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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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Technical Report

Prepared Under

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Contract AT(04-3)-515

for the USAEC

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I. INTRODUCTION

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

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

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

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

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

II. PLANT ENGINEERING

A. GENERAL

Considerable progress was made on the conventional facilities program during the quarter. Principal design emphasis was placed on the Control Building, the Target Area, and the 200 kV Receiving Substation. Construction of the Accelerator Housing, Klystron Gallery, and the research complex continued. The present status of a number of these facilities at the Sand Hill site is shown graphically in Figs. 1 through 5.

Stanford is cooperating with the Pacific Gas and Electric Company and the appropriate public agencies to obtain permits for a 220 kV tie-in line to SLAC. The possibility of placing this line underground, rather than overhead as originally planned, has been the subject of extensive study and review. The choice affects the design of SLAC's 220 kV Receiving Substation. It is anticipated that the line will be overhead, and the substation design is proceeding accordingly.

Plant Engineering continued its activities relating to space occupancy planning, conventional facility alterations, and the provision of craft support for all SLAC groups. This total effort is increasing. To supplement these activities, a time and materials contract for craft services was executed in March with the Industrial Maintenance Corporation of Richmond, California, effective for one year. The contract follows a similar one used primarily in support of the Test Laboratory and A&E Building programs since initial occupancy of the facilities.

The California State Division of Highways will construct an overpass bridge at accelerator station No. 83 as part of the Junipero Serra Freeway. The work will start August 29, 1964, and continue until early May 1965. The two adjacent Klystron Gallery sectors (Nos. 25 and 26) are scheduled to be completed coincidentally with the overpass. All other sectors will have been finished earlier.

B. DESIGN STATUS

Criteria work and preliminary design of the Target Area site developments and utilities continued throughout the quarter and are nearly complete. Criteria for the Data Assembly Building are under review. Title I work on End Stations A and B is 70% and 60% complete, respectively.

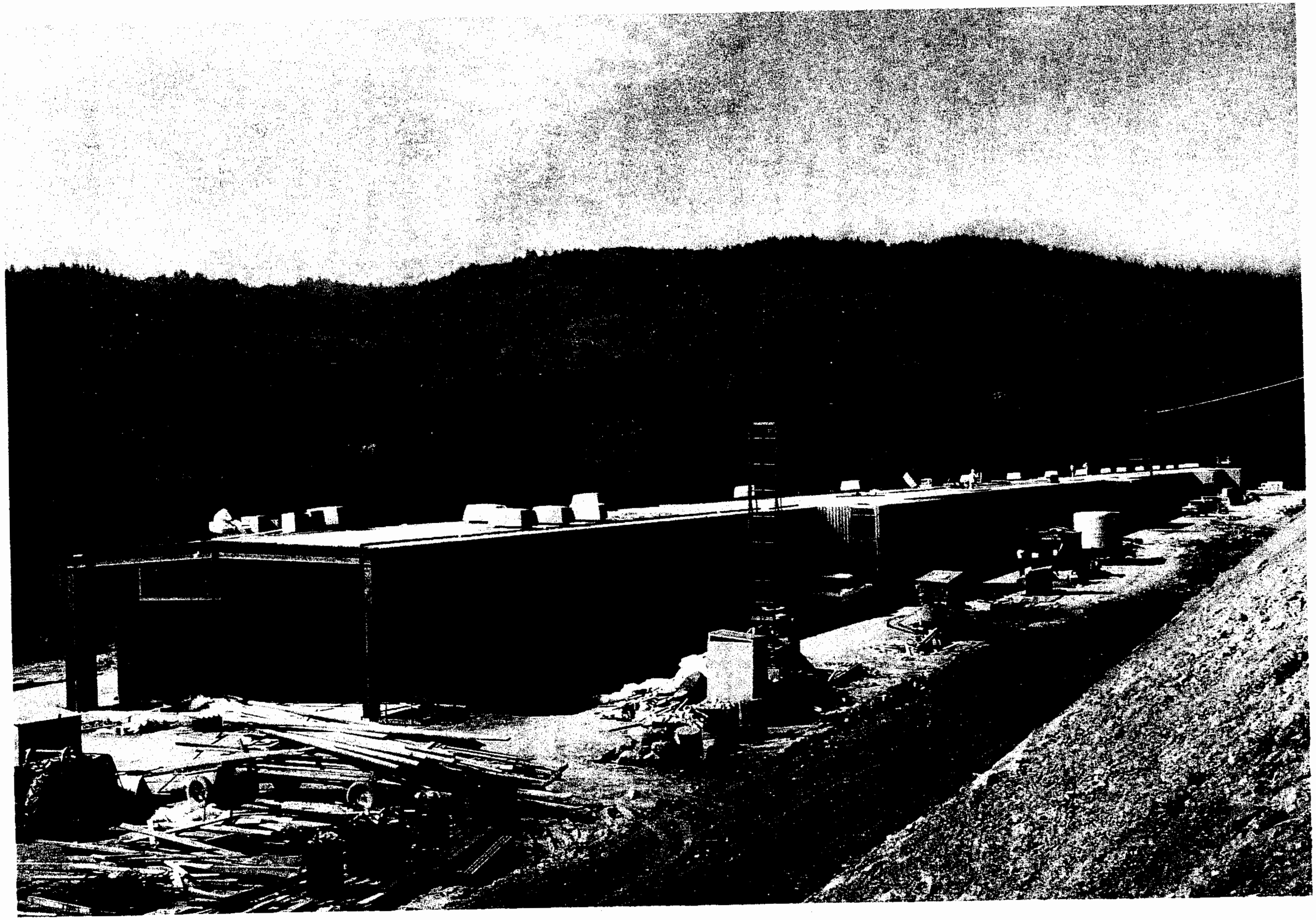

FIG. 1--First three Klystron Gallery sectors; looking southwest.

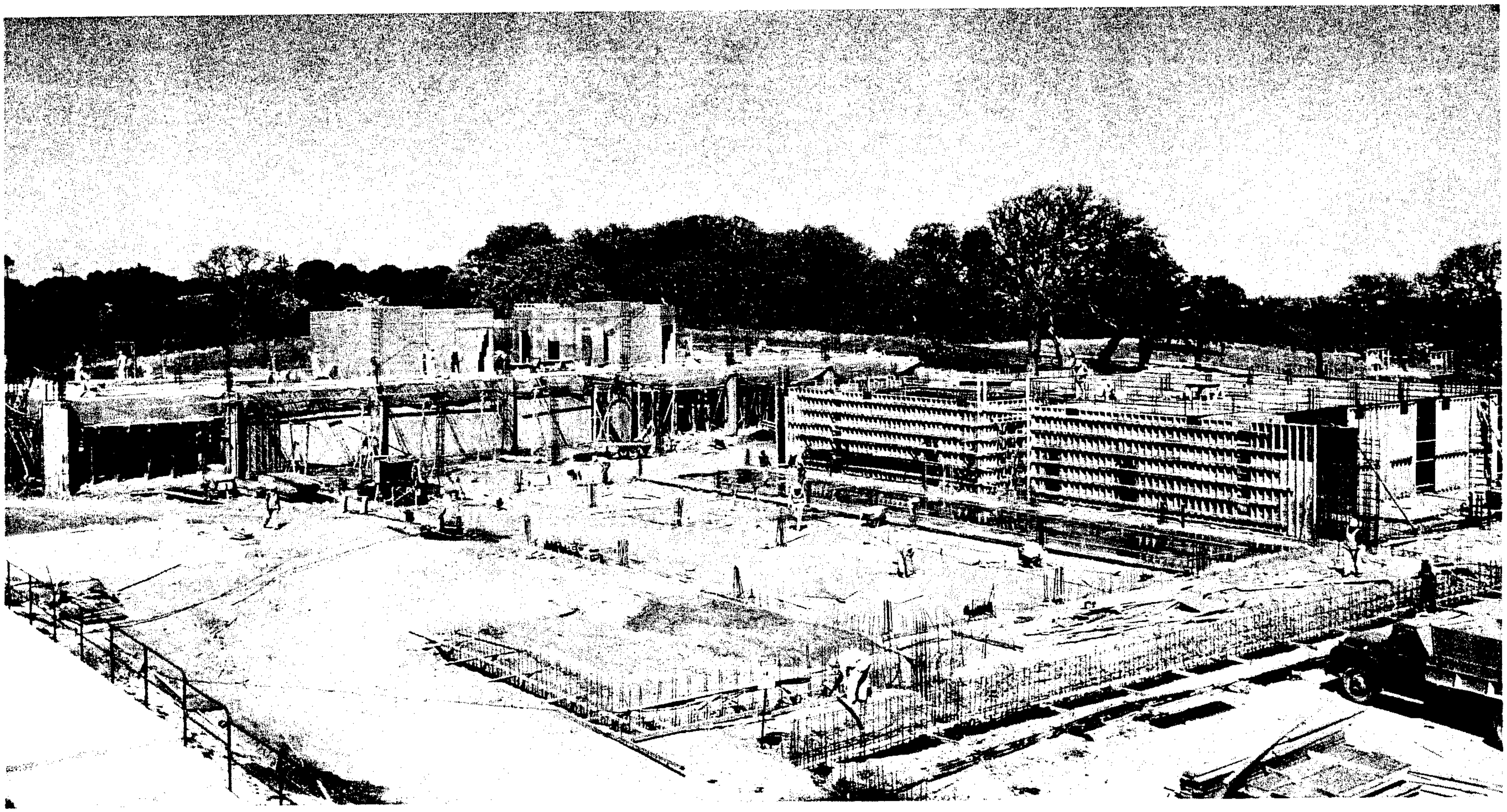

FIG. 2--Construction status of Central Laboratory.

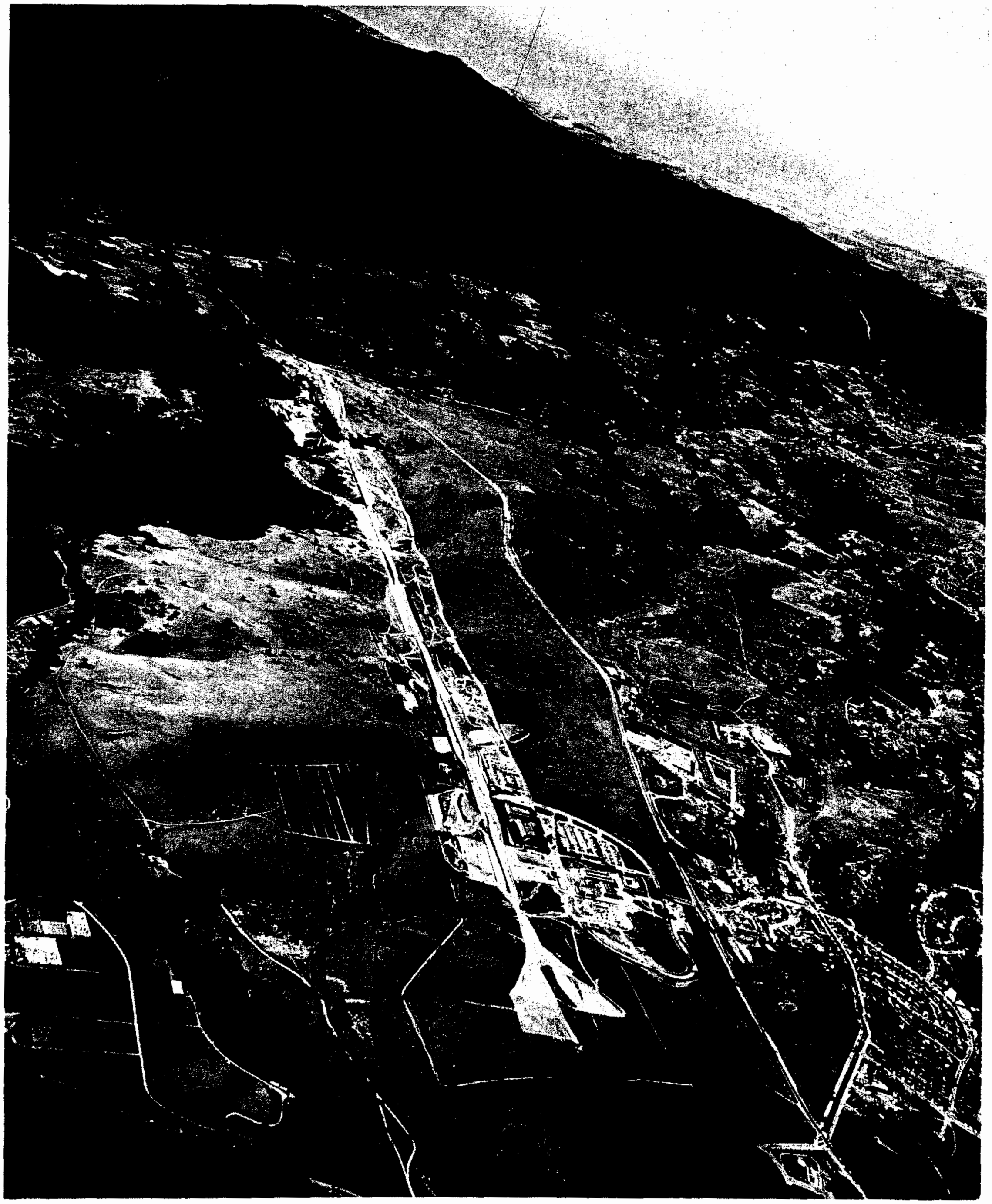

FIG. 3--Aerial photograph of the Stanford Linear Accelerator Center; looking west.

FIG. 4--Construction status of Heavy Assembly Building, with shops complex in background.

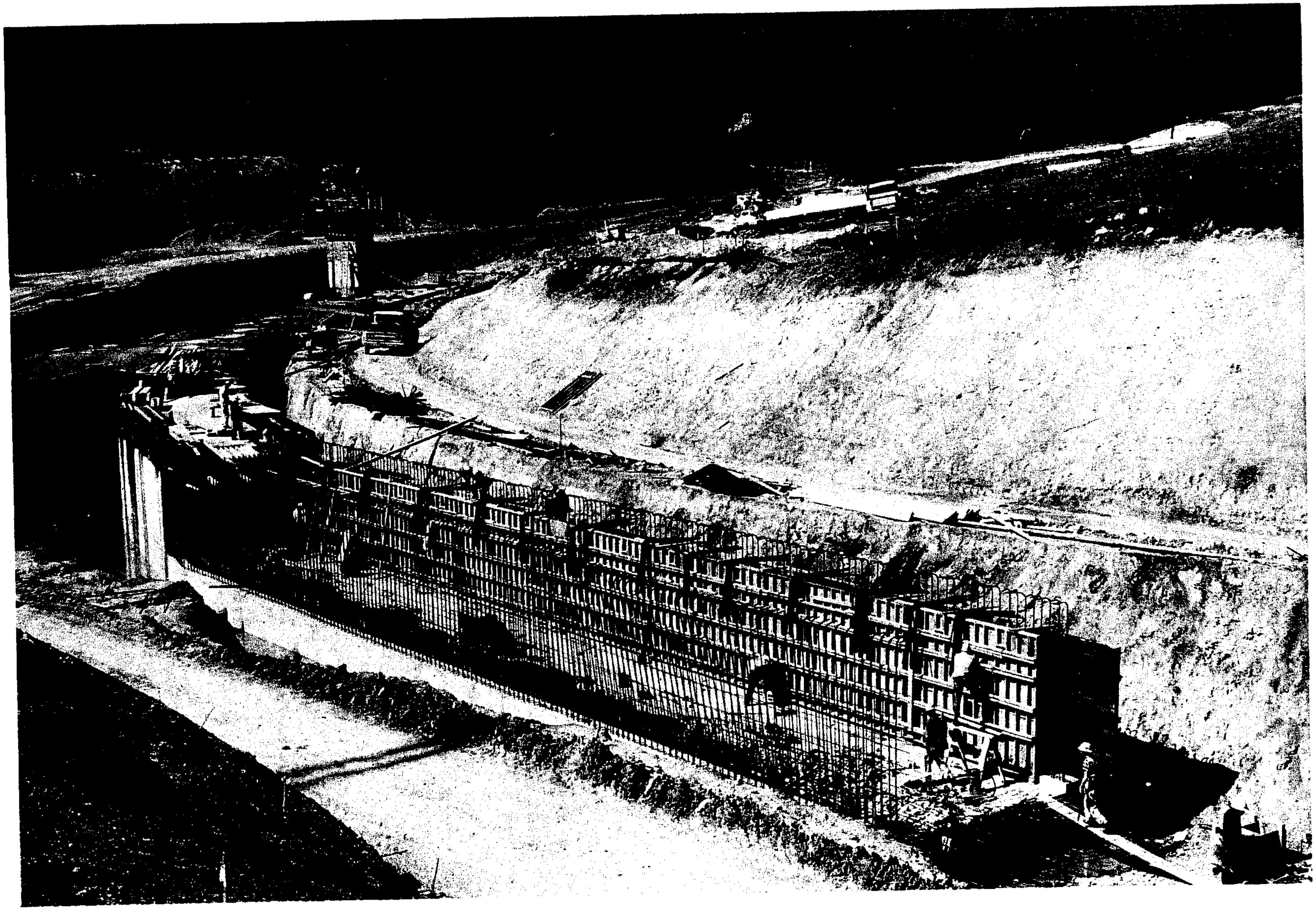

FIG. 5--Accelerator Housing at beam take-off No. 1; looking southwest.

The landscaping program awaits approval of preliminary design.

Final design (Title II) is well along on two major facilities. These, together with their percentage of completion, are: Beam Switchyard (45%), and the 220 kV Substation equipment package (65%). The latter is based on single-circuit, tapered-pole overhead 220 kV service to the project; it will include a 15 mVA increase in the capacity of the presently installed 60 kV Substation. Title II work on the Auditorium-Cafeteria was authorized in March and is underway.

Title II work was completed on a number of facilities, and bidding had advanced to the stage indicated below:

Materials Handling System (Beam Switchyard)

Request for proposals was issued March 18, 1964.

Klystron Gallery Utilities

Piping and site improvements (600-Y-1). The contract was awarded March 24, 1964.

Electrical (600-Y-2). Bids are to be opened in April 1964.

Cooling Towers (600-Y-1). The contract was awarded March 16, 1964.

Heavy Assembly Building Cranes

Bid opening was February 2, 1964, and the bids are now under review.

Control Building and Miscellaneous Site Improvements

The bid package will be mailed to prospective bidders in early April.

Chemical Cleaning Building

The contract was awarded March 27, 1964.

C. CONSTRUCTION STATUS

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

Facility	Percentage of Completion
Initial Site Utilities	98
Still Installation and Piping	99
Cleaning and Plating Area	97
Shops Complex Cranes	95
Accelerator Housing	44
Heavy Assembly Building	31
Central Laboratory	23
Klystron Gallery	10

All items of work associated with Increment No. 1 of the Klystron Gallery are substantially complete and ready for turnover to SLAC. Increment No. 2 is estimated to be 65% complete.

The Accelerator Housing work is proceeding satisfactorily. About 48% of the total concrete required has been placed, including the positron source section, the one-third beam take-off section, and sections of the off-axis injector No. 1. A field order was issued to the contractor to perform preparatory earth work in the Target Area. This allows completion of the total Klystron Gallery work one month earlier than would have been possible otherwise.

III. ACCELERATOR STRUCTURES

A. MOVE TO FABRICATION BUILDING

During the quarter, the Mechanical Design and Fabrication Department moved from the M-1 Building to the Fabrication Building at the permanent SLAC site. By the end of the quarter, all the department facilities except the Plating and Cleaning Shop, the Metallurgical Laboratory, and the Fabrication Shop had been moved, and nearly all items that had been moved were again in operation.

B. ACCELERATOR STRUCTURE

1. Instrumentation and Facilities for Low-Power Microwave Tests

A substantial effort has been devoted to the dismantling, moving, and subsequent installation of the instrumentation and low-power microwave test facilities in the Fabrication Building. By the end of the quarter, Station No. 1 (the tuning station) was nearly ready for operation. The controlled temperature water system had been largely redesigned and its installation was nearly complete. The vacuum system, control console, tuning mechanism, and the microwave equipment were all installed. The facility for automatically measuring and recording the phase shift of each cavity has been added; it is now possible to measure and record the phase shift, cavity-by-cavity, much more quickly and easily than before. The hydraulic system has been redesigned and is being installed. The system's performance has been greatly improved as a result of the design changes. The new system not only operates more quickly, but more important, it permits much more accurate control of the indenting of the cavities than did the previous system.

The installation of Station No. 2 (the quality control station) is not as far advanced as that of Station No. 1. The assembly of the quality control mechanism and the installation of the waveguide have not yet been completed. However, the vacuum and controlled temperature water systems are nearly complete, the hydraulic system is being installed, and the control console is almost finished.

2. <u>High Power Tests</u>

Because of the move of the high power test facilities to the Fabrication Building, only a small amount of high power test work was accomplished during the quarter. Before the move, 14 loads for the Mark III machine, two loads to be used in calibrating the Mark IV machine, two offset horizontal valves for Mark IV, and one vertical valve were tested in the M-1 Building. After the move, a microwave separator and a few loads were high-power tested in the Fabrication Building.

3. Instrumentation and Facilities for High Power Testing

During the quarter, Test Stands 1 and 2 were moved to the Fabrication Building. Test Stand 2 is now operational with all the instrumentation and facilities that it had formerly. Test Stand 1 has been partly installed. The modulator for this test stand is now being installed in a metal housing to reduce spurious signal radiation; the waveguide and vacuum systems have not yet been completed.

By the end of the quarter, the performance of the automatic phase measurement system had been improved to the point that it was nearly suitable for use in the test stand.

The attenuation measurement system had been tested in semi-automatic operation and had been found to perform satisfactorily in that fashion. As previously described, the system that has been planned is fully automatic. Presently the operator adjusts the precision rf attenuators manually to determine any change in attenuation through an accelerator section. A similar signal indicator on the output of the attenuator connected to the accelerator section output is also read. Then the two attenuators are ganged together and at every setting have the same attenuation. Therefore, changes in this latter reading, with changes in the rf power level in the accelerator section, indicate a corresponding variation in its attenuation.

4. Accelerator Section 10-Foot Support

Tests of a complete 10-foot support of the new design, when mounted on an accelerator section, have been satisfactorily completed. These tests show that this support meets the requirements of the design criteria in every respect.

The four accelerator sections and four 10-foot supports needed for the 40-foot assembly mentioned in the previous quarterly report* have been completed.

C. ACCELERATOR SECTIONS FOR THE MARK III LINEAR ACCELERATOR

During the quarter, all remaining accelerator sections and loads for the Mark III accelerator were completed and installed. Post-installation tests on the Mark III show very satisfactory performance.

A beam energy of 1.07 BeV was measured in one test under circumstances in which the condition of operation of the machine was somewhat less than ideal. It appears that, with the new accelerator sections, the beam energy is 7% higher than it was with the previous accelerator sections, under otherwise identical conditions. Also, with slightly changed conditions, effective operation of the machine has been achieved at 1.15 BeV. The new accelerator sections have also resulted in an improvement in the performance of the machine with respect to beam current. With the previous accelerator sections, about one-third of the injected current was available at its output. With the new sections, the output current equals about half the input current.

Operators have noted improvement in the machine with regard to both stability and the effect of power level on beam steering. The former appears to be due to the more effective cooling system of the SLAC accelerator sections. This is noted as an immediate return of the beam energy spectrum upon application of rf power after a brief shut-off. The relative independence of rf power level and steering is attributed to the use of couplers with symmetrized rf fields across the beam aperture. A comparison of beam deflections from this source made before and after the installation of the new sections shows a reduction in deflection of at least a factor of five. Other effects occurring on the Mark III machine obscured the test results so that a full determination of this effect was not possible. Further tests are being considered with the object of independently checking the coupler design.

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*"Two-mile accelerator project, Quarterly Status Report, 1 October to 31 December 1963," SLAC Report No. 27, Stanford Linear Accelerator Center, Stanford University, Stanford, California (February 1964).

D. HIGH-POWER WAVEGUIDE COMPONENTS

1. RF Waveguide Vacuum Valves

a. Test Data

Table I summarizes the test data on the rf waveguide vacuum valves discussed in a previous report.* During these tests, it was determined that insufficient spring force was causing poor electrical contact between mating surfaces in the backseat region, thus causing rf breakdown. In addition, it was decided to cool the valve during operation in order to prevent overheating. Both of these points are discussed below.

b. Spring Tests

A stiffer spring was tested to determine its loading as a function of the number of times it is cycled. After an initial set during the first 100 cycles, the spring showed a 1% to 2% decrease in spring force over the next 1300 cycles. At the end of these tests (≈ 1300 cycles), the measured spring force exceeded that quoted for the spring (151 lbs.).

The production valves will use this spring, and the required design changes have been incorporated into the production drawings.

c. Valve Cooling

Under high power rf conditions, the valve bodies exhibit a temperature rise. External body temperatures have been measured as high as 110°C. The relatively lossy indium ring around the rf coupling hole is suspected as the main source of heat. The valve should be maintained at a temperature considerably below 155°C, the melting point of indium. The cooling scheme shown in Fig. 6 utilizes the waveguide constant temperature water (113°F/45°C) as the coolant.

This cooling scheme utilizes the holes normally used for the heater rods to remelt the indium. A parallel flow arrangement is used because of the small hole size and the flow rate of the constant temperature water. No flow meters are required with this scheme because the valve is connected in series with the waveguide cooling, and interlocks in the flow circuit will be adequate.

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*Ibid.

TABLE I

TEST DATA ON RF WAVEGUIDE VACUUM VALVES

FREQUENCY 2856 Mc

Valve Number	VSWR*	α(dB)	Resonant Ring Peak Run	Resonant Ring Average Run	Test Stand	Remarks
A-1	1.02	0.1*	63.8 MW;11.5 kW	44.4 kW;41.1 MW*		
A-2	1.02		59.8 MW;10.75 kW	44.2 kW;40.8 MW	14.5 MW at 15.5 kW	All tests ran well.
A-3	1.05		66.4 MW;11.9 kW*	44.4 kW;41.1 MW*	14 MW at 15 kW	All tests ran well.
A-4	1.04		26.0 MW;4.68 kW*			Breakdown in backseat region during peak power test - due to weak spring.
A-5	1.06		66.5 MW;11.9 kW	44.5 kW;41.2 MW	12.0 MW at 14.2 kW	Backseat breakdown due to weak spring during initial test - repaired unit achieved levels indicated.
C-1	1.02	0.07*	52.0 MW;9.3 kW*	39.2 kW;36.3 MW*	14 MW at 14 kW*	C-1 and C-2 tested in series in resonant ring.
C-2	1.04	0.06*	52.0 MW;9.3 kW*	39.2 kW;36.3 MW*	14 MW at 14 kW*	In use on Test Stand No. 2. 49 closings without remelt as of end of February.
C-3	1.03		47.8 MW;8.6 kW			Backseat breakdown due to weak spring - average power and test stand runs not made.
C-4	1.02		53.2 MW;9.56 kW	40.2 kW;37.2 MW		Test on C-4 alone - test stand run to be made.
C-5	1.02	0.05	55.8 MW;10.0 kW	43.5 kW;40.2 MW	10.4 MW at 15 kW	Backseat breakdown due to weak spring. Repaired unit achieved levels indicated.
C-6	1.05		57.2 MW;10.3 kW	44.5 kW;41.2 MW	14.0 MW at 15 kW	All tests ran well. Operating in Test Stand No. 1.

*Data previously reported in SLAC Report No. 27

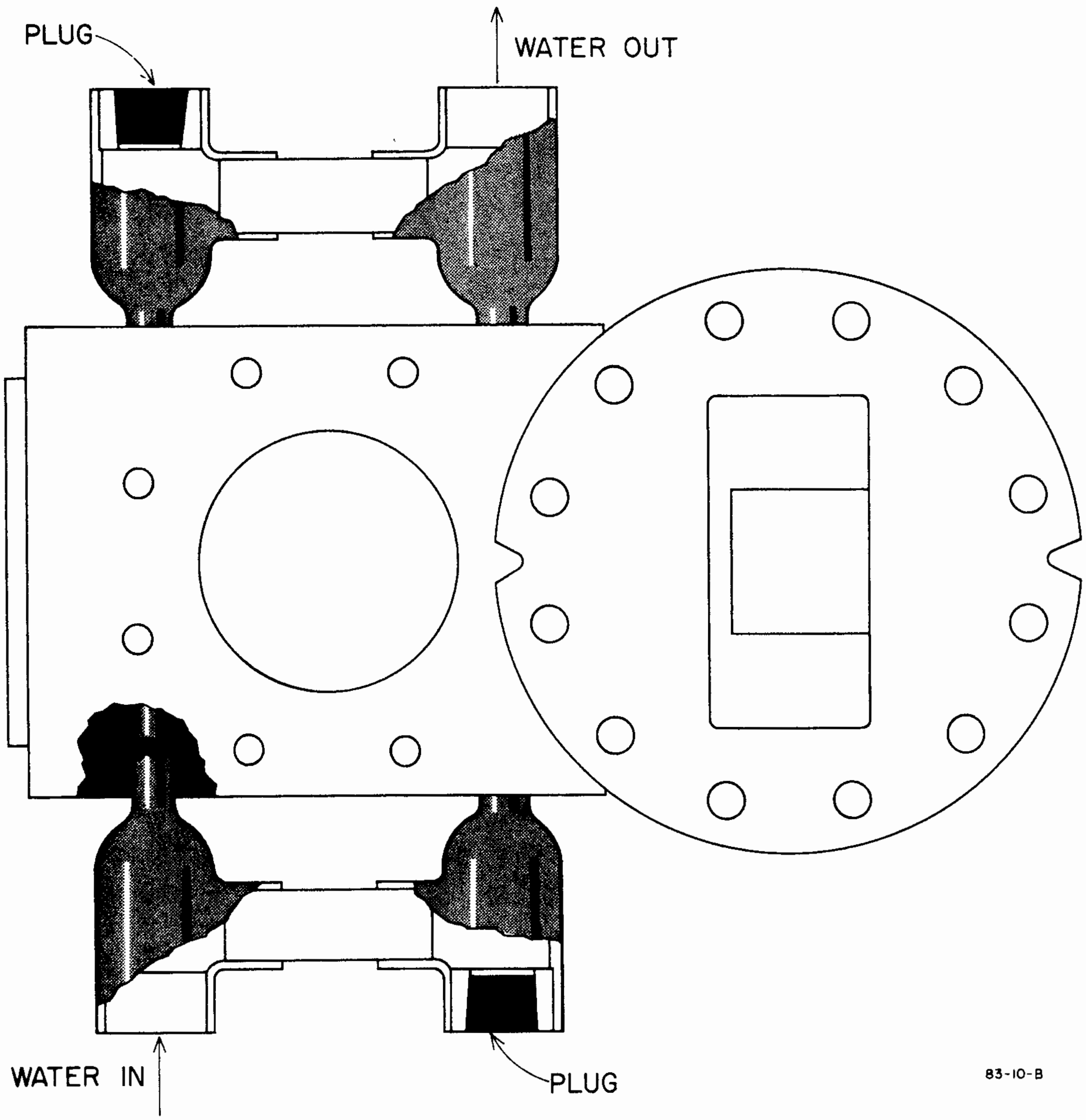


FIG. 6--Water cooling arrangement for waveguide vacuum valve.

The indium can be remelted by removing the threaded plugs, draining the water, and inserting the heater rods. In this way, the water system is a permanent hookup.

The effectiveness of this scheme on valve operation will be tested early next quarter.

d. Actuator

The actuating mechanism for closing the valve was re-evaluated. It was decided to abandon the costly, cumbersome air-driven cylinder arrangement in favor of a hand crank type actuator, because the number of closings will be relatively small (even two per week is large), and because speed of closure is not a criterion.

The new actuator will be mounted directly on the spring housing. An experimental version will be built and tested during the next quarter.

e. Production Drawings

The primary effort during the last quarter was directed toward the completion of production drawings and specifications and the submission of these items for bid purposes. This work was approximately 85% complete by the end of the quarter, with the remainder due for completion by April 30, 1964. (The spring modification and cooling scheme noted above have been incorporated into the production design and will appear with the valves.)

In addition to these drawings and specifications, flow charts showing the detailed steps in the fabrication of the valves were drawn up. Final approval of all parties concerned is still to be obtained.

f. Move to Site

During the quarter, all facilities for the valve program were moved to the site. During this time the test stand was upgraded both to improve its operation and to increase the number of test positions. Since the brazing operation was also moved, tests on the indium processing were begun to verify the techniques under the new operating conditions of hydrogen lines, furnace cans, etc.

2. Waveguide Layout

The gallery crossbar design has now been frozen. This item comprises the gallery power divider and the waveguide pieces that extend from it to the tops of the penetration waveguides.

3. Couplers

Initial designs have been completed for the stripline low-pass filters and the stripline directional couplers to be attached to the incident wave and reflected wave terminals of the Model A coupler. The couplers provide signals to be used in providing VSWR measurements, in displaying the incident and reflected pulse shapes, and in measuring the incident and reflected average power levels. The filters and the couplers are mounted in a package as shown in Fig. 7.

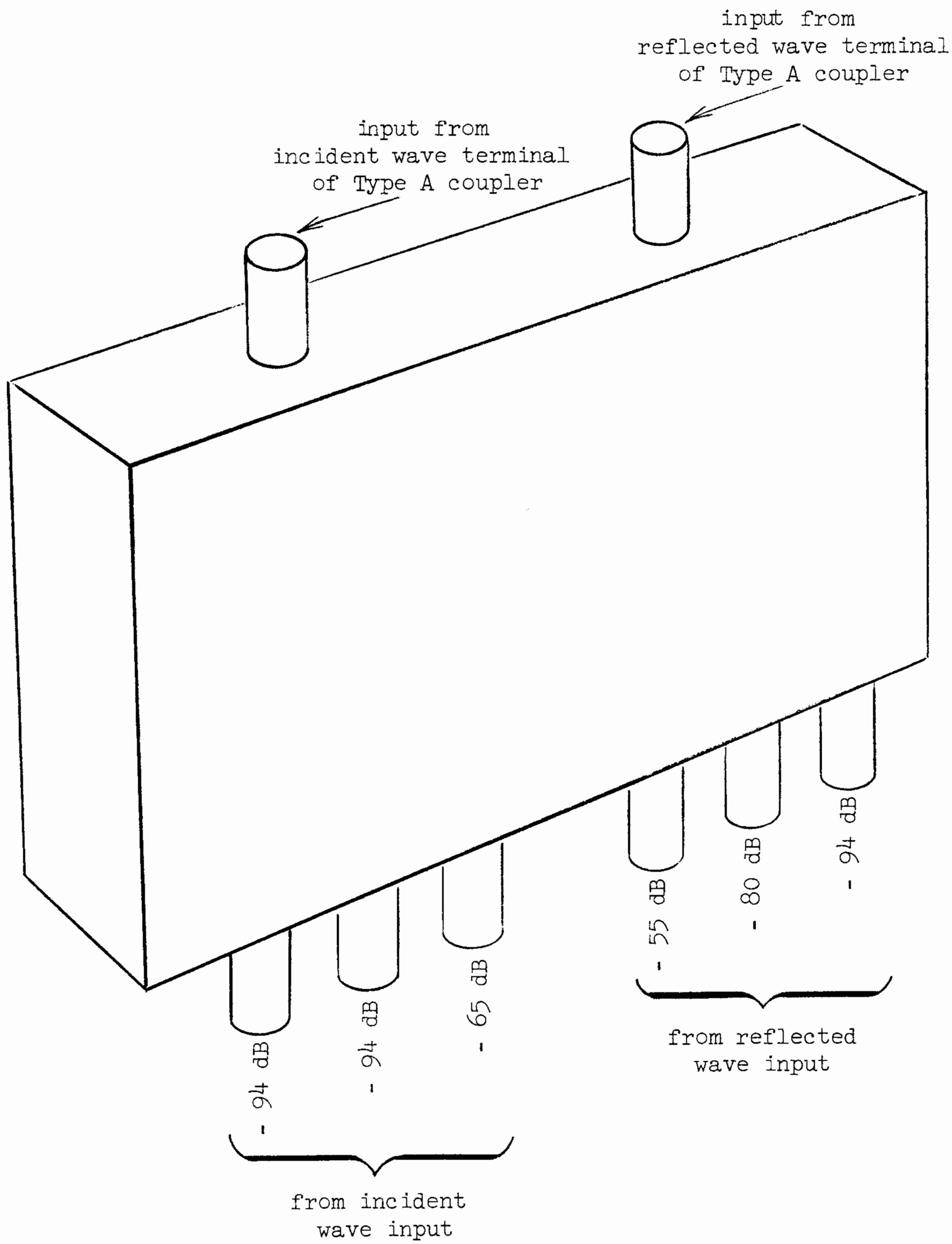
4. Loads

During the quarter, high power tests were run on the remaining 24 waveguide loads (out of a total of 34) for the Mark III machine. Of these, only 7 loads provided VSWR values beyond the ranges shown for the first ten loads in the previous quarterly report,* and these were only slightly outside the ranges.

The waveguide load design for the two-mile machine is similar to that for the Mark III accelerator. That is, the load consists essentially of a tapered section of rectangular waveguide made of type 410 stainless steel which is coated on the inside with Kanthal, using a metal spray process. The tapered section is surrounded by a water jacket. However, the two loads differ in one respect. The Mark III load taper has a seam around its circumference about midway along its length. There are two different taper angles on the two sides of the seam. In the load for the two-mile machine there is a single taper angle, and no such seam.

By the end of the quarter, preliminary drawings had been completed

*Ibid., p. 26



NOTE: The coupling figures in decibels as shown are taken with respect to the signals in the waveguide.

FIG. 7--Stripline dual coupler filter unit.

and fabrication in outside shops had been initiated for the parts to be used in the prototype load.

5. Test Tower

a. Phase vs Klystron Gallery Movement

During the quarter, phase tests were made in the waveguide transmission network in the test tower to determine the effect of moving the klystron gallery, relative to the accelerator housing, by one inch to simulate the effect of any possible earth movement. Four low power rf tests were run. In each test the sequence of treehouse movements vs time, shown in Fig. 8, was used. In this figure, the circled points are those at which phase measurements were made. The measured results of these tests are shown in Table II, and the accelerator section designations used in this table are explained in Fig. 9. The phase accuracy in these tests is estimated to be about $\pm 0.2^{\circ}$. The test results are gratifying, in that they indicate that the phase shifts to be expected with earth movement in the two-mile machine fall within tolerable limits.

TABLE II

PHASE SHIFT IN TEST TOWER WAVEGUIDE TRANSMISSION SYSTEM VS KLYSTRON GALLERY MOVEMENT

Accelerator Sections Sampled	Parts Sampled	Maximum Measured Phase Variation
j,k	Inputs	0.9°
j,ℓ	Inputs	0.9°
j,ℓ	Outputs	0°
j,k	Outputs	0.2°

b. Phase vs Power Level in High Power Tests

A series of measurements was made in the test tower to determine phase variations that occur with changes in the average rf power level. The specific concern here is that changes in the rf power dissipated in the waveguide and accelerator sections may cause corresponding temperature changes that can, in turn, result in appreciable phase changes in

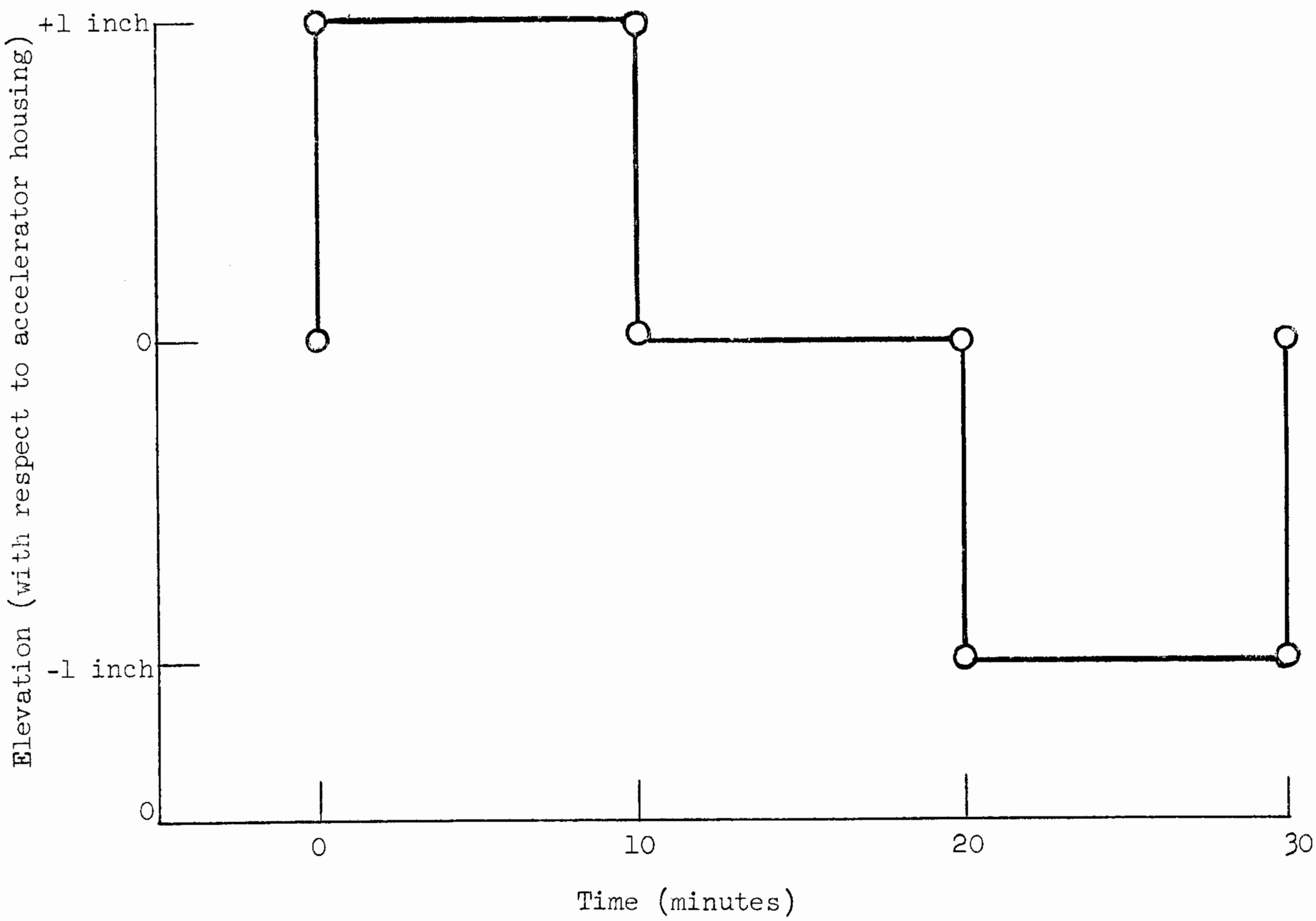


FIG. 8--Test Tower movement vs time sequence.

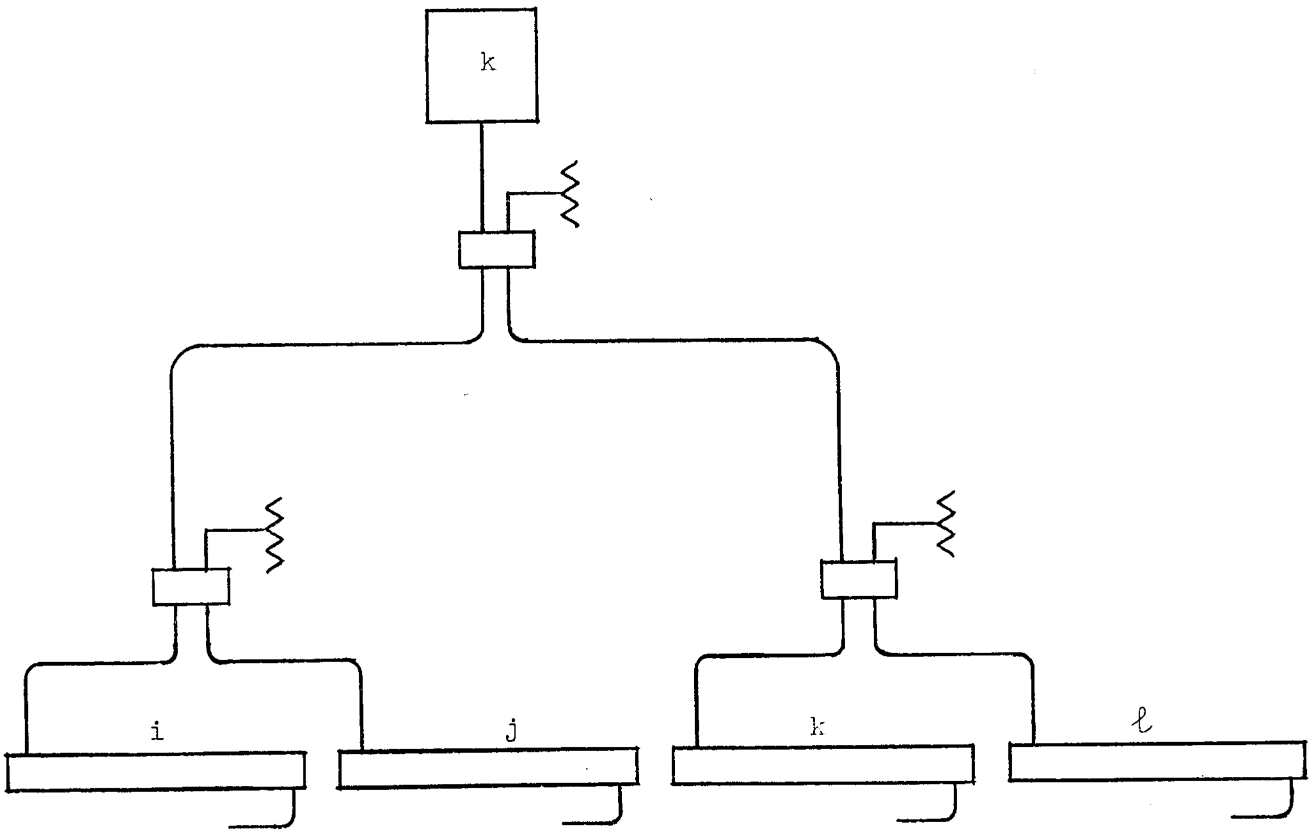


FIG. 9--Accelerator section designations.

the rf waves traveling through the sections. In the system tested, all of the waveguide and accelerator sections were water cooled. The cooling water was accurately temperature controlled at a single point in the test tower. A simple phase measurement system, similar to that shown previously,* was connected between the outputs of adjacent accelerator sections. Any change in the phase relationship between two such points was then measured with changes in average rf power level.

The first two tests were quite similar in nature and in results. In each, the outputs of two accelerator sections, fed from a single penetration waveguide, were compared in phase. The average rf power from the klystron in these tests varied from 4.0 kW to 16.5 kW. In each of these tests, the total phase variation over this range of power levels was less than one degree.

In the third test, one of the accelerator sections was fed from one penetration waveguide and the other accelerator section was fed from the other penetration waveguide. In this test the phase variation over the 4.0 kW to 16.5 kW rf average power level range was a little more than three degrees. This somewhat higher phase shift may result from the fact that phase changes in the penetration waveguides could have an effect in this test, whereas they could not in the previous tests.

The results of these tests seem to indicate good phase performance with rf power level change in the two-mile machine.

c. Time Domain Reflectometry

Time domain reflectometry has been tested as a technique for noting and locating discontinuities in the waveguide circuit after installation. The results have been encouraging, as indicated below. The test equipment shown in Fig. 10 was set up in the test tower. A series of 50 nanosecond pulses, at the frequency of 2856 Mc, was introduced into the circuit, and the return signal was measured as a function of time. By knowing the incident wave signal level as well, one can calculate the reflection coefficient and the corresponding VSWR, as a function of time, from these data. The distance between the directional coupler and any

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*Ibid., p. 29

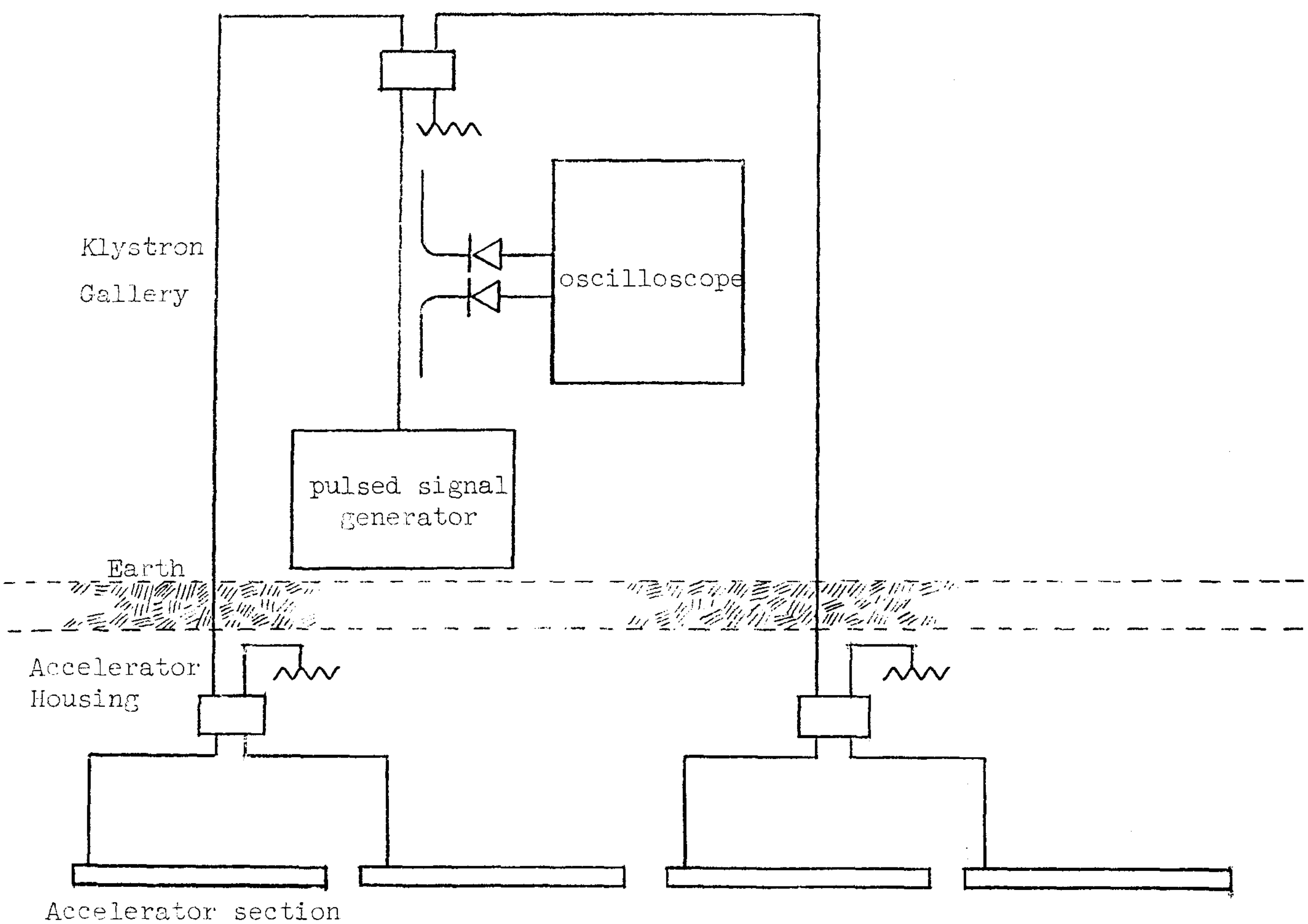

FIG. 10--Test equipment for time domain reflectometry tests.

discontinuity along the waveguide is proportional to the time interval between the incident pulse and the return pulse caused by that discontinuity. In fact, this distance equals half the time interval divided by the group velocity along the waveguide. The VSWR corresponding to each discontinuity can then be plotted as a function of the distance between the directional coupler and the discontinuity along the waveguide. Such a plot, based upon the preliminary measured data, is shown in Fig. 11. The calculated locations of various known discontinuities along the waveguide are also shown on this figure. Thus it appears that discontinuities can, in fact, be identified from these data. Further tests are planned to determine whether phase information also can be obtained.

6. Low Power Test Facilities for Waveguide Components

Plans have been made for measuring the rf phase shifts through the rectangular waveguide pieces to be installed in the two-mile accelerator. Following these measurements, any necessary phase corrections will be made by appropriately indenting the waveguide. Plans for phase testing are presented below for the following waveguide assemblies to be installed in the two-mile accelerator.

a. Gallery Crossbar

The gallery crossbar assembly connects the output of the waveguide vacuum valve to the top ends of the penetration waveguide inputs. It contains the gallery power divider. The objective of phase measurement and connection on this piece is to insure that the phase shift from the input to one of its output parts shall differ from the phase shift from the input to the other output part by an integral number of cycles.

Figure 12 shows a diagram of the system for making these phase measurements on the crossbar assembly. The crossbar is connected to the waveguide network to be employed specifically for this test, and to the phase measurement system described in the previous status report. Note that the waveguide switch can connect the phase measurement system to either leg of the crossbar through one arm of the special waveguide network. (The phase uncertainty in this switch has been measured and found not to exceed 0.1°.) Phase measurements are made with the waveguide switch in both positions. Prior to these measurements, the electrical

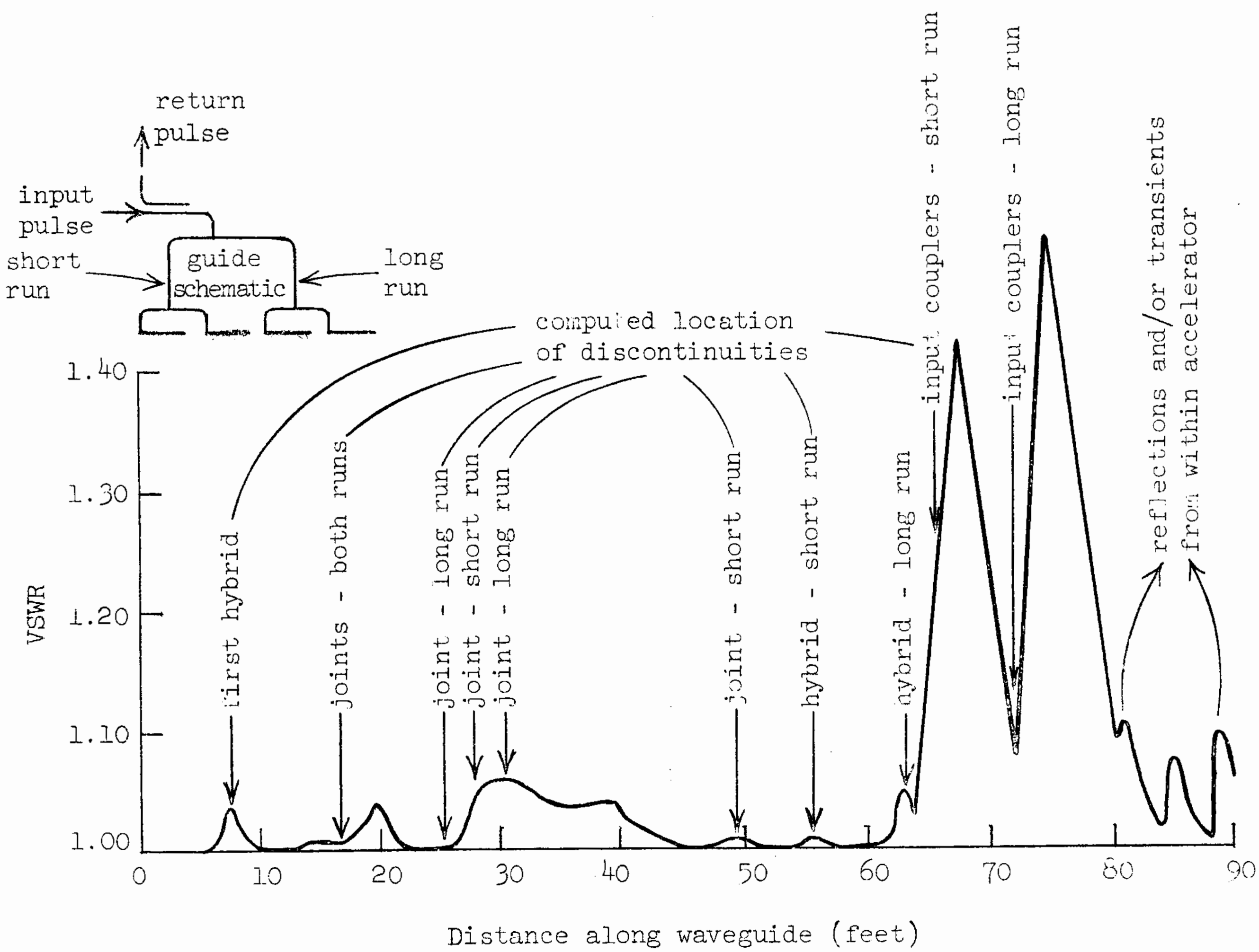

FIG. 11--Results of time domain reflectometry tests.

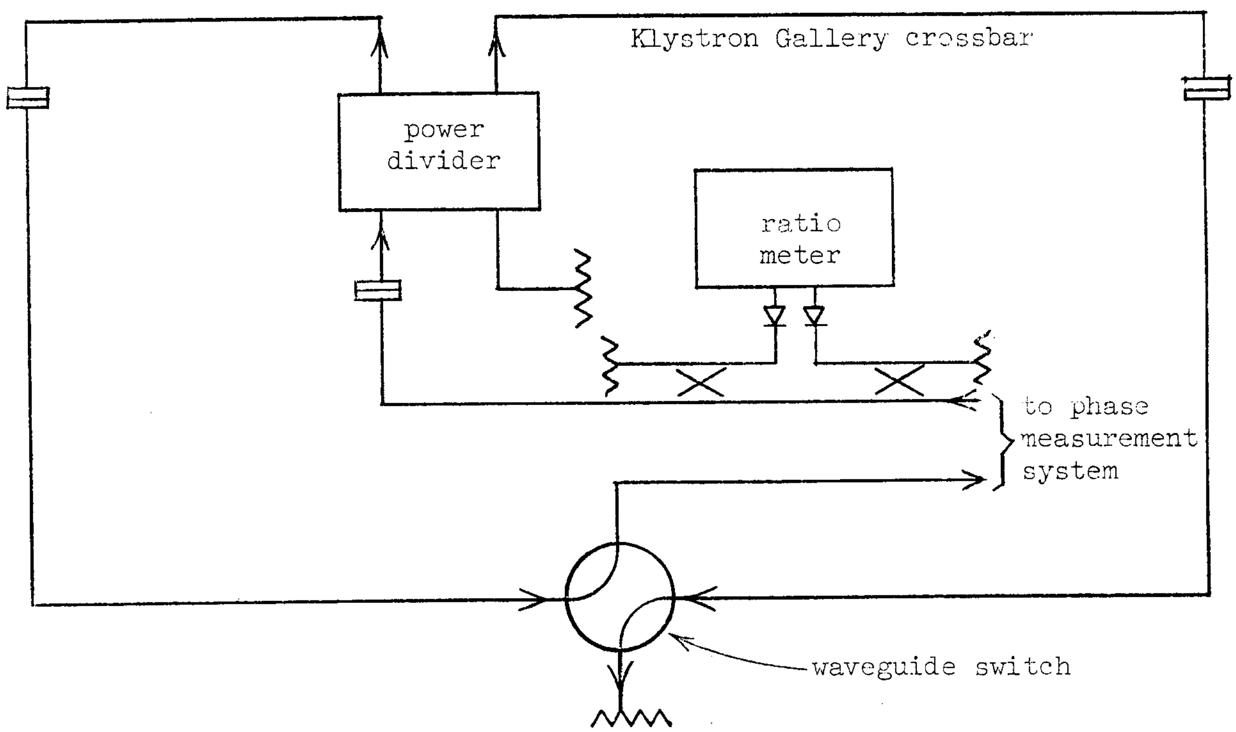

FIG. 12--Test setup for rf phase measurements on Gallery crossbar.

lengths of the two arms of the special waveguide network will have been compared by measurements made with a crossbar, and then with the crossbar reversed. From these measurements, the special waveguide pieces will be phase adjusted in such a way that their phase lengths differ by an integral number of cycles. After these adjustments are made on the special waveguide pieces, the phase measurements made with a crossbar assembly in place indicate any phase error in that assembly.

The waveguide test circuit also contains a waveguide reflectometer that is used to measure the reflection coefficient at the input to the crossbar assembly.

b. Accelerator Housing

The S-assembly is the waveguide circuit in the accelerator housing that feeds two accelerator sections from the output of one penetration waveguide. There are two S-assemblies, then, for each klystron in Stage I. Figure 13 shows the circuit diagram to be used in phase-testing the S-assemblies. A portion of this circuit is identical in principle to the crossbar test circuit, and is used to compare the two arms of the S-assembly in phase. The remainder of the circuit is used to compare each leg of the circuit in phase to a standard waveguide length. The ultimate objective of phase measurements and adjustments on the S-assembly is to make the phase lengths equal to a given value over the transmission paths through the S-assemblies that are used with a single klystron. This is one of the steps that must be taken to provide equal phasing to the four accelerator sections fed by a single klystron.

This waveguide test circuit also contains a waveguide reflectometer that is used to measure the reflection coefficient at the input to the S-assembly.

c. Penetration Waveguide

Because its ends are widely separated (by a length of about 37 feet), the phase measurement techniques applied to the penetration waveguide differ from those applied to the crossbar assembly and the S-assembly. The penetration waveguide contains no appreciable discontinuities (such as power dividers and bends), so a reflection type measurement can be used for its phase length. This method of measurement is described below. A problem with a reflection type measurement, however, is that it

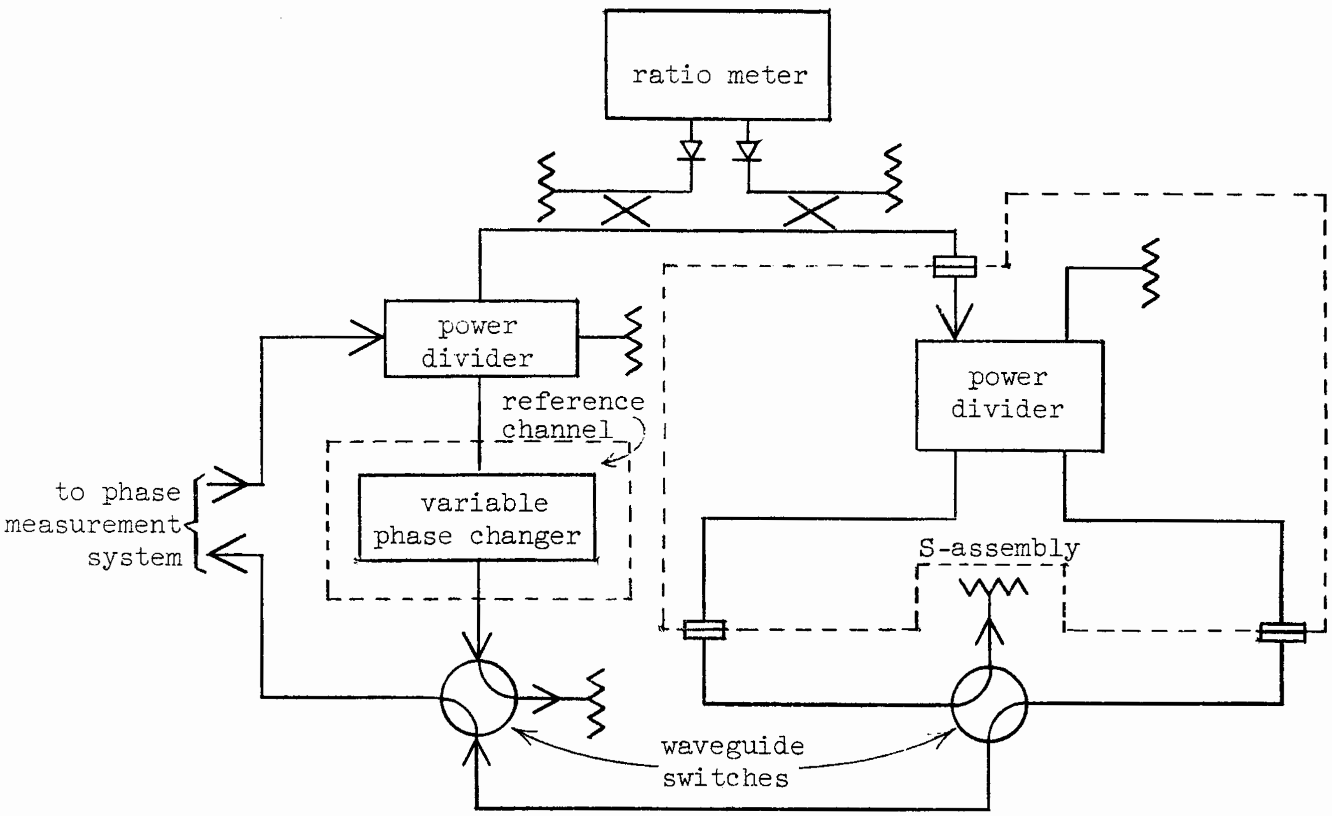

FIG. 13--Test setup for rf phase measurements on accelerator S-assembly.

can indicate an apparently correct phase length when, in fact, the phase length is 180° too long or too short. Calculations show that the tolerance on the waveguide "a" dimension can permit a phase error large enough to cause the 180° phase ambiguity. For this reason, there are two test circuits for the penetration waveguides.

The penetration waveguide is first installed in the circuit of Fig. 14, which, as shown below, is not susceptible to a 180° ambiguity. In this circuit, the penetration waveguide to be tested is compared to another penetration waveguide which has been accepted as the standard against which all penetration waveguides will be compared. As shown, the two penetration waveguides are connected between two magic-T's. With a signal introduced into one port of a magic-T as one end, the ratio of signal amplitudes that emerge from the magic-T output ports or the other end provides an indication of any difference between the phase lengths of the two penetration waveguides. If the two penetration phase lengths were equal, no signal would emerge from one of the ports. If the two penetration phase lengths differed by 180°, no signal would emerge from the other port. The penetration length under test is phase-tuned by indenting until the signal from the appropriate magic-T output port has dropped to a relatively low value, indicating that the phase length of the penetration waveguide is nearly correct (that is, the phase error does not exceed a few degrees).

The penetration waveguide is then moved to the test facility shown in Fig. 15. In this facility, a short circuit is connected to one end of the penetration waveguide, and a signal generator, all-slotted waveguide section is connected to the other end. The waveguide is phase-tuned by indenting until the null position, on the slotted line, falls at the proper point.

The waveguide walls bend slightly when the waveguide is evacuated because of the pressure difference between its inside and the outside. This slight bending causes an rf phase shift in the waveguide that can be appreciable over the lengths considered here. As a result, the final phase tuning for all of these waveguide pieces is done with the waveguide evacuated. For similar reasons the waveguide is temperature controlled by water flow during this phase tuning.

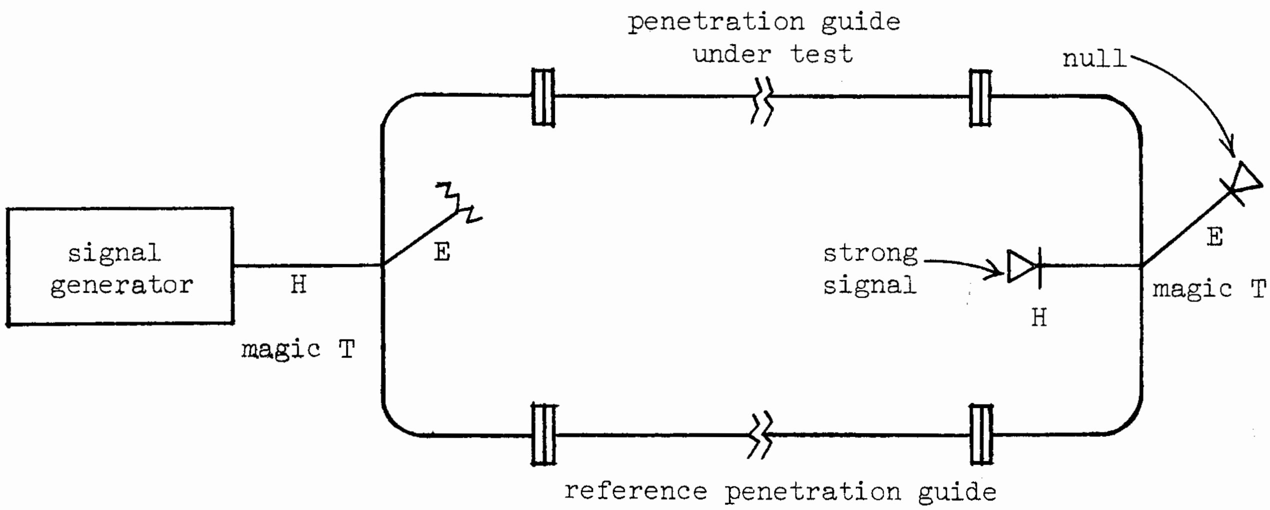

FIG. 14--Preliminary test setup for penetration waveguide rf phase.

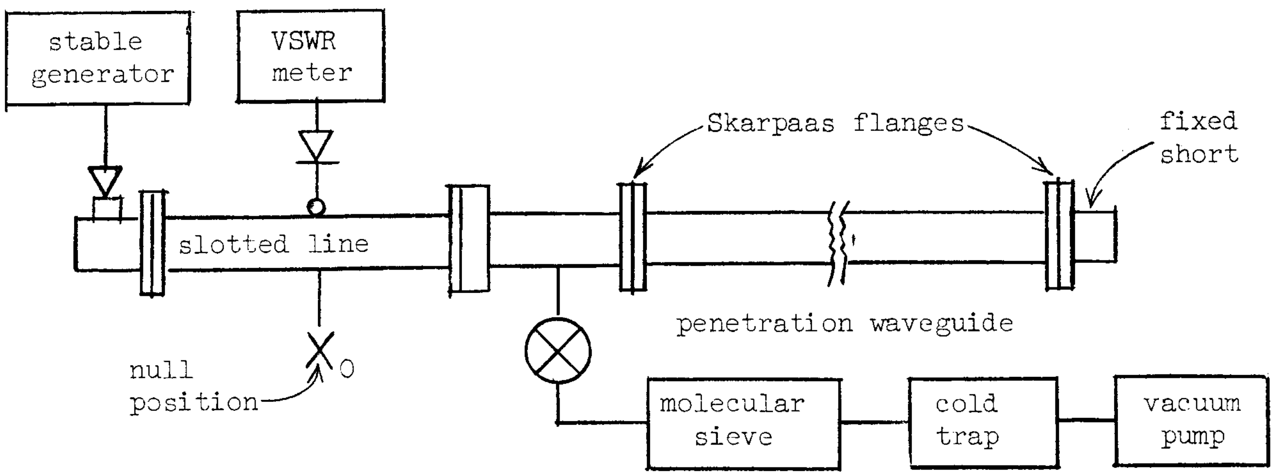

FIG. 15--Final test setup for penetration waveguide rf phase.

7. High Power Test Facilities for Waveguide Components

By the end of the quarter, the modulator, klystron, and instrumentation racks had been installed in the high power test stand for testing rectangular waveguide components. The modulator had been tested with a dummy diode load. The waveguide vacuum system and water temperature control system remain to be installed.

A calorimeter is under construction for the purpose of measuring the coupling coefficients of the Model A couplers.

A high power resonant ring for use in testing the waveguide valves has been completed. This device will permit a power multiplication of 13 dB. It has a fixed 14 dB coupler between the input terminal and the ring. Controls are provided by which the electrical length of the ring can be adjusted, and by which discontinuities in the ring can be matched out. The ring is equipped with its own vacuum system.

IV. KLYSTRON STUDIES

A. SUMMARY

During the quarter, RCA delivered three acceptable klystrons. Sperry has experienced difficulties during the transfer of their activities from Great Neck to Gainesville, which have prevented their shipment of the two tubes scheduled for delivery this quarter. Proposals were received from both Litton Industries and Eimac for the delivery of a small number of klystrons, and a recommendation of the selection committee to the AEC should be forthcoming during April.

The Stanford klystron fabrication operation has progressed satisfactorily during the quarter. Additional emphasis has been placed on the operation of Stanford klystrons in permanent magnets.

Only two Stanford klystrons failed during the quarter. However, there was a decrease in the total number of hours of operation on the Stanford tubes, resulting from the move to the site of some users.

Life tests have been initiated on klystrons procured from outside vendors. One purpose of these tests is to determine the compatibility of the klystron and pulse transformer tank assembly.

Work on window improvement is continuing. An additional window test station has been activated, in which six windows are operated in series between the klystron and the load.

Considerable thought is still being given to the problems of klystron installation and maintenance on the accelerator, and a 20-foot-long operating mock-up of the klystron gallery has been started in the Test Laboratory.

A modification has been negotiated with Eimac both to alter the delivery schedule of sub-booster klystrons and to give Stanford some additional shelf life warranty on the Eimac tubes.

B. SUBCONTRACTS

Three klystrons have been received from RCA in compliance with the delivery schedule agreed upon during the negotiations of the last contract amendment and were accepted as meeting "end-of-life" tube specifications. Of these, one also met all "final" specifications (jitter, phase, etc.)

except that the power output was a few percent below the specified 21 MW. A fourth tube shipped by RCA was dropped when transferred by the airlines and was damaged beyond repair.

Sperry has been unable to deliver tubes meeting our specifications on schedule for a variety of reasons. From a technical standpoint, they have been able to eliminate a great deal of the unacceptable oscillations and pulse widening.* Some of the gun oscillation problems that had apparently been solved reappeared, and additional problems were discovered, such as the uneven beam spreading in the collector that resulted in excessive collector boiling. In addition, a rash of inactive cathodes has delayed Sperry's progress. Both the engineering and management staff of Sperry have visited Stanford, and they have submitted a program by which they expect to resolve their present difficulties.

Both Eimac and Litton Industries have submitted proposals for the delivery of six klystrons to SLAC. Both companies are considering the use of special output circuits to improve the efficiency. An incentive type contract, in which the final price of a klystron depends on the ultimate power capability, subject to meeting the other specifications of noise and stability, has been suggested. The final recommendation as to choice of the companies has not been made yet.

C. FACILITIES

Some minor setbacks in the fabrication area occurred during the move to the site and have not permitted achievement of the full potential anticipated during this quarter. For example, some of the valves in the gas supplies were inadequate and permitted mixtures of nitrogen and hydrogen to flow in some lines. Two explosions resulted from these difficulties; no injuries and no serious damage were experienced, but the work was delayed. In addition, the expected shakedown period for new equipment such as furnaces has been experienced.

In the test area, the modulators and associated equipment have in general performed satisfactorily, and the down time necessitated by

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*"Two-mile accelerator project, Quarterly Status Report, 1 October to 31 December 1963," SLAC Report No. 27, Stanford Linear Accelerator Center, Stanford University, Stanford, California (February 1964).

maintenance does not appear to exceed 20 percent of the total usage. Some reflections were observed in the drive lines, which made evaluation of the klystrons under acceptance tests difficult until the line was equipped with a well-matched load. The problem has now been resolved by the Microwave Engineering group. The ignitrons in the modulators are being gradually replaced by thyratrons, which provide much more reliable, kickout-free operation.

A 350-curie cobalt 60 source has been ordered so that X-rays of both vendor-supplied and Stanford tubes can be taken before and after usage. It is expected that valuable information concerning the possible repair of purchased tubes can be obtained through the use of this machine. The concrete shielding for the facilities is now being installed.

A 20-foot-long mock-up of the klystron gallery has been planned, and installation of the klystron support beam has begun. The purpose of this installation is to insure that no unforeseen difficulties will appear in the handling of klystrons in the gallery, in the handling of the vacuum equipment, and in the other mechanical details which are difficult to judge from either a print or a scale model. In addition, it is expected that the mock-up will be activated next quarter as a fully operating test facility in which a sub-system including modulator, klystron, protection devices, vacuum, etc., can be tested in a geometry equal to that of the klystron gallery. Finally, some special tests on klystron behavior when feeding an accelerator load rather than a water load will be performed in that location. For these tests, it is planned to install one or two accelerator sections in the concrete block enclosure used for the cobalt source.

D. KLYSTRON FABRICATION AND DEVELOPMENT

Approximately 15 tubes and diodes were built (or repaired), baked, and processed during the quarter. Unfortunately, the yield was not as high as had been anticipated, and tests had to be discontinued on four tubes because of poor vacuum. In addition, one tube had sufficiently violent oscillations to prevent completion of tests. Of the other tubes tested, the mean value of the peak output power exceeded 20 MW, with one tube exhibiting a peak power output of 25 MW at an efficiency of 40 percent. These results were obtained in electromagnet.

During the quarter, emphasis has been placed on operation of tubes in permanent magnets. In permanent magnet operation, the mean value of peak output power supply exceeded 18 MW, with one tube measured at 20.5 MW. One window failure was observed during the tests at a power output much below that at which the tube had been operated.

Tests were undertaken during the quarter to eliminate the gun oscillations in Stanford-built tubes. Because it appears that the RCA tubes do not show gun oscillations, although they have the same basic electrical design as Stanford's tubes, it was decided to approach the problem through the mechanical design of the RCA tubes. To this end, the anode housing was shortened in an attempt to increase the coupling between the potential oscillation modes and the lossy oil in the pulse transformer tank. Two tubes were built with reduced housing length, one of which showed extremely weak oscillations, and these only if the heater power was raised to a value higher than normal; on the second tube, no oscillations have been detected as yet. In addition, tests were also made on another tube in which the anode hole diameter had been increased from 2 inches to 2.10 inches. With this modification, very weak oscillations were still detectable. Additional tubes will be built which include both the shortened anode housing and the increased diameter anode hole.

As reported above, considerable testing has been done in permanent magnets. It was determined that at present permanent magnets can be built with a field adequate to operate our tubes, but that a 5 percent improvement in maximum field would probably result in at least 5 percent improvement in power output. However, the main difficulty with permanent magnets appears to be the cancellation of the cross fields and the requirement of extremely accurate axial alignment of the tube in the magnet. In addition, improper handling of the magnets while they are in operation may result in the setting up of localized transverse fields that deteriorate the tube performance. It is probable that covering the magnet with a non-magnetic material will eliminate a great deal of this problem, but is will be essential to instruct maintenance and operating personnel in the klystron gallery not to approach permanent magnets with magnetic materials, especially when the tube is in operation.

Tests with the new gun designs have been hampered as a result of the accidents in the fabrication facility mentioned previously. As a result, no final decision has been made yet on the utilization of this new gun design for future tubes built at Stanford.

It is planned to procure additional permanent magnets so that Stanford tubes could be installed in the first sectors, should this be necessary to perform the sector tests.

E. STANFORD KLYSTRON USAGE

During the quarter, outside tube usage has been limited by the moving of the Mechanical Design and Fabrication group from the M-1 building to the new testing facilities on site.

One tube was removed from the Mark IV accelerator because of critical focusing observed after 200 hours of operation. A complete recalibration of Mark IV has been accomplished during the quarter, and reasonable correlation has been obtained between the measurements on the SLAC test stands and the new Mark IV measurements. On the other hand, there is no explanation yet for the observation that window temperature appears higher on the Mark IV than on the test stands when operating at the same power level.

A diode used for prototype modulator evaluation has logged more than 3000 hours of operation.

F. ACCEPTANCE AND LIFE TESTS

The acceptance test stand for the outside vendor tubes has operated satisfactorily, although some time was spent in elimination of noise pick-up on the scopes, which made accurate evaluation difficult. The noise-measuring sampling waveguide has not been completed yet, but the phase measuring equipment operates very reliably.

The first two RCA tubes began life testing at the end of the quarter on two of the test stands. One of them is installed in the prototype pulse transformer tank that will be used in the klystron gallery, and it is gratifying to know that the tube performance is not affected by the pulse transformer tank, and that the pulse transformer and isolation inductors in the tank are not affected by the stray field from the permanent magnet.

The stands will be gradually modified to operate with the thyratrons being procured by the modulator group, so that life information can be obtained on the thyratrons and klystrons, as well as the components in the pulse transformer tank.

G. INSTALLATION ON THE MACHINE

During this quarter, a final decision was made determining the handling equipment needed for initial installation of klystrons on the machine, as well as for handling the replacements of failed tubes. The equipment will consist essentially of a truck, a fork lift, several electric trucksters, and two "Hovair" platforms. The truck, pulling an electric fork lift on a special trailer, will carry a maximum of six klystrons to the entrance of the klystron gallery closest to the station to be filled. The klystron to be installed will then be transferred by the fork lift to a "Hovair" platform in the immediate vicinity of the station where it is needed.

In case of replacement, the second Hovair platform will be used to receive the klystron from the klystron support yoke, and to remove it to a temporary storage spot within a few feet of its station. The new klystron will then be brought in place on its Hovair platform, and the klystron yoke raised by hydraulic lift so that a vacuum-tight seal can be made between the klystron and the waveguide. The fork lift will pick up the replaced klystron and remove it to the truck so that the same operation can be repeated at the next station.

In the meantime, an electric truckster with adequate mechanical equipment and tools will be available at the station to perform the necessary operations to disconnect, reconnect, and start the vacuum system. Once the mechanical installation is completed, a second electric truckster carrying the necessary electrical test equipment will be brought in with adequate personnel to insure that the klystron and pulse transformer assembly are operating satisfactorily before the modulator is turned back on in the variable voltage substation.

Orders have been placed for the truck, the fork lift, and the electric trucksters, and specifications for the Hovair have been written. The support yokes have been ordered, and delivery of the initial quantity is expected in April. Additional water fittings to connect the pulse transformer tanks to the klystrons will be ordered early in the next quarter.

H. HIGH POWER KLYSTRON WINDOWS

1. Window Coatings

(a) Baked Windows

Five disks of the coated series* have been baked in the double vacuum klystron bake oven and tested on the high power ring. The windows were more gassy and failed after surface arcing at lower powers than unbaked samples. After bake they had a gray appearance, which is believed to be caused by contamination from the unfired molybdenum shield surrounding them during bake. Because this may have caused the change in performance, the test is being repeated under more carefully controlled conditions.

(b) Heavy Coating

A klystron window with a heavier coating than is normally used was run to 60 MW, 54 kW in the high power ring without damage. It will also be baked and retested.

(c) Window Life Test

Six coated klystron windows have been in operation for 240 hours at 10 to 12 MW, 10 to 12 kW levels. The entire system was baked to $400^{\circ}C$ for 48 hours before operation was started, resulting in a base pressure of $\approx 1 \times 10^{-7}$. In initial operation the windows have shown a deep blue glow or are dark.

All windows were initially cool, but one has become noticeably hotter and has a decided asymmetrical glow. Two others are somewhat warmer than the rest. The glow on the hotter windows has become somewhat more pink in hue.

(d) Window Operation on Accelerator Loads

Although coated windows have largely eliminated failures during klystron test, some windows still become hot on klystrons operating into accelerator sections. Attempts to correlate this with mismatch in the system have thus far proved negative, and the cause is not now known.

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*SLAC Report No. 27, op.cit., p. 43.

Further work on this problem will be done on the klystron gallery mock-up.

2. Effect of Tilt

Eight more windows have been tested on the low power ring, and one on the high power ring, to study the effect of window tilt on operation. Data from these and similar tests provide some evidence that a small tilt ($\approx$ 0.002 radian) perpendicular to the maximum electric field is harmful. There is also some evidence of change in the operating properties of the window as a result of non-destructive exposure to high rf fields. Additional study will be given to these problems in an attempt to provide more conclusive results.

3. Quartz Window

Tests were run in the low power ring on a mock-up and on a sample of a quartz-to-metal seal designed by Dr. Simon Sonkin. Both of these failed, the first in the quartz and the second due to breakdown at the diffusion seal. Although the low loss tangent of quartz is promising, its behavior* at high power is poor. Also, it seems difficult to modify this seal to reduce breakdown. It has therefore been decided to discontinue work on this design.

4. Other Window Work

(a) Grooved Windows

One of the grooved alumina windows was run on the high power ring to 80 MW peak power, failing by cracking at 45 kW average power. Further tests will be made next quarter.

(b) Klystron Output Window

The ghost mode in this window** has been shifted to 2770 Mc by increasing the thickness to 0.125 inch. The thicker disk is well matched at 2856 Mc when used in the original structure.

(c) Temperature Gradients

Four klystron windows, three uncoated and one coated, were tested in the high power ring. At failure, the gradients from center to edge on

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*SLAC Report No. 27, op.cit., p. 43.

**Ibid., p. 45.

the uncoated disks were 174°, 110°, and 118°C. The coated disk had a gradient of less than 3°C at 60 MW, 54 kW, and its center temperature was 134°C at this level. This window became hotter (for constant transmitted power) as the frequency was changed from the design value, probably due to the increased VSWR in the ring.

(d) Surface Studies

Studies have been started using electron microscopic and X-ray diffraction techniques to investigate the nature of coatings and effects of operation on window material.

5. <u>Other Work</u>

(a) Waveguide Components

Seven waveguide valves were tested on the low power ring. The test results appear in the Accelerator Structures portion of this report (Section III).

(b) Water-Cooled Phase Shifter

Water-cooled plungers have been installed in the high power ring phase shifter. These have allowed temperature readings to be taken on "cool" windows with the I-R thermometer. The uncooled plungers are being used in an impedance transformer for klystron testing.

(c) Cryogenic Pumping

Tests have been conducted on the possibility of using cryogenic pumping for the evacuation of the waveguide and manifold between the klystron window, the waveguide valve, and the 3-inch valve. The indications are that a combination cryopump and ion pump can be used successfully to evacuate that portion of the system to approximately 10^{-5} torr in about 10 minutes. The cryopump does not need to be regenerated for up to 12 operations a day when the system is let down to dry nitrogen gas, and the total consumption of liquid nitrogen is between one and two gallons per day. Additional tests will be conducted using tandem cryopumps and other combinations. The proposed system will be installed on one of the electric trucksters used for the installation.

I. SUB-BOOSTER KLYSTRONS

During the quarter an amendment to the sub-booster procurement subcontract was agreed upon, by which the tubes failing by shelf life will be replaced by Eimac without cost to Stanford, rather than the pro-rated cost specified in the initial contract.

Extensive work is being carried out at Eimac to determine the probable source of the relatively high failure rate of tubes on the shelf. As is usually the case when gas or shelf life problems have to be solved, a long period will be necessary before one can be certain that the solution has in fact been achieved, but Eimac is approaching the problem by controlled variations in manufacturing and processing techniques.

Several of the tubes received during the quarter still were not acceptable because of phase or amplitude variation in excess of the specifications, and it is possible that these defects are also, at least in part, caused by inadequate processing. As of the end of the quarter, Eimac deliveries were on schedule, and an adequate number of sub-booster tubes is available. Of the tubes now in use, one failed in 900 hours due to an operational error. One tube showed indication of multipactoring after 230 hours; two tubes showed indications of excessive second harmonic at 300 and 650 hours, respectively. Of the other tubes in operation, the total time logged is in excess of 600, 800, and 4100 hours.

V. ELECTRONICS

A. MAIN MODULATOR

1. Modulator Procurement

The main modulator contract, which was awarded to Ling Electronics in January, has worked out well thus far. Normal errors in the procurement drawings, usually associated with such procurements from prototype, have been found, corrected, and forwarded.

The initial order for these modulators is for 20 pre-production units, in order to prove out design and construction before the remainder of the order is started.

Thus far, Ling has ordered all the "blue book" parts (custom made items that we specified on a performance basis) and most of the remaining parts, and have received their first cabinet. They have set up a work area for building our modulators in their plant.

2. Prototype Tests

Trouble has been experienced with the de-Q'ing circuit because the silicon-controlled rectifier life has been too short. The life of these units has been generally one or two hundred hours, instead of many thousands of hours. Otherwise, the circuit worked well. However, this circuit was deleted from the above drawings, to be held until the problems could be worked out.

Several modifications of the circuit were effected in an attempt to improve its performance. Another SCR in series with the original one was added to increase hold-off voltage capacity. Thyrite resistive elements were connected across the SCR circuitry to reduce the negative voltage spike across the SCR's when the main switch tubes fired. Reverse diodes were placed across the SCR's in order to keep reverse voltage off them. Then, because it was felt that diodes were more able to withstand a quick voltage reversal than the SCR, diodes were placed in series with them in order to have the reverse voltage switching that is necessary in such a circuit. A small saturable reactor was put in series with the SCR in order to delay the build-up of current until the voltage across the SCR was at its minimum level. Such a technique reduces the power dissipated in the SCR. All these things did improve the life of the SCR.

As another alternative, we explored the possibility of using a small ignitron as a switching element in the de-Q'ing circuit. The ignitron worked fairly well, but it deionized too rapidly during a momentary voltage reversal during the conduction period. For proper circuit operation, the ignitron should have continued conduction until (1) all the energy stored in the charging choke was dissipated, or (2) the main switch tubes fired. In order to solve this problem we had to widen the ignitor pulse to a point beyond the momentary voltage reversal point (to about a total of 100 microseconds). This led to rather large and powerful firing circuits, but they could be miniaturized and fitted into the modulator cabinet, if necessary. One disadvantage in the ignitron circuit is that it requires water cooling, but if necessary, this can be provided.

Another SCR package circuit developed by International Rectifier Company was obtained during this period and installed on prototype No. 1. This circuit uses a hand-picked, high voltage SCR and series diode, and several smaller reverse diodes in series across the SCR. As of the end of March, this package unit had 1350 hours of operation on it. The only trouble experienced was that one of the small diodes in the string across the SCR went out. Otherwise the unit continues to work well.

As testing of these prototype modulators proceeded, occasional trouble with charging chokes was noticed. A few of these oil-filled units developed a momentary short from somewhere along the length of the high voltage winding to ground, thus causing an overvoltage in the SCR de-Q'ing circuit, rendering the SCR inoperable. This sort of thing has been witnessed on at least one charging choke during high-potting, and one or two other charging chokes have been lost. It is suspected that bad charging chokes could cause the short lives of our SCR's.

The time delay through the modulator was reduced 240 nanoseconds by the elimination of an LC despiking network in the grid of the KU 71 triggering thyratron. A 100-ohm wire-wound resistor was substituted for the despiking network; this minimized the grid spike fed backwards from the KU 71, and at the same time reduced time delay in firing that tube. Also, a coupling capacitor at the input to the triggering circuitry was increased, which helped to reduce total delay time. After these changes were made, the time delay through the modulator, using GL-7890 switch tubes, from the time the trigger enters the jack at the top of the modulator until the start of the output pulse on the cathode of the klystron, is about 650 nanoseconds.

3. Pulse Capacitors

Early in January we contracted for a pre-production quantity of pulse capacitors from Sangamo Electric Company. Shortly thereafter these capacitors began coming in, but the initial order failed to reach internal inductance specifications by about 30 percent. Having been informed of this, Sangamo redesigned the internal lead structure of the capacitor and brought subsequent units within specifications. As many of these units as possible are now undergoing life test.

4. Pulse Transformers

Early in January a contract was signed with Pearson Electronics Company for a pre-production quantity of pulse transformers. These units are coming in on schedule and within specifications.

5. Triaxial Pulse Cable

A sample quantity of 14-ohm triaxial cable was delivered to us in early January. Vendor-supplied connectors were specially designed and installed on six-foot samples of this cable. These units were tested and found to be satisfactory; some of the samples have almost 2000 hours test time on them at full power. Late in March a contract was let to Boston Insulated Wire Company for this cable. Procurement was also initiated for the triaxial cable connectors. Included in the invitation for bid was a provision for qualification samples. These samples have been ordered from bidders and will be tested during the next quarter.

6. Pulse Transformer Tanks

Contract negotiations for pulse transformer tanks from Dayco Metal Products Company were completed in March. Many other small procurements in connection with the pulse transformer tank assembly also got underway in March.

Late in March one of the prototype pulse transformer tanks was mated with an RCA klystron. After initial troubles with a leaky klystron "O" ring seal and klystron cooling water pipe leaks, the combination was run up to full power. Preliminary indications are that the combination is working well.

B. SWITCH TUBES

1. Contract

Late in January contracts were let for pre-production hydrogen thyratrons from both Kuthe Laboratories and General Electric. Only single tubes were ordered because these companies were confident they could produce single tubes to our specifications. The modulator, on the other hand, was kept flexible enough to take either dual or single tubes in order to have a safety factor. The initial orders are for 25 of the large KU 275A tubes and 25 of the medium-sized KU 274B tubes from Kuthe. General Electric received an order for 50 of the 7004 tubes, a medium-sized tube about equivalent to the KU 274B. All tubes carry a life guarantee.

As of the end of January, Kuthe Laboratories delivered three 275A tubes and two 274B tubes within specifications. General Electric is having trouble holding the anode time delay variation within the specified 150 nanoseconds.

2. Life Data

(a) GL 7890

The third set of GL 7890 tubes failed after 1537 hours of essentially full power operation into a diode load on prototype No. 2. The second set lasted 1700 hours, and the first set 1505 hours.

The first set was subsequently sent to General Electric, where it was found that rebuilding of the tubes was possible. The rebuilt tubes were then installed in prototype No. 2 and were run about one hundred hours. From this preliminary run (which was interrupted by the arrival of the Kuthe tubes), the performance of the rebuilt tubes appeared satisfactory. The economics of such a rebuilding operation is not known to us at present because there is not much life data on rebuilt tubes. However, the Kuthe people have also rebuilt tubes, and they claim it affords a good possibility for keeping our thyratron replacement costs down.

The Mark IV accelerator has GL 7890 thyratrons in its modulators. As of March 3, 1867 filament hours and 748 plate hours had been run on their tubes, and they are still operating satisfactorily.

We have noted that the anode time delay variation in the two-tube GL 7890 setup increases from an intial 20 nanoseconds to 60 nanoseconds after 800 hours life. This is still quite good in view of the 150 nanoseconds allowed in our specifications.

(b) KU 275A

The KU 275A tube in the Ling modulator used by the Mechanical Design and Fabrication group is still running satisfactorily, but running hours build up slowly due to the fact that the modulator is not operated regularly. In March only 1095 hours had been logged on it. The first tube used by this group ran 1866 hours before failure.

C. SUB-BOOSTER MODULATOR

A bidders' conference for sub-booster modulator procurement was held early in January. Demonstrated were one of our sub-booster modulators in operation and a microwave phase measuring equipment setup to show the bidders a method of measuring pulse top flatness. They were at liberty to change various switch tube voltages in order to get a feeling for the need for power supply regulation, etc. The modulator had a new regulated high-voltage power supply. The pulse top flatness was close to 0.04 percent.

The contract for these modulators was awarded to Manson Laboratories. First deliveries are to begin in September.

We are in the process of building an additional sub-booster modulator, which will help to alleviate a shortage of these units. All long-lead-time parts have been ordered, and some sub-assemblies finished.

D. IONIZATION CHAMBER FOR ACCELERATOR PROTECTION

A 330-foot model of Panofsky's long ion chamber was installed at the Mark III accelerator. Preliminary results show that the position of beam interception may indeed be deduced from the time of arrival of the signal.

E. DATA TRANSMISSION

Engineering Design Plans were issued on the status monitoring and beam shut-off systems. The status monitoring system was approved by management, and specification of the necessary equipment has been started. A decision was made to lengthen the reaction time of the beam shut-off system from 100 μsec to 1 msec. The pulse magnet monitor in the beam switchyard will shut off the injector through a separate 50 μsec network.

A technical description of the remote control system was issued and equipment for a test system ordered.

Evaluation of various data handling equipment was continued although interrupted by removal of the equipment from the M1 - M2 area to the Electronics Building. All equipment under test continues to perform satisfactorily.

F. BEAM GUIDANCE

The beam monitor system for the accelerator reports beam position and intensity as observed at the end of each sector. The information is generated in the form of three pulses: (1) a pulse proportional to the instantaneous beam current; (2) a pulse proportional to the instantaneous beam current times the horizontal displacement; and (3) a pulse proportional to the instantaneous beam current times the vertical displacement. The information is conditioned and presented to the beam operator in Central Control in the form of charge and horizontal and vertical displacement for each sector. For multiple beam operation, the information will be transmitted on a pulse-by-pulse basis to Central Control, where the information for each beam is separated and displayed.

The general features of the system are as follows:

1. Four analogue signals will be derived on a pulse-to-pulse basis at each sector. These are:
   a. A signal Q proportional to the total integrated charge.
   b. A signal $\ln Q$ proportional to the logarithm of the total integrated charge.
   c and d. Signals x and y proportional to the horizontal and vertical displacement of the beam from the accelerator axis.

2. The range of linear Q to be measured is 60 dB. A range-switch for linear Q will allow a single telemetry channel to be used for the entire 60 dB amplitude range; the switch will be a stepping type that can be operated from Central Control. Essentially only one beam can be monitored at a given time. Three or four ranges per decade will be provided for optimum accuracy.
3. For the remaining three signals, $\ln Q$, x, and y, it is proposed to time-share a single baseband (hardwire) telemetry channel. The range of $\ln Q$ represents 60 dB.

It is assumed that: (1) the position signals come from a microwave monitor; (2) a microwave intensity monitor provides the normalization signal; and (3) a magnetic charge monitor provides the signal for the precise determination of Q.

G. PERSONNEL RADIATION PROTECTION

A preliminary description of the equipment to be provided for personnel radiation protection was issued for review.

VI. MICROWAVE ENGINEERING AND INJECTION

A. INJECTION

1. Main Injector System

a. A scale model (1 inch = 1 foot) of the main injector klystron gallery (Station 000.00 to Station -70.58) is being built and is about 70 percent complete. The remaining items to be incorporated in the model are the layouts of the waveguides and vacuum, klystrons and supports, and the various modulators.

b. The requirements for the instrumentation racks have been revised. A new layout is incorporated for better space utilization, which provides more bays of racks. A mock-up of rack wiring techniques, using patch-board and other improved methods to facilitate maximum interconnecting flexibility, is now in progress in an area adjacent to the injection test stand (No. 13).

c. Water requirements, penetration layouts, cable trays and electrical lighting have been finalized with the Systems Engineering and Installation Department.

d. Preliminary design is now concentrated on waveguide components, vacuum systems and other control equipment.

2. Off-Axis Injector System

a. During this quarter it was found necessary to extend the alcove 30 feet to the west to accommodate the existing equipment layout. A scale model illustrating the alcove and the accelerator housing is completed. However, installation of equipment in the model remains to be done.

b. Cold testing of the S-quadrupole for the inflector system is to be completed by the end of April. The complete inflector system is scheduled to be tested with the Mark IV accelerator beam during the latter part of 1964. Specifications for the inflector magnet power supplies are being prepared.

3. Electron Guns and Modulators

a. Electron Gun Design

Using the SLAC gun computer program, a preliminary design for a gridded convergent Pierce type gun has been achieved. Electron trajectories have been plotted, and the beam edge potential distribution has been found to follow very closely the theoretical radial distribution in the equivalent spherical triode. With the grid potential approximately 1.5 percent of the anode potential, the gun has a perveance equal to 0.1×10^{-6}. The problem of maintaining good beam optics when the perveance is reduced by lowering the grid voltage has been studied. Computer trajectory plots indicate that adequate beam shape can be maintained down to very low currents by disconnecting the outer part of the focusing electrode from the grid so that its voltage may be independently adjusted.

A mechanical design for the gridded gun has been worked out. The design will be completed when sufficient details of the cathode and ceramic envelope are known.

b. Existing Guns

Gun Model 1-1, installed on the Mark IV accelerator in November 1963, has been performing over 700 hours with no reported failure. A second complete gun, Model 1-1, and a third stem, both for replacement purposes, were fabricated this quarter by the Mark IV Tube Shop.

Gun Model 2-2, installed on the injection test stand on January 21, 1964, has been performing satisfactorily.

Gun Model 3-1 reached the end of its emission this quarter, and a new filament and Phillips Type B cathode were procured. Because of an accident incurred in processing the cathode, it was found desirable to coat it with an oxide mixture and process it. The gun was not baked because of a leak that developed in the filament stem and which was sealed with Hysol epoxy. Emission was greater than two amps after processing. The gun was installed on the beam analyzer.

c. Beam Analyzer

The beam analyzer was used this quarter with incomplete instrumentation for trouble-shooting purposes. A voltage breakdown phenomenon between the collector cup and the surrounding target to ground was interfering with the measurements. This was finally eliminated by shielding it from any primary or secondary electrons from the beam with a glass sleeve insulator.

d. Manson Modulator

The first Manson modulator, Model 4-1, was received on March 16, 1964. So far, acceptance testing through the quarter has indicated compliance with the specifications in all major aspects. The testing is about 70 percent complete.

4. Injection Test Stand

During this quarter the injection test stand (No. 13) was operated successfully, and several new installations were completed. The main results are described below.

a. Bunch Monitor Cavities

The cavities to detect induced beam power at both the fundamental and fifth harmonic frequency were tested with the beam in air. For a 50 mA peak beam transmitted through the 5th harmonic cavity, a peak output power of about 3 watts was observed. The fundamental frequency cavity was also operated and performed as expected from theory. Design was initiated on a composite bunch monitor assembly to be tested under vacuum.

b. Accelerator Magnetic Focusing

The full complement of focus coil power supplies was installed, and the magnetic field curve as shown in Fig. 18 was found to produce optimum beam transmission for an input current of about 0.75 amps peak. Preliminary results show that optimum focusing for high beam currents is also close to optimum for low beam currents. Tests were made to determine the sensitivity of beam transmission to focusing fields. It was found that an individual focus coil current could be changed by 20 percent before beam transmission dropped by 2 percent. A decrease in current in one coil could almost completely be compensated by an increase in current in adjacent coils. A 10 percent drop in current through all coils produced a 20 percent drop in beam transmission. Further studies will be made on the effects of focusing on bunch size and energy spectrum.

c. Prebuncher and Buncher Tests

The effects of the prebuncher and buncher on both transmission and bunch size were investigated. The output of the 5th harmonic cavity was used as an indicator of relative bunch size. Figs. 19a and 19b respectively

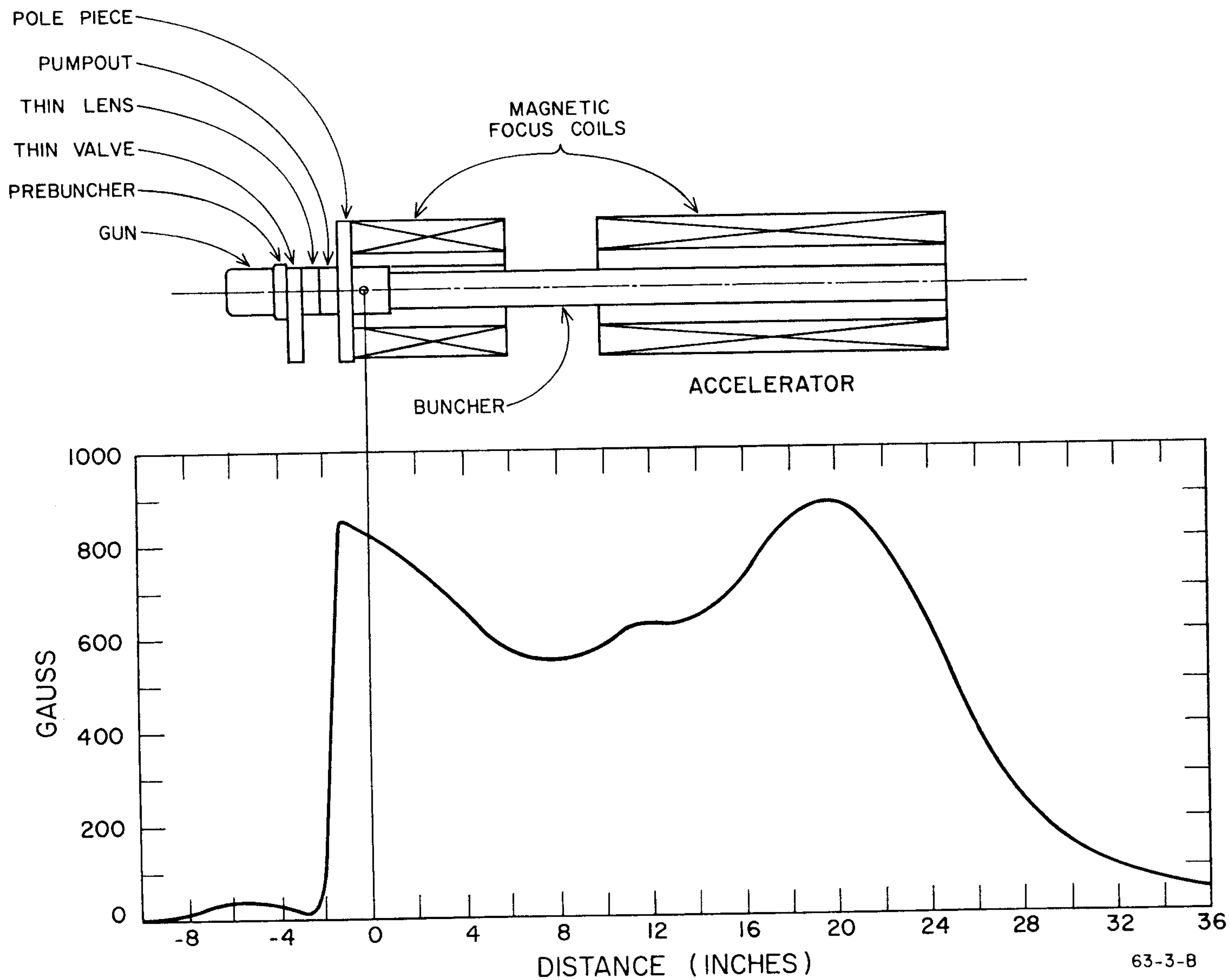


FIG. 18--Optimum axial field distribution for maximum beam transmission.

show the 5th harmonic and Faraday cup outputs as a function of prebuncher phase and power. The prebuncher presently in use unfortunately multipactors at high power levels, which limits the field attainable in the cavity. It is felt that in the absence of multipactoring, the curves of Fig. 19b would show a peak and fall-off similar to the buncher curve of Fig. 19d. The buncher had similar effects on beam transmission and bunch width, as shown in Figs. 19c and 19d.

d. Spectrum Measurements

The momentum spectrometer has been used to measure the energy spectrum under a variety of conditions. Three representative spectra are shown in Fig. 20. The first graph shows the energy spectrum for maximum 5th harmonic output, which corresponds to best bunching. The second graph shows the spectrum obtained after tuning up the accelerator for best transmission (500 mA). The third graph shows the spectrum after tuning the accelerator for highest energy. Figures 21 and 22 show the effect of beam loading on the energy and energy spectrum. The spectra in Fig. 21 were taken by changing the gun grid pulse voltage and without retuning the injector, except for adjusting the pre-buncher phase. This adjustment was necessary because the gun modulator voltage loads down significantly. The spectra are labeled with the peak current from the injector accelerator section. As the filling time of the two-foot section is 0.08 μsec and the beam pulse length is 1.0 μsec, these are essentially steady-state spectra. It is pleasing that over this range of current the spectrum width is quite constant, changing only from 1.8 percent to 2.2 percent (half-intensity points).

The beam loading data in Fig. 22 is taken from Fig. 21. The straight line has a slope

$$\frac{dE}{dI} = 1.1\ \frac{\text{MeV}}{\text{amp}}$$

The theoretical expression is

$$\frac{dE}{dI} = \frac{rL}{2}\left(1 - \frac{2\tau}{e^{2\tau} - 1}\right)$$

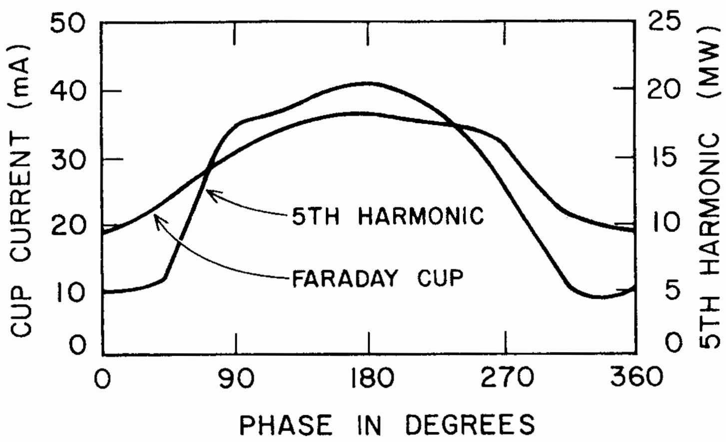


FIG. 19 a - PREBUNCHER PHASE

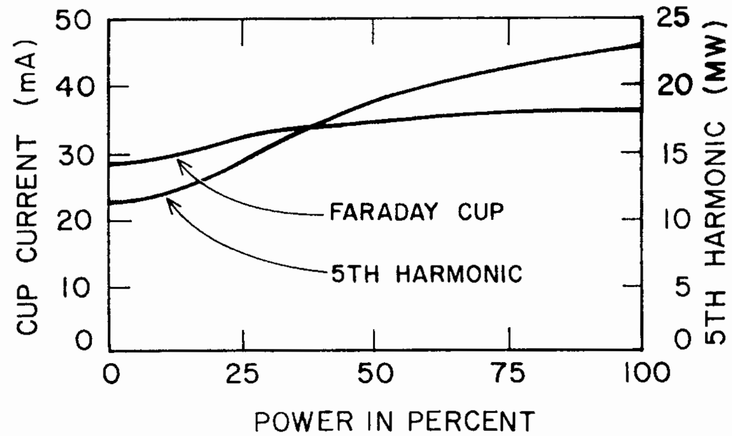


FIG. 19 b - PREBUNCHER POWER

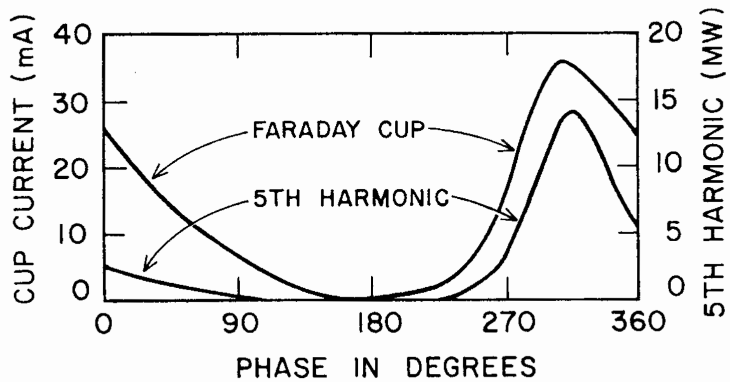


FIG. 19 c - BUNCHER PHASE

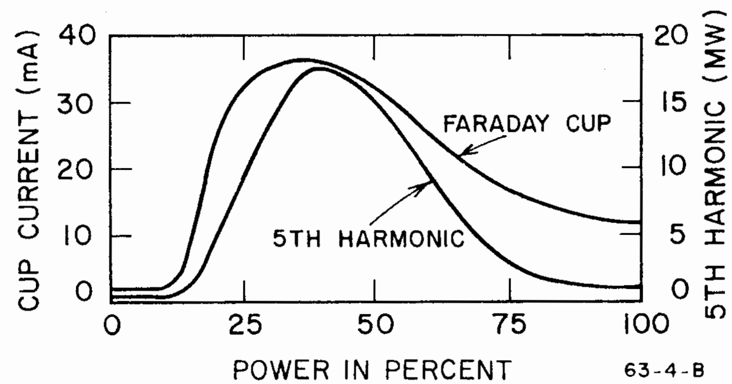


FIG. 19 d - BUNCHER POWER

FIG. 19--Effects of phase and power of prebuncher and buncher.

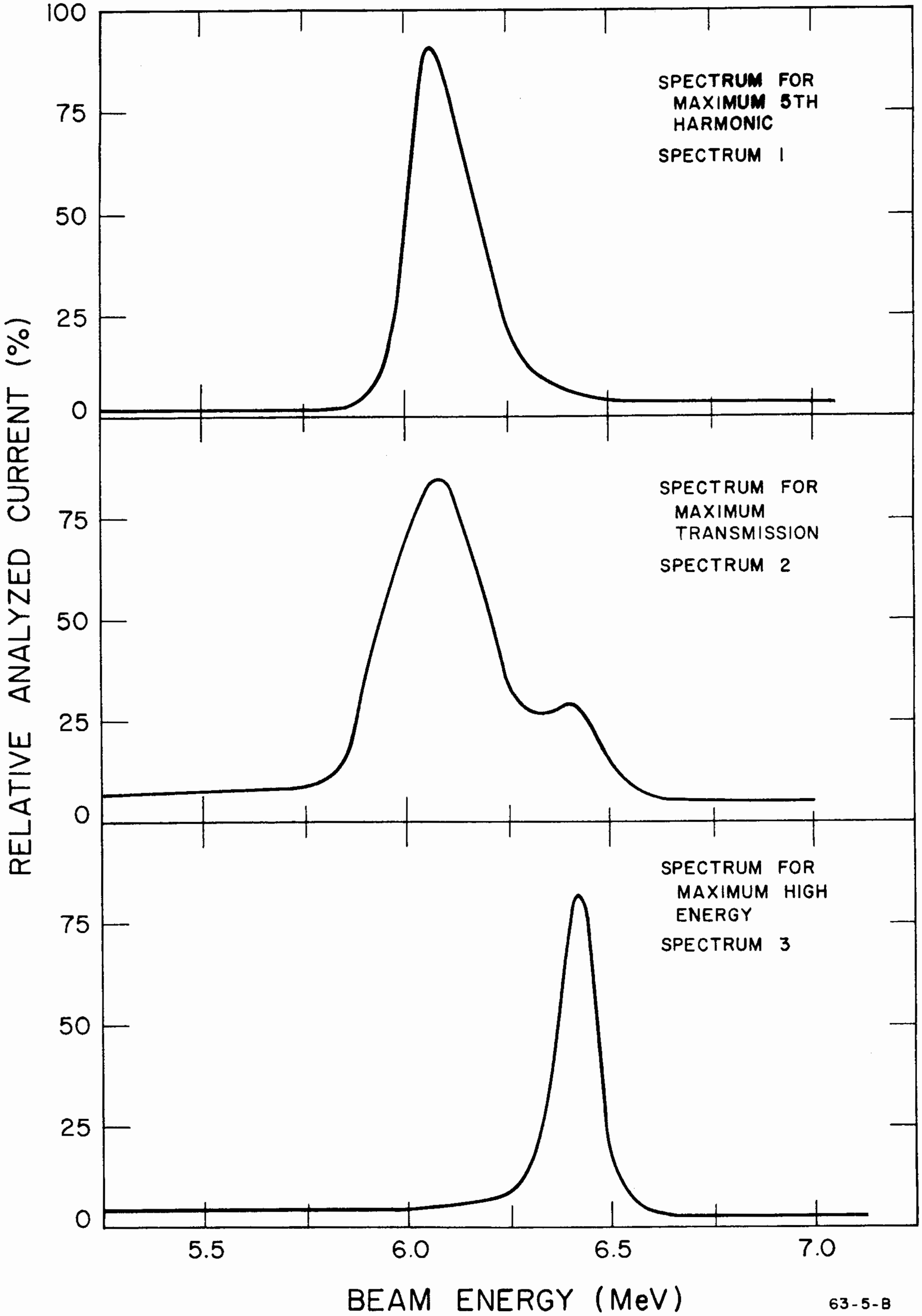


FIG. 20--Energy spectra.

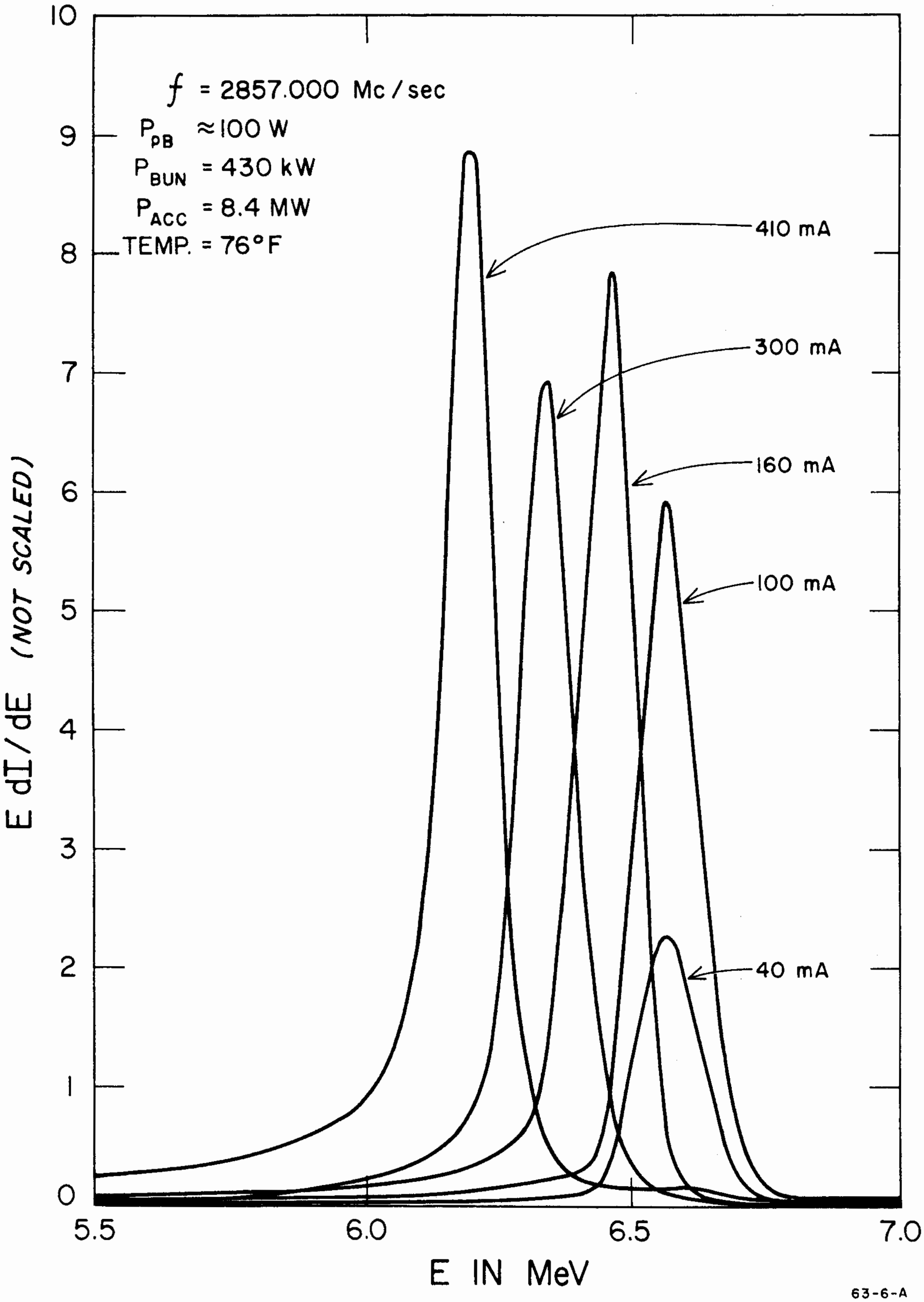


FIG. 21--Injector energy spectra.

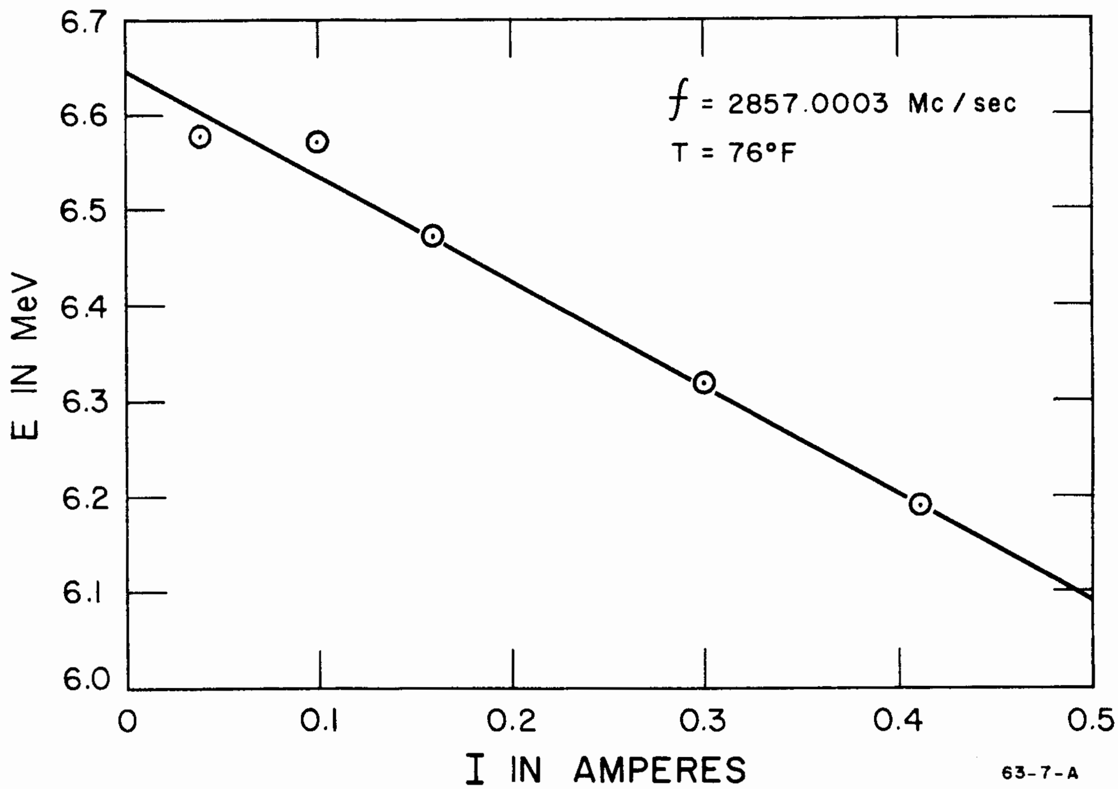


FIG. 22--Beam loading data (taken from Fig. 21)

Using $r = 53 \times 10^6$ Ω/meter

$L = 0.525$ meter

$\tau = 0.0772$ nepers (rf cold test of this pipe)

one obtains

$$\frac{dE}{dI} = 1.08 \text{ MeV/amp}$$

e. Gun Current Enhancement Effects

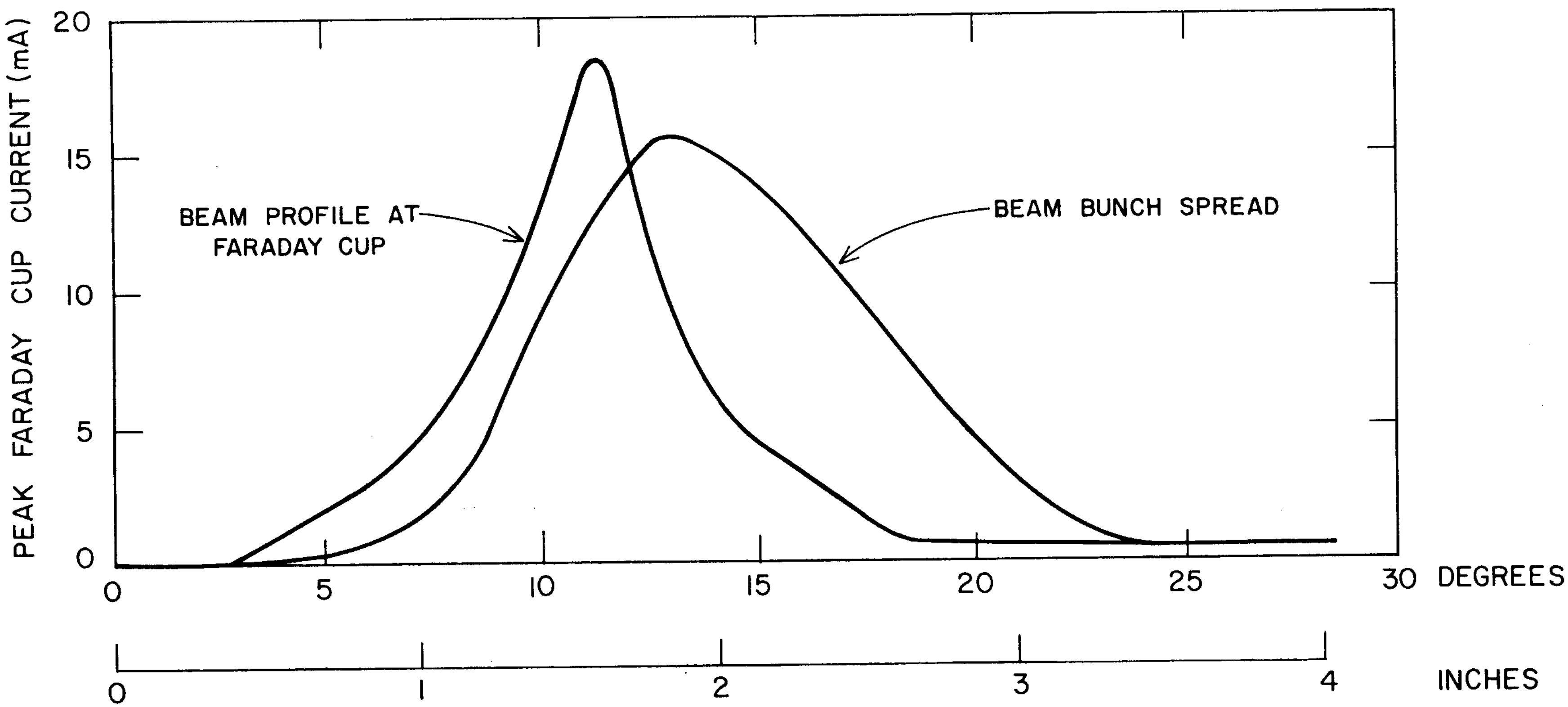
During operation of the accelerator, it has been noted that certain settings of buncher and prebuncher timing and focusing can cause an increase in the beam current emitted by the gun. This effect is most pronounced when the gun cathode is operated in the temperature-limited region. The phenomenon may be caused by ions from the accelerator striking the cathode, but it is not completely understood at this time. The detailed results will be discussed in the next report.

f. Beam Analysis Subassembly

Fabrication of this assembly was completed, but leaks in two bellow joints were found and are now being repaired. The rest of the assembly has been installed in the output of the accelerator, including the water cooling for the viewing paddle and the beam slits. The remote drives are being checked out.

g. Beam Sweeper and Sweep Tank

Fabrication and installation of the beam sweeper and sweep tank were completed to the extent that a vacuum could be obtained, and the beam turned on. First measurements of bunch size with the beam sweeper were made, although the measurements were crude because of the unfinished status of the auxiliary equipment. Figure 23 shows the results of the first bunch width measurements made with the beam sweeper. Accelerator tuning was optimized for best beam profile (smallest spot size) at the Faraday cup. Figure 23 also shows the resulting beam profile as measured by steering the beam across the Faraday cup slit. When the sweeper instrumentation is completed, more precise bunch measurements will be made.



63-8-A

FIG. 23--Bunch width as displayed by beam sweeper and beam profile at Faraday cup.

5. <u>Beam Knockout</u>

The beam knockout system originally proposed utilized a video pulse technique to eliminate the dark current. Subsequent discussions with various interested parties have shown that a system based on a subharmonic resonance sweep would be more useful for experiments planned with the accelerator. The new proposal consists of two beam knockout stages. The system should be capable of producing a series of single bunches of electrons followed by quiet periods of 12.5 nanoseconds during the 1.6-microsecond beam pulse. Both stages are driven by phase-synchronized rf drivers producing power at the 72nd subharmonic of 2856 Mc/sec at a level of about 100 kW.

The first stage consists of deflection plates located in the gun region. The beam is swept in the transverse direction at a rate of 39.667 Mc/sec, i.e., at the rate at which the field goes through zero at the 72nd subharmonic frequency. Inflector plates following a collimating slit correct for the transverse momentum imparted to the electrons, which pass through the slit slightly off the zero of the sweeping field. These electrons are injected into Sector 1 of the accelerator and reach the second stage of the beam knockout system at the end of this sector. This second step consists of a half-wave non-concentric coaxial cavity. The beam is passed through a quarter-wave section of this cavity. The Sector 2 accelerator sections act as the stripping slits for the deflected part of the beam.

During the next quarter, studies will continue on the new beam knockout system, and specifications will be prepared for the two high power drivers and the high level deflection cavity.

B. DRIVE SYSTEM

1. <u>Overall Status of the Drive System</u>

All basic design parameters for the drive system have been determined and most major procurement contracts are in effect. Below is a brief summary of their status.

a. Main and Sub-Drive Lines

The main and sub-drive line contract is in effect with Dielecric Products Engineering, Raymond, Maine. Delivery of Sectors 1 and 2 is scheduled for early April 1964. All acceptance tests performed at the subcontractor's plant were witnessed by SLAC personnel for Sector 1, except the high-power test and the group velocity test for the sub-drive line. So far the Sector 1 lines meet specifications.

b. Varactor Frequency Multipliers

The varactor frequency multiplier contract with Remanco Incorporated, Santa Monica, California, is in effect, with delivery of the pre-production quantity of six units taking place in late March. Acceptance testing has begun.

c. Main Booster Amplifiers

The contract for the two main booster amplifiers was completed during this quarter with the delivery of both units. Acceptance tests are expected to be complete by the end of April 1964.

d. Sub-Booster Klystrons

The sub-booster klystron contract continues in force with klystron delivery following the modified schedule. Solutions to the problems concerning the deterioration of vacuum and short shelf life are being investigated by Eimac.

e. Sub-Booster Modulators

The sub-booster modulator contract was let to Manson Laboratories, Wilton, Connecticut, in March 1964. The Heavy Electronics group is handling the contract with the Microwave Engineering group participating as necessary.

f. Master Oscillators

The technical specifications for the procurement of the master oscillators were completed. Distribution of the bids to prospective contractors is expected in early April 1964.

g. Drop-Out Cables

The cables joining the sub-drive line couplers to the 24 MW klystrons through the isolator-phase shifter-attenuator package, called drop-out cables, require a high stability of rf phase as a function of temperature and a low attenuation. Standard RG-214 flexible cable does not meet these requirements. For this reason, phase temperature stability measurements were performed on several samples of 1/2-inch semi-flexible cables. Because there will be approximately 900 units of these cables, pressurization is impractical; therefore the decision was made to use solid-supported inner-conductor, phase-compensated cable. These cables are on order.

2. Microwave Test Stand Operation

During this quarter, the test stand was used to check the phase stability of most components in the rf chain from the oscillator to the 24 MW klystron amplifier. In addition, tests were performed to further investigate the transient behavior of a sample accelerator section when fed with a variable rise time rf pulse. The data is presently being analyzed. In addition, studies were made of the harmonic content of several stable oscillators used in the test stands.

The high power available from the test stand was also used to check the electrical breakdown limits of 7/8-inch semi-flexible cables to be used in the phasing system. It was found that in most samples the connectors and adaptors failed before the cable; however, the power-handling capability was much greater than the peak power anticipated in the actual system.

The new water load for the 24 MW klystron described in the previous quarterly report was received and has performed at full power.

C. PHASING SYSTEM

1. Procurement of Isolator-Phase Shifter-Attenuator Assembly

Twenty-five isolator-phase shifter-attenuator assemblies and five control phase shifters were received during this quarter from Sperry Microwave Corporation, Clearwater, Florida. In-house acceptance tests are now in progress and it is anticipated that these will be completed by the middle of next quarter.

2. RF Head

Construction of two units was completed during this quarter, and specifications are being compiled to enable the outside procurement of the remaining 28 units to commence as early as possible.

3. Programmer

The construction of two programmers for Sectors 1 and 2 was completed during this quarter. These will undergo tests with the new isolator-phase shifter-attenuator assemblies in the sector simulator.

4. Linear Detector Design

Variations in the characteristics of the thermionic diodes used in the linear detectors of the phasing system result in an increase of the input standing wave ratio. Tests are being undertaken in order to determine the required characteristics of the diodes and to minimize the above-mentioned variations.

5. Momentum Spectrometer Stations

The design criteria report on the momentum spectrometer stations was continued through this quarter. Detailed design drawings for the momentum spectrometers have been completed and the procurement cycle has been initiated. Final calculations on the energy defining slit and beam dump have been completed; the results will be incorporated in the design criteria report on injection phasing.

6. RF Cavity for Drift Section

The design of the rf cavity completed during the last quarter is being revised in order to increase the shunt impedance. This increase was found to be necessary because of the additional power required by the normalizing circuits of the beam position monitors. The new design is scheduled for completion early in the next quarter.

7. Beam Position Monitor

Experiments have been carried out on various types of position monitors, including models suitable for use in the beam switchyard. In all types, good correlation between signal and position was obtained. At the present time emphasis is being placed on the TM_{012} resonator, and a final design is scheduled for completion in the next quarter.

D. OPTICAL ALIGNMENT SYSTEM

During this quarter the Microwave Engineering Department was given responsibility for the optical alignment system. The Mechanical Design and Fabrication Department is handling the actual mechanical details and Systems Engineering and Installation continues to supply technical and installation assistance as required.

1. Target Design

The concept of using rectangular Fresnel zone plates as alignment targets has been tested at the Brisbane tunnel. Alignment sensitivity is in agreement with calculations. The ruled area of the target used is 4 inches wide and was made by Klarmann Laboratories, Waltham, Massachusetts, according to the process of ruling and chemical milling planned for production targets. A check of the dimensions of the rulings in the target showed them to agree with the design values within a standard deviation of 0.0007 inch. Preliminary results indicate that it may be possible to use photographic techniques in air to evaluate the quality of a target. It is hoped that in this way a direct check of the target quality can be readily obtained, rather than using expensive inspection procedures to evaluate the production technique. The important parameters relating to symmetry will still be determined by suitable inspection.

2. Leveling

During the last quarter a decision was made to separate the alignment function from the transverse leveling function; thus, the triple targets originally planned will no longer be needed. The leveling function will be performed by some simple form of leveling with remote readout. The optical alignment procedure is therefore reduced to the detection and positioning of a single spot.

E. MAGNETIC SHIELDING

The specification for the accelerator magnetic shielding has been completed. The design calls for strips 8-5/8 inches wide by 16-1/8 inches long by 0.006 inch thick, to be wrapped around the accelerator and banded in place. Except for special pieces at the ends and center of each accelerator section, all pieces will be identical.

The best shielding results were found using a moly-permalloy material called HYMU "80" manufactured by the Carpenter Steel Company of Reading, Pennsylvania. Using this material as a standard, it has been found possible to obtain a shielding factor of above 20 in a long cylinder. Averaged over the length of the accelerator, where there are many unshielded gaps, it is expected that the net shielding factor will be about 13 or more. Because there are competitive materials with virtually the same composition as HYMU "80," the specifications permit a vendor to submit a bid based on another product provided that the bid is accompanied by a sample of that shielding and that our tests show it to be equivalent to HYMU "80".

VII. SYSTEMS ENGINEERING AND INSTALLATIONS

A. ACCELERATOR RESEARCH AND DEVELOPMENT

Research and Development programs for the vacuum system were essentially concluded during this quarter. In a continuation of the gauge evaluation program, Hughes gauges were tested; it was found that these gauges generally did not operate satisfactorily in the 10^{-9} torr range. Tests were run with Linde cryosorption pumps on the test tower, and pressures of 5×10^{-5} torr were obtained after about three hours of pumping. One test was run on a roughing system with a mechanical pump and liquid nitrogen trap. The ion pump was valved in at one micron, and a pressure of 2×10^{-5} torr was achieved after only 60 minutes total pumping time.

Tests were run to check pumpdown times from both air and dry nitrogen with a roughing system consisting of a 15 cfm mechanical pump, molecular sieve trap, and LN_2 trap. The results were in close agreement with comparable data taken on the "Purple Coffin" roughing system. Typically, starting from air, pressures of 1×10^{-3} torr were reached in 50 minutes and 2×10^{-4} torr in one hour, 25 minutes.

Research and Development testing for the support and alignment system was concluded in January.

B. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. General Accelerator Design

Layout plans for the complete accelerator were updated and posted for project perusal.

Final contract drawing changes are underway on the water and electrical systems subcontracts for the main injector. Design work on the off-axis injector is being delayed until the main injector changes are completed.

The definitive drawing of a standard drift section has been updated to reflect the latest design changes.

2. Standards and Specifications

Book 1 of the SLAC Standards Manual will be reissued as three books covering (1) project standards, (2) drafting standards, and (3) engineering specifications. A program for evaluating, revising, and updating each standard is underway.

3. Model Shop

Models completed or in process during this quarter included those of the off-axis injector, Central Control console, main injector, SLAC power line, and support girder transporter, as well as models of the electric cart and fork lift to be used in klystron handling, a model of accelerator Sector 14, and models of dummy components for the drift section mockup.

4. Installation Drawings

Drawings for the electrical services installation were updated to reflect the latest changes in the main injector. Cooling water system drawings were issued for bid; revisions on the final dimension check are nearly complete. Drawings of the electronic system for Sectors 1 and 2 were issued for project review.

5. Vacuum System Procurements

During the quarter, contracts were awarded for the vacuum system installation, the three-inch and six-inch valve assemblies, and the getter ion pumps. Under the latter subcontract, four pre-production ion pumps were received and tested, but failed to meet the speed requirements specified. Pumps with modified power supplies at a higher voltage of 6.8 kV (the original units were rated at 4.75 kV) will be resubmitted early next quarter.

Procurement specifications for the all-metal valves and the one-inch flanges were issued for bid. Bids were received for the manufacture of the small roughing valves; samples for testing have been ordered from two bidders.

6. Supports

Fabrication specifications for the klystron support frame were issued for bids, and the contract has been awarded. Bids for the vertical and horizontal support jacks were received and are now under review. Drawings and specifications for fabrication of the support girders were issued for bid in February. The AEC is reviewing the drawings and specifications for the intergirder connection pins and bearings.

On March 1, 1964, future responsibility for supports was transferred to the Mechanical Design and Fabrication Department, except for the klystron support frame, the vertical and horizontal jacks, and the jack support hardware.

7. Alignment

Alignment target actuator specifications were issued for AEC and project review in February.

Future responsibility for the alignment system was transferred to the Accelerator Physics Department, effective March 1, 1964.

8. Cooling Water

The installation subcontract for the cooling water system has been awarded.

Preliminary sizing of piping and heat exchangers to be used at the positron source has been determined.

An addendum to incorporate pipe unions into the supply and return lines to the accelerator water jackets 8 feet, 2 inches above the floor was issued to bidders on the installation work for the accelerator pipe connections.

A recommendation that a 95% tin - 5% antimony solder be used for the cooling coops was presented to the cooling water system review committee.

9. Electrical Services

The subcontract for the electrical services installation has been awarded.

Checking of the shop drawings for the variable voltage substations continued during the quarter. Field trips were made to check the progress of 12 kV sections of these substations. The problem of protecting the substations temporarily, pending the installation of circuit breakers at the master receiving substation, is under review.

10. Auxiliary Machine Shielding

Final detailing of the auxiliary shielding for the accelerator is in process. Methods of fabricating and installing air seals are being investigated.

11. <u>Electronic System</u>

Definitive drawings of the cable plant installation for the tests on accelerator Sectors 1 and 2 are 85% complete. The trigger cable is out for bids, and installation specifications are being reviewed.

Bids were received for batteries and battery chargers for the battery plant, and contracts for these items have been awarded.

The rack program is well underway, with a subcontract for the rack frames awarded and the assembly and wiring drawings for the FIAT racks 75% complete. A first draft of the fabrication specification for the FIAT racks was prepared for review. In addition, rack profiles and partial criteria for the alcove racks were received and are being reviewed. A draft of the time and materials contract for rack assembly and fabrication was issued for internal review.

Work on the internal communications system has also received emphasis during the quarter. The subcontract for the public address system was awarded. In addition, efforts are being made to complete terminal connection of the aerial telephone cable between the Electronics Building and the main injector. This will be utilized for temporary communications in the Klystron Gallery during the construction period. A proposal to provide telephone service to the operational area of the project from the existing switchboard, instead of from new equipment to be installed in the Control Building, was submitted, reviewed, and approved. For present use, a temporary service channel terminal has been completed and installed in the Electronics Building preparatory to serving Sectors 1 and 2 over the temporary pole line cable.

A criteria report for the personnel safety interlock system was received. Installation specifications and drawings will be started when equipment and engineering details become available.

C. ACCELERATOR INSTALLATION

1. <u>Schedules</u>

Meetings were held with the water, vacuum, and electrical systems subcontractors to review the proposed schedules for testing of Sectors 1 and 2. Water and electrical subcontractors were notified to begin work in Sector 1 early in April.

2. Subcontracts

Vacuum and electrical system subcontracts were updated to reflect changes made during the bid period.

A revised delivery schedule and minor dimensional change orders for the five-inch manifold were issued for incorporation into the vacuum system subcontract.

Klystron frame outrigger changes were set forth for inclusion in the water system subcontract.

3. Procedures

SLAC installation and acceptance procedures were finalized and will be made available during the next quarter. Revised estimate forms were procured; daily report, progress report, and modification request forms are being reviewed.

VIII. MARK IV PROGRAM

A. OPERATION

This quarter is the first one during which the Mark IV accelerator has been run consistently at high peak and average powers and on regular schedules for the major part of the quarter. During previous quarters, the machine had been operating on a continually improving basis, but with considerable time out for making changeovers to improved equipment. Virtually all operating shifts scheduled for this quarter were actually run, and the experimenters continued with the work they had been doing.

One test of machine operating reliability that was made was a continuous, around-the-clock run of four eight-hour shifts, with no shutdowns of more than about ten minutes. One entire eight-hour shift had only two momentary gas burst shut-offs.

The last few weeks of the quarter were used for doing calibrations on the machine, for the purpose of making an accurate measurement of the no-load electron energy gain in the second acceleration structure as a function of input microwave peak power to that section. Calibrations of the attenuation factor (or coupling) of the high-power waveguide directional couplers were made, along with a floating wire calibration of the output analyzing magnet. The klystron tank capacitive high voltage dividers also were calibrated while the opportunity presented itself. The desired measurements were taken, just at the end of the quarter, but the calculations to determine the energy gain versus power have not been completed.

The klystron in socket No. 1 was changed on January 6. The klystron in socket No. 2 has been there since December 9, 1963, and all four type 7890 thyratrons are the tubes installed in the summer of 1963. During this quarter, the actual high voltage operating time of each of the above tubes amounted to approximately 540 hours.

The total accumulated running time of the thyratron switch tubes as of the morning of April 2, 1964, was as follows:

Modulator	Heater Hours	Anode Hours
1	2321	882
2	2245	894

B. MACHINE MODIFICATIONS

The line reactors for high voltage power supply No. 2 were received and installed, and the power supply was put back into service.

The closed circuit TV system was delivered, and was put to use with very satisfactory results.

Further installation of local telephone equipment was done, making several additional and much-needed circuits available for use.

Vacuum gauge amplifiers, which were modified during the previous quarter, were installed and used.

Toroid coils were installed for viewing the electron beam current pulse at three positions: between the accelerator sections, after the second section, and after the slit on the output analyzing magnet.

Three unsatisfactory thin valves in the accelerator vacuum system were reworked to fit them with gold seats. Upon re-installation, the valves functioned as expected.

A general-purpose, portable diffusion pump was built and put into use.

C. PROGRAM FOR THE NEXT QUARTER

A survey of the needs for the Mark IV accelerator showed that it would take at least until October 1964 to complete the backlog of work on a two-shift-per-day basis. Therefore, it is planned to continue with two shifts until October 1, reducing operations to one shift per day at that time, and terminating Mark IV operations at the Hansen Microwave Laboratory early in January 1965.

It is apparent that the Center will have need for a small accelerator for the foreseeable future. It is planned to set up such a machine at the main site, so that operations can be continued after termination of the Mark IV activity. Several alternative combinations of existing equipment and housing are being considered, along with possible additions and/or changes, so that proposals can be made to SLAC management for selection of a facility which would give the greatest technical capability within the limits of what is economically both justified and feasible.

IX. PRE-OPERATIONS RESEARCH AND DEVELOPMENT

[Contract AT(04-3)-515]

A. THEORETICAL PHYSICS

1. Publications

The following articles and reports have been completed and submitted for publication:

(1) S. D. Drell (with J. D. Walecka) "Electrodynamic Processes with Nuclear Targets" (Ann. Phys., in press).

(2) S. D. Drell (with A. C. Finn and A. C. Hearne) "Restrictions of Form Factors and Coupling Constants" (Bull. Am. Phys. Soc. 11, 450 (1964).

(3) S. D. Drell, "Form Factors of Elementary Particles" (Enrico Fermi International School of Physics - Academic Press).

(4) S. M. Berman (with R. J. Oakes) "Angular Correlations in Production Processes" (submitted to Phys. Rev.).

(5) S. M. Berman,"Unification of Electroproduction and Photoproduction" (submitted to Phys. Rev.).

(6) M. Bander (with G. L. Shaw) "Bootstrap Calculation of the ρ-meson Regge Trajectory" (submitted to Phys. Rev.).

(7) M. Bander, "Low-Energy Neutron-Neutron Scattering Parameters" (Phys. Rev., in press).

(8) H. P. Noyes, "The Analysis of Low-Energy Nucleon-Nucleon Scattering" (submitted to Congrès International de Physique Nucléaire, Paris).

(9) R. J. Adler, "Meson Exchange Contribution to the Deuteron Electromagnetic Current" (PhD. thesis).

(10) Y. S. Tsai (with C. K. Iddings and G. L. Shaw) "Depolarization of Spin 1/2 Particles by Electromagnetic Scatterings" (submitted to Phys. Rev.).

2. Form Factors

It is known that two general form factors depending on energy loss and momentum transfer characterize inelastic electron scattering from nuclei in first Born approximation in $\alpha = 1/137$. The same two form factors appear in all electrodynamic processes connected by one photon exchange with nuclei. This observation is used to compute cross sections and to discuss experiments which are aimed at probing electrodynamics by scattering of pair-producing electrons or muons from nuclear targets.[1] It has been shown that the Pauli form factor F_2 of the nucleon or any fermion must vanish for infinite time-like momentum transfer if there exists an unsubtracted spectral representation for the photon propagator. Successful calculation of the vacuum polarization contribution to quantum electrodynamics suggests no need for a subtraction in the propagator which would introduce an additional arbitrary parameter into the theory. Consideration has been given to the relation between zeros in propagators, dispersion relations for form factors, and magnitudes of coupling constants in quantum field theory.[2] A series of lectures on the properties of electromagnetic form factors, including a discussion of their relationship to conserved vector currents and weak interactions has been published.[3]

3. Production Processes

A simple and general method for studying processes in which resonances or unstable particles are produced has been developed. The method exhibited consists of analyzing the experimental data in terms of all the possible independent angular correlations among the decay products of the produced particles. The usefulness of this method of analysis is illustrated by showing how the correlations provide extensive tests of various dynamical models of the production process itself.[4] A general formalism which unifies electroproduction and photoproduction has been developed. This could form the basis for a new and not heretofore attempted program of physics which should be a unique program at SLAC. The idea is to use "coincidence" electroproduction experiments to separate the kinematical features from the dynamical aspects of a general photoproduction process. The discussion illustrates how the above mentioned separation can be accomplished for an arbitrary production process.[5]

4. Studies in the Strong Interactions

An N/D calculation of the π-π scattering and Regge parameters previously discussed has been completed and submitted for publication.[6] The results are not in good agreement with experiment, presumably due to the

[1] These references are to the publications listed above.

use of elastic unitarity. Inelastic effects are clearly important in the understanding of the recently discovered $P_{\frac{1}{2},\frac{1}{2}}$ resonance in π-N scattering at 550 MeV, and a dynamical calculation of these effects is in progress.

Reinvestigation of the proposed method for determining the n-n scattering length from π^- capture in deuterium yielding $2n + \gamma$ shows that by including multiple scattering corrections, the theoretical uncertainty is reduced (by a factor of 4) to ±1 f.[7] An experiment (by a UCLA-Seattle-Berkeley collaboration) to better than this statistical accuracy is nearly complete, and assistance in the analysis is being given to the experimenters. Comparison of the $^1S_0$ effective range given by previously reported analyses of the low energy n-p and p-p scattering reveals a charge-dependent difference of 10 – 20% in the opposite direction to that expected from coulomb effects. Examination of the charge-dependent effects possible due to $\pi^{\pm} - \pi^0$ mass and coupling constant differences shows that these are an order of magnitude too small to explain the effect. It is concluded that there is a substantial charge-dependent contribution from the $I \neq 0$ boson systems exchanged in this state, which is hard to reconcile with current models of the two-nucleon interaction.[8] Calculation of the contribution of the π-ρ intermediate state to the exchange electromagnetic current in the deuteron yields a negligibly small correction to the static quadrupole moment (which is believed to be understood) but a correction to the static magnetic dipole moment which comes close to explaining an outstanding discrepancy in low energy nuclear physics;[9] the π-γ-ρ parameter value used in the calculation has subsequently been confirmed by photoproduction experiments reported at the latest APS meeting.

5. Applications of Quantum Electrodynamics

A careful study has been made of the depolarization of spin-1/2 particles by electromagnetic scatterings. Among other results, this shows conclusively that polarized electrons produced at high energy can, under appropriate conditions, be slowed down to energies where their polarization can more easily be studied without a substantial loss of the initial polarization.[10] In connection with the proposal to use $e^+ + e^- \rightarrow 2\gamma$ to obtain monochromatic γ-ray beams, the bremsstrahlung formulae for $e^+ + e^- \rightarrow e^+ + e^- + \gamma$ and for $e^+ + P \rightarrow e^+ + P + \gamma$ have been calculated;

numerical results are being obtained. A program has been written to give the Compton scattered photon and electron rates for a bremsstrahlung beam passing through matter, for use in computing background to spark chamber experiments, giving tables of angular and energy distributions for two types of low energy cutoff; numerical work is nearly complete. μ-pair photoproduction coincidence rates in a spark chamber have been computed and are being tabulated.

B. EXPERIMENTAL PHYSICS

1. Group A

The principal interest of Group A is in preparing for a broad range of electron scattering and photoproduction experiments at SLAC. The early experiments are likely to be extensions to higher energy of the relatively straightforward work that has been done in these fields at the Stanford High Energy Physics Laboratory and at CEA. Positron scattering experiments are also planned. The principal research instruments will be one or more large magnetic spectrometers which are now being studied.

The spectrometer design is set by the requirements of the experiments which are as yet unspecified in detail. Based on experience at the Mark III linear accelerator at Stanford and at the Cambridge Electron Accelerator this group anticipates building about two magnetic spectrometers rotating around a common target in End Station A. One spectrometer would have a maximum momentum of about 20 BeV/c, a solid angle of about 0.1 msr, and an angular range of about 0° to 20°. Another spectrometer might have a maximum momentum of about 9 BeV/c, a solid angle of about 5 msr, and an angular range of about 0° to about 180°. Generally, the momentum resolution sought after is about $\Delta p/p = \pm 0.1\%$, and some care is being taken to try to have the lengths of the various orbits be the same ("isochronicity" for constant velocity). Contemplation of these spectrometers has only just begun, and the parameters are by no means fixed as yet.

2. Group B

a. Studies of Hydrogen Bubble Chambers

A group consisting of Brechna, Haldemann and Guiragossián has been studying the cost and usefulness of several possible HBC's. They have inspected chambers at BNL, CEA and ANL.

For SLAC the general ground rules for HBC operation during the initial phases of machine operation have been taken as follows:

(a) Initial energy — 10-14 GeV.

(b) No positron source available.

(c) A pulse of the desired energy below the maximum will be available twice per second. The intensity will also be variable.

(d) There are experiments that will be interesting to do within 3-6 months after beam turn-on.

As a result the conditions on the chamber are, first, that it be available by January 1967; and, second, that it be as large as possible and still be compatible with such a fast time schedule.

The general concensus has been to propose to build a chamber between 1 and 1.3 m in diameter with a depth of approximately 0.5 m and a magnet which will deliver at least 20 kg and perhaps as much as 30 kg. Cost estimates vary between 2.5-4.0 million dollars depending on the conditions.

In order to help determine the chamber size two programs are being undertaken. First, a modification of the Berkeley FAKE program has been made by W. B. Johnson to investigate the missing mass spectrum in the reaction $\pi^+ + p \rightarrow \pi^- + p + \pi^+ + \pi^+ + \pi^0$. Normal errors, derived from other experiments, are assigned each outgoing track on a random basis; and many events are generated, also randomly, so that one generates an actual experiment as closely as possible. This is being done for both diameters and fields as well as for different momenta of incoming particles. Second, the effect of the size of magnetic field on slow electrons from electron pairs and from low energy knock-ons is being studied.

b. Particle Beams

Three particle beams, mainly for bubble-chamber use, are being studied. The first is a separated K beam using an rf separator; the second, an almost monoenergetic gamma ray beam; and the third a pencil muon beam. A first attempt at these beams indicates that all three can be brought to a chamber about 200 feet from a target with only minimal motion of the chamber required so as to be able to operate with any of the three beams.

c. Pion Beta Decay: (W. B. Johnson, R. R. Larsen in collaboration with R. B. Bacastow, C. Ghesquiere and C. Wiegand at LRL).

This experiment is presently using about 30% of the 184-inch cyclotron time collecting data. The scanning of the pictures is being done at SLAC and we are beginning to measure the events on the recently acquired Vanguard equipment. A high-pressure hydrogen gas target has been designed and is under construction. This will be used for stopping π^- to calibrate the apparatus. The accuracy of the calibration measurements will determine the number of beta decay events we seek.

d. K^+P Interactions at 2.7 BeV/c: (W. B. Johnson, R. R. Larsen in collaboration with W. Chinowsky, R. Newman and J. Schultz at LRL).

We have acquired 55,000 pictures of 2.7 BeV/c K^+ mesons in the BNL 20-inch hydrogen chamber. These will be scanned and measured at LRL and SLAC.

3. <u>Group C</u>

The principal interest of Group C is in the design and construction of a high-energy electron-proton colliding-beam storage ring at the SLAC site; a proposal for this facility was recently submitted to the AEC. The SLAC accelerator is uniquely suited to act as an injector for a storage ring of this sort.

If the storage ring proposal is not authorized, or if it is significantly delayed, the main efforts of Group C will likely be concerned with the preparation of an experimental program for End Station A.

Members of Group C are presently participating in a collaborative Stanford-Princeton experiment at the Stanford High Energy Physics Laboratory, which makes use of the 500 MeV electron storage rings at that laboratory.

A program to study the capabilities of wide-gap spark chambers was initiated. Such chambers may be useful, for example, in detecting reaction products in electron-positron colliding beam experiments at high energies (3 BeV). Tracks of cosmic rays were observed travelling from plate to plate of a chamber with a 6-inch plate separation. A Marx type generator was used to produce high voltage pulses of about 80 KV. Attempts are being made to obtain tracks for particles which do not necessarily go from one plate to the other.

4. Group D

Group D is concerned with the preparation of a group of photoproduction studies at SLAC. A part of the motivation for this work stems from the fact that electromagnetic production processes are in general simpler to interpret than the kinds of production processes that occur with protons. It appears likely that the principal research instrument for this work will be a large-volume spark chamber. Several possibilities exist in developing a suitable gamma-ray beam: (1) a parasitic beam may be developed which does not interfere with other experiments; (2) a monoenergetic beam may be developed by positron annihilation in flight, or by one of several other techniques presently being studied.

Conceptual design has been started on a large-solid-angle spark chamber array for performing photoproduction experiments. This device is specialized for studying peripheral reactions in which a large amount of momentum is transferred to some of the secondary particles and very little given to others. Two large magnets are required, one in the forward region to handle the high-momentum secondaries, and one surrounding the interaction region to study the low-momentum components.

Background calculations for Compton photons and electrons have been performed. Calculations are under way for pair-produced electrons. Kinematics studies have been started for the reaction $\gamma + p \rightarrow p + \pi^{+} + \pi^{-}$ where large momenta is given to the π's, or in the other case to the secondary proton.

A study has been started of the feasibility of using the 6° parasitic beam or locating in target area A. Calculations have been done of the yield of μ pairs and background estimates are now being made.

5. Group E

A principal interest of Group E will be in the development of one or more large-volume magnets which can be generally useful in a variety of experiments at SLAC. The early work of Group E will likely be carried out in End Station B on the straight ahead beam. An example of the kind of experiment which presently seems of interest is a study of muon scattering with the use of a large spark chamber.

The activities of this group in the first quarter of 1964 have been devoted to three main research projects. These are: the experimental study of the reaction $p + p \rightarrow D + \pi$ at the Cosmotron at BNL; the design of an experiment to study $n + p \rightarrow n + p$ reaction at the Bevatron at LRL with incident neutron energies of 1-6 BeV; and a partial wave analysis of the π-p differential ela tic cross-section at energies from 1 to 5 BeV.

C. DEVELOPMENT PROGRAMS

1. RF Particle Separators

A fourth prototype separator (Lola IV) of relative group velocity of -0.015 has been constructed and submitted to cold tests. Bead and needle perturbation measurements were made to determine the transverse shunt impedance r_T. (These same techniques have yielded values of r_T for Lola II and Lola III which are within 20% of the r_T determined from the deflection tests at Mark IV.) We find that the deflection capabilities of Lola II, III and IV are essentially identical and that a decision of which design to adopt will depend on other criteria such as frequency stability, acceptance, etc.

A high-power test was made on Lola II by subjecting it to ~ 15 MW for several hours with no surprises. Inspection of the structure after test indicated no pitting.