this may be due to the magnetic-dipole interactions between the two protons, which are ignored in the conventional analysis, and this problem is under study.

L. HEALTH PHYSICS

The Research Area monitoring system is partly installed and operating. Further stations will be added as fast as cables are available. Four remote stations plus the entire central station are presently available.

The portable gamma monitors have begun to appear off the assembly line. Most of the first ones were inoperative due to destruction of the pressure seal on the ion chambers during construction. After this was fixed, they seemed to work quite well. The last of these should be ready and tested by early November. There are enough available for the most urgent needs.

All commercial tritium measuring systems were rejected as being inadequate or too expensive. Instead a large Kanne Chamber (55 gallons) is being constructed for tritium measurements. Until it is ready, tritium measurements in air will be made by using grab sample ion chambers and by collecting the water from the air and measuring it in a liquid scintillator.

Shielding calculations were made for the K-meson and positron dump in End Station B, the central K^- beam, beam dump east, and various other situations. A set of range-energy tables has been calculated for muons considering pair production, bremsstrahlung, and nuclear interactions as well as ionization loss in various materials up to 100 GeV. Two internal reports have been published on muon shielding problems.

Several Berkeley programs for determination of neutron spectra from threshold detector data have been converted to the 7090 computer and are operating. A HASL program for unfolding neutron spectra from proton recoil data in nuclear emulsions has also been adapted to the 7090 and is being checked out. Both of these methods will be used in the near future to determine neutron spectra around the accelerator.

A program has been written to analyze the data from the peripheral monitors. The final result is a plot such as is shown in Fig. 23 . The small bump on September 20 on the lower (neutron) curve is due to the first attempt to get a beam into beam dump east. Although the accelerator doubled the background for only two one-hour periods, the effect still shows clearly on the day's average. The other four peripheral monitoring stations are being constructed now and should be installed in November.

A new film badge system was put into operation during this period. Emergency thermoluminescent dosimeters were also issued. These will be carried in the billfold and read out on a yearly basis or in the event of a suspected high exposure.

Some measurements made on the accelerator include the ducting of high energy and fast neutrons in the Accelerator Housing and an investigation of the radioactivity produced in the tune-up dump water system. The latter gave results consistent with previous theoretical calculations. It also showed that demineralizers are ineffective in holding up 0^{15} and C^{11} but seem to hold N^{13} quite well.

A brief study was made of the use of plastics as integrating dosimeters. One of the most promising, which has not been previously studied, was lexan (polycarbonate). It appears one could measure doses in the range 10^5 to 10^8 rads by

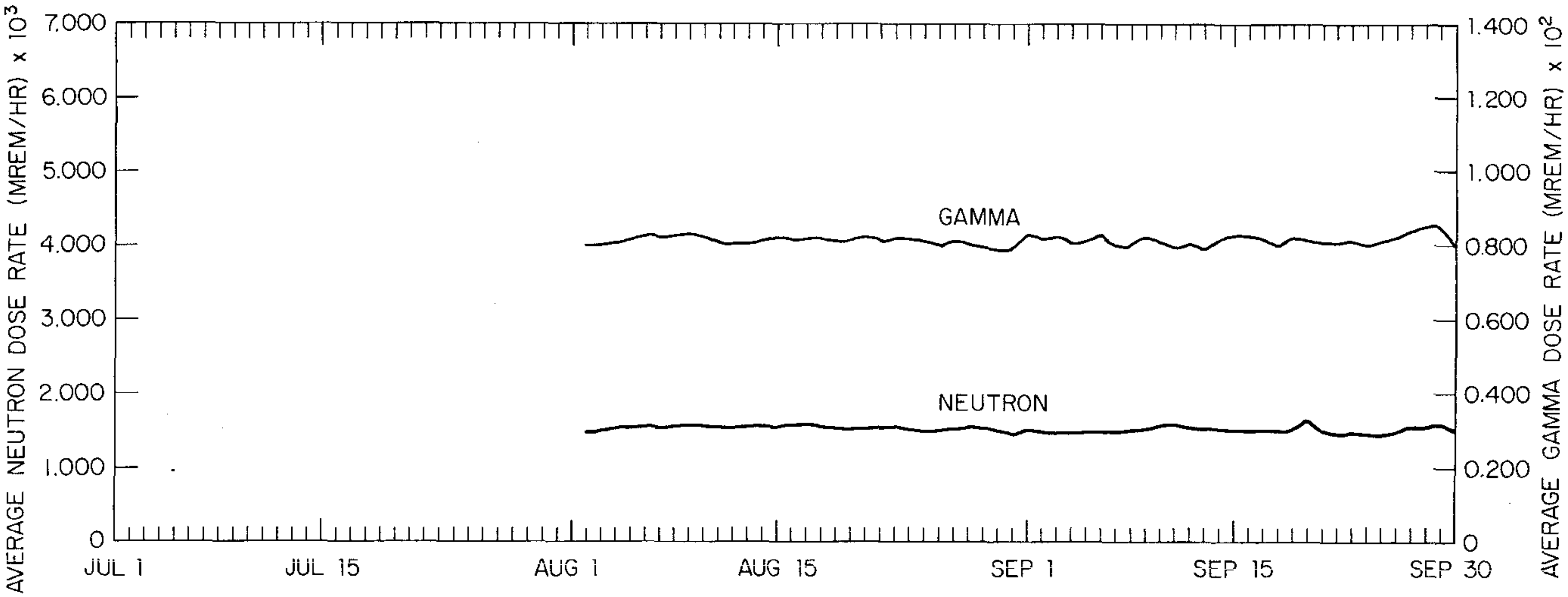

FIG. 23 -- AVERAGE NEUTRON AND GAMMA DOSE RATE DATA TAKEN AT PERIPHERAL MONITOR STATION NUMBER 2, JULY – SEPTEMBER 1966.

measuring the optical transmission of small samples of lexan. Fading over periods of 38 days should cause no more than a factor of two error. Visual inspection of the color of the plastic should enable one to estimate the absorbed dose to the nearest decade. Another useful material for estimating radiation damage is polyvinyl chloride, which is clear up to 10^6 rads, dark brown at 10^7 rads, and black at 10^8 rads.

Some work was started on the measurement of thermoluminescent light spectra. A new method was tried which has many advantages over earlier methods. Indications are that it will work, but initial results are erratic.

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