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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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Technical Report

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for the USAEC

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## I. INTRODUCTION

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

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

The terms of Contract AT(04-3)-400 provide for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision is made for an initial complement of general-use research equipment with which it will be possible to perform certain exploratory studies, such as measurement of the intensity and energy distribution of various secondary-particle beams. However, AT(04-3)-400 does not provide for the more specialized items of research equipment that will eventually be necessary for a full program of experimental physics with the machine. A program of research preparation is now underway at SLAC under the support of another AEC contract.

## II. PLANT ENGINEERING

### A. GENERAL

Considerable progress was made on the conventional facilities program during the quarter. The peak of the design effort for the two-mile machine and its supporting facilities has now been passed. The design phase for the experimental facilities in the Target Area is building up, however, and will parallel the continuing construction of the Accelerator Housing, Klystron Gallery, and the buildings in the main project group. The Aetron-Blume-Atkinson work force decreased from 137 people in the previous period to 131 at the end of September.

Engineering assistance was provided in connection with space occupancy planning and conventional facility alterations. The latter was particularly applicable to the Test Laboratory and the Administration and Engineering Building. This general area of service work is increasing as project facilities are completed and put into operation.

Rough grading for the projected Junipero Serra Freeway crossing at accelerator station No. 83 was completed. This work, carried on by the California State Division of Highways, is phased in with the site construction schedule in order to avoid interference with the SLAC program.

### B. DESIGN STATUS

Target Area criteria have been under intensive study during the quarter. This effort has been spearheaded by the Research Division, with the assistance of various individuals in the SLAC and ABA organizations. A scope document will be issued early in October as a basis for developing detailed criteria.

Preliminary design of the site landscaping program was completed in September; authorization to proceed with the next phase has been requested of the Atomic Energy Commission. Title I work is underway on the Beam Switchyard and on the Cafeteria, Auditorium and Shop Dining Room grouping.

Final design (Title II) is in progress on a number of facilities. These, together with their percentage of completion, are as follows: Klystron Gallery Utilities, 90; over-all site improvements, 57; 220 kv Substation and Switchhouse, 46; Control Building, 30.

Design of the Central Laboratory and the Heavy Assembly Building was completed. These two facilities will be constructed under one contract

as a Research Complex, and bid opening is scheduled for October 15, 1963.

#### C. CONSTRUCTION STATUS

The status of major conventional facilities now in the construction phase is as follows:

<u>Facility</u>	<u>Percentage of Completion</u>
Initial Site Utilities	98
Utility Building "A"	98
Initial Accelerator Housing	98
Electronics and Stores Building	84
Fabrication Building	79
Loop Road	23
*Main Accelerator Housing	2
*Klystron Gallery - Bid opening, September 20, 1963	

\*Because of their critical schedule requirements, the contracts for both of these facilities contain provisions for liquidated damages.

Several SLAC groups commenced occupancy of the Administration and Engineering Building during August. As of the end of the report period, this facility and the Test Laboratory are fully occupied and the construction work is essentially complete.

Construction-contractor personnel at the Sand Hill site now total 140 people, as contrasted with 175 previously. The present status of construction work on a number of the facilities at the site is shown graphically in Figs. 1 through 5. The concrete batch plant, shown in Fig. 3, has been provided by the Main Accelerator Housing contractor, who is permitted to furnish concrete to other on-site contractors. Of special interest was the use of an air-lift for placing heating and ventilating equipment on roof areas of the Shops Complex, as shown in Fig. 2.

#### D. UTILITY SERVICES

The Pacific Gas and Electric Company is constructing a 220 kv transmission line along the Skyline route. A correlated project is the

proposed tie-in line to furnish electric power to SLAC at the Sand Hill site. Stanford is cooperating with PG&E and the appropriate public agencies to obtain the necessary permits.



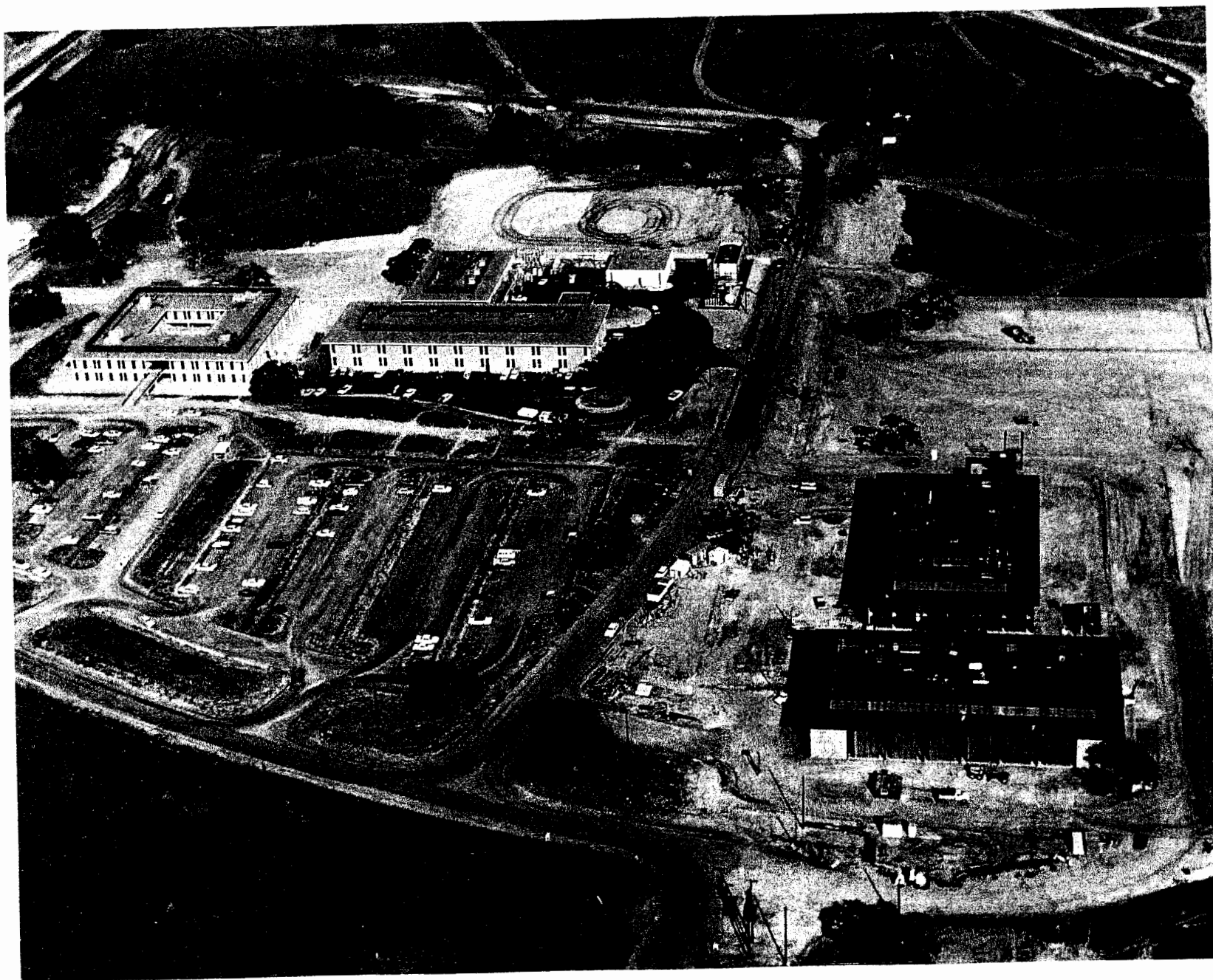


FIG. 1--Aerial photograph of the SLAC laboratory area.



FIG. 2--Fabrication Building and the Electronics and Stores Building  
on the Sand Hill site.

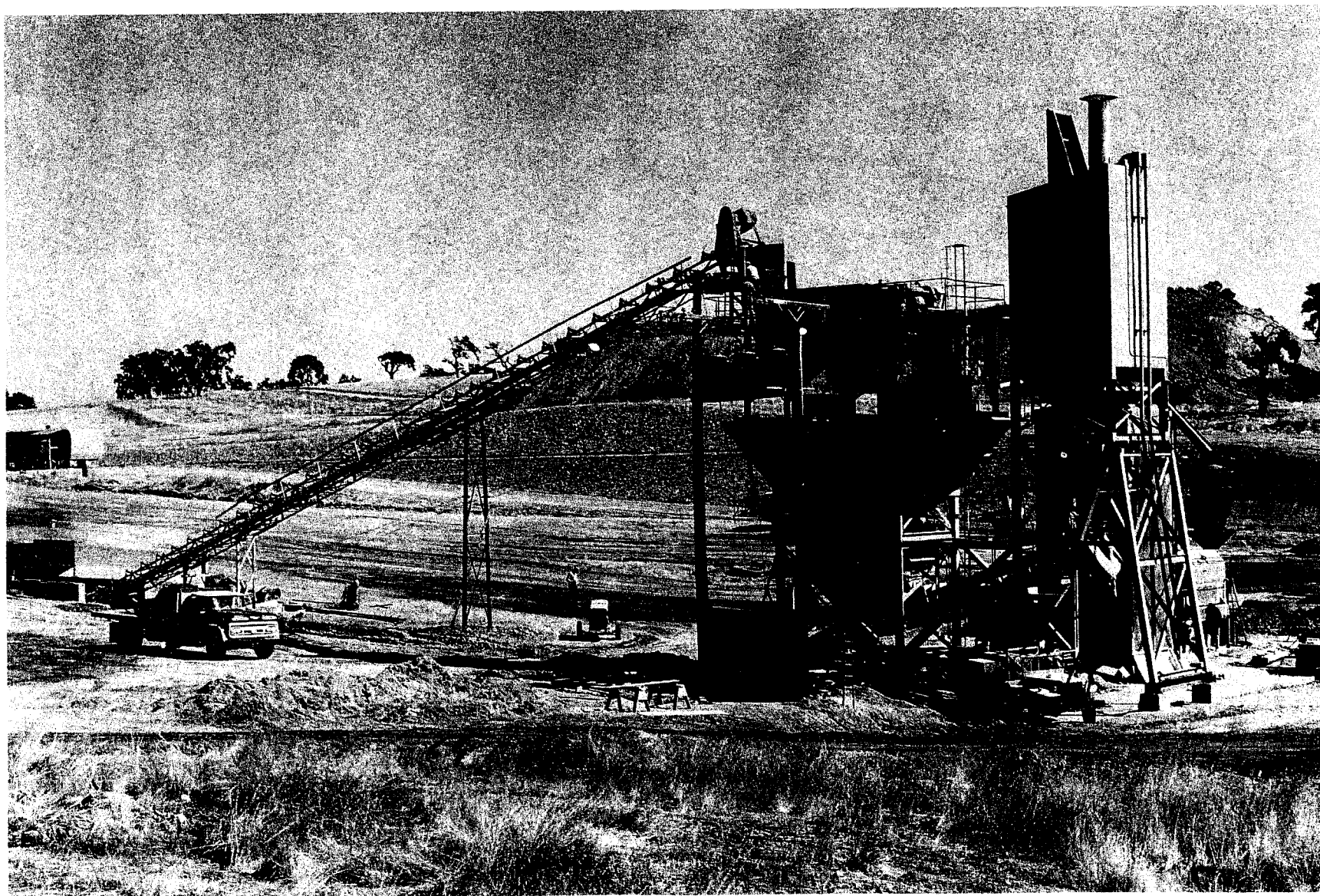


FIG. 3--Concrete Batch Plant, located at the Sand Hill site.



FIG. 4--Long-range view of the accelerator site from the west end.



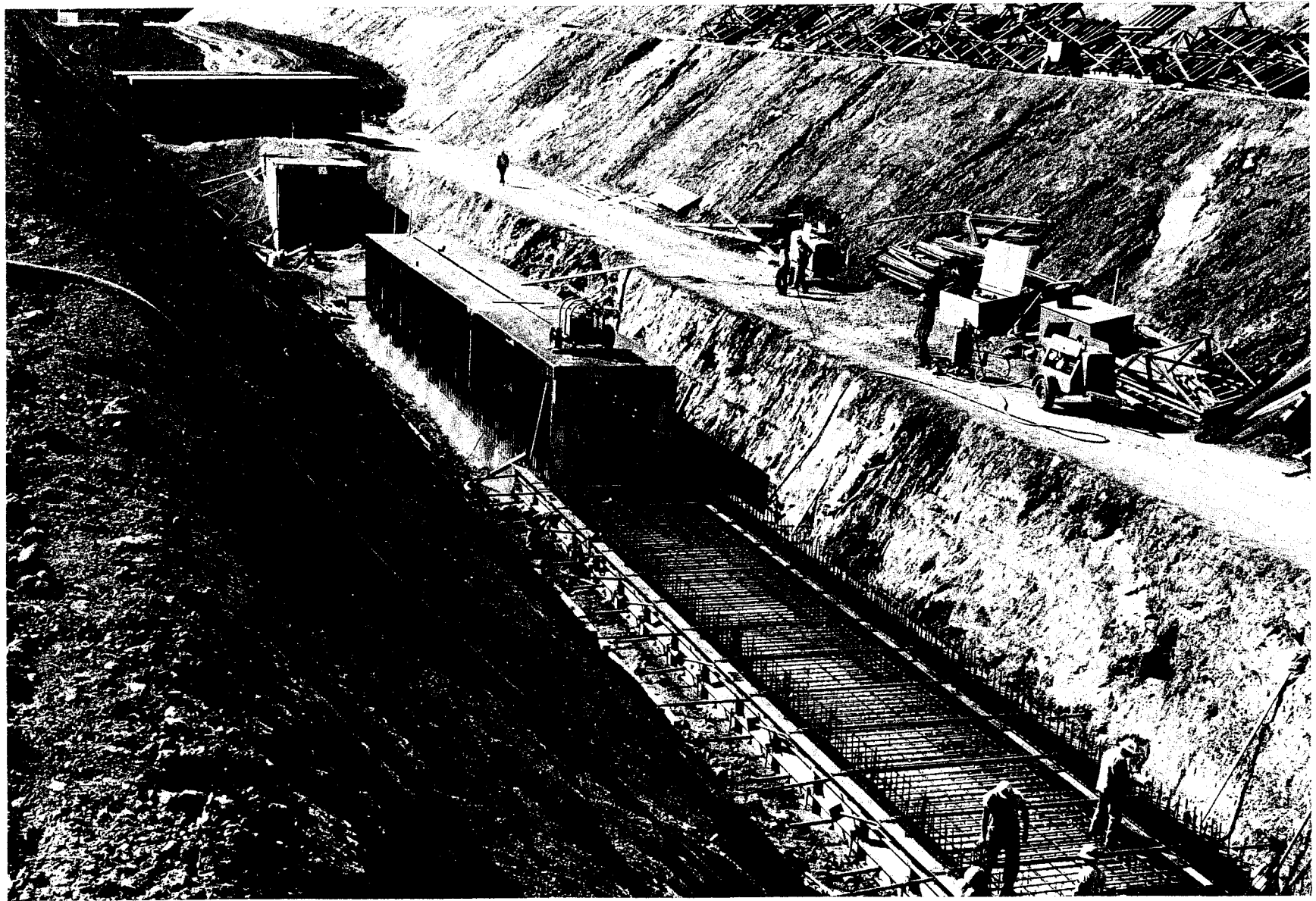


FIG. 5--Setting interior wall forms for the Accelerator Housing.

### III. ACCELERATOR STRUCTURES

#### A. ACCELERATOR STRUCTURE

##### 1. Instrumentation and Facilities for Low Power Microwave Tests on Accelerator Sections

###### a. Microwave Test Equipment

The commercial phase measurement system discussed in previous reports<sup>\*</sup> has been received, tested, and found satisfactory. Satisfactory performance was also obtained when this system was tested in conjunction with the waveguide network connecting it with the accelerator section input. This system is set up to operate with the tuning machine. An identical system was ordered in September for use in quality control measurements; delivery of the second system is expected in December.

One of the precision phase standards was completed, tested, and found to perform satisfactorily. Tests were performed in which the phase standard was cycled 500 times. (In each cycle the device steps through three individually preset positions in sequence.) Following this, it was tested for accuracy of phase repeatability in each position through 100 additional cycles. The second phase standard is being constructed.

An attenuation measurement system for use with the quality control system was developed, tested, and found to yield satisfactory accuracy.

###### b. Vacuum System for Dielectric Control

A dual-channel vacuum system was perfected for use with the tuning machine and the quality control machine. The function of this system is to maintain accurate control of the dielectric constant inside the accelerator sections while they are tuned and tested on the two machines. The system maintains a vacuum of  $5 \times 10^{-3}$  mm Hg, which is quite satisfactory for this purpose.

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<sup>\*</sup> See "Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1963," SLAC Report No. 16; and "Two-mile accelerator project, Quarterly Status Report, 1 April to 30 June 1963," SLAC Report No. 18, Stanford Linear Accelerator Center, Stanford University, Stanford, California.

### c. Tuning Machine

The electrical control unit was installed on the tuning machine and performs satisfactorily. The hydraulic system was improved and now drives the indenters at sufficient speed. The vacuum seals in the machine were improved to yield the vacuum performance discussed above.

### d. Quality Control Machine

The quality control machine now under construction is expected to be completed during the next quarter.

## 2. Coupler Tuning and Matching

Work was continued on a simplified technique for coupler tuning and matching. By this technique, the coupling iris dimensions are not to be changed after the iris is machined. The coupler cavity would then simply be matched and tuned by indenting its walls, rather than the laborious cut and try iris adjustments that have previously been required in order to tune and match the iris and the coupler cavity.

As the first step in providing this technique, the coupler cavities were redesigned to make the coupling iris walls thicker, permitting more accurate iris machining. Couplers of this new design were incorporated into three accelerator sections. The cut and try technique will be used to adjust the size of the irises on these accelerator sections; however, the resulting iris dimensions will then be incorporated into the design of the accelerator section. In subsequent accelerator sections, irises will be machined to these latter dimensions prior to tuning. Hopefully, further changes in iris dimensions during the tuning process will not be necessary.

## 3. High Power Tests of Accelerator Sections

During this quarter four accelerator sections were tested, and a considerable amount of data was recorded on the eight-channel strip chart recorder.

In one of these tests, an accelerator section was baked at 100°C after processing. This was done to determine if baking would reduce the rate at which outgassing occurs at certain power levels. It was found that bakeout after rf processing did not reduce the outgassing rate or improve the performance of the accelerator section.

Because the rf performance of this accelerator section was satisfactory in all respects before baking and since baking caused no appreciable improvement, no further bakeout tests on accelerator sections were planned.

#### 4. Facilities and Instrumentation for High Power Testing

Test Stand No. 1 was improved during the quarter through the addition of several new facilities. First, the high-power vacuum waveguide and flanges were replaced by items designed for use in the two-mile machine. A new ion vacuum pump system was installed and tested. The test results, obtained while accelerator sections were being processed with high rf power, were encouraging. Finally, a Type A vacuum valve<sup>\*</sup> was installed. This valve is located between the klystron and the remainder of the high power waveguide circuit. Its function is to hold a vacuum in the waveguide circuit and the accelerator section while a klystron is being replaced. Its rf operation has been good and it has maintained a high vacuum seal in the closed position.

Test Stand No. 2 is nearing completion. The modulator for the klystron was installed and tested. The high power waveguide circuit, using waveguide and flanges of the two-mile machine designs, is completed. The instrumentation and control racks are nearly complete. The instrumentation installed includes vacuum gauges, a frequency counter, microwave power meters, an oscilloscope for observing pulse waveforms, and an eight-channel strip chart recorder. A second ion vacuum pump is being procured for Test Stand No. 2.

#### 5. Water Jacket

Water jackets were brazed to accelerator sections 23, 25 and 26. Sections 23 and 25 were tested in the high power rf test stand over a range of average input power levels up to 15 kw.

Several minor modifications in the water jacket configuration were tried. For example, cooling tubes were attached to the input and output waveguide transitions in an attempt to decrease the temperature

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<sup>\*</sup>SLAC Report No. 16, op. cit., p. 14.



rise at the accelerator ends. The improvement in temperature uniformity was found to be only marginal and the concept was abandoned. In addition, the accelerator temperature in the vicinity of the water input tees was found to be somewhat lower than average, as a result of entrance effects. To correct for this in subsequent water jacket assemblies, the inlet tees were separated from the accelerator section.

On the basis of the temperature measurements made in the tests discussed above, the resulting water jacket design was considered final. The final design is like that previously reported,\* except that the inlet tees are separated from the main body of the accelerator section.

Procurement of water jacket parts for approximately 1000 accelerator sections for the two-mile machine is well underway. Bids have been received and contracts awarded for the production of all parts. Samples of several of the parts have been received and are being evaluated.

#### 6. Accelerator Section Ten-Foot Support

The design of the ten-foot support (strongback) is being modified on the basis of newly developed information. It has been found that the temperature of the accelerator sections in the two-mile machine can vary over a wider range than had been expected previously, particularly during initial turn-on. Thus, a greater relative axial movement between the accelerator structure and its support must be provided by the ten-foot support. [This modification applies only to the two-mile machine; it will not be necessary for those strongbacks to be used on the Mark III machine (see Section B).]

To meet the new requirement, the vertical support members that support the accelerator section from the ten-foot beam are being modified to provide greater flexibility. A promising design of this flexible support is now being tested.

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\* SLAC Report No. 18, op. cit., p. 16.

## B. ACCELERATOR SECTIONS FOR THE STANFORD MARK III ACCELERATOR

On July 26, SLAC agreed to supply a complete complement of accelerator sections and terminating rf loads to replace those existent on the Stanford Mark III linear electron accelerator. Specifically, SLAC will supply 25 ten-foot accelerator sections, mounted on ten-foot supports; 6 eight-foot accelerator sections, mounted on eight-foot supports; and 31 terminating rf loads.

All accelerator sections will be of the constant-gradient type. The ten-foot accelerator sections will be of the same design as the one to be used for the SLAC machine. The design of the eight-foot sections is derived by removing a two-foot length from a ten-foot section just beyond the input coupler, and by modifying the input coupler design accordingly.

Tests will be performed on the Mark III accelerator both with its existing accelerator sections and after the new SLAC sections have been installed. Previous operational tests of SLAC accelerator sections have taken place on the Mark II and Mark IV machines, both of which are 20 feet long. The results of such tests on the 310-foot-long Mark III accelerator are particularly important in evaluating the performance of the SLAC accelerator sections because operational tests (with a beam) are not planned for the two-mile machine before 1966.

This plan will also permit a valuable pilot production run that will test the techniques developed for fabrication, inspection, testing, and storage of the accelerator sections. It will bridge the gap between the experience that has been gained in producing a few sections at a time and the rapid-rate, large-scale production required for the two-mile machine.

SLAC personnel will mount the new accelerator sections in place, connect them, install the rf loads, and connect the inputs to the feed waveguides. All other efforts required for the replacement will be provided by Mark III personnel.

## C. HIGH POWER WAVEGUIDE COMPONENTS

### 1. Waveguide Valve

During the quarter steps have been taken toward reaching a final

design for the waveguide valve. It was found that the Type B<sup>\*</sup> valve incorporates the following disadvantages as compared to the Type A valve.<sup>\*\*</sup>

- (a) The need to move the waveguides that connect to the valve inward or outward axially causes a problem. The relative movement is about 3/16 inch. No such movement is necessary with the Type A valve.
- (b) In cycling tests made to date, indium re-melt is necessary much more frequently in the Type B valve than in the Type A valve. It appears that this results from the difficulty in the Type B valve in regulating the clamping force with sufficient accuracy. Additional design effort might well overcome this problem by improving the valve's actuating mechanism.

On the other hand, if the Type A valve were used in the standard waveguide layout,<sup>†</sup> special provisions would be needed to locate its indium seat in a horizontal plane. Since the valve would be located in a vertical waveguide run and the waveguides on the valve are horizontal, additional waveguide pieces would be required to connect to the valve.

To overcome this difficulty and the problems associated with the Type B valve, the Type C valve (shown in Fig. 6) was developed. Basically, this is a Type A valve modified to provide vertical collinear input and output waveguides while the indium seat remains horizontal. If this valve were used in the standard waveguide layout, its indium seat could be re-melted with the valve in place. Note that valves Type A and Type C differ only in the design of the waveguide stubs that connect to the valve body. Mitered bends, which contain metallic wedges

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<sup>\*</sup>"Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963); p.14.

<sup>\*\*</sup>SLAC Report No. 16, op. cit., p. 14.

<sup>†</sup>SLAC Report No. 18, op. cit., p. 21.

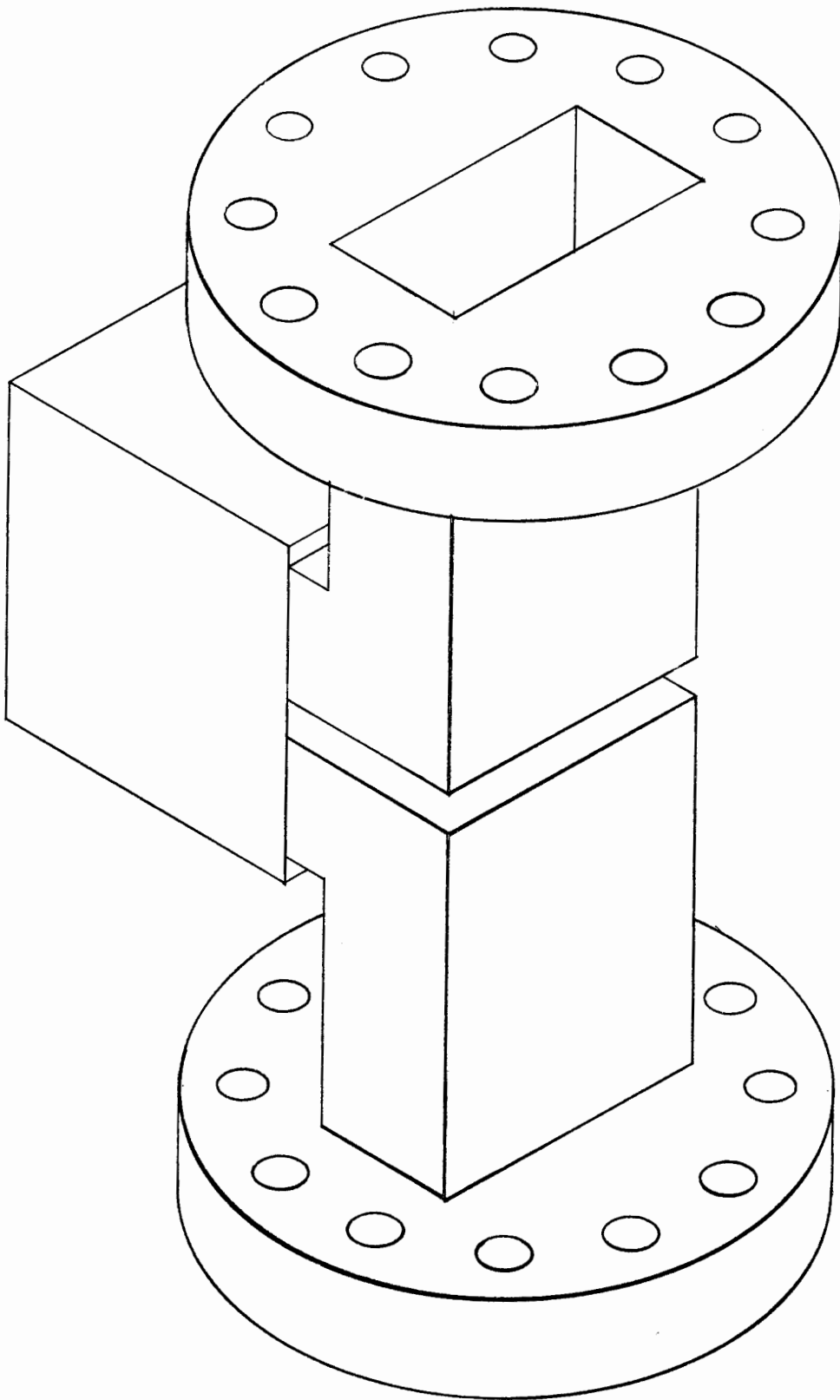


FIG. 6--Type C valve.

for impedance matching, are used in the waveguide stubs for the Type C valve. Initial low power tests on one unit of the Type C valve indicated good performance in VSWR and insertion loss.

During the previous quarter, construction was started on twelve Type A valves and 12 Type B valves.\* Construction of the 12 Type B valves was tentatively discontinued after the problems with this valve became apparent and after rather good results were obtained with the Type A and Type C valves. Of the 12 Type A valves on which construction was started, six were converted to Type C valves.

In the next quarter, the six Type A valves and the six Type C valves will be completed. These valves will then be tested for vacuum performance in cycling tests, for attenuation and VSWR in low power microwave tests, and for arcing and localized heating in high power microwave tests.

## 2. Waveguide Layout

The standard waveguide layout presented in the previous Quarterly Status Report has been installed in the Test Tower (Treehouse). The tests that have been performed on this waveguide network are discussed below.

The lengths of the waveguide segments that form this network have now been fixed to an accuracy of  $\pm 0.01$  inch. To do this, accurate calculations of the phase delays through these segments were made to insure proper phasing of the rf signals at the inputs to the accelerator sections. In addition, the input phase errors that result from a frequency shift of 0.1 Mc were shown by calculation not to exceed 0.7 degree. Finally, a careful check was made to insure that these waveguide dimensions are compatible with the locations of klystrons, penetration holes, accelerator input ports, etc.

Flanged joints were added to the output ports of the hybrids located in the accelerator housing to facilitate conversion to Stage II. The hybrids must be removed for this conversion, but the waveguides that connect them to the accelerator section inputs can be left in place. If the flanged joints were not present, the waveguides would be removed with the hybrids, which would require that the vacuum lines to the pumpouts

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\* SLAC Report No. 18, op. cit., p. 18.

in the waveguide be cut. Because cutting and rewelding these vacuum lines would be a difficult and expensive operation, the principal advantage of these flanges is that they permit the vacuum lines to be left intact during Stage II conversion.

### 3. Power Dividers

The development of a short-slot side wall hybrid for use in the standard waveguide layout\* of the two-mile linear accelerator was begun during the quarter. It was decided to take the hybrid used in the SLAC vacuum resonant ring as a starting point for this design. This ring has operated at power levels exceeding 100 megawatts peak and 100 kilowatts average.

Certain modifications were required to adapt this hybrid to the present purpose, leading to the design shown in Fig. 7. The center-to-center spacing between terminal waveguides was increased to provide joints between the hybrid box and the terminal waveguides that can readily be made vacuum tight. After this change was made, it was found necessary to change the length and width of the box in order to retain satisfactory performance. At the end of the quarter, tests were being conducted to optimize these dimensions.

### 4. Test Tower

The test tower waveguide configuration was changed during the quarter to Stage II, as shown in Fig. 8. The accelerator section and the waveguide were insulated to permit measurement of klystron power output by comparing the directional coupler performance with calorimeter measurements. A number of measurements were made to establish the relationship between the calorimetric data and the directional coupler data, and it was observed that good agreement between these two could be achieved only when measurements were made during thermal equilibrium conditions. Thermal equilibrium was found to be possible after a steady state run of several hours. Prior to making calorimetric runs, the directional couplers in the test tower waveguide run were calibrated against reference attenuators purchased from Weinschel Engineering Company. It is believed that the coupling coefficients of the directional couplers in the test tower are known within 1/10 db of their true value.

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\* SLAC Report No. 18, op. cit., p. 20.

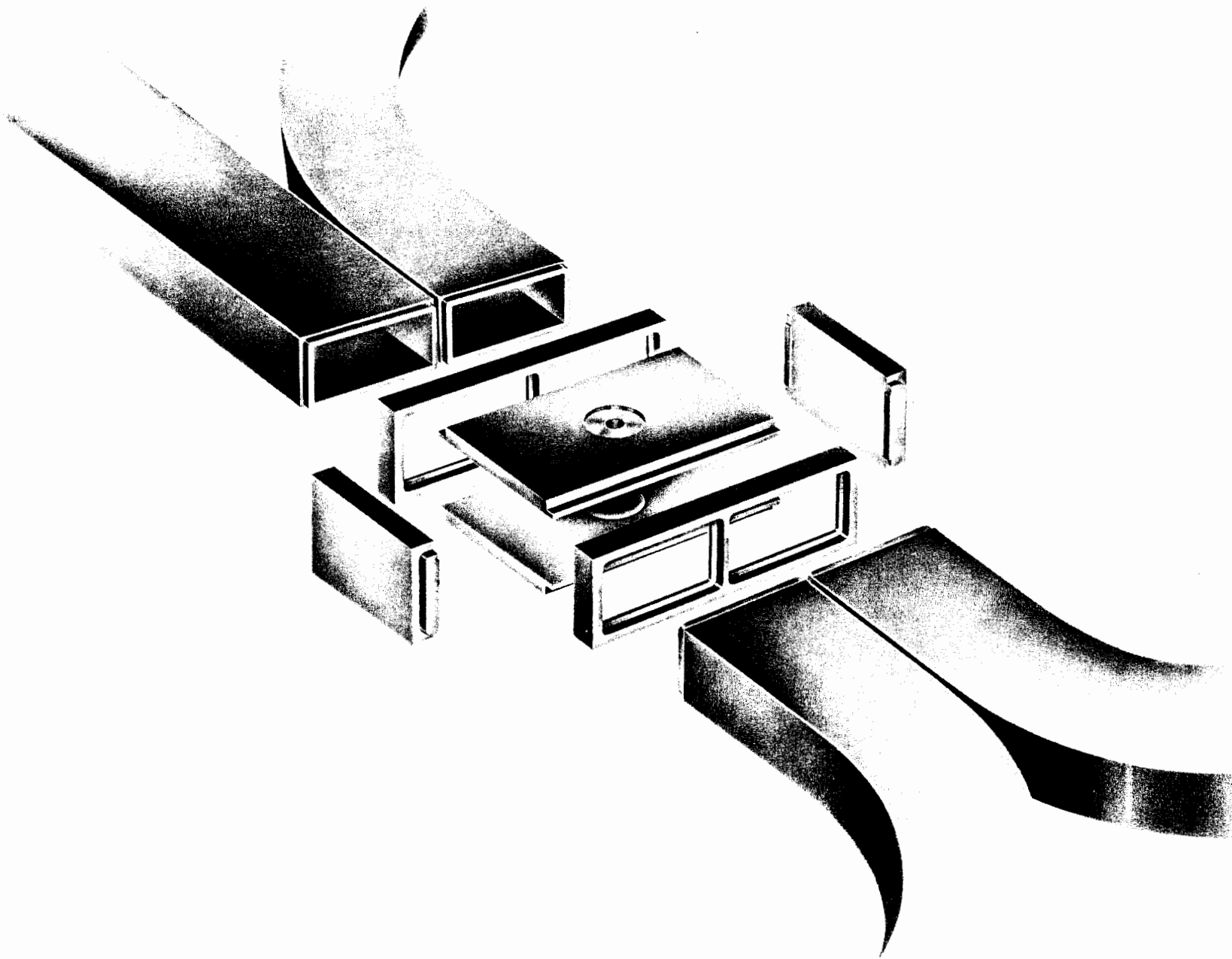


FIG. 7--Power divider.

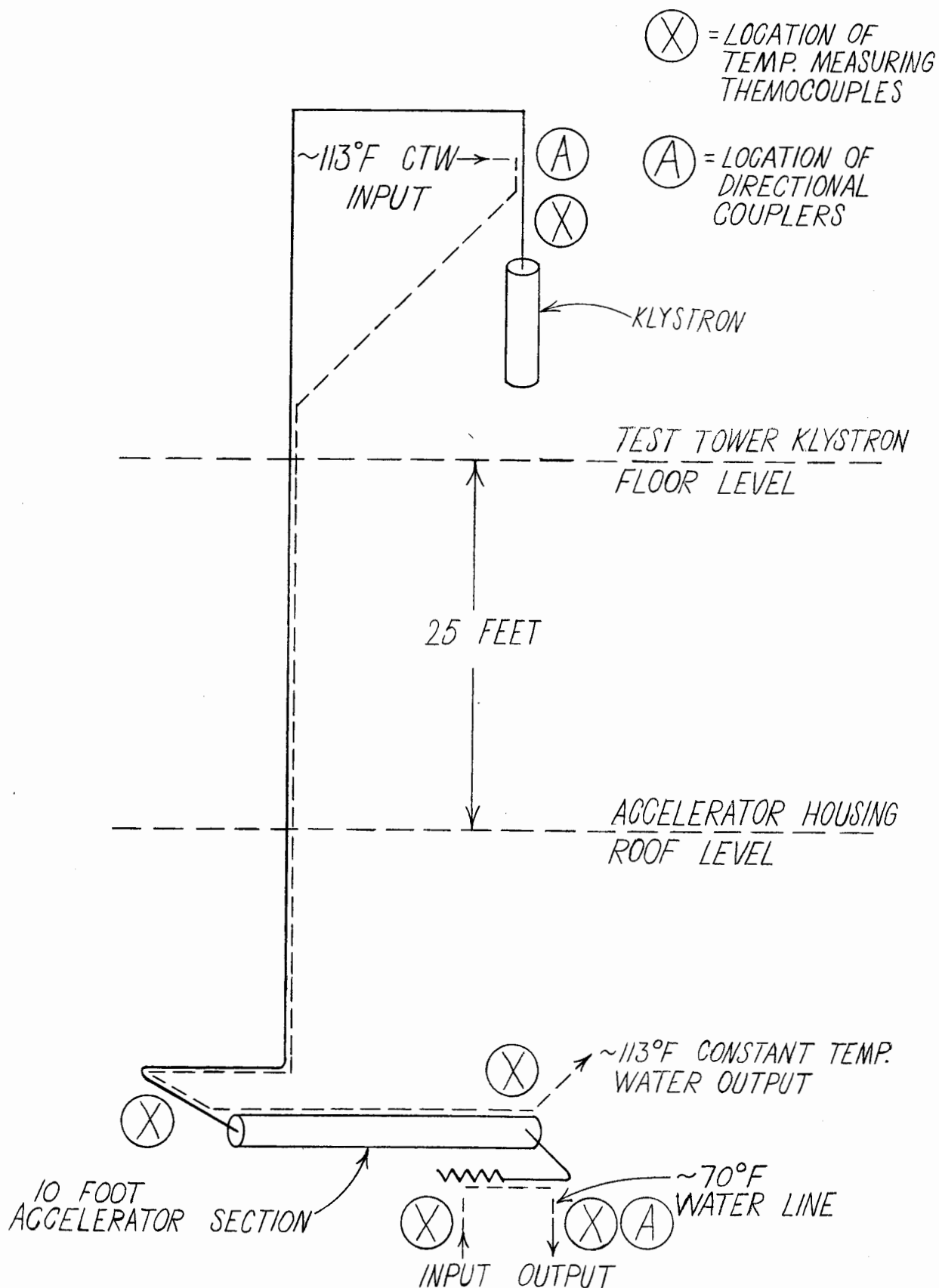


FIG. 8--Test tower waveguide configuration  
Stage II.



A satisfactory test was made on 10 September 1963 under warm, ideal conditions, in which there is relatively low heat loss from the waveguide and accelerator to the walls of the tunnel housing the accelerator section. Figure 9 gives a plot of the metal temperature of the accelerator section used during this test and the inlet cooling water temperature. It may be observed in Fig. 10 that the hot measurement for accelerator section attenuation agrees within 0.16 db with the cold test measurement data. There is good agreement between the power loss in the load as measured by calorimetric data and that indicated by the directional couplers. It is significant that the indicated waveguide loss between the klystron and the input to the accelerator section is 0.3 db. This is to be compared with a theoretical loss of 0.34 db for the 54 feet of waveguide connecting the klystron to the accelerator (neglecting losses due to internal mismatches).

A series of tests was made at the test tower to determine the effect on the performance of the vacuum system when the number of vacuum pumpouts and their location are changed. Figure 11 shows the location of the pumpouts available in the waveguide system. Various pumpouts were blanked off during tests, and it was observed that adequate performance at all operating power levels could be achieved by using a pumpout at the klystron window and pumpouts at the inputs to each of the accelerator sections. Based upon these tests, pumpouts only at the klystron window and at the accelerator inputs are planned for the SLAC system. The Stage II configuration of the test tower has operated satisfactorily with a klystron output power of 18 MW peak, 17 kW average. This level was the maximum available from the klystron and modulator system.

As shown in Fig. 8, a section of the waveguide from just above the klystron output to the klystron house floor level was not equipped with water cooling. It was observed that at the 17 kW average power level, the skin temperature of the waveguide that was uncooled rose 90°F above ambient, a value close to that predicted. The results of this test emphasize the need to control the temperature of those waveguide components or lines whose electrical characteristics change with this large a temperature variation.

After the above tests were completed, the waveguide layout in the

test tower was removed, and a new set of waveguides was installed in the configuration known as Stage III in the test tower program.\* It is planned that during the next quarter a series of phase tests will be made to determine the phase sensitivity of the waveguide system to changes in spacing between the klystron floor and the accelerator itself.

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\* See SLAC Report No. 18, op. cit., p. 21.

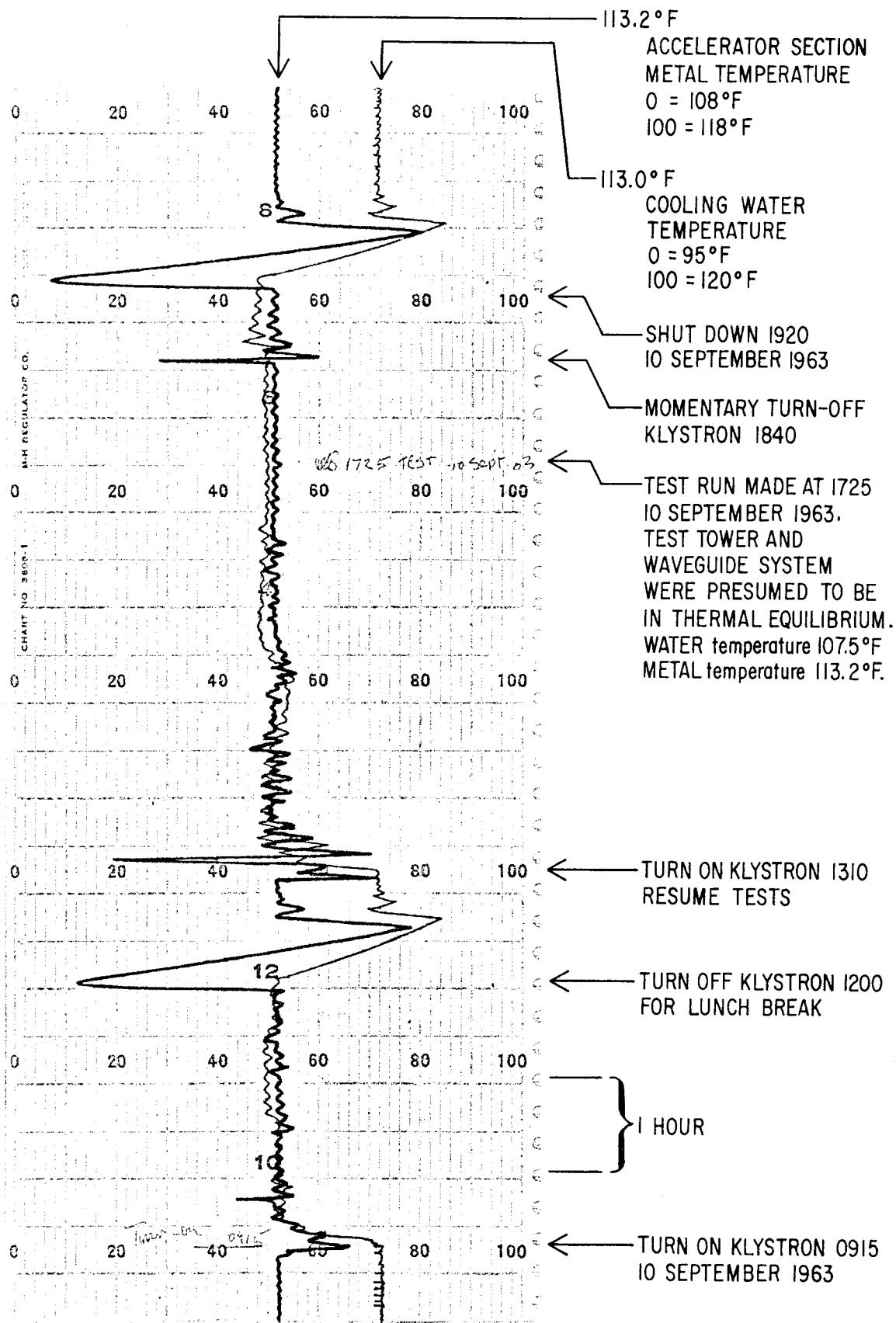


FIG. 9--Plot of accelerator metal and water temperature of Stage II test tower waveguide configuration.

CALORIMETRIC TEST - STAGE II TEST TOWER

PERFORMED 10 SEPTEMBER 1963

Pipe inlet temperature 107.5°F

Pipe outlet temperature 110.6°F

$$\Delta T_1 = 3.2^\circ\text{F}$$

Pipe water flow rate 13.4 gallons/minute

$$\text{Power loss in pipe} = 3.2 \times 13.4 \times \frac{500}{3414} = 6.27 \text{ kilowatts}$$

Load inlet temperature 69.4°F

Load outlet temperature 74.0°F

$$\Delta T_2 = 4.6^\circ\text{F}$$

Load water flow rate 4.75 gallons/minute

$$\text{Power loss in load} = 4.6 \times 4.75 \times \frac{500}{3414} = 3.21 \text{ kilowatts}$$

Total power into accelerator section = 9.48 kilowatts or + 69.77 dbm

Measured power at klystron output = 10 kilowatts or + 70.00 dbm  
(by directional coupler)

Indicated waveguide loss = 0.30 db

Measured power into load = 3.2 kilowatts or 65.07 dbm  
(by directional coupler)

Indicated pipe attenuation 69.77 - 65.07 = 4.70 db

Low power measured attenuation 4.86 db

FIG. 10--Calorimetric results for test tower.

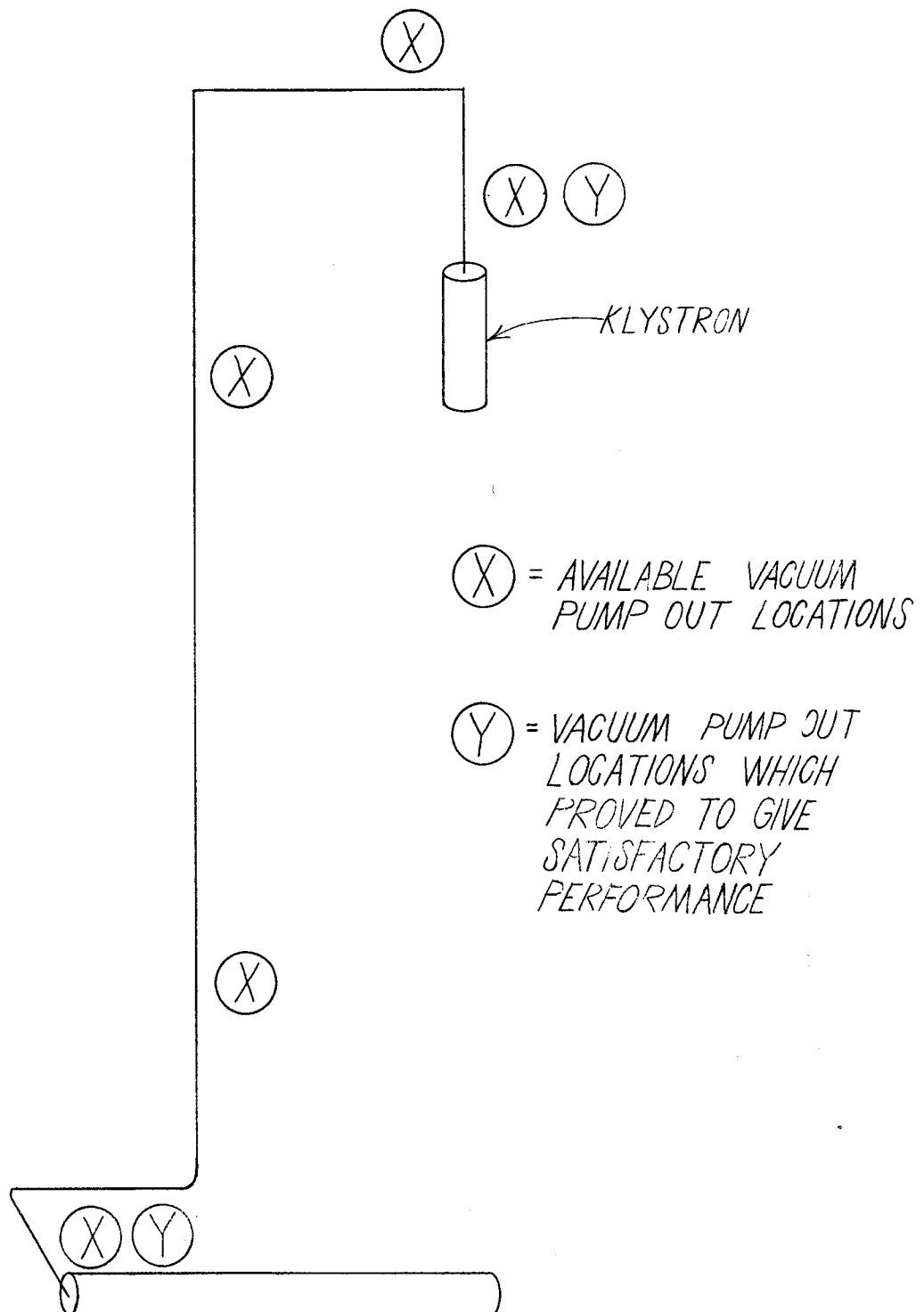


FIG. 11--Waveguide arrangement showing available pumpout locations.

#### IV. KLYSTRON STUDIES

##### A. SUMMARY

Monitoring of the work of subcontractors for klystron procurement continued during the quarter. The first tube was received and will be checked for compliance with SLAC specifications during the next quarter. Work on Stanford-built tubes was continued; so far the oscillations that had been troublesome and were eliminated as reported last quarter have not reappeared.

A less expensive and more easily fabricated focusing electrode has been designed for the gun, and additional improvement work is being planned. Diodes to be used for initial tests of test stands and for tests by the Modulator Group are available. Detailed design of klystron support is complete, and initial tests were carried out on the first model. The window study activity on the effect of coating is continuing, and the results are extremely encouraging.

##### B. SUBCONTRACTS

The discrepancies among the beam voltage measuring techniques used at Sperry, RCA, and Stanford have been resolved. Accordingly, tube measurements taken at the subcontractors plants should be easy to correlate with the measurements taken at Stanford during acceptance tests. As a result of the reduction of calibration, the apparent power output reported by Sperry and RCA is somewhat less than had been reported previously. However, Sperry has been able to demonstrate several tubes producing 18 Mw or more in permanent magnet. One of these tubes was shipped to Stanford, but mechanical difficulties (window breakage during the last test, vacuum leaks, and the like) have prevented Sperry from shipping us more than one tube up to now. On the other hand, difficulties with oscillations in Sperry tubes seem to have been overcome.

RCA is experiencing difficulty in matching a permanent magnet to their existing tube design; because of this difficulty, it was not until the end of September that they realized 17.5 Mw (approximately) in a tube focused by permanent magnet. In general, the gain of the RCA tube is quite adequate.

No measurements have been taken by Stanford on either the Sperry or the RCA tubes to insure that all other specifications (phase, noise, etc.) have been met. It is hoped that in the next quarter a more complete knowledge of the performance of the subcontractors' tubes will be available.

#### C. PERSONNEL MOVE TO THE TEST LABORATORY

In July the Klystron Group began moving into the new facilities on site. At this time three test stands were made available for the group. The test stand for window tests and its associated equipment were not moved until September, and the four remaining test stands were still not available for klystron operation at the end of the quarter. This shortage will cause difficulty in running acceptance tests for the RCA and Sperry klystrons. In addition, many shutdowns have been experienced both in the new test stands and in the drive circuit; thus, the total number of klystrons which have been tested and processed has not been as great as had been anticipated.

The equipment for the installation in the tube fabrication area has not yet been received in full in spite of promises of much earlier delivery. Some of the equipment that has been received was damaged in shipment, resulting in further delays. The procurement of a hydrogen brazing furnace was also delayed for various reasons, and it is now promised for delivery in December. Until that time, the Klystron Group will not be able to resume full operation.

#### D. KLYSTRON FABRICATION AND DEVELOPMENT

A total of 14 tubes and 7 diodes were processed during the quarter. Two tubes and one of the diodes had to be reworked by the tube shop because of poor vacuum. The tube performance, although not quite as high as that reported for tube G-3 in the previous status report, was consistent with our previous experience. Two experimental tubes were built using a new gun design. The first of these showed high anode interception (approximately 10%), but it still had reasonably good performance, with an efficiency in excess of 30%. The initial gun design error has been corrected, and the second tube built with the new Stanford design

gun underwent exhaustive tests during the quarter. The gun design appears satisfactory, the interception is extremely low, and the magnetic field requirements are not critical, except in the immediate vicinity of the gun. However, since this gun is designed as a Pierce gun, the tube efficiency is not as high as one should obtain with a partially confined flow gun. The maximum efficiency measured was 36% to 37% at approximately 200 kv. A peak power output of 18.5 Mw at 250 kv, with a microperveance of 1.9, has been observed with this gun with a magnetic field of approximately 800 gauss in the interaction region.

Additional improvements of the gun and klystrons have been under study. The shape of the gun focusing electrode has been redesigned to improve the ease of fabrication and to increase the accuracy of the final shape. In addition, calculations indicate that the beam diameter of the new gun is smaller than that required for optimum efficiency and gain. Accordingly, two approaches are planned for the next quarter: (1) A tube will be built using the present Stanford gun design, but with the drift tube diameter reduced from 1.125 inches to 1.0 inch. (2) A modification of the gun will be introduced to increase the beam diameter by approximately 20%.

#### E. STANFORD KLYSTRON USAGE

During the quarter, eleven Stanford klystrons and four diodes were put into operation. Six klystron failures and two diode failures were observed. Of the six klystron failures, one was caused by a shorted filament, the others by window failures. Two windows failed after approximately 5 hours due to puncture and cracking, one after approximately 60 hours, one after 280 hours, and one after 475 hours of operation. The vacuum interlock system on some of the operating stands is apparently inadequate at present. On the other hand, Mark IV reports an operating time of 780 hours for a tube that is still operating satisfactorily.

#### F. ACCEPTANCE AND LIFE TESTS

All equipment necessary for acceptance and life tests has been ordered. Most of it has been received and assembled, and two remaining items related to noise measurements are now being fabricated. Because the acceptance test stand was not available for use at the end of the quarter, acceptance



tests on the initial tubes received from Sperry and RCA will be carried out during the next quarter on one of the presently operating test stands. Life tests will not begin until a sufficient number of tubes from the vendors has been accumulated.

#### G. SUB-BOOSTER KLYSTRONS

During the past quarter, eight sub-booster klystrons were received from Eimac. Life testing for some of the Eimac sub-booster klystrons began in July using a special sub-booster modulator equipped with a driver and a trigger generator. During the quarter, 700 hours of life test were run on one of these klystrons, and it is still performing satisfactorily. Unfortunately, faster data acquisition was not possible because of other equipment troubles.

It was also decided to run regularly scheduled tests to check the status of tubes that had been received but were not in use in other test stands. As a result all such tubes were tested in September, and it was discovered that five of the tubes no longer met all specifications. Negotiations are now under way with Eimac to resolve the disposition of these tubes.

#### H. HIGH-POWER KLYSTRON WINDOWS

##### 1. High Vacuum Resonant Ring Tests

###### (a) Ring Performance

The all-metal ring (Fig.12) was recently run as high as 170 Mw peak, 153 kw average power with intermittent breakdown at the window test piece. Because of the radiation hazard and the possibility of damaging the input windows, the ring was operated for only a few seconds at this level. Stable operation for longer periods has been possible up to 135 Mw peak, 121 kw average power.

###### (b) Phase Shifter Cooling

Seventy-five percent of the parts to replace the present phase shifter plungers with water cooled plungers have been machined. The new stainless steel bellows assemblies have been delivered. The water cooled plungers will be installed during the next quarter. This modification will eliminate erroneous temperature readings from the infrared detector due to

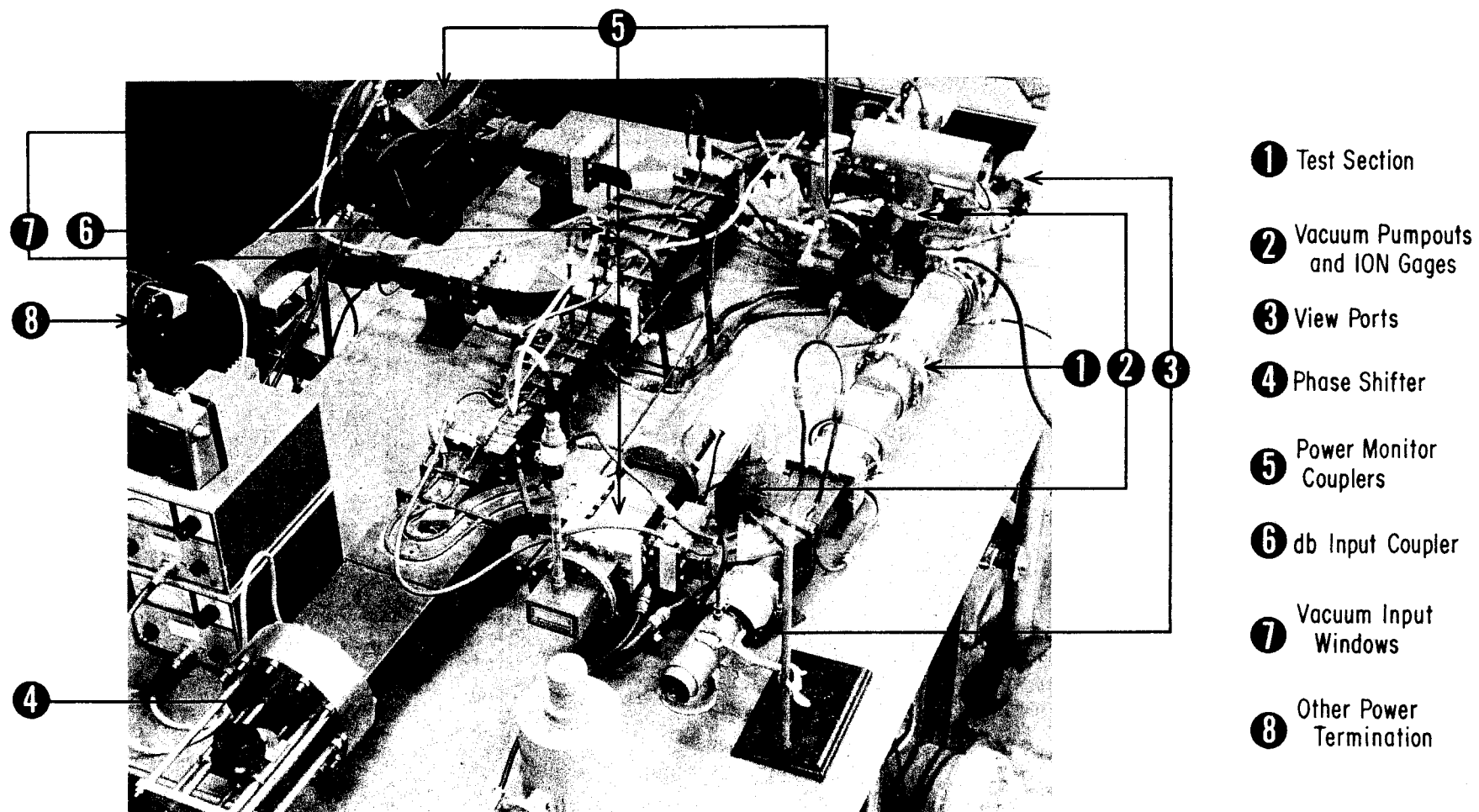


Fig. 12--All-metal high vacuum resonant ring.

I-R from the hot plungers scattering from the walls.

(c) Titanium-Coated Window Test Series.

The study of the effect of coating parameters (voltage, time, and pressure) on window failure is nearing completion. Six sets of three 1/8-inch by 3-inch-diameter alumina disks were coated, using a different combination of coating parameters for each set. The first sample in each set was usually tested within a day after being removed from the coating facility. The second sample in each set was tested about 50 days after being removed from the coating facility.

In order to avoid possible premature failures during the initial outgassing, the windows are "nursed" up to about 60 Mw as slowly as is necessary to keep the pressure below about  $2 \times 10^{-7}$  torr (sometimes as long as two days, depending on previous pumping time). The loading behavior reported previously occurred with the coated windows in this test series between about 900 kw and 6 Mw, but it does not appear as pronounced.

The coating parameters and test results to date are outlined in Table I. The gas atmosphere used was argon. The current and voltage of the discharge are given. The titanium filaments were kept at  $950^{\circ}\text{C}$ . The initial arcing level is that at which a surface arc (which does no damage) first appears. The power is then raised until the arcing causes internal failure.

The results shown in Table I are somewhat inconclusive, but they do indicate that the coating is helpful. However, some uncoated windows have done equally well.\* Exposure to air for long periods of time appears to have no adverse effect on window performance. The effect of a bake cycle remains to be evaluated, as does the importance of a slow increase of power (and low pressure) in conditioning the window. Although no life data is available, there have been no failures of coated windows used on klystrons.

Unfortunately, no window temperature measurements with the I-R detector can be made until the water cooled phase shifter plungers are installed.

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\*"Two-mile accelerator project, Quarterly Status Report, 1 April to 30 June 1963," SLAC Report No. 18, Stanford Linear Accelerator Center, Stanford University, Stanford, California (August 1963); p. 38.

TABLE I

## COATED WINDOW TEST RESULTS

Sample	COATING PARAMETERS				PERFORMANCE	
	Pressure (microns)	Voltage (rms volts)	Current (mA)	Time (min)	Initial Arcing Level (Mw)	Level No Failure (Mw)
1a	60	2000	40	20	72	132
1c	55-60	2000	40	20	135	No Failure* (135)
2a	80-100	1500	25	20	60	60
2c	80-100	1500	25	20	60	120
3a	80-100	1000	-	20	48	100
3c	80-100	1000	-	20	110	No Failure* (171)
4a	40-60	2000	40	15	72	120
4c	40-60	2000	40	15	72	No Failure* (180)
5a	100	2000	40	15	75	120
5c	100	2000	40	15	Now Under Test	
6a	150	2000	40	15	50	120
6c	150	2000	40	15	Not Yet Run	

\* The highest power level run before removal is in parentheses.

X-ray radiation at the test window is sufficiently attenuated by the 0.350-inch-thick stainless steel sleeve (Fig. 13) such that measurements characteristic of each type of coating are impossible to make. After the window has been damaged and consistent breakdown occurs, the radiation increases markedly and may be as high as 500 milliroentgens per hour directly above the window sleeve. The reading is not consistent even on the same sample; therefore, no reliable primary electron energy measurements could be made.

#### (d) Harmonic Generation in the Ring

Energy at the second and third harmonics of the operating frequency was measured from one of the viewport windows (Fig. 14). Using a filter to eliminate harmonics from the klystron, it was discovered that the harmonics were being generated within the ring. The second harmonic was detected when a window test piece was present in the ring, while the third harmonic was detected only when a straight waveguide section replaced the window test piece. The presence of the harmonic in either case was characteristic of a particular electric field strength, suggesting multipactor in a moderate electric field gradient as the harmonic source. Using a dc magnetic field to disturb and thus to locate the presumed discharge, it was found to exist in the vicinity of the phase shifter plungers. The removal of the window test piece could merely shift the ring from the second to third harmonic resonant length.

Measurement of the harmonic power indicates that it is low, and for the purpose of the present tests it will be ignored. However, it will be monitored continuously for safety reasons and possible future study.

### 2. Resonant Cavity Tests

Two more samples were tested in a  $3/2$ -wavelength cavity with the sample in the voltage maxima of the middle resonance. The first sample was a smooth (20-30 microinch finish) disk which exhibited loading behavior like that of the smooth disks reported on previously. The second sample was coated exactly like samples 1a and 1c in Table I and showed no significant loading.

The cavity tests are being discontinued for the time being while the data from them is being evaluated.

### 3. Resonant Ring Tests

A total of ten window test structures were processed on the resonant

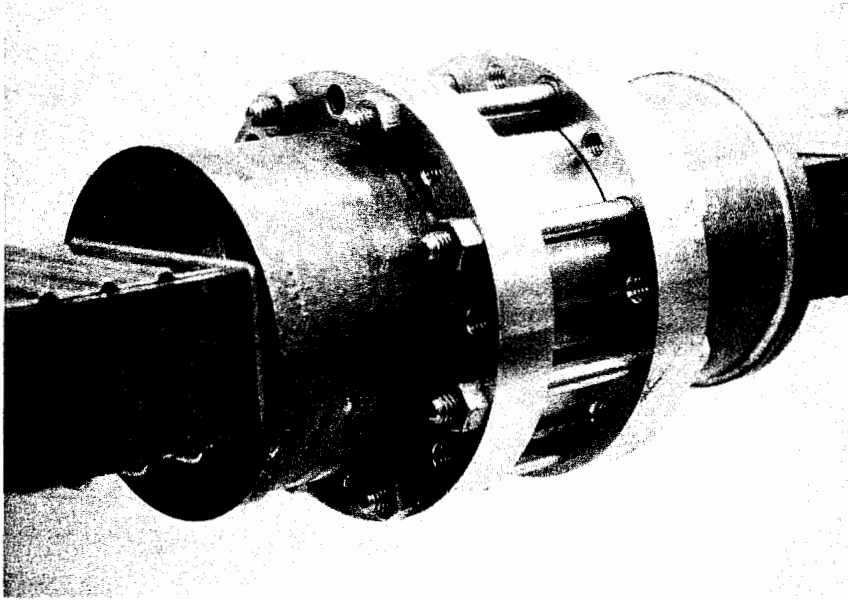


FIG. 13--All-metal symmetrical window test piece used in tests on coated disks.

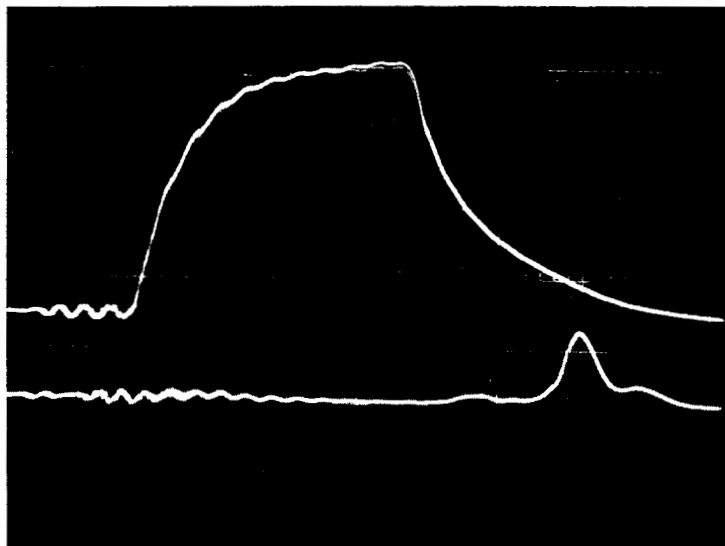


FIG. 14--Second harmonic in ring: top, fundamental pulse shape; bottom, second harmonic pulse -- moves in time to occur at same power level as main power is changed.

ring during the period.

(a) Internal Damage Tests

The investigation of internal failure begun last quarter\* was continued with the testing in a pressurized atmosphere of two additional half-wavelength windows of Coors AD-96. One of the two windows failed internally, the third such failure produced during the testing of five windows. In the last three tests the ceramic disk was purposely cocked during mounting in order to exaggerate the deviation from orthogonality of the window-waveguide geometry, because this window tilt is suspected of being instrumental in triggering the internal failure mechanism. Table II lists the tests performed in the sequence to date. The lack of complete consistency in the test results is perhaps an indication of the random occurrence of the internal voids in ceramic; such voids, as suggested in the RCA hypothesis, may be a necessary condition for the internal failure mechanism.

(b) Eimac Window Tests

Tests of windows that had operated previously at maximum available peak and average power without failure were performed. These windows, E-16 (quartz with 1/32-inch grooves, uncoated\*\*) and E-4 (grooved AL-300, coated with titanium suboxide<sup>†</sup>), were retested in order to develop surface temperature data made available by use of the recently acquired infrared detector.

Nominal surface temperatures of 105°C (E-16) and 107°C (E-4) were taken during operation at 44 kw average power. Neither figure could be accepted as a true temperature, however. The reading on E-16 may be inaccurate due to the ability of the grooved quartz window to scatter to the detector element infrared radiation traveling through the window from any heat source within the ring. The reading on E-4 is suspect because of the abrupt decay of the infrared detected ( $\sim 0.6$  sec) and because of a temperature differential of  $\sim 30^\circ$  between the load and generator sides of the window. We are therefore uncertain as to the main source of the infrared detected. However, in both cases the correction from the

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\* SLAC Report No. 18, pp. 39, 41-43.

\*\* SLAC Report No. 18, pp. 39-40.

<sup>†</sup> See "Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963); pp. 42-45.

TABLE II

## INTERNAL DAMAGE TEST RESULTS

Window Number	Max. Peak Power	Power At Which Failure Suspected	Description of Failure	Window Tilt from Normal Plane (a)	
				Generator Side	Load Side
1	34 Mw	28 Mw	Internal damage, crack on generator side	~ 0.006 inch (b)	< 0.002 inch
2	31 Mw	28 Mw	Internal damage, crack on generator side	~ 0.006 inch (b)	< 0.002 inch
3	42 Mw		No failure	0.004 inch	< 0.002 inch
4	35 Mw		No failure	0.004 inch	< 0.002 inch
4 (c)	42 Mw	35 Mw	Internal damage, cracks on both sides	0.010 inch	0.004 inch
5 (d)	39 Mw		No failure	0.021 inch	0.015 inch
5 (c)	45 Mw		No failure	0.021 inch	0.015 inch

- (a) Tilt measured as difference between maximum and minimum depth of the window surface with respect to the face of the adjacent flange
- (b) Not measured; estimated from measurements on later windows
- (c) Tilt exaggerated purposely
- (d) Plane of maximum tilt not through top and bottom of window as in all other tests (displaced by ~ 45°)



nominal to the true temperature is downward, indicating a very low ambient surface temperature for both windows and providing further evidence that multipactoring is absent.

(c) Surface Roughness Tests

Two additional AL-300 windows were tested in a continuing investigation of the possible effect of surface roughness on window performance. Another "roughened" aluminum window (240 microinch finish) was tested in the Model A geometry and survived peak power up to 74 Mw and average power up to 34 kw with only slight damage (small chips and a few small punctures). Again the window behavior was nearly indistinguishable from that of smooth disks from the same lot of windows.

A smooth window (35-40 microinch finish) was tested while mounted in a symmetrical matching structure (the same geometry now being used in the high vacuum ring tests). This window was operated at peak powers up to 100 Mw and average powers to 45 kw with no damage and no instability of the kind noted in earlier tests in this sequence. Further tests of smooth windows in this geometry will be performed.

(d) Other Ring Tests

A zirconia window (Norton Refractories) was tested in the symmetrical matching structure. Like the last zirconia window,\* it failed due to extreme central heating at a power of 10 Mw, 2 kw. These tests seem to confirm the inadequacy of this substance as a window material because of its poor thermal conductivity.

Another 1/16-inch quartz window was tested and failed at 39 Mw. Surface temperature was measured and was observed to reach a nominal value of 630°C. This window did not exhibit the cyclic heating and clean-up phenomena observed on the last quartz window tested;\*\* rather, the surface temperature was observed to rise gradually with increasing ring power until reaching the level at which breakdown occurred. Breakdown also appeared to be thermally dependent in that arcing did not begin immediately upon reaching the threshold of breakdown (originally 39 Mw), but only after the window temperature had risen to equilibrium. This temperature dependence no longer held true once the window surface had

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\* See "Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1963," SLAC Report No. 16, Stanford Linear Accelerator Center, Stanford University, Stanford, California (May 1963); p. 44.

\*\* SLAC Report No. 16, p. 44.

ruptured.

Two brazed-in Model A windows were tested and destroyed during an evaluation of the STL high speed camera. Failure levels were 52 Mw (with failure at a flaw in the seal) and 63 Mw (with failure in the form of punctures and a crack).

#### 4. Other Window Work

##### (a) High Speed Camera Evaluation

A high speed image converter camera was demonstrated by a representative of Space Technology Laboratories. It was hoped that the instrument would be able to photograph different stages in the development of the "glow" commonly observed on or around microwave windows as well as the arc discharges that occur during and after window failure. Unfortunately, the intensity of the window "glow" was not detectable by the camera during its maximum exposure time of 200 nanoseconds. An estimated two orders of magnitude more gain would be required before the camera could record this phenomenon. Several photos were taken of arc discharges at the window, which provided information as to the location in time and the duration of the event; otherwise the information provided by the high speed camera is equivalent to that available with standard photographic equipment.

##### (b) Grooved Window Dies

Die plugs for cold-pressing grooved alumina disks have been designed and fabricated. The design is similar to that used by Dr. Heil to produce the grooved alumina windows tested recently with Eimac; the only alteration is a curvature at the bottom of the window grooves. The curvature is intended to reduce the field gradient inside the ceramic at the bottom of the grooves, because this gradient is believed to be responsible for most of the punctures suffered by grooved alumina windows.

Windows formed in these dies are now on order from Wesgo and should be available for testing in late October.

## V. ELECTRONICS

### A. SUMMARY

The work of the Modulator, Light Electronics and Instrumentation and Control Groups is reported as a single Departmental endeavor. The work of the groups is discussed below, in roughly the order listed above; but where the work of the groups overlapped, the report is appropriately condensed.

The major accomplishments of the quarter have been on the preparation of a bid package for klystron-modulator procurement, the preparation of several design studies of trigger-system components, and the preparation of criteria for data handling for Central Control.

### B. MODULATOR SWITCH TUBES

The search for better switch tubes continued during this period. It tapered off because the modulators used for these tests were gradually removed for operation in other areas, leaving only Prototype No. 1 modulator.

Much operating data was obtained on switch tubes during this period, but little life data was acquired because so little time was available.

#### 1. GL-7890

The GL-7890 thyratron continues to be a very good prospect. The first pair of GL-7890's, which operated so well in Ling No. 11 modulator, was installed in Prototype No. 1 modulator. The tubes operated well for a total of 1505 hours, including the time they were in Ling No. 11 modulator. Most of this operation was at full power and into a water load. A small percentage of it was into a diode load, rarely exceeding 200 kv. The tubes are being sent back to the manufacturer to determine if repair is feasible. If so, the cost of keeping such tubes in their sockets might be reduced considerably. The replacement cost for the first pair of these tubes would be excessive in light of the operating budget for the two-mile machine.

A second pair of GL-7890's, obtained last June, has been operated in Ling No. 11 and Prototype No. 1 modulator for 589 hours total running time. They appear to be equally as good as the first set and are still

operating.

The Mark IV accelerator obtained six new GL-7890 thyratrons to replace the ignitrons in their RCA modulators. The Heavy Electronics Group tested these tubes individually before their installation in the Mark IV modulators. The data thus obtained was helpful in the specification writing for switch tubes, and indicated the characteristics to be considered in acceptance testing of switch tubes.

## 2. General Electric 7000

General Electric, in an effort to discover the cause of anode time delay variations, has loaned pairs of thyratrons for our experimentation. The tubes are all air-cooled and substantially the same, except that one type has a gradient grid (the 7000) and the other does not (the 7004).

The first tube tested was the 7000, H<sub>2</sub> filling, 33 kv anode voltage, 7 amp average current, and 100 amp rms ratings with a 400 cm<sup>2</sup> cathode area. One tube is capable of handling the modulator switching operation.

Inasmuch as it has no gradient grid, the 7000 operated as high as 40 kv but no higher. At this anode voltage it did not show long runs between kickouts. The anode time delay variations were about 400 nanoseconds maximum, which is too much. This tube was tested only about 24 hours to get an indication of its operating characteristics.

## 3. General Electric 7004

This tube is almost identical to the 7000, but with the addition of a gradient grid. The anode hold-off voltage was much better. The tube was operated as high as the power supply on the RCA modulator would go (46 kv). It ran 195 hours between kickouts at full power.

Its anode time delay variations were a maximum of 250 nanoseconds, which is almost one-half that of the single-grid version but still not good enough. This tube was run 791 hours before it was shipped back, still in good operating condition.

## 4. General Electric 7001

This hydrogen thyatron is a single-grid version, the forerunner of the Z-5212. It has a cathode area of 800 cm<sup>2</sup>, with 33 kv anode voltage, 8 amps average current, and 140 amperes rms current ratings. One tube can handle the modulator switching job.

As was found with the 7000 tube, the hold-off voltage on this thyatron is marginal. It would operate at 40 kv, but it did not run long between kickouts. Its anode delay time variations were not good, about 400 nanoseconds being maximum.

The tube was run for approximately 24 hours to get a feel for its operating characteristics.

#### 5. General Electric 7005

This thyatron is a gradient-gridded version of the 7001. Its ratings are the same as the 7001 except for a 50 kv anode hold-off capability. The anode delay time variations are extremely good (about 10 nanoseconds maximum).

It has had a total running time of approximately 450 hours as of the end of September and is still operating. Most of this operation is at full power and into a water load.

#### 6. M. O. Valve - E-2986

The E-2986 tube in the "purple coffin" modulator now has about 800 hours operating time on it, mostly below 19 kv power supply voltage with a klystron load on the modulator.

A second E-2986 tube was installed in the Ling modulator in the "tree house." This tube has operated approximately 100 hours with a klystron load and power supply voltages around 18 kv.

This tube is to be produced in Illinois by Warnecke Electron Tubes, Inc., under license from the M. O. Valve Co.

#### 7. Switch Tube Procurement

The switch tube problem has been a difficult one to solve, and because more tubes are needed to keep the test modulators operating, it was decided to procure them separately and supply the modulator fabricator with enough tubes to perform tests on production modulators. Specifications for such tubes were drawn up and have been approved by the AEC.

### C. MODULATOR PROTOTYPES

#### 1. Prototype No. 1

This modulator has been operating for approximately 1100 hours as of the end of September. Most of the operation has been into a water load;

two different diode loads were used, but they would not take full power. As of September 26th, a third diode had been placed in operation as a load for this modulator.

Much valuable experience and data have been gained from the operation of this modulator. Tests were run on: (1) ac line-current harmonic content as a function of LC filtering in the power supply output, (2) ac line-current start-up transients, (3) power supply output voltage transients as a function of start-up and load dropping caused by reducing the repetition rate or stopping triggering, (4) power supply efficiency, (5) modulator efficiency, (6) output pulse shape as a function of load impedance changes, (7) evaluation of charging and clipping diodes, (8) de-Q'ing, and (9) evaluation of our prototype pulse transformer tank and cables.

Working drawings based on Prototype Modulator No. 1, along with performance specifications on about 25 custom-made components in that modulator, were submitted to the AEC, mainly for approval of our procurement method. They were approved the latter part of September.

## 2. Prototype No. 2

A production-type cabinet and all the parts necessary to build this modulator were obtained. Our experience with Prototype No. 1 helped us to obtain better parts and to do a more efficient job in building the modulator. As of September 26, the modulator was very nearly completed.

## 3. De-Q'ing

The dissipative de-Q'ing circuit was improved during this period; a better charging choke with tighter coupling between primary and secondary was obtained. This enabled us to de-Q as much as 20% with an improvement factor of at least 10, e.g., if the power supply output voltage changes by 5% due to an ac line voltage shift, the modulator output pulse amplitude can be held constant to 1/2%.

We have had trouble with the silicon controlled rectifiers used as switching elements in this circuit. Proper heat sinking has helped, but the life of the silicon controlled rectifiers is still only a couple of hundred hours. Several new ideas to solve the problem are being worked on. New firing circuits for the silicon controlled rectifiers were designed. They improved the operation of the de-Q'ing circuit, but amplitude jitter is still present when de-Q'ing is less than 1/2%.

## 4. Charging and Clipping Diodes

During this period two sets of I.R.C. charging diodes and one

Westinghouse unit failed during operation. The main problem seems to be that these diodes are not large enough to handle the larger peak charging currents caused by de-Q'ing. The second prototype modulator will have larger diodes (IN1196A) on heat sinks. These diodes have worked well in all three RCA modulators. The Tung Sol clipping diodes have been troublesome in some of the Ling modulators and will be changed to IN1196A diodes.

#### D. MODULATOR PULSE TRANSFORMERS AND TANKS

##### 1. Pulse Transformers

To date, one manufacturer has been able to supply pulse transformers that meet SLAC requirements. Two transformers each from three other manufacturers have been tested. All have failed during life test under conditions of maximum power and voltage operation. The longest time to failure was 365 hours.

Because the pulse transformer problem is a difficult one to solve, it was decided to procure them early ourselves. Specifications were drawn up and approved by the AEC, and the bid package has been distributed to nine manufacturers.

##### 2. Transformer Tank

A modified pulse transformer tank with an integral oil expansion chamber has been designed and fabricated. Assembly will be completed and testing begun during the month of October.

Since the last Quarterly Status Report, there has been one major design change. It was decided that the coaxial capacity voltage divider that was part of the klystron socket corona shield would be abandoned, and a commercially available instrument substituted for it.

To date, the original pulse transformer assembly has 1031 hours of operation without fault. Seventy to eighty percent of this time has been at full power (67.5 kw) and at beam voltages up to 270 kv.

##### 3. Triaxial Cable

Procurement of a satisfactory triaxial input cable to transmit pulse power from the modulator to the pulse transformer is still a problem.

The only known commercially available triaxial pulse cable with suitable electrical ratings was obtained and put on test. This cable failed after three hours of full power operation. Several cable manufacturers have evidenced interest in the problem, but after receiving the requirements, they have declined to quote. A local consulting engineering firm designed and built a cable and connector assembly to SLAC specifications. This cable also failed after three hours' operation.

The best solution at the present time appears to be a commercially available special high-voltage coaxial cable. This cable has been converted to a triaxial cable by slipping a tinned copper braid over its outer jacket. Triaxial plugs and jacks for this cable have been obtained and the complete assembly is on test.

#### E. SUB-BOOSTER MODULATOR

Driver circuits on the sub-booster modulator were improved, making it possible to produce two identical flat-topped pulses spaced 20 to 100 microseconds apart. Rise time was reduced to 0.25 microsecond. Damped oscillations, which appeared on the top of the output pulse, were traced to the lack of a 50-ohm resistor between the voltage divider and the viewing cable.

Work has continued on the regulated high-voltage power supply. In parallel with this, specifications were drawn up and prices obtained from companies who are capable of building such units.

Internal arcing has occurred in many of the 4 PR 1000 tubes used as switch tubes in the sub-booster modulator. This problem has been traced to manufacturing trouble and will be rectified.

#### F. MEASUREMENT AND ACTUATION DEVICES

The technical requirements of the modulator-klystron protection equipment have been modified as a result of continuing changes in the design of the modulator. These changes have (1) eliminated the requirement for an overvoltage protective device, (2) altered the input signals to the klystron impedance fault detector (perveance monitor), (3) changed the sector reference supply for dc voltage control from 60 volts to 600 volts, (4) eliminated the possibility of having short (less than 1 second)



interruptions of klystron operation and (5) reduced the input trigger level from 100 volts to 50 volts. The first three changes have resulted from the adoption of the de-Q'ing circuit for regulation of the modulator output level. The fourth change was made as a result of experience gained in operating the prototype modulator, and the last from a desire to improve the trigger circuitry driving the modulator.

Although breadboards for the circuitry (for protection and control of the modulator) had been completed, further development will be undertaken after clarification of the new requirements resulting from the above modifications.

#### G. BEAM GUIDANCE AND MONITORING

##### 1. Beam Monitor

The resonant type of beam position monitor was tested using an actual electron beam on both the Mark IV and Mark III accelerators. In both cases, the objective was to correlate the electrical output from the sensor with the beam position, indicated by a fluorescent plate and TV camera.

The tests on the Mark IV accelerator were inconclusive because it was not possible to obtain a well-collimated beam; the beam cross section approximated that of the disk-loaded accelerator structure.

The Mark III experiments were carried out with a beam of smaller cross section. Two runs were made. In the first, the qualitative results were very good, although quantitatively the output signal obtained was about half that expected. The second run was made to discover the cause of this discrepancy, as it appeared that it might be explainable due to scattering of the beam before it reached the position sensor. Unfortunately, the results obtained were erratic because the beam intensity was fluctuating. Tests using a better-collimated beam will be carried out in the next quarter on the Mark IV accelerator.

Further work was carried out on broad-band position sensors. This concept will also be tested shortly on the Mark IV machine.

An investigation into the use of a number of possible types of microwave position monitors has been started in conjunction with the Microwave

Engineering group. An experiment in which the beam particle separator\* was used as a position monitor appears promising. A shortened version of this device is presently being constructed and will be tested soon. In addition, a position monitor based upon the separator described by Peter Phillips\*\* will be tested, as will a Saclay type of position monitor.

A beam intensity monitor suitable for incorporation in the accelerator structure has been fabricated. It was tested using a simulated beam, and its performance was as expected. It is hoped to test this soon on the Mark IV accelerator.

## 2. Degaussing

Work on the degaussing experiment is proceeding. This experiment will examine the efficacy of using degaussing wires alone, a magnetic shielding structure alone, or a combination of both of these in order to reduce the ac and dc magnetic fields at and near the accelerator axis so that the fields are equal to or less than some desired value. A flux gate magnetometer and two types of shielding material are on order and should be delivered soon. These two shielding materials were chosen because they do not saturate below a field strength of one Oersted. One type of shielding material has a relative permeability of between 6000 and 8000, the other of 25,000.

## H. THE TRIGGER SYSTEM

The overall functional specifications for the trigger system were issued during the past quarter. The design reports on the Master Trigger Generator and on the Main Trigger Line were completed. Design reports on the Sector Trigger Generator and on the Pattern Generator are in preparation. The prototype design of the Master Trigger Generator and Comparator was completed during the quarter; three generators and a comparator are ready for life test. A main trigger line is to be a 50 ohms,

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\* For description see O. H. Altenmueller, R. R. Larsen and G. A. Loew, "Investigations of traveling-wave separators for the Stanford two-mile accelerator," SLAC Report No. 17, Stanford Linear Accelerator Center, Stanford University, Stanford, California, (August 1963).

\*\* Peter Phillips, "The separation of high energy particle beams by microwave techniques," Ph.D. Thesis, Department of Physics, Stanford University, Stanford, California (November 1960)

1-5/8 inch diameter semi-flexible coaxial cable. The sampling devices to feed each sector trigger generator are still being investigated.

#### I. DATA HANDLING

The design criteria report for the Signal Battery System was approved with minor modifications, and a procurement specification is now in preparation.

Procurement specifications for the public address and paging systems have been approved by management.

Detailed technical specifications for the operational telephone system have been prepared for management approval.

A technical specification for the Cable Plant has been prepared and a purchase order issued for the inter- and intra-sector cables for Sectors 0, 1, and 2.

Design Criteria reports have been or are being prepared which describe the proposed features of the Data Handling sub-systems. These sub-systems are:

- Status Monitoring
- Analog Measurements
- Remote Control
- Beam Monitoring Data Transmission
- Beam Shut-Off Protection Network

Evaluation testing of various system and equipment designs was continued during the period. Extensive testing of time-division multiplexing equipment for status monitoring has been very satisfactory.

Equipment has been ordered for evaluating two different technical methods for remotely monitoring dc analog measurements.

#### J. CONTROL SYSTEM

In connection with an intensive review of the data transmission requirements for Central Control, an updated list of control signals was prepared. Six types of signals were recognized:

- (1) Binary status or go/no-go signals
- (2) DC analog measurements
- (3) 360 pps pulse-amplitude-modulated signal for beam monitoring

(4) On-off controls

(5) Positioning controls

(6) 360 pps binary pattern (gating) signals to trigger generators

The following number of signals of each type is required:

	<u>Status</u>	<u>Analog</u>	<u>P.A.M.</u>	<u>On-Off</u>	<u>Positioning</u>	<u>Pattern</u>
Per sector:	48	6	3	10	5	2

For injection, water towers, and other isolated points, the following signals are required:

	<u>Status</u>	<u>Analog</u>	<u>P.A.M.</u>	<u>On-Off</u>	<u>Positioning</u>	<u>Pattern</u>
From isolated points:	70	35	-	24	14	8
From the 30 sectors:	<u>1440</u>	<u>180</u>	<u>90</u>	<u>300</u>	<u>150</u>	<u>60</u>
Total:	1510	215	90	324	164	68

The above totals do not yet include signals for personnel protection interlocks, nor do they make any allowance for alignment of the accelerator or operation of the switchyard. However, the list is now believed firm enough to allow starting the design of the Control Console area.

#### K. OTHER ACTIVITIES

##### 1. RFI Monitoring

We are continuing the monitoring of the radio frequency interference background around the Test Stand area. Results have shown less RFI at the new Laboratory Test Stand area than at the earlier temporary site. This survey will be continued in all areas of the accelerator.

##### 2. Radiation Monitoring

Preliminary experiments with a "long-cable ion chamber" were undertaken, and costs were estimated both for long cable and for separate, smaller boxes along the tunnel.

##### 3. Test Stand Installation

The Ling PM67 modulators that were located in the klystron test area and window test area in the M-1 Building were moved into the test stand

areas 04 and 06 in the Test Laboratory. A wiring check and chassis clean-up were performed before the test stands were turned over for operation.

Test Stands 01, 02, and 10 are being reworked for thyatron switch operation. Test Stand 13 (Injector Test) has been installed, and wiring is continuing per the Microwave Engineering requirements.

#### 4. Beam Switchyard Energy Spectrum Analyzer

Checkout of the energy spectrum analyzer electronics was completed early in September. Initial tests on the Mark IV accelerator were begun (without beam) on September 6. Tests with beam were conducted for the first time on September 20. The electronics has been functioning satisfactorily, but due to the high noise levels, no significant test results have been obtained. Efforts are being made to increase system common mode rejection. It is also proposed that the electronics be moved to a lower noise environment.

## VI. MICROWAVE ENGINEERING

### A. INJECTION

#### 1. Injection Test Stand

The components for initial rf power and beam turn-on have been installed on the injection test stand, No. 13. Experiments are scheduled to start in October. The following major activities took place during the past quarter.

- a. All waveguide components were checked and are vacuum tight.
- b. The accelerator and the 0.75 c buncher were tuned and are vacuum tight.
- c. The portable shielding has been installed.
- d. The supports for all existing components have been fabricated.
- e. The vacuum manifold and pumps were installed and processed.
- f. The water cooling system was installed.
- g. The interlock wiring is close to completion.
- h. The inflection magnet with a fixed slit and foil windows on both the off-axis arm and the output arm is near completion.
- i. The Faraday cups, originally used on the Mark IV accelerator, are available.

As originally planned, the initial system will consist of an electron gun, a pre-buncher, the buncher and two-foot accelerator section, the spectrometer magnet, the complete waveguide circuitry, and a dry load to be supplied by the Mechanical Design and Fabrication Group. The beam analysis components (the beam viewer, the current monitor, the adjustable slit and the bunch monitor cavities) are either in the final design stages or are partially fabricated for installation. Completion of all wiring will take place during the next quarter.

#### 2. Electron Guns and Modulators

A design report for the injection test stand gun modulators, model 4-1, was published in August. This report is a brief review of the gun modulators being built by Manson Laboratories, Stamford, Connecticut. Immediately following, a preliminary design criteria report was published to cover the requirements of the final gun modulator,

model 5-1, to be used on the two-mile accelerator. The features which differentiate the requirements spelled out in these two reports are (1) remote operation of the modulators, (2) multiple beam operation, and (3) beam current stability. These features are not required for the test laboratory modulators but will be necessary in the final system.

An alteration was made in the differential pumping system installed on the Mark IV injector. A new manifold and an ion getter pump were installed. In addition, a toroidal beam current monitor with a sensitivity of 2 volts/amp was placed between the pumpout and the accelerator. The differential pumping maintains a vacuum of 1 to  $2 \times 10^{-7}$  torr in the gun region during accelerator operation. This is a factor of 10 better than the vacuum in the input waveguide to the first section of the accelerator. Additional pumping has improved gun emission. For example, on September 26 the gun was emitting up to 1.7 amperes of peak current at 25 watts of filament power. There is no sign of drooping emission at any filament power between 25 and 35 watts.

The beam analyzer has been mechanically completed, leak checked, and is ready for manual operation. The motors and readout transducers will be altered and installed in the next quarter.

The construction of the bakeout station is in progress and should be ready for processing guns during the next quarter.

In order to develop an in-house capability for designing electron guns, a computer program has been started for solving Poisson's equation and calculating electron trajectories, using a relaxation method. This calculation will include space charge effects, magnetic focusing and relativistic effects.

### 3. Off-Axis Inflection System

A preliminary design criteria report for the off-axis inflection system was published in August. The design of the magnets required for this system is presently underway in close cooperation with the Research Division. The system which was finally adopted has bending magnets with a 68 centimeter radius of curvature.

TABLE I  
CALCULATED PERFORMANCE OF OFF-AXIS INFLECTOR  
BEAM ENERGY: 25 Mev  $\pm$  5.0%

Parameter	Unit	Input	Output
x	cm	$\pm$ 0.50	$\pm$ 0.72
$\theta$	$\times 10^{-4}$ rad	$\pm$ 3.3	$\pm$ 5.41
y	cm	$\pm$ 0.50	$\pm$ 0.67
$\phi$	$\times 10^{-4}$ rad	$\pm$ 3.3	$\pm$ 3.37
z	mm	$\pm$ 0.80	$\pm$ 0.83

During the past quarter, it was decided to move the positron source from the 10th to the 11th sector. This means that both the compensating magnets and the momentum spectrometer will no longer have to pass the low-energy positrons.

## B. DRIVE SYSTEM

### 1. Overall Design of the Drive System

All basic design parameters for the drive system have been determined. The overall procurement status is outlined below.

- a. The design report for the main and sub-drive line systems was completed and distributed and the specifications were sent out for bid on August 29th.
- b. The design report for the varactor frequency multipliers was completed and distributed, the specifications were sent out for bids, and the bids were opened on September 4th. A selection is imminent.
- c. The main booster amplifier contract let to Energy Systems Incorporated (formerly Radiation at Stanford) on June 10th is in progress.
- d. The sub-booster klystron contract let to Eimac on July 19, 1962, is in progress and tubes continue to be delivered.
- e. The sub-booster modulator design and fabrication is being handled by the Heavy Electronics Group.
- f. The design report for the isolator-phase shifter-attenuator assemblies was completed and distributed; the specifications were sent out and bids were opened on September 11th. A selection will be forthcoming very soon.



## 2. Varactor Frequency Multipliers

Studies of the phase stability of varactor frequency multipliers as a function of input drive power have continued throughout the quarter. It has been found possible to minimize the phase variation by proper adjustment of the bias voltage. A waveguide phase bridge is being constructed to measure phase stability with an accuracy of  $\pm 0.1^\circ$ . This bridge will be used to continue in-house testing and in preparing for the acceptance tests of the final units. It is not practical to carry out life tests on varactor diodes in-house on a sufficiently large scale to obtain statistical information. However, two multipliers installed in the Mark IV driver have now been operating over 6000 hours with no malfunctions, and their behavior will continue to be observed in the future.

## 3. Main Booster Amplifier

The main booster amplifier, under subcontract with Energy Systems Incorporated, is undergoing final design and construction has started. A 476 Mc/sec, three-watt driver will be furnished by SLAC for the testing of this amplifier. In addition, SLAC will furnish a water load, a flow meter and the necessary thermometers. All of this equipment is either on order or available in-house.

## 4. Mark IV Driver

Overall operation of the Mark IV driver during the past quarter has been satisfactory. A single major failure took place and was remedied by replacement of a rectifier in the filament supply of the SAS-60 klystron.

## 5. Master Oscillator

Evaluation of frequency stability and remote operation requirements for the master oscillator has been more difficult than anticipated, and final performance specifications will not be completed until the next quarter. Specifications will then be sent out for a quantity of three units.

## 6. Test Stand Driver System

The second drive line system in the test stand laboratory has been installed and checked out. The system consists of two parallel 1-5/8-inch

rigid coaxial lines with directional couplers appropriately spaced. The two lines are insulated and a water line is enclosed within the insulation. Testing of this setup will allow further design evaluation.

#### 7. Group Velocity Measurements

The search for an improved method of measuring group velocity continued. The methods used to date, such as shorting the line and measuring the frequencies for a null at a fixed distance from the short, or measuring the phase shift of the incident wave through two consecutive couplers for several frequencies, have several limitations. The accuracy required is below the capabilities of the instrumentation. As the length of the lines is increased, the attenuation increases and the measurement becomes more difficult.

The method described below circumvents these difficulties. Two signals are propagated simultaneously through the test line. At the beginning and the end of the test line, a portion of the incident wave is fed to two mixers. Only the difference frequency signal from the mixers is used. The phase difference between the output of the two mixers is directly proportional to the group delay of the test piece. This method has the following advantages:

- a. It measures group delay directly.
- b. The physical distance between the two coupling points, and hence the length of the cables from these points to the phase bridge, is not critical because the frequency is low and attenuation is negligible.

An experiment was performed to verify the dependence of the group delay of the transmission line upon the electrical length between reflections. The experiment was done in waveguide by placing two obstacles (in the form of aluminum blocks) in two waveguide directional couplers. A length of standard S-band in series with a phase shifter was placed between these couplers, and the group delay of the assembly was measured at 2856 Mc/sec. A variation of 1 to 2.13 in the value of  $c/v_g$  as a function of phase was obtained.

An in-house model of a  $0^\circ$  and  $30^\circ$  phase shifter for positron acceleration was designed and constructed. An input VSWR of 1.05

was obtained in either position and the insertion loss could not be detected; the maximum VSWR at any position along the dielectric was less than 1.07. No error in resetability was found. The input and output flanges of the phase shifter are 3-1/8-inch EIA standard. A similar phase shifter in 1-5/8-inch line was constructed and is ready to be tested.

### C. PHASING SYSTEM

#### 1. Beam Induction Technique

It was decided to use the beam induction technique to phase individual klystrons. The reasons underlying this decision have been presented in the design criteria report, "Automatic Phasing System for High Power Klystrons." The final design report will be submitted for project approval early next quarter.

Basically, the rf detection system will use a pair of linear detectors terminating the E and H arms of the Magic Tee, with the rf reference and unknown applied to the colinear arms. A phase wobbler will shift the phase of the reference signal by  $180^\circ$  between pulses. With presently available thermionic detectors, a level variation of the unknown of 50 db results in an output modulated variation of less than 4 db. This system can be incorporated easily into an automatic control system. Experiments carried out on the Mark IV accelerator show that the system can phase a klystron over a large range of beam current with the same accuracy as the usual beam energy maximization technique, and it achieves this in considerably less time.

The intermediate frequency system proposed in the previous status report\* was abandoned after a preliminary study showed that a relatively constant IF power could be obtained, but that the change in the junction capacitance of the detectors resulted in significant phase errors.

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\*"Two-mile accelerator project, Quarterly Status Report, 1 April to 30 June 1963," SLAC Report No. 18, Stanford Linear Accelerator Center, Stanford University, Stanford, California (August 1963).

## 2. Programmer Design for Automatic Phasing System

The choice of the beam induction technique has considerably simplified the design of the programmer. A prototype programmer has been constructed and preliminary tests indicate that increased reliability and a decrease in the time required to cycle through one sector phasing operation are obtained. Final design reviews for the programmer will be held early in the next quarter, after which construction for the first two sector units will begin.

A test set has been built that will be used to check out production models of the programmer before installation in the sector control racks.

## 3. Sector Simulator

Measurements were made using the first design of the beam induction programmer. The errors of  $\pm 7^\circ$  in phasing were the same as those obtained in early experiments using the hybrid programmer. A large fraction of these errors is due to the design of the phase shifter and its brake. In September the complete sector simulator was moved from the temporary building to the Test Laboratory, at which time the system was overhauled. A new series of tests is being prepared using the sub-booster klystron to obtain power ranges comparable to those in the accelerator.

## 4. $360^\circ$ Continuous Phase Shifter

Neither of two design approaches for a  $360^\circ$  continuous phase shifter described in the last status report resulted in a satisfactory unit. The approach using two helical antennae had an insertion loss of the order of 10 db that could not be decreased; both electrical and mechanical considerations forced abandonment of the strip line approach. A third design has now been undertaken using the principle of the Fox phase shifter. This unit should be completed early in the next quarter, at which time a series of extensive tests is planned.

## 5. Momentum Spectrometer Design

The preliminary design of the momentum spectrometer associated with the main and off-axis injectors continued throughout the quarter. Each system contains an analyzing magnet, a secondary emission monitor, and a beam stopper. Considering the tunnel space available, it appears

that a magnet with a bending radius of 2.5 feet and a bending angle of  $30^\circ$  will be satisfactory. Such a magnet will require approximately 9 kilogauss for a 200 MeV beam. Detailed calculations for this magnet are now being done by the Research Division.

The temperature of the secondary emission monitors has been calculated to be below  $200^\circ\text{C}$  and hence no complicated cooling system should be required. Design details of this monitor will be undertaken with the assistance of the Research Division. The design requirements for the beam stopper are undergoing review and this work is scheduled to proceed during the next quarter.

#### 6. RF Cavity for Drift Section

A model of the rf cavity has been made for the mock-up of the standard drift section. This model consists of the rf cavity together with its associated flanges, waveguide and cable transition.

#### 7. Beam Position Monitor

At the request of the Light Electronics Group, investigation of microwave beam position monitors was begun. Three types of monitors are being investigated.

- a. A  $\text{TM}_{012}$  mode rectangular cavity
- b. A three-cavity version of the particle separator developed at SLAC\*
- c. A four-loop monitor described by Bergere, et al.\*\*

Models of the first two types have been built and tests on the Mark IV accelerator were started. Results will be presented in the next status report.

### D. GENERAL RF STUDIES

#### 1. Beam Breakup Studies

The beam breakup studies announced in the previous status report were performed on the Mark IV accelerator. By injecting power at C-band frequencies into the output coupler of the first (constant impedance) accelerator section, it was possible to break up a beam of

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\*O. H. Altenmueller, R. R. Larsen and G. A. Loew, "Investigations of traveling-wave separators for the Stanford two-mile linear accelerator," SLAC Report No. 17, Stanford Linear Accelerator Center, Stanford University Stanford, California (August 1963).

\*\*R. Bergere, A. Veyssiere and P. Daujat, "Linac beam position monitor," Rev. Sci. Instr. 33, 1441-1449.

approximately 64 milliamps of peak current. The accelerator was operating at 2857.448 Mc/sec. An 800-watt peak power signal at 4326 Mc/sec was capable of splitting the electron beam along the axis of the couplers sufficiently to deflect more than 20% of the beam current into the upper and lower edges of the accelerator disks. As expected from theory, it was found that as the beam current was decreased, the power required to produce the above deflection increased significantly. Although accurate results were difficult to obtain with the present set-up for a current of 46 milliamps, for example, the maximum available power from the C-band generator (about 1 kilowatt) was no longer sufficient to deflect the beam. The total current available from the machine was unfortunately not large enough to create any regenerative self-exciting beam breakup. However, upon installation of the new constant gradient accelerator section in the Mark IV accelerator, it will be possible to get a qualitative comparison between the old and new sections as to their susceptibility to beam breakup. Of course, a much higher threshold of required C-band power is expected because the modular dimensions of the new sections are no longer constant.

## 2. RF Particle Separator

This program continues to be carried out in cooperation with the Research Division and all information on this subject is reported in the section pertaining to that division. A report entitled, "Investigation of Traveling-Wave Separators for the Stanford Two-Mile Linear Accelerator," was presented in August at the Dubna Conference on High Energy Accelerators, Moscow, U.S.S.R.

## 3. Measurements of Transverse Shunt Impedance

As reported earlier, the main difficulty in measuring the transverse shunt impedance associated with deflecting structures, beam positioning monitors, etc., comes from the fact that the measurement of the space harmonic component of the fields as a function of radius is hard to obtain. A more systematic method is being developed which uses a set of micrometers to measure the radial distance accurately, both for the dielectric rod used to obtain the total shunt impedance and for the bead required to obtain the field variation along the z-axis

and variable radial distances. In addition, a small computer program has been set up to feed in the experimental results and obtain the values of the fundamental space harmonic amplitude  $a_0^2 / \sum a_n^2$ .

## VII. SYSTEMS ENGINEERING AND INSTALLATIONS

### A. ACCELERATOR RESEARCH AND DEVELOPMENT

#### 1. Vacuum System

##### (a) Gauge Evaluation

Additional gauges and power supplies from three manufacturers were received for evaluation and tested. Readings from gauge to gauge varied by a factor of three. A four-channel high voltage power supply is in fabrication and will be used for testing gauges on the ion-pumped test dome.

##### (b) Valve Evaluation and Test Program

The 6-inch prototype valve was completed and appears to meet the design criteria established in the large valve development program. Two small bakeable all-metal valves furnished for evaluation were tested, found to be defective, and returned for replacement.

##### (c) Roughing Systems

The turbomolecular pump installed in the Test Tower was operated successfully during this quarter. The proposed Welch 1000 liters/sec turbomolecular pump that had been considered as a possible roughing system for the accelerator will not be available until 1966, which diminishes the possibility of considering this type of pump at present. Cryosorption pumps will be tested in October.

##### (d) Vacuum Piping

Outgassing studies continued on additional samples of stainless steel pipe. An electro-polished pipe run through the entire heat processing cycle gave a final outgassing rate of  $5 \times 10^{-12}$  torr-liters/sec/cm<sup>2</sup>, which was slightly higher than the rate of all other samples. Pipe samples were obtained from one manufacturer; one piece was cleaned by glass bead honing, and the second was chemically cleaned. The glass bead honed pipe based out at less than  $1 \times 10^{-13}$  torr; the chemically cleaned sample based out at about  $2 \times 10^{-12}$  torr-liters/sec/cm<sup>2</sup>. An interesting observation was that after exposure to air (following bakeout and subsequent pumping) both samples based out at very nearly the same rate of



$5 \times 10^{-12}$  torr-liters/sec/cm<sup>2</sup>.

(e) Mark IV Program

Getter-ion pumps are operating satisfactorily on the Mark IV accelerator. The high vacuum valve over the upstairs diffusion pump was modified to incorporate a Viton seat to provide reliable closure of the valve.

(f) Purple Coffin Test Stand

Copper outgassing rates have been measured as a function of processing time and storage conditions.

After 23 days under vacuum (except for 24 hours at nitrogen and up to  $10^{-4}$  range from water load leak) and 44 hours of rf processing, the measured outgassing rate of copper dropped from  $5 \times 10^{-11}$  torr-liters/sec/cm<sup>2</sup> to  $2 \times 10^{-12}$  torr-liters/sec/cm<sup>2</sup>.

To establish some basis for measurement of the cleanliness of the pipe from a microwave viewpoint, the time required to reach 15 kw while keeping waveguide pumpout pressure in the  $10^{-7}$  range was used.

During the tests the outgassing rate was continually dropping. However, the time required to reach 15 kw did not drop in any consistent manner. After a 24-hour letup to nitrogen, the highest outgassing rate ( $2 \times 10^{-10}$  torr-liters/sec/cm<sup>2</sup>) was accompanied by a processing time of 10 minutes, whereas after four days (at less than  $5 \times 10^{-8}$  torr) the rate was  $8 \times 10^{-12}$  torr-liters/sec/cm<sup>2</sup>, while the time to reach 15 kw was five hours. There seems to be no direct correlation between outgassing rates and gas burst behavior of a pipe during rf processing.

(g) Test Tower

Full power single disk-loaded waveguide tests were started, first with the waveguide pump blanked off at the Klystron Gallery floor, then with blank-off removed. There was no appreciable difference in performance, except that at the unblanked pumpout the pressure was a factor of 2 to 4 lower than with the blanked pumpout.

The vacuum system was separated from the copper in order to install Test Tower Stage III waveguide configuration. The outgassing rate of vacuum stainless steel alone was  $1.4 \times 10^{-12}$  torr-liters/sec/cm<sup>2</sup>, whereas the average rate for copper and stainless steel just before letup was  $2.2 \times 10^{-11}$  torr-liters/sec/cm<sup>2</sup>.

## 2. Supports

A design for the inter-girder connection was approved in July and the 24-inch o.d. aluminum support girders were received. Girder connection components and the 24-inch pipe were fabricated into two 40-foot and one 10-foot support girders. The assembly is completed except for the bellows that effect the inter-girder vacuum seal. Early tests indicated that the overload shear pin device was inadequate; it was replaced by a member that fails in tension, and the design is being evaluated. The klystron support frame mockup has been completed except for the dummy load supports, which are now being fabricated.

## 3. Alignment

Final evaluation of the alignment system was completed. Work in the Brisbane Tunnel is nearing completion. An electrically-driven vibrating scanner is being evaluated and the possibility of using a high power 1/2-inch excursion speaker is being studied. Both these methods have the advantage of variable scanning amplitude while the alignment observations are being made. A computer-designed grid will be evaluated at the Brisbane Tunnel. An off-the-shelf optical sinusoidal scanner is also being evaluated.

## 4. Cooling Water

Corrosion test equipment has been installed in the Test Laboratory. All loops have been flushed out, chemically cleaned, and purged of contaminants. The purity of available makeup water is not adequate, and steps are being taken to obtain satisfactory water so that testing can begin.

# B. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

## 1. General Design

### (a) Design Coordination

Detailed review of drawings and specifications for the water, vacuum, and electrical subcontract bid packages is underway. Definitive layout drawings are continually being updated to reflect changes in size and location of equipment.

A full scale mockup of a standard drift section is being built for support tests and evaluation. It will also be used to firm up arrangements of components and connectors to be mounted on the drift tube.

(b) Standards and Specifications

Updating of standards continues. Twenty-nine modulator component procurement specifications were prepared. Data sheets covering electronic components and mechanical hardware have been prepared for distribution.

(c) Model Shop

Full size models of the drift section components are being prepared.

A 1-1/2-inch = one foot (1/8-th scale) model of four bays of the Klystron Gallery showing typical penetration and equipment arrangement is being prepared, together with a 3/8-inch = one foot full sector model that will be used for bidder information.

2. Installation Drawings

A report describing the installation drawing program was issued for Center information in July.

Drawings are 77 percent complete for inclusion in bid packages for vacuum, cooling water systems, and electrical services installation sub-contracts.

3. Vacuum System

Getter-ion pump specifications were approved by the AEC and issued for bids.

Specifications for cold cathode gauges and power supplies and for manually operated 3-inch and 6-inch valves are being prepared for project review.

Specifications for the installation of the vacuum system for the two-mile accelerator are underway.

4. Supports

The bid package for the support girder pipe was approved by the AEC and is out for bids. The specification for the klystron support frame is underway; final details are being added to the drawings.

#### 5. Alignment

Cost estimates for the various phases of remote jack actuation were prepared and are being reviewed. A prototype mechanism will be fabricated for the support girder mockup. The design of the monument-supported target is well underway. The target has been reduced to a 6-inch square because motion of the target inside the support girder is limited to plus or minus one inch.

#### 6. Cooling Water

The circulating pump and heat exchanger technical specifications were prepared, reviewed, approved by the AEC, and sent out for bids in August, and contracts were awarded to low bidders in September.

A decision was made to incorporate all cooling water work (piping, instruments, insulation) in one bid package. Technical specifications are underway for the cooling water installation subcontract.

#### 7. Electrical Services

The subcontract for variable voltage substations was awarded to General Electric.

A preliminary draft of technical specifications for the electrical services installation bid package has been issued for project review and comment.

#### 8. Auxiliary Machine Shielding

A report covering requirements at accesses for personnel, equipment, and accelerator services was issued.

### C. ACCELERATOR INSTALLATION

#### 1. Test Stands

All EDI work on test stands has been completed. The subcontract for Phase II work was awarded in July and the work completed in September.

#### 2. Equipment Procurement, Installation, and Testing

Equipment procurement for the accelerator is underway, and delivery schedules are being prepared in accordance with the Accelerator Housing and Klystron Gallery completion schedules. Plans for complete installation and testing within Sectors 1 and 2 are underway.

## VIII. MARK IV PROGRAM

### A. OPERATION

This quarter was a transition period, during which it was evident that the activity at the Mark IV accelerator had become largely that of machine use, rather than installation and trouble shooting. Nearly every item of experimental work listed in the preceding quarterly report was engaged in to a substantial extent. The sections of this report devoted to other SLAC groups should be referred to for details of the experiments and their results. Of particular note was the work done with the microwave particle separators.

The Mark IV accelerator has been running smoothly at a power level satisfactory for the experiments being performed. However, the full power ratings for Stage II of the two-mile machine have not yet been reached. The operation appears to be satisfactory at 360 pulses per second at klystron voltages up to 200 kilovolts, although the pulse rate has normally been held at 180 pulses per second or less due to marginal cooling of klystron No. 2 and to excessive shut-offs due to gas burst fault signals. The major improvement in machine operation during this quarter has been in the essentially complete elimination of shut-offs due to switch tube hold-off failures.

### B. MACHINE MODIFICATIONS

Thyratrons (Type 7890) were installed in the Mark IV modulators. The entire effort required nearly four weeks. In the period of almost three weeks that remained in the quarter, scheduled experimental operations were resumed, and the machine ran with virtually no trouble due to the modulators.

A larger water pump and motor were delivered and installed, but the system performance was not improved. An investigation is underway to determine the reasons, and it is expected that minor piping changes or, possibly, pump modifications will clear up this anomaly.

The injector vacuum system was improved by the addition of a 50 liter/second ion pump and a vacuum pumping restriction between the injector and the main machine vacuum to prevent possible higher pressure in

the main system from appreciably affecting the injector pressure. A non-intercepting (toroidal) beam current monitor was installed in the injector vacuum space to monitor the pulsed beam current leaving the injector. These modifications were made by the Injection Group.

Rework was completed on the large vacuum valve between the standby diffusion pump at the klystron and the ion pump. The diffusion pump has been retained in the system for emergency use and for leak checking access.

#### C. PROGRAM FOR THE NEXT QUARTER

The various technical and research groups in SLAC have requested sufficient use of the Mark IV accelerator that operating schedules have been set up for substantially all of the two following quarters. It is planned to continue operating two eight hour shifts per day, five days per week.

The schedule allows a total of five weeks during the next quarter for installation work on the machine. New acceleration sections, directional couplers, transmission waveguide components, waveguide vacuum valves, and vacuum system connection components, along with new beam component support stands, alignment devices, and high power collimators, will be installed during the first part of the next quarter.

A further shutdown of two weeks at the end of 1963 will be available for installation work that will have developed by then, including the installation of an acceleration section with an axial magnetic field produced by solenoid coils. This section will be placed in the position next to the injector, and its use should effect improvements in electron beam capture, beam optics, and efficiency of transmission of the beam.

A current-regulated solid state power supply has been ordered, and it is expected that this unit can be delivered and put into use during the next quarter.

A cold cathode vacuum gauge has been received and will be mounted in the accelerator for evaluation. This gauge will be placed on one arm of a tee and a Bayard-Alpert type gauge will be on the other arm so that comparisons can be made.

Eight new vacuum gauge amplifiers are now on hand and will be placed in service as soon as they can be modified electrically to suit the special requirements of the Mark IV system.

The lower control room, which has been used for storage since its use was discontinued some years ago, will be set up as an experimenter's position. This will provide relief from overcrowding in the main control console area, and will also reduce experimental problems due to electrical noise interference.

It is planned to rearrange electronic equipment racks in the main control area to provide more space for experimenters and their equipment. This is a considerable job and may not be accomplished during the next quarter.

An internal system of communications incorporating both loudspeakers and telephone-type equipment will be installed for safety warnings and for use during installation and running of experiments.

The closed circuit television equipment will be expanded and improved.

Solid state diode rectifier stacks have been received and will be installed in high voltage power supply No. 2. This will make possible the operation of each klystron at as high a voltage as possible without regard to limitations of the other.

Klystron No. 2 does not have high enough collector water flow and will be replaced by a new klystron, which should also have a higher voltage rating.

## IX. RESEARCH DIVISION

### A. TARGET AREA

Planning of the Target Area, defined as the complex of buildings, yards and utilities situated downstream of the end of the accelerator proper, has begun, and several of its main features have been decided upon. See Fig. 15.

Neglecting the beam switchyard, which is in a more advanced stage of design and which is reported on separately, some of the main features of the Target Area are summarized below.

Five beam lines have been adopted, of which two (beams A and B, leading to the corresponding End Stations) will be fully developed from the time of beam turn-on; a third beam line is the undeflected beam (to be used for weak interaction physics with neutrinos and muons); a fourth beam line (beam A') is visualized for future development of the End Station A area; the fifth beam line is a parasitic gamma-ray beam compatible with most of the experimental work of End Station A.

Both end stations will incorporate 2 feet of concrete shielding in their walls and roof; their internal dimensions will be 125 x 200 feet for A, and 75 x 150 feet for B.

The total electric power to the Target Area during the early stages of operation will be 33 MVA, of which some 22 MVA will be available to the experimental equipment in or around the end stations. A water cooling system capable of dissipating 30 Mw will also be provided. A summary of the criteria to be followed in the design of all Target Area utilities has now been prepared.

### B. MAGNET DEVELOPMENT

#### 1. Beam Switchyard Magnets

##### (a) $3^{\circ}$ Bending Magnets and Power Supplies

Design is finished and specs were written. Bids for a prototype magnet have been received.

Two power supplies for 100 volts and 1000 amps are built, and one of these has been delivered to SLAC. Tests concerning current regulation, stability, etc., are planned and will start shortly.



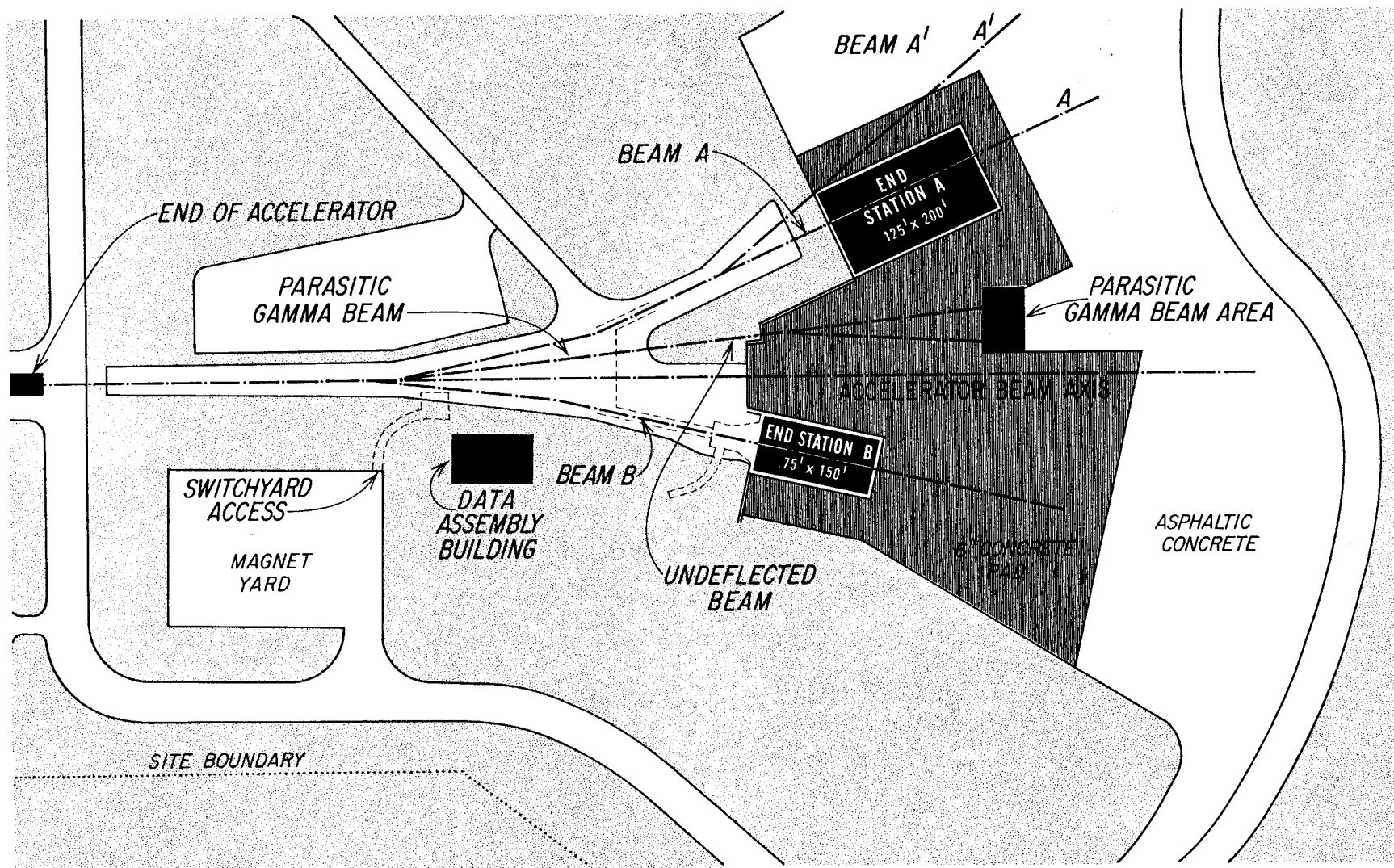


FIG. 15--Schematic drawing of the target area.

(b) Symmetry Quadrupole

The design has been finished and the specs written. The bids concerning one prototype have been received and evaluated. Several small changes in the design are being considered, for economic reasons. The delivery schedule for this magnet is not tight.

(c) Switchyard 8-cm Quadrupoles

The prototype of the magnet will soon be ordered.

(d)  $0.1^\circ$  Pulsed Magnet

The prototype of the pulsed magnet will soon be contracted for. All work concerning water-cooled cables, lamination, forms, etc., has been finished and specifications written.

(e) Steering Magnets

The dc and pulsed steering magnets, which will be placed in the beam area between the accelerator and the beam switchyard, have been designed. Normally the pulsed steering magnets (correcting the beam position in horizontal and vertical planes) will be operating. In emergency cases the dc magnets will be switched automatically as they give the same correction. The magnets are located in one of the last drift sections of the accelerator.

(f) Emergency Magnets

In case of failure in the pulsed magnets (d), two  $0.25^\circ$  dc emergency magnets are foreseen on each side of the pulsed magnet along the beam. The emergency magnets will be switched on automatically when a failure occurs in the pulsed magnet.

The design of these magnets is finished and the drawings are in preparation.

## 2. Quadrupole Triplets and Power Supplies Along the Accelerator

As stated in the last report, a set of one quadrupole triplet per drift section has been foreseen along the accelerator. The triplet is designed, the specification written and approved, and the triplet will be ordered in November 1963.

One quadrupole was built at SLAC and magnetic measurements have been conducted. The tests are not yet finished.

It is planned that a mock-up drift section will be built. In this

mock-up a set of triplets and steering magnets will be installed.

The purpose of this triplet is to permit measurement of both the magnetic center and the higher harmonics. The triplet is now in the manufacturing process.

The specifications for a power supply of 6 amps and 32 volts are written. A schematic diagram showing the triplet and power supplies is shown in Fig. 16.

### 3. Magnets for the Injector

At least two electron sources are planned for the two-mile linear accelerator. The basic requirement of the off-axis inflection system is to take the 25 MeV beam from the injection system and bend it through  $45^\circ$  without in any way degrading the quality of the beam. The arrangement of magnets worked out by the injector group is given in Fig. 17. Two types of specialized magnets are used in the system, as follows.

#### (a) Quadrupoles

The beam passing through the quadrupole is very flat and about 13.5 cm wide. A 10 percent hexopole field must be superimposed on the quadrupole field in the horizontal magnet plane. Calculation of this magnet is somewhat complicated because any asymmetry in the magnet to produce a hexopole field generates a dipole field. However, a calculation method was developed, and the magnet is in the design stage.

#### (b) Bending Magnets

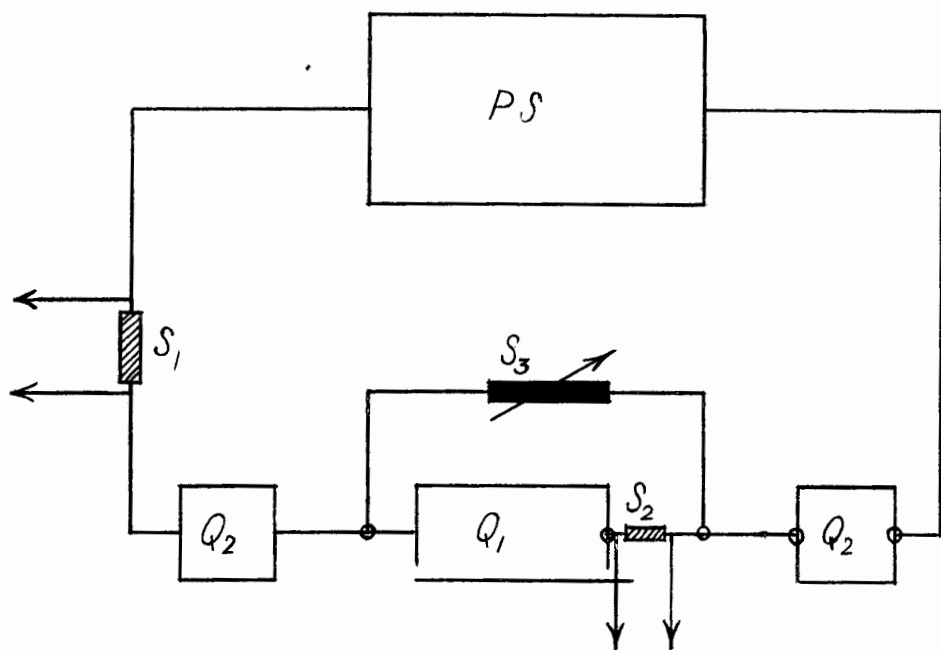
A prototype bending magnet with a rotating pole face is foreseen. The magnet has been calculated and is in the design stage.

### 4. Cryogenic and Superconductive Magnet Research

The Colin E. Little liquifier has arrived. Some of the dewars and equipment have been purchased.

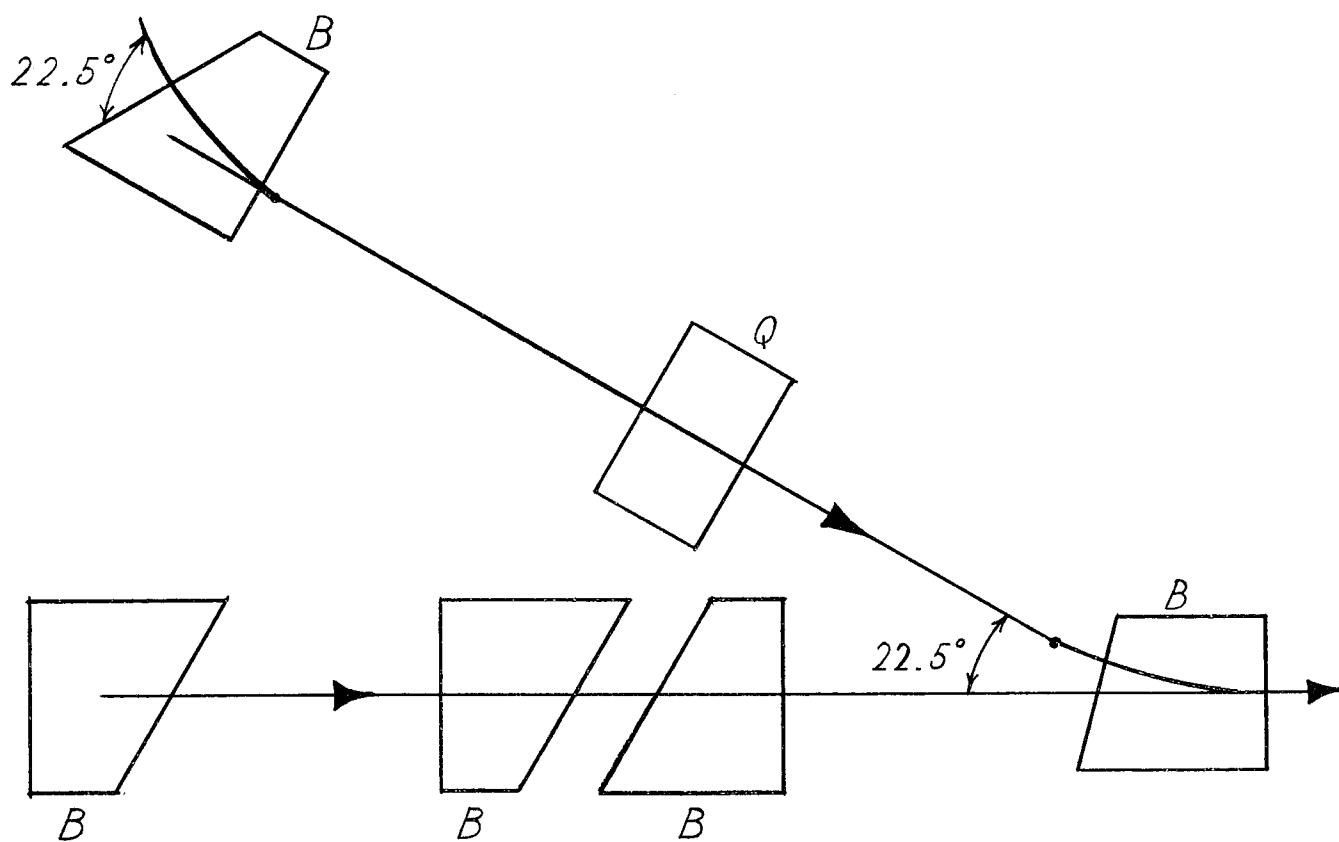
We are planning and working on radiation tests on superconductive wires and magnets. The design of a dewar suitable for cooling superconductive wire that will be radiated is in progress. Another dewar allowing the exchange of different superconductive magnets is also in the design stage. Both dewars are equipped with thin stainless-steel windows that allow the beam to hit either the superconductive wire or the magnet.

Radiation tests on a conventional superconductive magnet are in



PS POWER SUPPLY 6 AMPS, 32 VOLTS  
 Q<sub>1</sub> MIDDLE QUADRUPOLE  $\ell \cdot \frac{\partial B}{\partial X} = 2000$  GAUSS  
 Q<sub>2</sub> SIDE QUADRUPOLE  $\ell \cdot \frac{\partial B}{\partial X} = 1000$  GAUSS  
 S<sub>1</sub>, S<sub>2</sub> CURRENT MEASURING SHUNTS  
 S<sub>3</sub> CURRENT ADJUSTING SHUNT

FIG. 16--Schematic drawing of the quadrupole triplets and power supplies for one drift section of the accelerator.



*Q* = QUADRUPOLE HEXOPOLE COMBINATION  
*B* = BENDING MAGNETS

FIG. 17--Arrangement of quadrupole and bending magnets for the injector.

preparation; preliminary tests have been conducted.

#### 5. Radiation of Insulation

The coils of the beam switchyard magnets will be subject to severe irradiation. A number of insulation materials have been tested on the Yale University linear accelerator. The highest integrated radiation dose hitting insulation was  $3.5 \times 10^{13}$  ergs/gram. A glass fibre impregnated with a modified epoxy was mechanically damaged about 90 percent, but electrically showed no change from its original condition.

Insulation plates with very high alumina content (special development) were also subjected to radiation up to the total level of  $10^{12}$  ergs/gram integrated value.

Compared to conventional insulation, the epoxies chosen appear to be better by a factor of about 300, in resistance to radiation damage.

### C. MAGNETIC MEASUREMENTS

#### 1. Triplet Measurement

To accomodate the small bore of the machine triplets, miniaturization of all quadrupole test devices is in progress. This includes a magnetic center-locator (described in this report), a special set of coils for harmonic analysis, and an effective-length measuring device.\* Actual measurement of the prototype quadrupole has begun with field mapping, effective length measurements, and harmonic analysis.

#### 2. Harmonic Analysis of Quadrupoles

Study has been progressing in the area of the correlation of quadrupole quality with its multipole components. Various coil configurations have been used with the idea of suppressing or promoting a given multipole component. Also, various materials for fabricating the coils have been used to determine the best one for our purposes.

#### 3. Integrators

Two volt-second integrator systems have been assembled for use with flipping-coil magnetic measurement devices. Both are at least as good as

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\* For description see "Two-mile accelerator project, Quarterly Status Report, 1 April to 30 June 1963," SLAC Report No. 18, Stanford Linear Accelerator Center, Stanford University, Stanford, California (August 1963).

1 part in  $10^4$  and have a print-out feature for quick reading. One system uses a Miller integrator read-out with a digital voltmeter that drives a printer. The other system employs a voltage-to-frequency converter and a frequency converter. It also has digital read-out and drives a printer.

#### 4. Temperature Measuring Device

A semi-automatic temperature measuring device to be used in measuring the magnets has been designed and partially assembled. It will use thermistors as sensors; the resistance and temperature will be read out on a digital ohmmeter and then fed to a printer which automatically indexes the measurement and records the temperature.

#### 5. Magnetic Center Locator for Quadrupoles

The instrument described previously\* has been redesigned with many improvements and has now been tested again. It was found that the magnetic center of a quadrupole can be determined to within  $\pm 0.001$  inch. At present a new device is being built for use on the prototype magnets. Also, a miniature device is being built for use with the triplet quadrupoles.

#### 6. EMR

The helix slow-wave structure and its associated feed and matching structure have been fabricated. Resonance signals with greater than five to one signal-to-noise ratio have been observed in pulsed fields from 1.4 kg to 2.1 kg (3.95 to 5.85 gc). Usable signals have been observed with thirty feet of coaxial cable between probe and electronics.

#### 7. Gated Integrator

A new design of the ac integrator has been fabricated and tested. The new integrator is free from repetition rate effects, and harmonics generated due to non-linearity in the equipment are down at least 75 db at 1000 cycles.

#### 8. DC Integrators

Design and testing of the dc Miller integrators are complete; linearity and absolute stability of one part in 7000 have been achieved under normal

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\* "Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1963," SLAC Report No. 16, Stanford Linear Accelerator Center, Stanford University, Stanford, California (May 1963).

operating conditions. An integrator using a voltage-to-frequency converter with a reversible counter has been partially tested. Tests presently indicate that an absolute accuracy of 0.02 percent is easily achievable at somewhat lower cost than the Miller integrator scheme. Testing will continue.

#### 9. Pulsed Magnet Pulser

The prototype of the magnet pulser is under construction. The main capacitor bank has been received, given preliminary tests, and installed in the prototype. The design for the drivers of the main switch tubes has been completed. A "Q-spoiling" network has been designed to regulate the amplitude of the current pulse and is presently being tested for accuracy.

### D. BEAM SWITCHYARD INSTRUMENTATION AND CONTROL

#### 1. General Aspects

Because of high radiation levels in the beam switchyard, access will be prohibited when the beam is on and restricted for long periods after the beam has been shut down. Therefore, auxiliary instrumentation and apparatus will be placed in a separate building to protect it from radiation damage and to make servicing under these circumstances possible. The auxiliary apparatus consists of power supplies for the magnets, vacuum equipment, signal amplifiers for the various monitors, beam observation and steering equipment, etc. The building is separated from the switchyard by about 40 feet of earth shielding, and only one tunnel and a number of penetrations are planned between the two locations for signal cables, power cables, cooling water, and other connections. A part of the building will serve as a local control room for the switchyard.

The layout described above and the fact that the equipment in the beam switchyard is spread out over a large area require a complicated cable system. The expense of the cable plant is increased by the fact that special cable insulation (e.g., magnesium oxide) is required in the lower part of the double-decked switchyard structure. Alternative solutions for this cable plant have been studied, taking into account the requirements for water connections, vacuum pipes, etc., and considering



the location for the building either on top of the earth shielding or off to the side. A solution with the building on the earth slope at the north side seems acceptable, particularly because of the favorable time schedule for construction.

## 2. Components

### (a) Beam Spectrum Monitors

We intend to place in each of the deflected beams two types of spectrum monitors. The first is a high-resolution analyzer ( $\Delta E/E = 0.1$  percent) placed before the slit. This analyzer has been described in an earlier status report;\* it covers an energy range of  $\pm 2$  percent  $\Delta E/E$  for beam A, and  $\pm 6$  percent  $\Delta E/E$  for beam B. Because the energy fluctuations can be larger than these limits when the beams are being set up, we will supplement the high-resolution analyzer by a rough spectrum monitor. This monitor will be placed in front of the first quadrupole lenses, and will cover  $\pm 8$  percent  $\Delta E/E$  with a resolution of 1 percent  $\Delta E/E$ .

Initial tests have been made at the Mark IV accelerator with a prototype of the high-resolution analyzer, including the display electronics. Some improvements have been found necessary in the support for the secondary-emission foils before tests can be continued. When this prototype is working properly, we plan to include this instrument on a long-term basis, in the control console of the Mark IV accelerator for evaluation and for use as an analytical tool for this accelerator.

Mechanical design of the rough spectrum monitor will be very similar to a half section of the high-resolution spectrum analyzer. A simple display system is being developed for this monitor using lamps which show in percentage the energy deviation of the beam.

### (b) Beam Current, Beam Position, and Beam Profile Monitors

The characteristics of the beam monitors for the switchyard are somewhat different from those of the monitors along the accelerator in that, in general, a greater precision is needed, a greater aperture is required, and more care must be taken of damage by radiation and disturbance by scattered charge.

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\* SLAC Report No. 16, op. cit., p. 70.

Several principles for these monitors have been under consideration: electrostatic, electromagnetic, microwave cavities, synchrotron light from the magnets, secondary emission of foils, de-excitation light of a residual gas, and others.

The most promising technique for beam current monitoring seems to be a current transformer and, at some positions, a microwave cavity. For beam position monitoring, the use of synchrotron light from the pulsed magnet, the quadrupole lenses, and the bending magnets seems promising, along with a microwave cavity and differential secondary-emission foil monitors.

A promising technique for a beam profile monitor has not yet been found, although several ideas are being considered.

Some experimental work was done in the past quarter to test these techniques at the Mark IV accelerator, and it will be continued during the following quarter.

### 3. Control Procedures for the Switchyard

A study has been initiated to establish the procedures of setting up and handling three simultaneous beams for the three experimental end stations. This study will list every detail involved in the switchyard, and all interactions with the accelerator and end stations. As a second stage to this study we will also consider to what extent the use of automatic data-handling equipment for the control procedures is advisable or even necessary.

## E. EXPERIMENTAL PHYSICS

### 1. 16 to 25 GeV/c $\pi^-$ and Protons into the BNL 80-inch Hydrogen Bubble Chamber

J. Ballam, M. Kreisler, F. Martin, W. Panofsky and M. Perl. A proposal has been made to BNL for the setting up and running of a high energy 16 to 25 GeV/c  $\pi^-$  and proton beam into the new BNL 80-inch hydrogen bubble chamber. This is the first very high energy exposure to be prepared for a very large bubble chamber and a very large amount of new data is expected. The proposed beam is now being designed, and will be an unseparated beam compatible in its position with the existing lower energy separated beam.

2. Large Angle and Very Small Angle  $\pi^- + p$  Elastic Scattering at 3.7 BeV/c

M. Perl (in collaboration with E. Marquit, D. Sinclair, B. Roe, and J. VanDerVelde at University of Michigan). Pictures already taken in the BNL 20-inch hydrogen bubble chamber are being analyzed very carefully for large angle and very small angle  $\pi^- + p$  3.7 BeV/c elastic scattering.

3. Polarization in Proton-Proton Elastic Scattering

M. Perl (in collaboration with M. Longo and L. Jones at University of Michigan). A counter experiment to measure the polarization of the recoil proton in proton-proton elastic scattering from 0.7 to 3.0 BeV (kinetic energy) has been constructed, and was calibrated at Carnegie Tech in August. The experiment is scheduled to be carried out at the Cosmotron at the end of 1963 or beginning of 1964.

4. The Reaction  $p + p \rightarrow d + \pi^+$  and Total Cross Section for Production by  $p + p$

M. Perl (in collaboration with O. Overseth and L. Jones at University of Michigan). This experiment is a counter experiment scheduled at the Cosmotron in early 1964. Its purpose is first to study the two-body reaction  $p + p \rightarrow d + \pi^+$  to see if this reaction can be explained by virtual nucleon exchange. The second purpose of the two-body reaction study and the deuteron total cross section study is to look for two nucleon resonances. The third purpose is to develop a technique for identifying high energy deuteron production in order to make a spark chamber study of reactions like  $p + p \rightarrow d + \rho$ . The equipment is now being constructed.

5. Pion Beta Decay

A Berkeley-SLAC collaboration experiment to measure the probability of pion beta decay has been started at the 184-inch LRL synchrocyclotron. An array of spark chambers inter-leaved with lead plates and scintillators has been assembled to detect the decay of the final state  $\pi^0$ . A small multiple-plate chamber has been constructed to record the stopping  $\pi^+$  and the final-state positron. A stopping pion intensity of  $\approx 5 \times 10^4 \text{ sec}^{-1}$  has been attained. Present efforts are being directed towards a reduction of background triggers (presently about  $10^3$  times greater than

the expected effect) and improvement of the large chamber modules.

6. RF Particle Separators

Work performed with rf particle separators during the past quarter is discussed fully in a separate report.\*

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O. H. Altenmueller, R. R. Larsen and G. A. Loew, "Investigations of  
ling-wave separators for the Stanford two-mile linear accelerator,"  
Report No. 17, Stanford Linear Accelerator Center, Stanford Uni-  
y, Stanford, California (August 1963).

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