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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 October to 31 December 1963

February 1964

Technical Report
Prepared Under
Contract AT(04-3)-400
and
Contract AT(04-3)-476
for the USAEC
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TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

This is the seventh Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the first 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 goes into effect on January 1, 1964 (but was preceded by a short-term preliminary interim Contract AT(04-3)-476 which actually supported the work reported in this document) so that this development work is presently in a very 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

Design and construction of the conventional facilities continued throughout the quarter with considerable progress made in both phases of the program. The present status of a number of facilities at the Sand Hill site is shown graphically in Figs. 1 through 5.

The Pacific Gas and Electric Company is constructing a 220 kV transmission line along the Skyline route. An associated project is the proposed tie-in line to furnish power to SLAC. Stanford is co-operating with PG&E and the appropriate public agencies to obtain the necessary permits.

Following completion of the criteria work, new schedules were established for the Target Area. Construction of the major facilities in this part of the site program is now scheduled to be completed in 1965 as follows: Beam Switchyard, August; End Station "A," November; End Station "B" and the Cryogenics Facility, December. Correlated budget estimates are being prepared.

The design coordination meetings regularly held with customer groups have been extended to the construction phase. Monthly meetings or field inspection trips are now being scheduled to keep interested parties informed of availability dates, field changes, etc.

Engineering assistance was provided in connection with conventional facility alterations and space occupancy planning. Approximately 20,000 square feet of new temporary facilities plus 9000 square feet of prefabricated buildings to be relocated from the Building M-1 area will be required on site to house SLAC functions. In addition, it will be necessary to partition the Electronics and Stores Building for office and laboratory use. It is proposed that this work commence next quarter.

B. DESIGN STATUS

Criteria reports covering End Station "A" and End Station "B" were received from ABA in December and are being reviewed. A report outlining the utilities and site improvements required in the Target Area

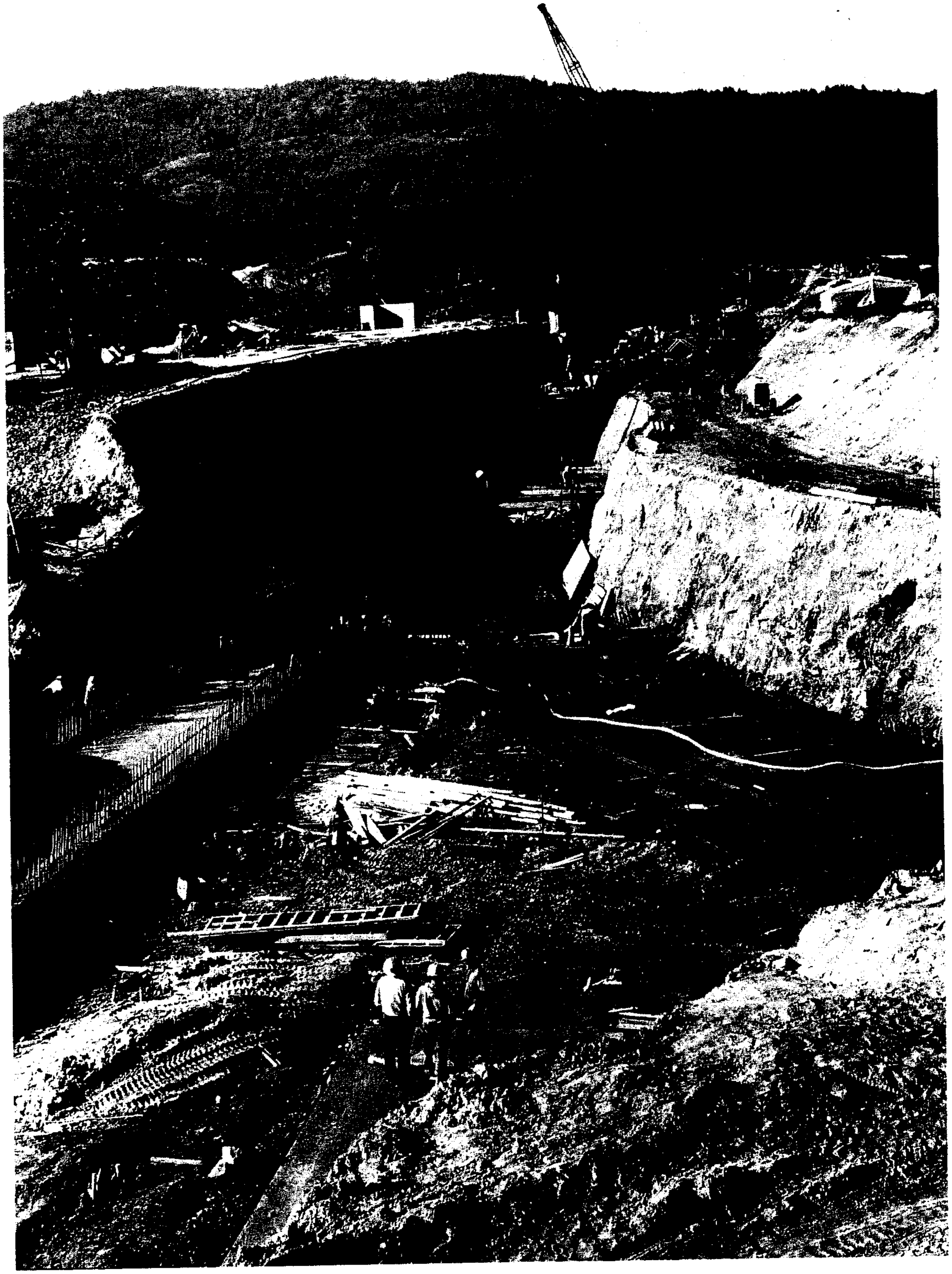

FIG. 1--Accelerator Housing at beam take-off No. 1; looking southwest.

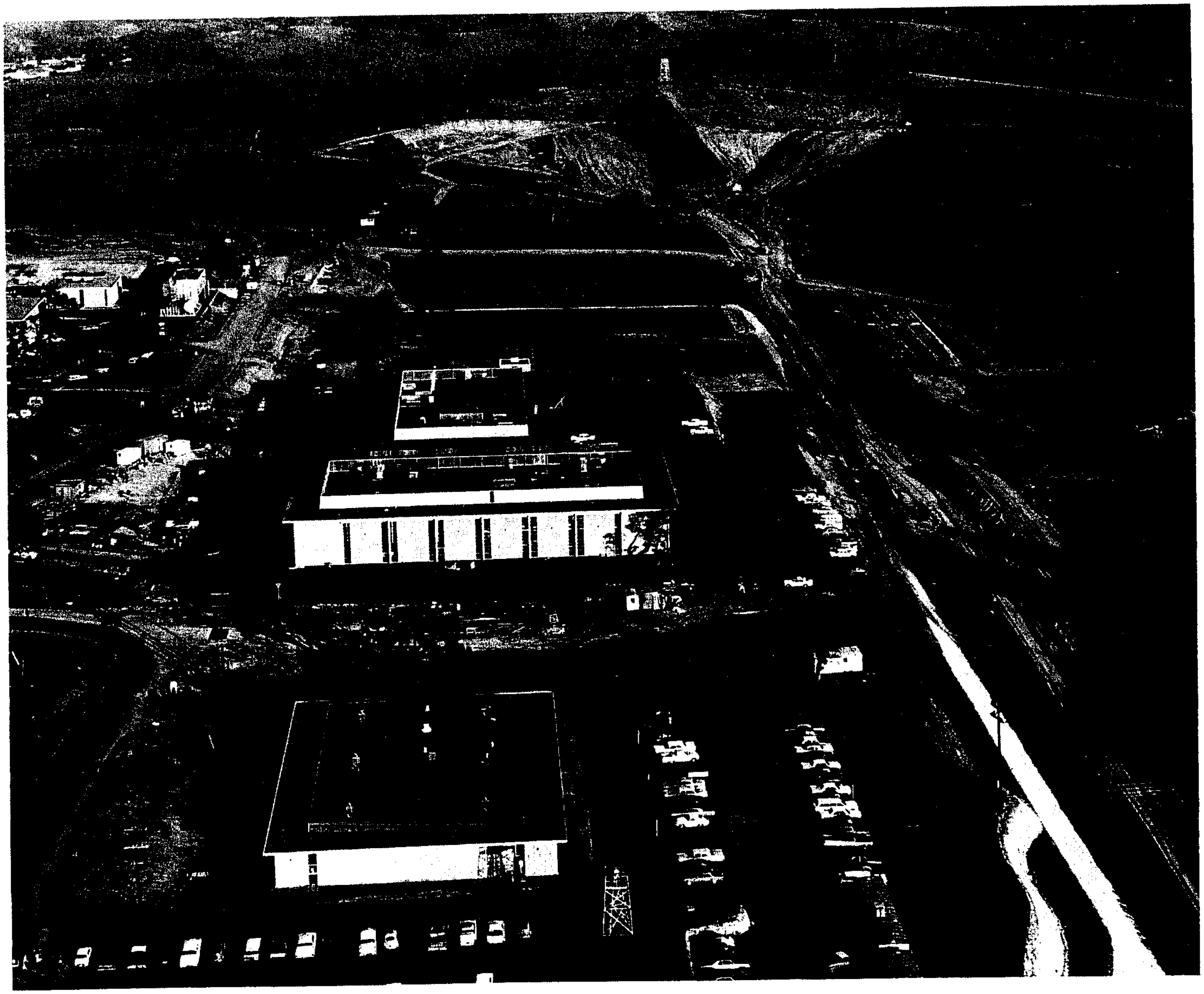

FIG. 2--Aerial photograph of shops complex, with target area delineation
in background.

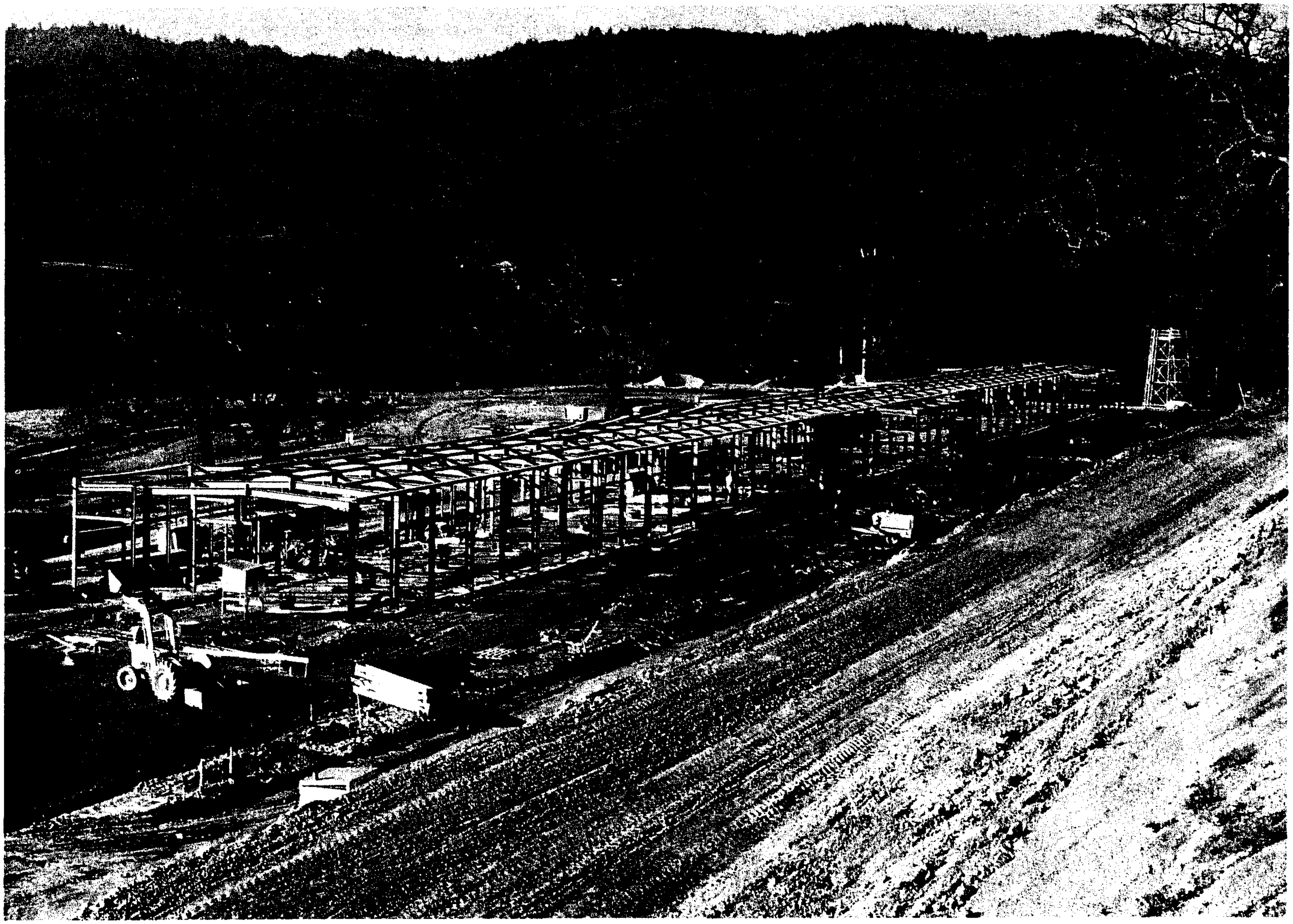

FIG. 3--First section of Klystron Gallery; looking southwest.

FIG. 4--Construction status of Central Laboratory, with Test Laboratory in background.

FIG. 5--Accelerator Housing construction, now 18% complete; looking east from Station 19.

is in preparation by ABA. Preliminary design (Title I) of End Station "A" will start early in January. Preliminary design is essentially complete on the Beam Switchyard and is 60% along on the Cafeteria, Auditorium, and Shop Dining Room grouping. Title I work is complete for the initial site landscaping. It is planned to split the landscaping into six packages for Title II and contract purposes.

Final design (Title II) is in progress on a number of facilities. These, together with their percentage of completion, are as follows: Klystron Gallery Utilities, 90; Control Building, 90; 220 kV Substation Equipment, 90; overall site improvements, 60; Chemical Cleaning Building, 70. Specification revisions were made in the Miscellaneous Site Improvements package. It is planned to incorporate this work in the Control Building Contract.

Boron will be used as a thermal neutron absorber in the concrete of the Accelerator Housing at the positron source structure. ABA has conducted tests on concrete mixes with colemanite and boron frit additives for this purpose.

C. CONSTRUCTION STATUS

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

Facility	Percentage of Completion
Initial Site Utilities	98
Electronics and Stores Building	96
Fabrication Building	97
Loop Road	95
Main Accelerator Housing	18
Klystron Gallery	3
Central Laboratory	2
Heavy Assembly Building	2
Cleaning and Plating Area	3

The first sector of the Klystron Gallery is well along in construction (see Fig. 3); completion is scheduled for March 30, 1964. Work on the Accelerator Housing is proceeding satisfactorily, the 2nd increment of the contract work having been completed on December 21st. Both the Electronics and Stores Building and the Fabrication Building were made available to SLAC for beneficial occupancy during the quarter.

III. ACCELERATOR STRUCTURES

A. ACCELERATOR STRUCTURE

1. Instrumentation and Facilities for Low Power Microwave Tests

All parts of the quality control machine have been built and the machine is now being assembled. The commercial phase measurement system to be used with the quality control machine has been received, and the precision phase standard has been constructed, tested, and found to be satisfactory.

2. Coupler Tuning and Matching

The simplified coupler tuning and matching technique outlined in the previous status report* has proved successful. The coupling iris dimensions were fixed and incorporated into the design of the accelerator sections installed on the Mark III accelerator. During the quarter a number of accelerator sections were tuned without changing the iris coupling, thus fulfilling expectations that filing of the irises can be eliminated.

3. High Power Tests of Accelerator Sections

During the early part of the quarter, a variety of microwave components were subjected to high power testing. These included accelerator section No. 29, on which extensive phase and temperature tests were run; a type C waveguide vacuum valve; and several high power loads.

Tests on accelerator sections and loads for the Stanford Mark III accelerator began in early December. By the end of the quarter, 15 ten-foot accelerator sections, 4 eight-foot accelerator sections, and 16 waveguide loads had been high-power tested.

4. Facilities and Instrumentation for High Power Testing

Test Stand No. 2 was completed and put into operation during the quarter. The high power klystron was installed and tested, and the vacuum system was completed, after installation of an ion pump and certain other components.

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*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1963," SLAC Report No. 23, Stanford Linear Accelerator Center, Stanford, California (October 1963).

Type C valves were installed on test stands 1 and 2.

The phase measurement equipment for use with the test stands has been received. A number of modifications are being made by the supplier in preparation for tests prior to acceptance.

5. Water Jacket

During the quarter, final design type water jackets were mounted on accelerator sections 27 through 58. The assembly technique was improved by holding the accelerator section vertical while the water jacket parts were mounted. (Previously, the assembly work had been done with the accelerator section held horizontally.) Because of improved production techniques, the water jacket assembly work for the Mark III accelerator has gone smoothly, despite the rather tight schedule.

Tests carried out during the quarter in the high power rf test stand were performed on the final water jacket design to verify its performance. The accelerator surface temperature was maintained constant during the tests. A block diagram of the temperature control arrangement is shown in Fig. 6. The water flow rate was the prescribed 13 gpm. The measured temperatures for accelerator section No. 29 are shown in Figs. 7, 8, 9, and 10. The temperatures were measured at average input power levels of 0, 5, 10, and 14.8 kW respectively; the last of these power levels represented the maximum practical capability of the test stand at the time these measurements were taken. All of these figures are composites of two or more test runs. Each dot on the figures represents an average value, and the vertical line shows the full range covered by the temperature values measured at that point.

The surface temperature control sensor was located on cavity No. 60. It can be seen from the figures that the temperature at that point was held constant within 0.1°F at all power levels. Other points on the accelerator section varied considerably more with power level changes. Cavity No. 60 was chosen as the control point because use of that point was found to yield the smallest phase shift with power level changes. The measured temperatures all fell in the range of 113.0°F to 114.7°F.

6. Accelerator Section Ten-Foot Support

The design modification discussed in the previous quarterly report has been completed. Vertical support members of the new design have been

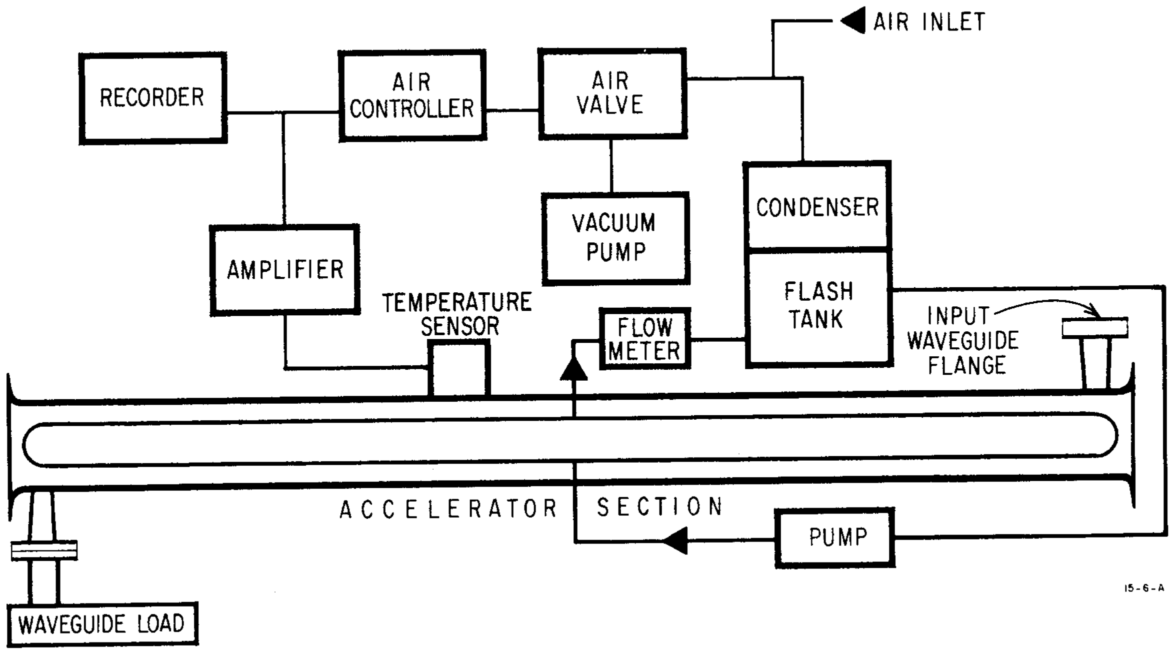

FIG. 6--Temperature control system for accelerator section.

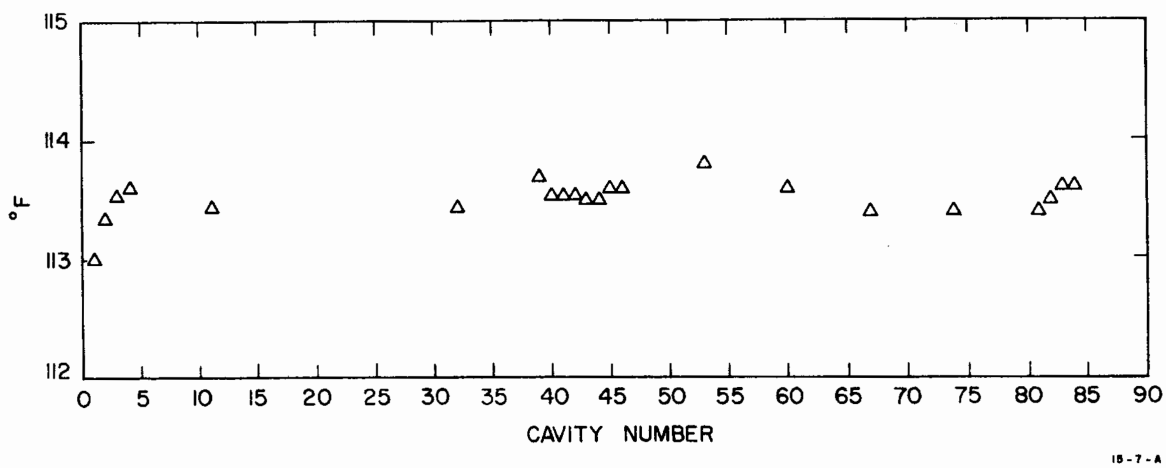

FIG. 7--Measured temperatures on accelerator section - 0 average input rf power.

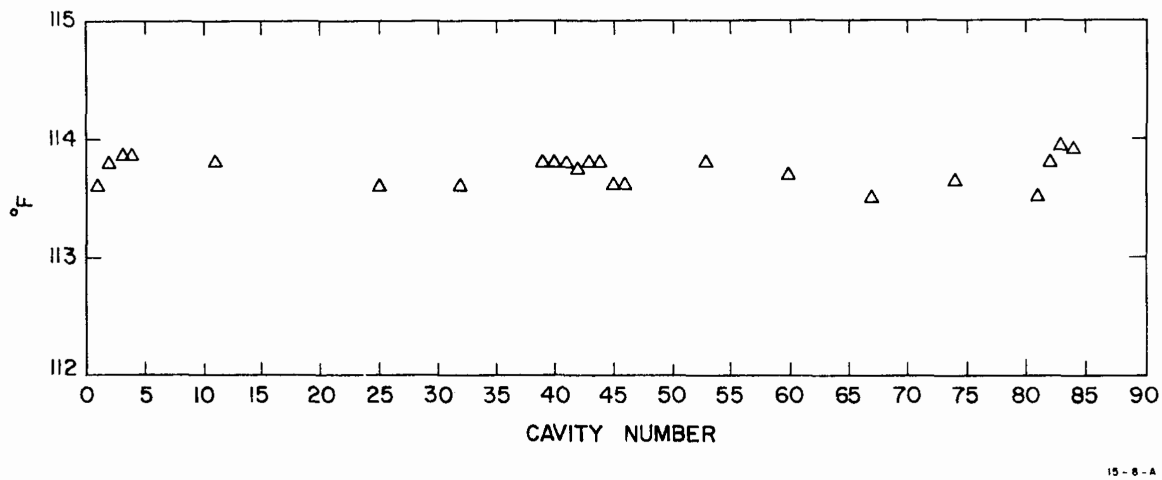

FIG. 8--Measured temperatures on accelerator section - 5 kW average input rf power.

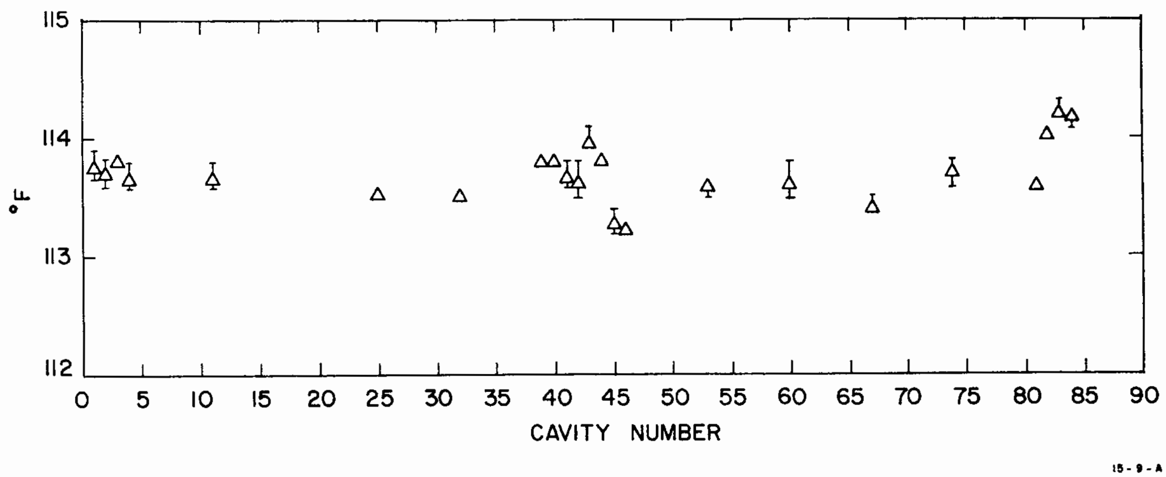

FIG. 9--Measured temperatures on accelerator section - 10 kW average input rf power.

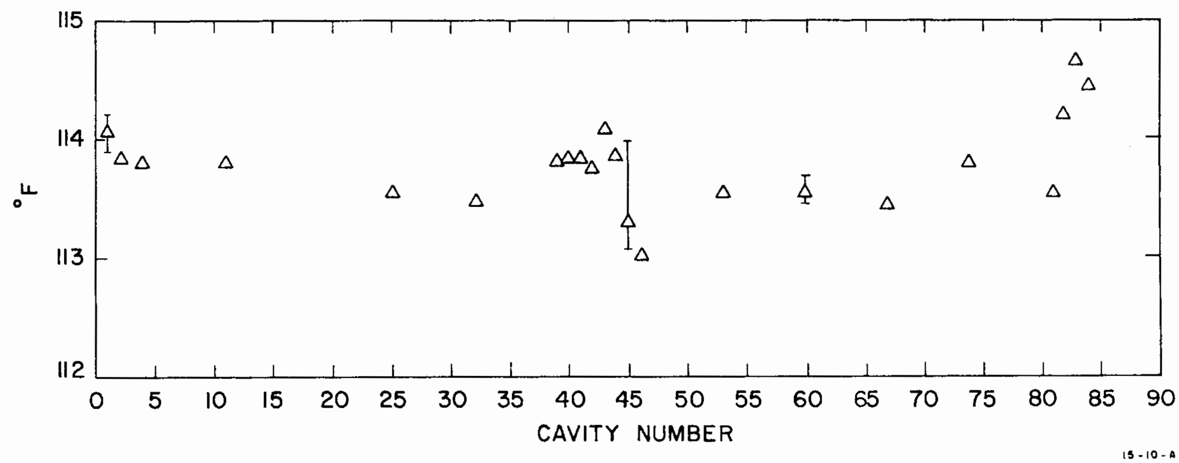

FIG. 10--Measured temperatures on accelerator section - 15 kW average input rf power.

tested for load carrying ability. These members must be flexible enough to accommodate the relative axial movement that occurs between the accelerator sections and the 40-foot support girder with temperature variations. In these tests, the vertical support member was deflected ±0.350 inch, which is the maximum possible range, through 600 cycles. The vertical support member carried a load of 200 pounds on the end of a lever arm that extends 38 inches out beyond the accelerator section axis (the maximum specified load) with satisfactory performance. Previous calculations and tests had demonstrated the performance of the remaining parts of the strongback when considered individually. Because the above tests and calculations predicted success for the new design and because the strongback schedule is very stringent, the design was frozen at this point. The work of preparing drawings and specifications for the vendor-supplied parts is in progress.

Tests with an accelerator section mounted on a strongback of the new design are in progress. These tests will repeat all of the loading conditions to which the vertical supports were subjected. The principal value of these tests is that they permit the measurement of deformation in the accelerator section and in the strongback under conditions that simulate those encountered in operation.

Preparations are underway to assemble four accelerator sections with four strongbacks and associated waveguide, vacuum piping, and loads on a 40-foot support girder. This structure will then be used to practice and test assembly and alignment techniques.

B. ACCELERATOR SECTIONS FOR THE STANFORD MARK III ACCELERATOR

Of the 25 ten-foot accelerator sections and 6 eight-foot accelerator sections required, 15 ten-foot sections and 4 eight-foot sections had been completed by the end of the quarter. Of these, 14 ten-foot accelerator sections and 2 eight-foot accelerator sections had been installed on the Mark III accelerator. Also, 16 of the 31 waveguide loads required had been completed, of which 9 had been installed.

The fabrication and installation schedule set on October 15, 1963, has been maintained. Accelerator sections have been produced consistently at the rate of one accelerator section per day.

C. HIGH POWER WAVEGUIDE COMPONENTS

1. Waveguide Valve

The six type C valves and five of the six type A valves mentioned in the previous quarterly report were completed during the quarter. The remaining type A valve was damaged during indium processing and is being reworked. Type A* and type C** valves differ basically in that type A has straight waveguide stubs, while the type C valve has stubs with 90 degree bends. In addition, the type C valve has a larger coupling hole and somewhat different shorting plate locations. A number of tests were conducted on the waveguide valves during the quarter, and are reported below.

All valves required some tuning (by indenting the waveguide walls) in order to achieve suitably low values of input VSWR. However, the type C valves required less tuning than type A valves, and improved processing techniques are expected to further reduce the tuning effort required for the type C valves. Table I shows the VSWR data taken on these valves after tuning. It was found that good input VSWR values could be achieved readily for all eleven valves. Insertion loss measurements made on valves A-1, C-1, and C-2 yielded very satisfactory values; these data are also shown in this table. During the next quarter, insertion loss measurements will be made on all remaining valves.

During the quarter, five of the valves were tested at high power. Table II shows the data for these tests. Note that for each valve there were two resonant ring tests; Test No. 1 was higher in peak power and Test No. 2 was higher in average power. Valves A-1, A-3, C-1 and C-2 all performed satisfactorily in the resonant ring high power test. For each of these valves, the electrical contact between the stem and bonnet was momentarily broken about 50 times during Tests 1 and 2. The rf power was turned off each time this contact was broken. This is an important part of the high power testing, because the only significant question regarding the high power performance of these valves is the quality of the electrical contact. The levels shown in Table II for

*"Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March, 1963," SLAC Report No. 16, Stanford Linear Accelerator Center, Stanford University, Stanford, California (May 1963); p. 14.

**SLAC Report No. 23, op. cit., p. 14.

TABLE I

LOW POWER TEST DATA

Valve Number	VSWR	Attenuation
A-1	1.02	0.1 db
A-2	1.02	
A-3	1.05	
A-4	1.04	
A-5	1.06	
C-1	1.02	0.07 db
C-2	1.04	0.06 db
C-3	1.03	
C-4	1.02	
C-5	1.02	
C-6	1.05	

TABLE II

HIGH POWER TEST DATA

Valve Number	Resonant Ring				Test Stand	
	Test No. 1		Test No. 2			
	Peak	Average	Peak	Average	Peak	Average
A-1	63.8 MW	11.5 kW	41.1 MW	44.4 kW	--	--
A-3	66.4 MW	11.9 kW	41.1 MW	44.4 kW	--	--
A-4	26.0 MW	4.68 kW	--	--	--	--
C-1	52.0 MW	9.30 kW	36.3 MW	39.2 kW	14 MW	14 kW
C-2	52.0 MW	9.30 kW	36.3 MW	39.2 kW	14 MW	14 kW

these valves indicate the maximum available power in the resonant ring with the valves in place. Maximum power levels for C-1 and C-2 in the ring were lower than for A-1 and A-3 because C-1 and C-2 were tested by mounting them in series; their combined insertion loss reduced the resonant ring gain.

Valve A-4 suffered breakdown in the backseat region at the power levels shown; the backseat electrical contact was broken about 40 times prior to breakdown.

The suspected cause of the breakdown is poor electrical contact between mating surfaces of the stem and bonnet; because high rf currents must flow between these surfaces, poor contact can cause severe arcing. In order to provide more positive contact, the sliding bushings between the valve stem and bonnet assembly are being replaced by ball bushings. Completion of this improvement and subsequent freezing of the design are expected during the next quarter.

In addition to the resonant ring tests, two of the valves were tested and performed quite well in the high power test stand. Valve C-2, installed in Test Stand No. 1 early in December, has operated satisfactorily through 16 vacuum closings without remelt and through a variety of operating conditions characteristic of those encountered in processing ten-foot accelerator sections. Plans call for all six type C valves and all six type A valves to be subjected to high power tests, both in the resonant ring and in the test stands.

It seems likely that the high power klystron provides appreciable components in its output signal, at frequencies above the operating frequency. It is therefore interesting to consider the rf performance of the valve at such frequencies, particularly the VSWR of the valve. A high VSWR at any particular frequency for which the klystron has an appreciable component in its output can result in problems such as localized heating in the waveguide and undesired signals from the coupler located between the klystron and the valve.

VSWR measurements were made on the type C valve from 4.0 to 6.0 Gc, in both the TE_{10} mode and the TE_{01} mode. Table III shows the results of these measurements.

When these valves are in operation on the two-mile machine, precautions will be required in remelting the indium seats. With insufficient heating, the remelting will not be complete. With excessive heating, the indium may spread out from the seat to the copper-plated inside surfaces of the valve body. Because indium alloys readily with the copper, it can damage the copper parts of the valve. With the valve in the operating machine, there is no way to watch the indium as it melts; it is convenient only to measure the temperature at certain points on the outside surface of the valve as a function of time. To develop a procedure for remelting the indium in operational valves, melting tests have been conducted on a valve body with the bonnet removed and replaced by a glass plate through which the indium can be observed. In these tests, the temperatures at various points both inside and outside the valve body are measured as a function of time. Simultaneously, the melting of the indium is observed and a record of melting progress vs time is recorded. Similar data is taken for the cool-down cycle, after remelt is completed. This test has been conducted for the type A valve and will be performed on the type C valve during the next quarter.

In general, then, results of the valve tests performed during the quarter are quite encouraging. Good input values of VSWR were obtained for all eleven valves that underwent low-power testing, and the three valves measured for insertion loss yielded quite satisfactory values. Of the five valves that were high-power tested, four gave very good performance in the resonant ring tests; the cause of the breakdown in the remaining valve is being corrected by replacing the sliding bushing of the valve stem with a ball bushing. Furthermore, two of these valves also performed quite well in test stand operation.

2. Waveguide Layout

The dimensions of the standard waveguide layout have now been frozen.

During the quarter, plans were made for the non-standard waveguide layouts. These are waveguide layouts that feed only one, two, or three accelerator sections from a single klystron rather than the usual four. The elimination of an output from a waveguide layout removes a hybrid as well. When the hybrid is removed, the waveguide length must be adjusted appropriately in order to retain the proper phasing. Plans call for

TABLE III

VSWR MEASUREMENTS ON TYPE C VALVE

	TE_{01}	TE_{10}
Frequency	VSWR	VSWR
4.0	6.80	> 25.00
4.1	> 26.00	> 22.00
4.2	> 22.00	5.40
4.3	> 18.00	10.20
4 4	11.60	16.50
4.5	9.10	4.42
4.6	2.75	11.90
4.7	6.30	8.10
4.8	1.65	> 35.00
4.9	3.35	> 21.00
5.0	1.54	> 40.00
5.1	3.20	4.02
5.2	1.96	8.40
5.3	9.90	> 30.00
5.4	11.50	> 30.00
5.5	5.30	2.42
5.6	10.50	> 60.00
5.7	1.66	15.80
5.8	7.00	> 30.00
5.9	4.98	4.55
6.0	9.50	7.50

making the waveguide length adjustments by short-cutting the H-plane 90-degree waveguide bends which, in the standard waveguide layout, are on the lower end of the tunnel hybrids.

3. Couplers

Figure 11 shows the final design of the directional coupler to be used on the output of the klystron. Its nominal coupling coefficient is 60 db. The previous design had only a single output terminal and could only couple to a wave that travels in one direction. The present design, now frozen, has two output terminals and can couple to waves that travel in both directions. For an application like the VSWR interlock, in which both waves must be measured, the coupler has the advantage that only a single unit must be mounted to the waveguide.

Another advantage of this design is the provision for welding the coupler into place after its loop orientation has been adjusted for optimum directivity. In the previous design, the coupler was held in place by tightening four screws after adjustment, and there was always the possibility that the coupler could become misaligned by loosening the screws.

4. Loads

The loads for the Mark III linear accelerator consist 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. The basic design of this load was made by Dr. Perry Wilson of Stanford University's High Energy Physics Laboratory. The experience obtained with these loads has indicated that this design approach is promising for the loads to be used on the two-mile machine. Figure 12 shows a composite of VSWR vs average rf input power measurements on 10 randomly selected loads for the Mark III machine. For each frequency, the triangle gives the average of the values of all loads, and the vertical line segment gives the full range of VSWR values for all loads.

5. Test Tower

During the quarter, tests were run in the test tower in which the klystron floor was adjusted up and down with respect to the accelerator

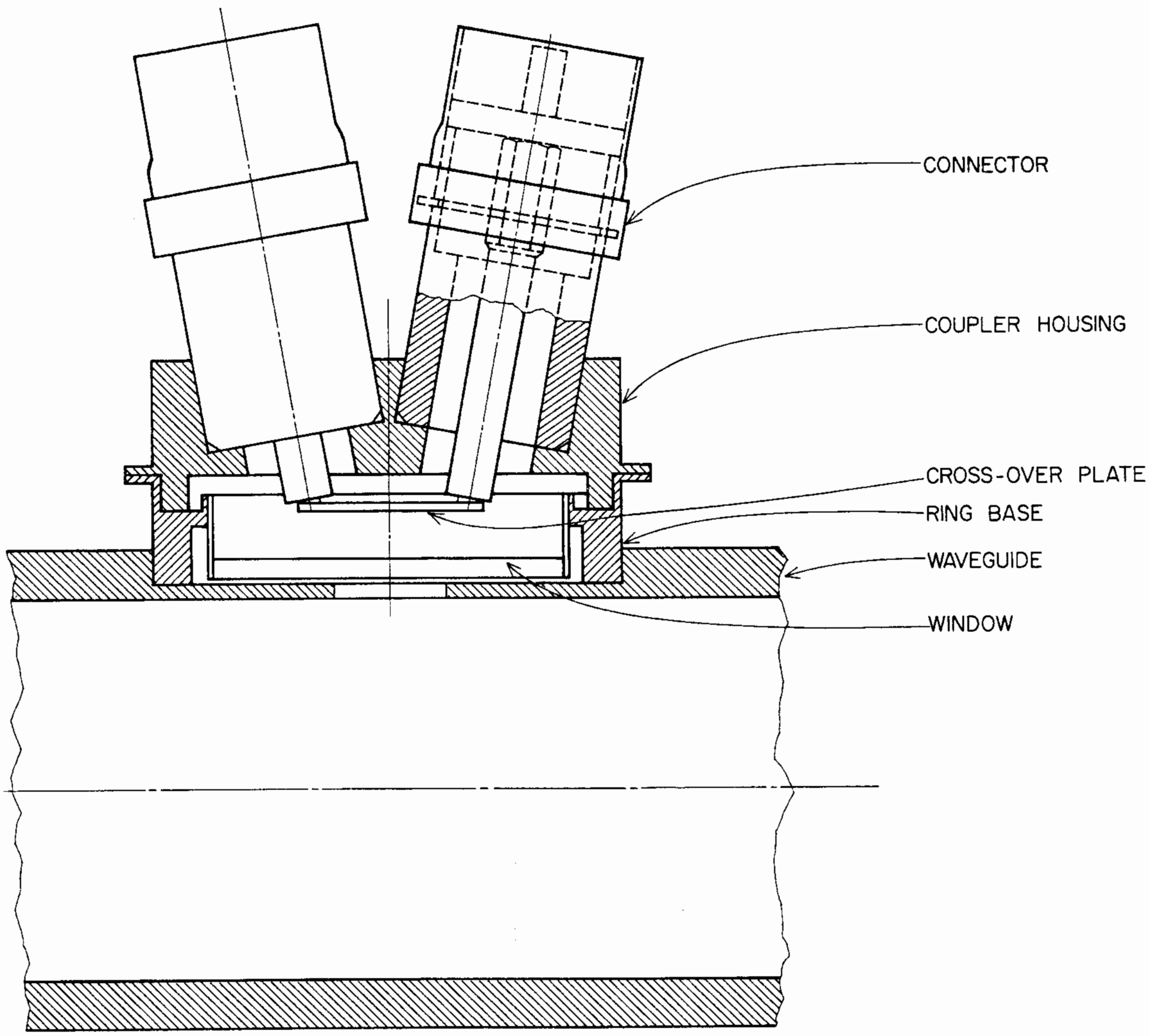

FIG. 11--Directional coupler.

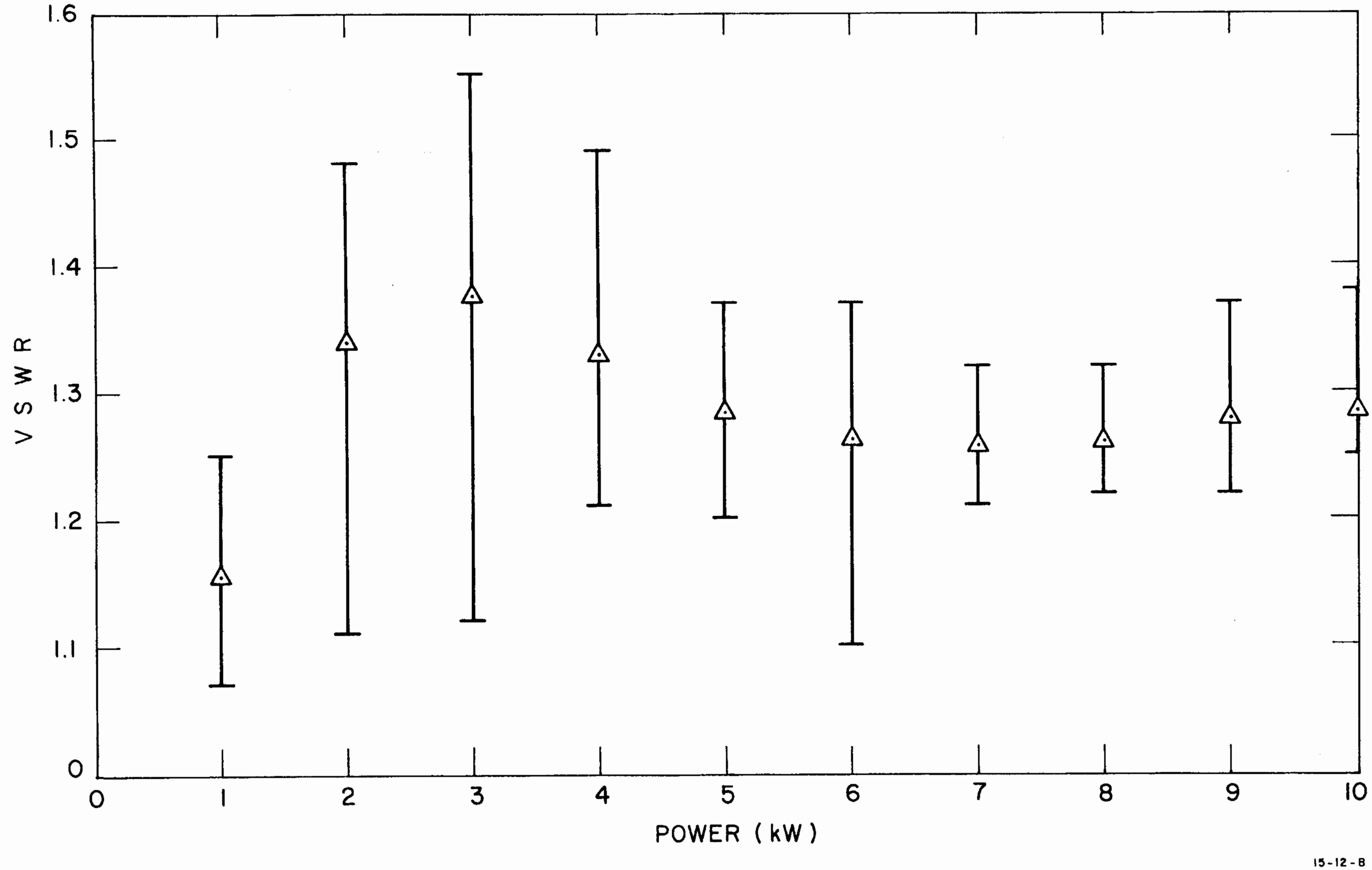

FIG. 12--VSWR vs average rf input power.

in the tunnel. The maximum movement was up one inch and down one inch. These tests were intended to simulate movement between the klystron floor and the accelerator waveguide that might occur in operation of the two-mile machine. Such movement might result from earth movement between the accelerator housing and the klystron floor, or it might result from alignment adjustments on the accelerator waveguide.

The following aspects of performance were measured during these tests:

1. The vertical shear force directed against the waveguide flange at the accelerator inputs as the klystron floor level is moved.
2. The performance of the vacuum system as the klystron floor level is moved.
3. The incremental phase shift between reference point A (see Fig.13) at the klystron and points B and C near the accelerator as the klystron floor level is moved.
4. Any malfunctions in operation of any of the test tower systems as the klystron floor level is changed.

During these tests, the waveguide system and the accelerator sections were evacuated, the water cooling system was operating, and the system was operated at an rf power level of 7.4 kW average. The vacuum levels were: 1.8×10^{-7} torr at the klystron window; 1.2×10^{-7} torr at the 8-inch manifold; and 1.0×10^{-7} torr at the accelerator input. The klystron floor level was moved through a total of 10 cycles. In each cycle, the klystron floor was moved down one inch below its normal level, then up one inch above the normal level.

No change in the vacuum system performance was observed during this test. Phase measurements were made between point A and point C at the input to the waveguide load on the second accelerator section. These measurements were made using the system shown in Fig. 14. Throughout these tests, there was no detectable phase change between points A and C. Because prior tests had shown that this phase measurement system could detect phase changes as small as three degrees, any phase change between points A and C must have been less than that amount. During the tests, no system malfunctions were observed.

Figure 13 shows the arrangement used for measuring the vertical shear forces at the input of two of the accelerator sections. A platform

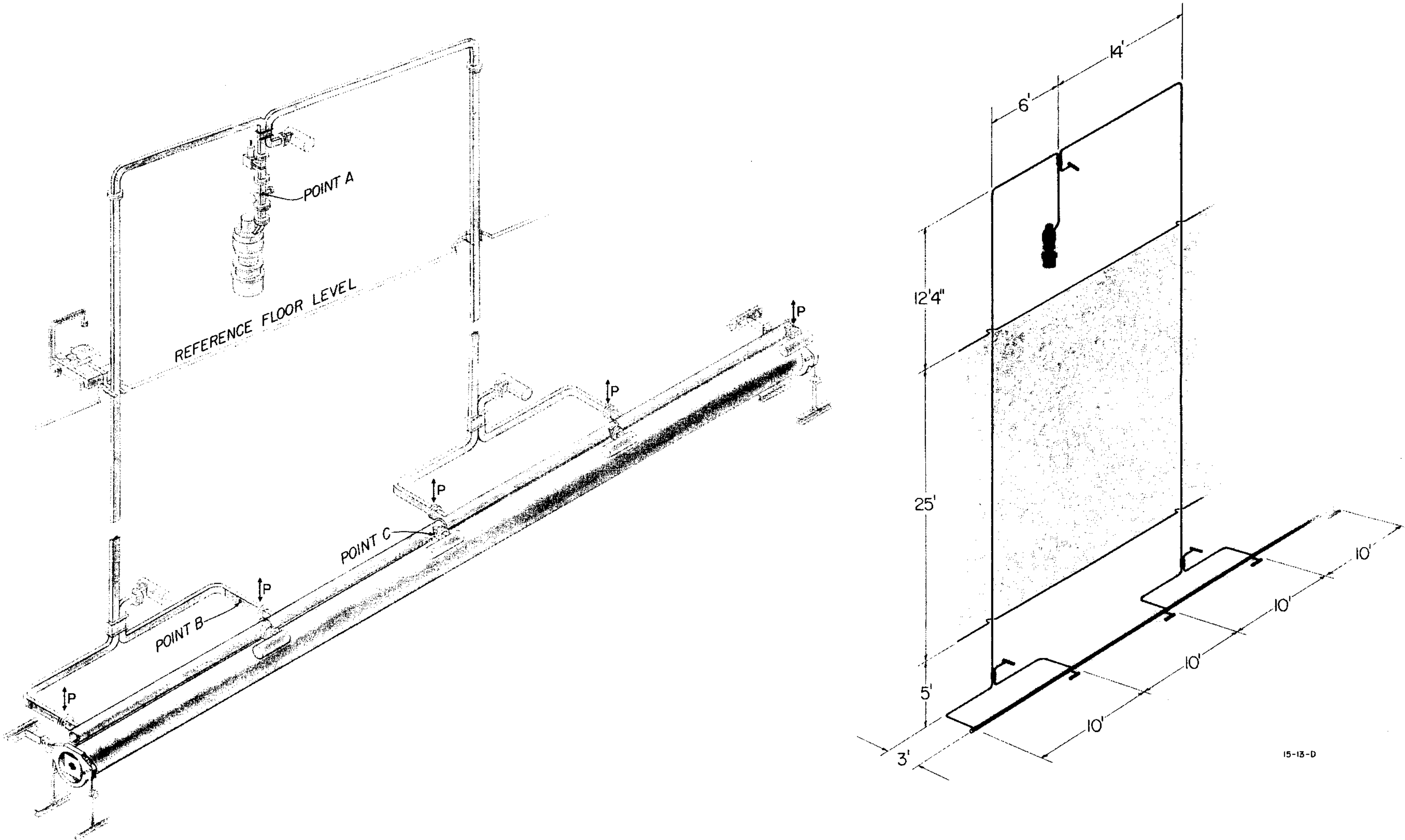

FIG. 13--Test arrangement for measurement of vertical shear forces at accelerator section inputs.

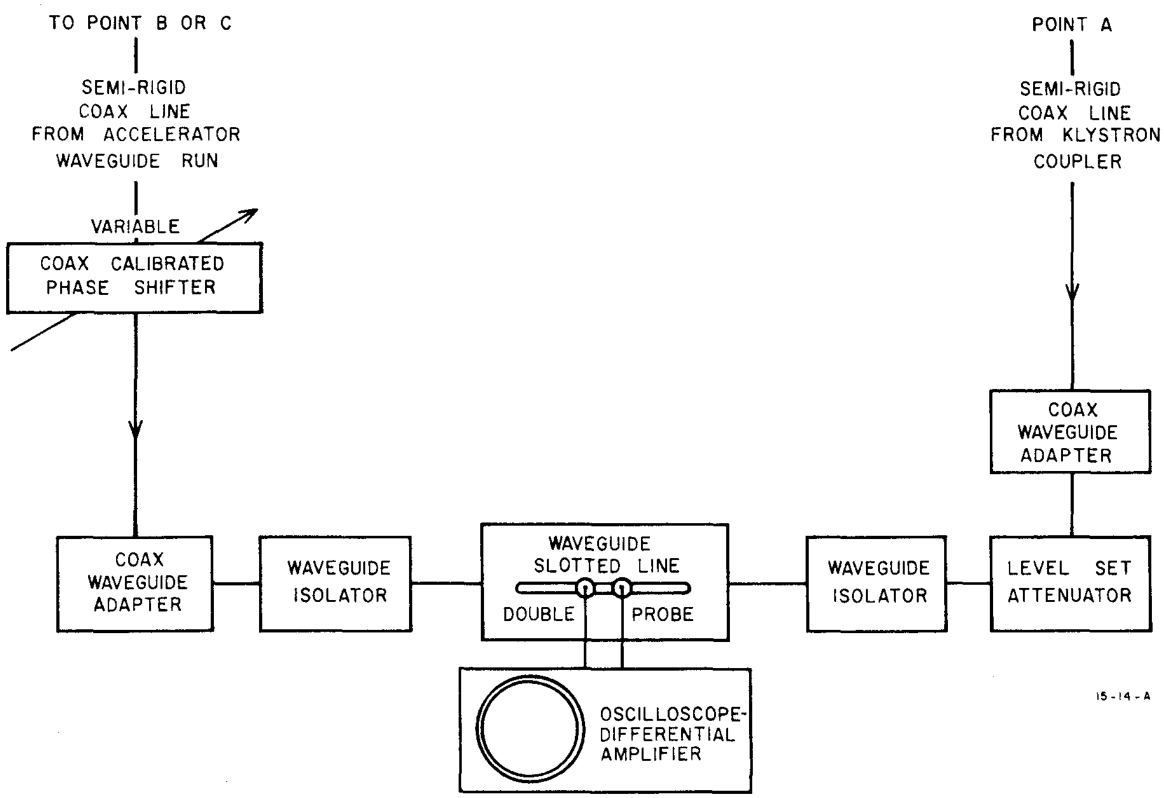

FIG. 14--Diagram of phase shift test equipment setup.

scale was used to replace the rigid connection between one of the penetration waveguides and the klystron floor. Because such a scale has no deflection when balanced, one can measure the variation of forces directly.

In Fig. 15, the vertical shear force, P, at each waveguide input of the accelerator sections is plotted for several up and down cycles of the klystron floor. Segment 1, for the movement from normal level down one inch, covers the first quarter cycle. Note that this segment is non-linear, because of the yielding which takes place in the annealed copper waveguide. Segments 2, 3, 4, and 5 cover the first and third cycles beyond segment 1, and segments 6 and 7 cover the tenth cycle. The progressive increases in the slant of successive cycles plotted in Fig. 15 result from work hardening the copper.

6. <u>Low Power Test Facilities for Waveguide Components</u>

Low power rf test facilities are being prepared for use in testing the waveguide components to be produced for the SLAC machine. These facilities will permit the expeditious measurement of the following electrical characteristics of components:

Reflection coefficient

VSWR

Coupler directivity

Coupler coupling coefficient

Insertion loss

Phase shift

These facilities are being set up to permit the appropriate low power rf characteristics to be measured on each component, prior to its installation in the two-mile machine.

Figure 16 shows the block diagram of the test facility that has been prepared for use in measuring high attenuation values (in the range of 10-90 db). As shown, this circuit uses the substitution method, in which the item to be tested is inserted into the circuit between a matched load and a matched generator. The isolators and pads shown between the test section and the load and generator provide the needed matching for the load and generator. The signal at the output port of the test piece is measured by a superheterodyne receiver. This receiver contains a very

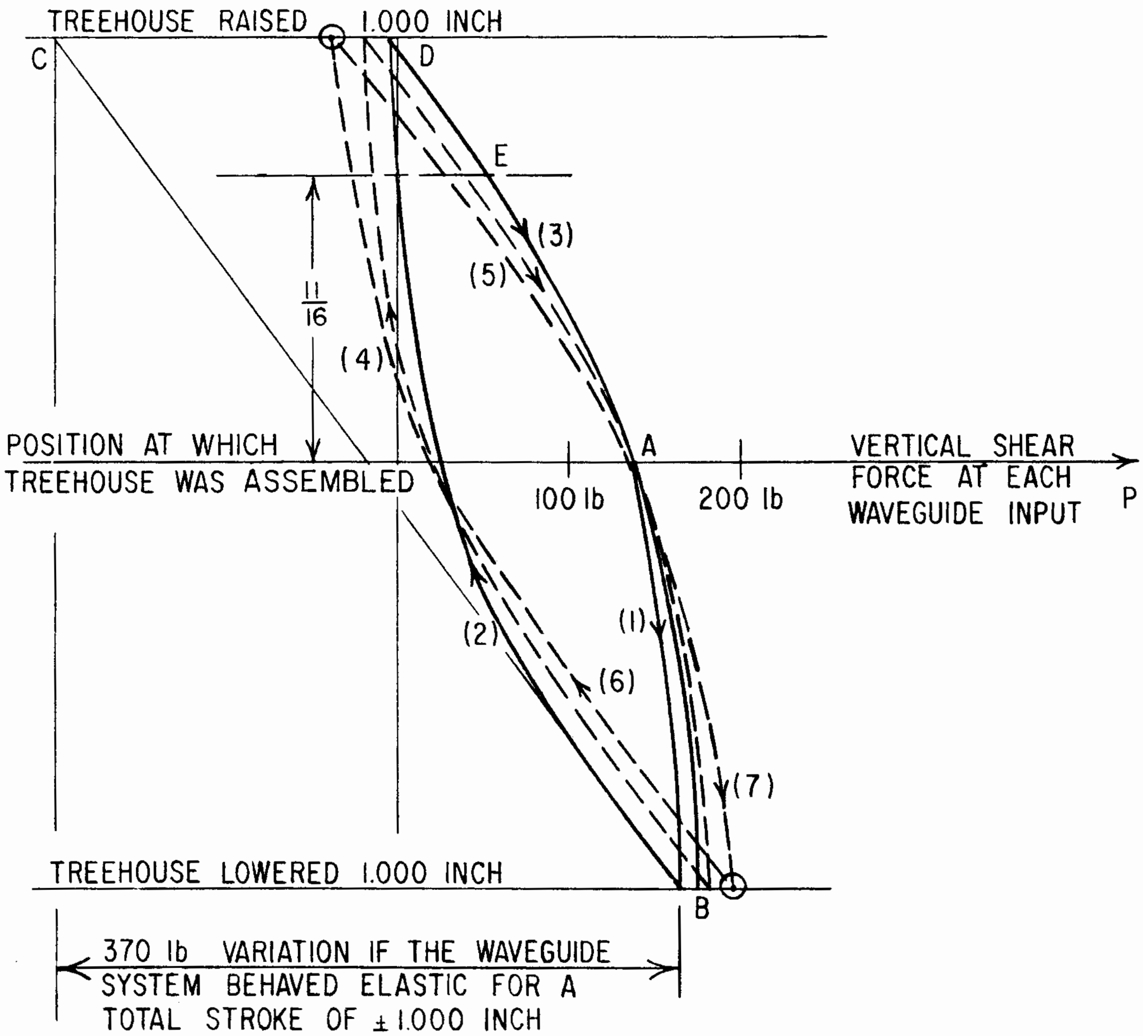

FIG. 15--Vertical shear force at accelerator section input vs vertical movement.

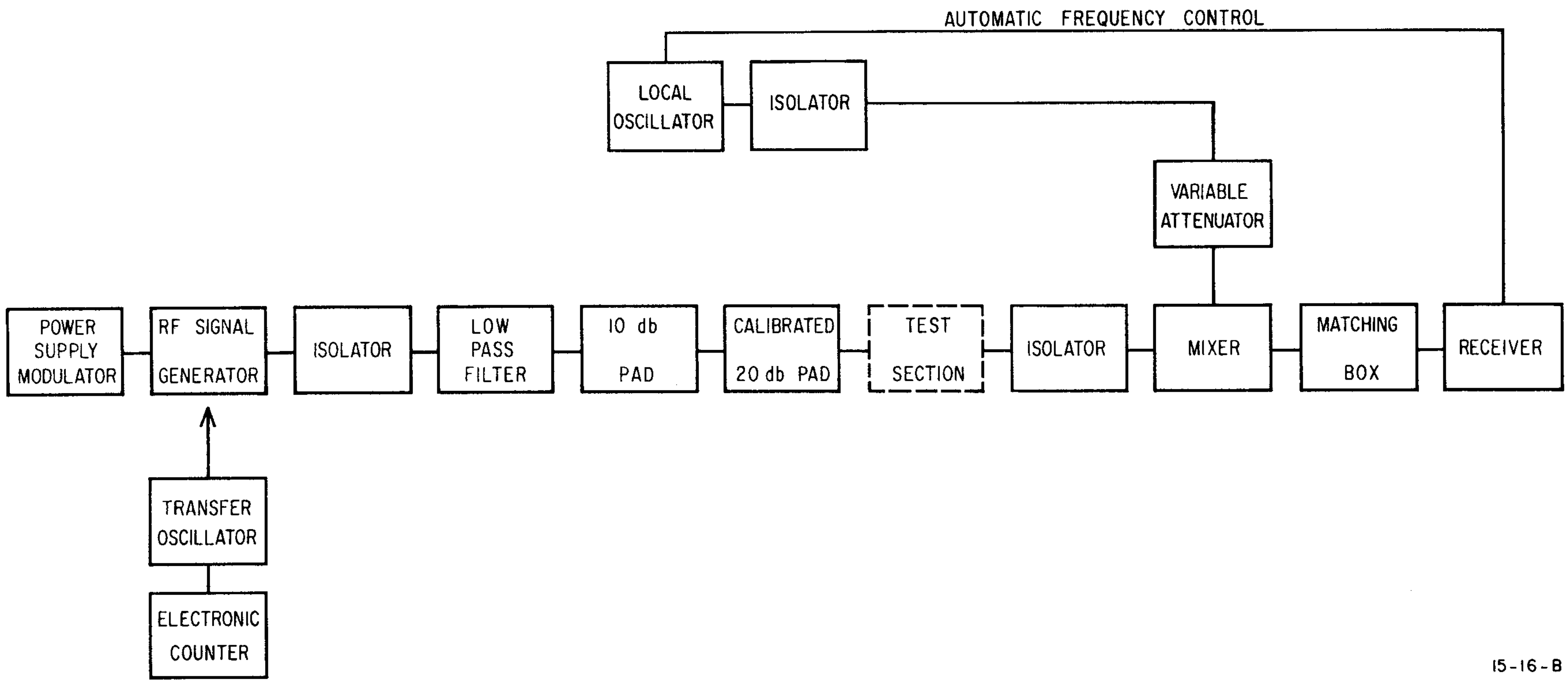

FIG. 16--High attenuation measurement setup.

accurate calibrated attenuator that operates at the intermediate frequency of 30 Mc.

In operation, the received signal is first measured with the test piece removed and with the receiver attenuator set for a rather high attenuation. Then the test piece is inserted and the receiver attenuator is readjusted to bring the receiver output back to its original reading. The attenuation of the test piece is taken to be the amount by which the attenuation of the receiver attenuator has been reduced.

Figure 17 shows the block diagram of the test facility for measuring low attenuation (insertion loss) of components such as waveguide valves, directional couplers, and power dividers. This facility is set up to measure either coaxial or waveguide components by the substitution method. In this circuit, the rf signal that comes out of the test piece is detected by a bolometer. The bolometer output then passes through the calibrated attenuator before entering the synchronous differential null detector. Note that another signal, from the signal generator output, enters another bolometer and the bolometer output is a second input to the synchronous detector. The detector provides a null indication when these two 1000 cps input signals are equal in amplitude. Because it is a synchronous detector, it rejects noise at frequencies outside a narrow band around 1000 cps. In operation, the calibrated attenuator is adjusted for a null indication, with and without the test piece in place. The attenuation of the test piece, in decibels, equals one-half the change in attenuation value in the calibrated attenuator. Note that when the circuit is balanced for a null at one signal generator power level, it remains balanced at somewhat different power levels; that is, the null indication is insensitive to small fluctuations in signal generator power level.

Figure 18 shows a block diagram of the facility for measurement of reflection coefficient. The ratio of the incident and reflected waves is measured by a ratio meter in order to avoid the effect of fluctuations in the signal generator output power. The sweep oscillator, oscilloscope, and X-Y recorder permit the operator to measure quite readily the reflection coefficient over a band of frequencies.

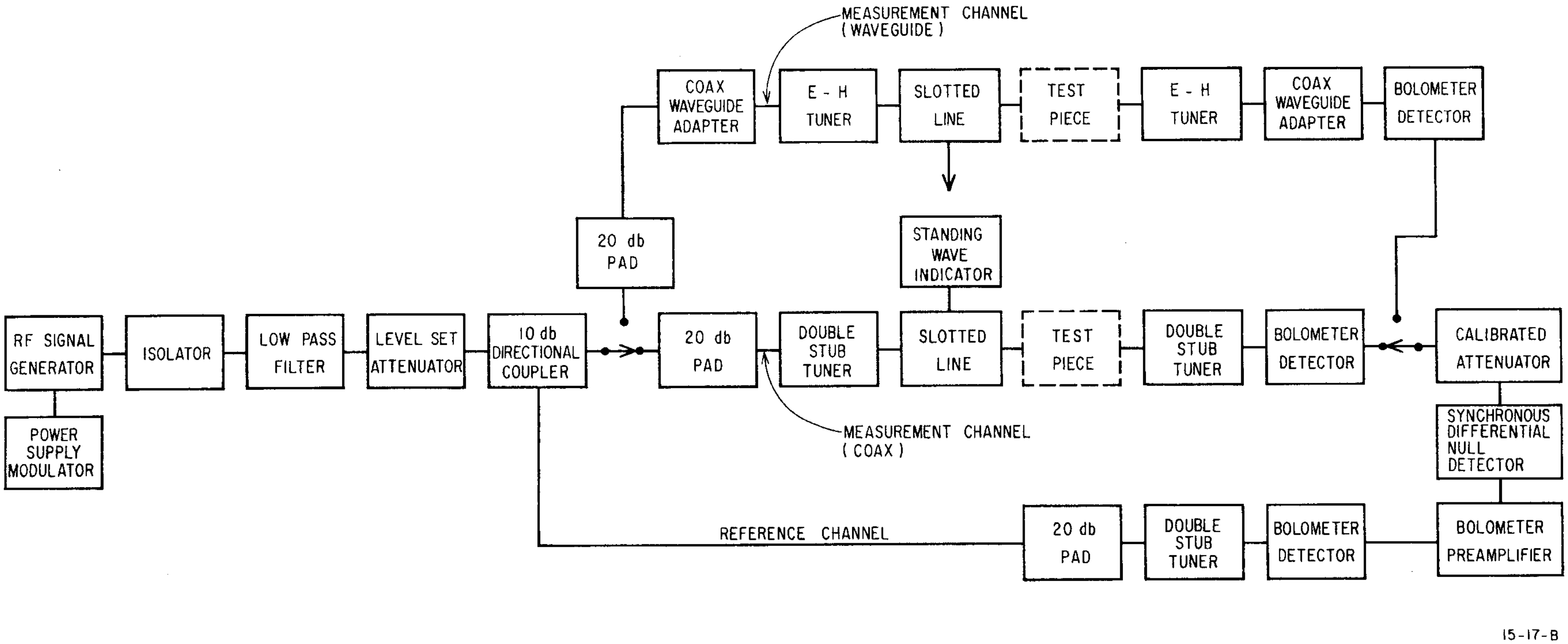

FIG. 17--Dual channel insertion loss test setup.

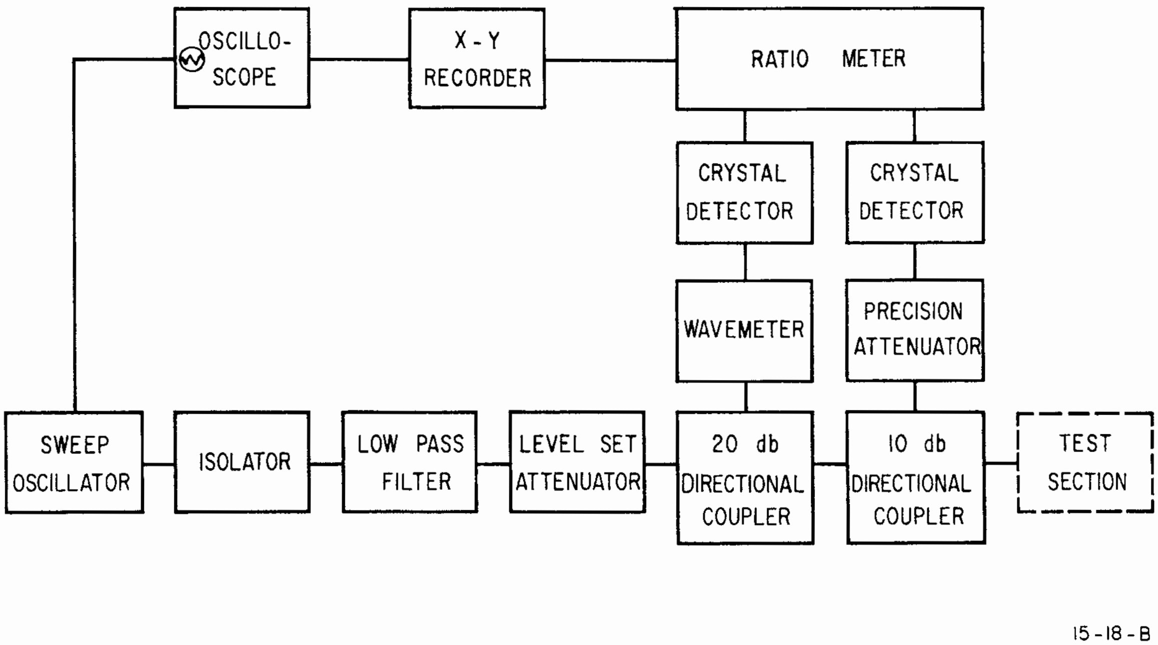

FIG. 18--Waveguide reflectometer setup.

Figure 19 shows a block diagram of the phase measurement facility. This equipment is very similar to the phase measurement equipment used with the tuning machine and the quality control machine. The bridge, composed of four hybrid junctions in conjunction with the two detectors and the ratio meter, serves to make the phase measurements insensitive to the amplitude of the signal to be measured over a rather wide range of signal levels.

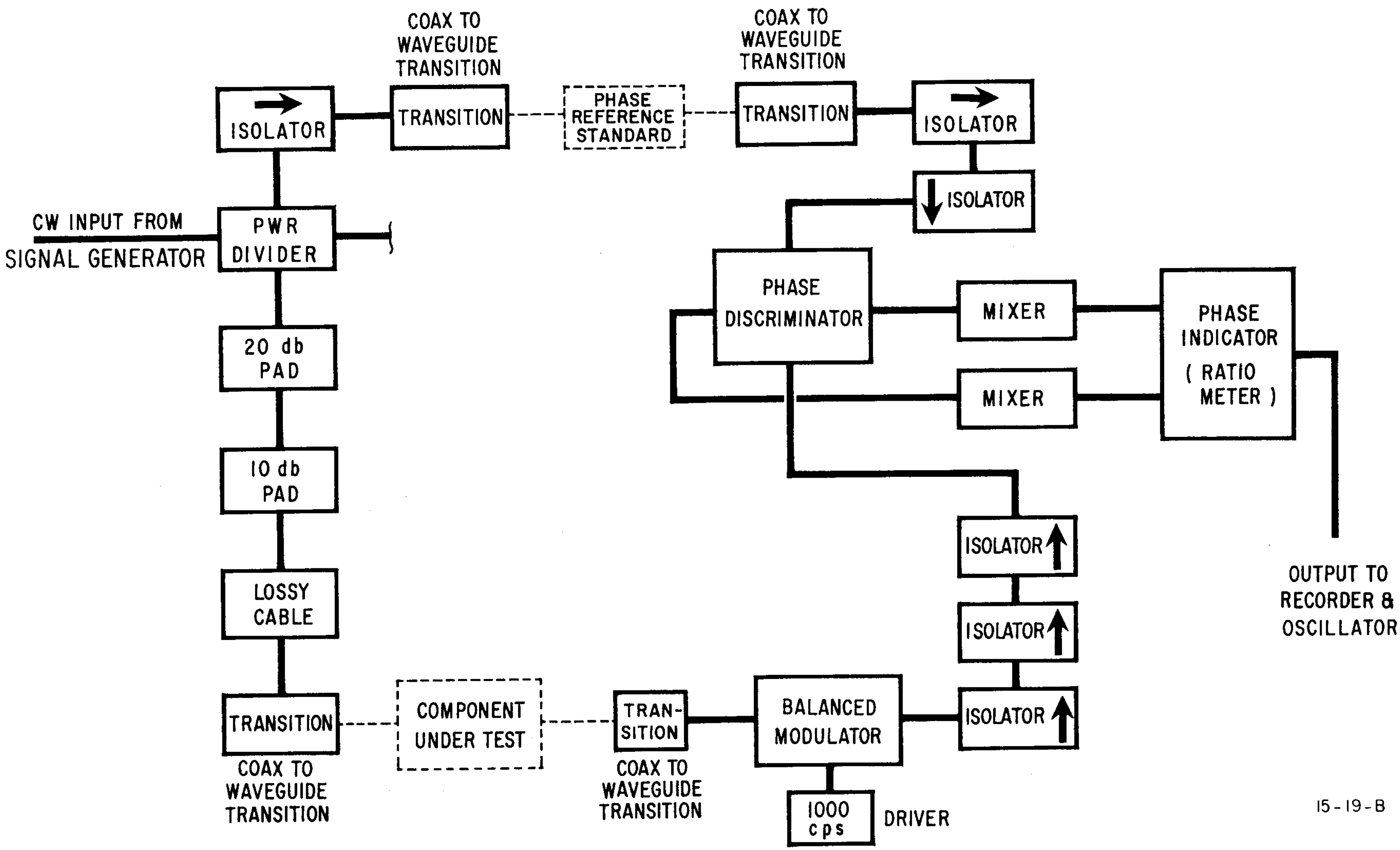

FIG. 19--Phase measuring instrument.

IV. KLYSTRON STUDIES

A. SUMMARY

During the quarter, progress has been made by our subcontractors in achieving acceptable klystrons, but to date no klystrons meeting all specifications have been received. As a result of the delays, negotiations for delivery schedule changes have been completed with both Sperry and RCA. In addition, an insurance program has been started and requests for proposal for delivery of a small number of klystrons have been sent to Litton Industries and Eimac.

The move to the Test Laboratory by the Klystron Group is now essentially completed, but the fabrication operations have been greatly hampered during the move by unforeseen delays in receiving equipment and unforeseen difficulties with some of the utilities installed in the Test Laboratory. Because of these delays, fabrication and development work on Stanford klystrons has not progressed as rapidly as had been hoped. However, an adequate supply of klystrons and diodes is on hand, and encouraging initial results have been obtained with full strength permanent magnet focusing.

Of the many Stanford-built tubes used by other groups at SLAC, the majority of failures is still caused by window cracking. There appears to be some lack of correlation between the actual experience and the measurements obtained in the circulating ring. Further study to resolve these possible differences is needed, and much additional testing is planned on windows.

Some difficulties have been experienced with the Eimac sub-booster klystrons, especially with regard to shelf life and delivery schedule. Negotiations will have to be carried out during the next quarter in this area.

B. SUBCONTRACTS

Two tubes have been received from Sperry, one on September 25* and one on November 4. Both tubes were tested and found to be non-conforming to our specifications. In general, the main problem with the Sperry tube is oscillations. Both tubes exhibited very strong gun oscillations, resulting in spurious phase shifts on the output, which make the tubes unacceptable for the tight specifications imposed for the phase stability of the machine. In addition, one of the tubes exhibited pulse lengthening; that is, the rf output, having been started by excitation of the drive, would continue even after the drive pulse was turned off until the end of the beam pulse. This pulse widening is presumably caused by body oscillations at a frequency very close to the drive frequency.

Further monitoring of the work at Sperry indicates that they apparently have found a solution to the pulse lengthening problem, which appears to be caused by returning electrons from the collector region. As of the end of December, the only Sperry tube which did not exhibit gun oscillations had overall poor performance because of poor vacuum in the tube.

RCA shipped one tube on December 19 for test and evaluation purposes. The tube will be checked during January 1964. Visits to RCA indicate that they have not seen gun oscillations, they have apparently good control of the body oscillations, their power output may still be marginal, and they have had cathode emission problems (the heater power required for the tube they shipped is too high to be acceptable).

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*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1963," SLAC Report No. 23, Stanford Linear Accelerator Center, Stanford University, Stanford, California (October 1963).

C. MOVE TO TEST LABORATORY

During this quarter the Klystron Group was gradually able to occupy the eight test stands allocated to its activities. For various reasons, such as the need of equipment by other groups, the final acceptance of all test stands by the group did not take place until December. In general, the test stand operation has been satisfactory, in spite of one serious break in the water system that sprayed and flooded the equipment in three test stands, and some difficulties in getting the sub-booster modulators and drive lines to operate according to specifications.

The tube fabrication is now moved and was operating near full capacity by the end of the quarter, but the total effort that had to be spent in correcting and adjusting equipment and facilities has greatly decreased the total output of that section during the quarter. For example, some of the furniture ordered was received late and in such bad condition that it could not be used, and it took almost a month to resolve the problem. As another example, it was discovered that the hydrogen lines installed in the building were so dirty that it would be impractical to clean them, and they had to be removed and new lines installed with properly made solder joints.

D. KLYSTRON FABRICATION AND DEVELOPMENT

Twelve klystrons and two diodes were tested and processed during the quarter. Probably because of the move, more tubes exhibited poor vacuum during processing than is customary. It was discovered that one bake station was not performing satisfactorily when first reinstalled. A majority of the tubes tested showed gun oscillations, but only one exhibited body oscillations. Measured peak power output varied from 18 to 20 MW with maximum efficiencies of 32 to 37%.

The first full strength permanent magnet (1100 gauss maximum) was received, and a standard tube was tested in this magnet. The cross magnetic fields are still troublesome and require careful shaping to achieve good tube performance. However, with proper adjustment of the field (by field straighteners) a peak power of 12 MW was obtained at 200 kV and 16.1 MW at 225 kV. Oscillations (appearing to be gun oscillations) prevented obtaining data at 250 kV.

Work has been continuing on development of a new gun that would be less sensitive to the magnetic field and less susceptible to oscillations. A computer program has been established for gun design that should allow the introduction of slight variations in the gun and its characteristics without the expense of a complete tube test. At the present time, two variations of a gun design have been developed and appear to be satisfactory. The first version should give a beam diameter of approximately 0.6 inch and should then be operable with a drift tube diameter of 1 inch. The second version should have a beam diameter of between 0.7 and 0.75 inch, making it operable with the present drift tube diameter of 1-1/8 inches. The advantages of the small drift tube are (1) additional decoupling between the cavities, which should decrease the tendency for body oscillations; and (2) better coupling coefficient from the beam to the cavity gaps, resulting in higher gain and higher efficiency. The disadvantage of the small beam is the requirement for higher focusing fields. Until both guns are tested it will not be known which has the best overall performance, considering availability of permanent magnets, possibility of gun oscillations, and the ease of manufacture.

E. STANFORD KLYSTRON USAGE

At the present time Stanford klystrons are being used by SLAC groups in seven sockets, and diodes are being used in one socket. During the quarter a number of tubes have been lost by window failures after operating times varying from 70 to 975 hours. In addition, one tube was removed from operation after 500 hours because of cathode arcing at voltages in excess of 230 kV. The causes of the window failures are still uncertain. In most cases windows used on the test stands with an accelerator load appear to run considerably warmer than those being run with a broad band load or those being tested in the recirculating ring. Further confirmation of this evidence will be looked for during the next quarter; in addition, studies to determine the possible differences in operating modes will be undertaken. Careful monitoring of window temperature is being instituted to provide the necessary information.

F. ACCEPTANCE AND LIFE TESTS

The equipment needed for acceptance tests has been received, with the exception of the noise measuring equipment (sampling waveguide). The phase measuring equipment is operating satisfactorily and is used for both the sub-booster klystrons and the final amplifiers. A basic data acquisition system has been received, including the main analog data system (Dymec 2010E) and the data summary punch. The punched card format was set up and some thought was given to the evaluation of data. Once 250 tubes are in continuous operation, it will be imperative to have easy access to the information on these tubes to permit evaluation of their performance. Most of the programs will be written in the international language, "algol," and run on the Burroughs 5000 at the computer center.

In view of the new delivery schedule proposed by Sperry and RCA, it is unlikely that life tests on their tubes will begin before April 1964.

G. INSTALLATION ON THE MACHINE

Considerable thought was given during the quarter to the equipment and manpower needed to receive, test, and install klystrons on the two-mile accelerator, as well as to test them once they are in operation on the machine, and to remove and return them to the manufacturer for repairs after failure. The final solution to these problems will undoubtedly continue to evolve over the next few years, but we expect to have by the next quarter a definite handling plan so that the necessary equipment (fork lifts, trucks, etc.) can be purchased in time for the installation of sectors 1 and 2. The mechanical design of the klystron support yoke has been checked, and a full scale model and the complete drawings and specifications for procurement have been approved. These items should be purchased early in the next quarter for delivery of the first 20 in April.

H. HIGH-POWER KLYSTRON WINDOWS

1. High Vacuum Resonant Ring Tests

The coated window tests begun last quarter have been completed; Table I shows the performance data on the samples. No significant difference appears as a function of the chosen coating parameters. Samples that were tested after 50 days "shelf life" gave as good or better results as those tested shortly after coating. Additional tests will be run on windows similarly coated, but after baking the coating in vacuum, which had not been performed on the windows tested here.

Tests were also run to determine the temperature of the window as a function of power and as a function of misalignment of the window within the mounting sleeve, using an infrared thermometer to measure the temperature at the center of the window. Some uncoated AL-300 windows ran at 300°C in the center while others ran below 100°C at 24 MW peak, 22 kW average power. In addition, it was found that the "attitude" or "tilt" of a window appears to have a noticeable effect on window temperature; specifically, if the tilt is such that there is at the center of the window a component of electric field normal to the window, the temperature of the center is in a majority of cases higher than if there is no normal component of electric field. Additional tests will be conducted next quarter to confirm these conclusions.

During the quarter the input window to the ring failed from overheating at 5.3 MW, 4.8 kW, and it took several days of baking after this accident to obtain the desired base pressure of 10^{-8} torr. The input windows (Type A) were replaced by SLAC klystron windows.

2. Low Power Resonant Ring Tests

The "reduced gradient" groove structure described in the previous status report has been received from Wesgo. This window design is a variation on the grooved window designed by Dr. Heil (formerly of Eimac). The first 3 windows tested gave results similar to those of the original design tested last year,* with two failures, one at 34 MW, one at 66 MW,

*"Two-mile accelerator project, Quarterly Status Report, 1 October to 31 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963); pp. 42-45.

TABLE I

COATED WINDOW TEST RESULTS

Sample	Coating Parameters				Performance	
	Pressure (microns)	Voltage (rms volts)	Current (mA)	Time (min)	Initial Arcing Level (MW)*	Level of Failure (MW)*
1a	60	2000	40	20	72	132
1c	55-60	2000	40	20	135	No Failure ** (135)
2a	80-100	1500	25	20	60	60
2c	80-100	1500	25	20	60	120
3a	80-100	1000	-	20	48	100
3c	80-100	1000	-	20	110	No Failure ** (171)
4a	40-60	2000	40	15	72	120
4c	40-60	2000	40	15	72	No Failure ** (180)
5a	100	2000	40	15	75	120
5c	100	2000	40	15	60	60 ***
6a	150	2000	40	15	50	120
6c	150	2000	40	15	108	No Failure ** (132)

* Duty cycle = 0.0009.

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

*** Failed from thermal stresses (see text).

while the third window withstood the full peak and average power available (86 MW, 44 kW). Additional tests will be run with windows both as received and titanium coated.

In the course of the investigation of the effect of surface finish of the windows on performance, various indications have been observed which point toward a possible connection between window "attitude" and window performance. Five windows were tested on the low power ring, but no simple correlation could be determined between window attitude and window performance.

Several waveguide plumbing components, including waveguide valves of various designs, were subjected to high power tests in the resonant ring. Details on the performance of these assemblies are to be found in the Accelerator Structures portion of this report (Section III).

3. Other Window Work

An analysis made on the AL-300 ceramic presently used as a klystron window (0.111 inch thickness × 3.330 o.d.) has revealed the presence of a TE_{21} ghost at 2865 Mc (based on assumed dielectric constant of 9.20). No other modes were discovered close to the operating frequency, the next nearest being a TM_{01} ghost at $\approx$ 2720 Mc. Cold test measurements verified the presence of the TE_{21} ghost, which was located at 2855 Mc in the window sample used in the measurement.

In order to shift this ghost mode from its present position, the window thickness has been increased to 0.125 inch. Rough experimental measurements indicate that the currently used window structure will remain matched with the window of the increased thickness, and the TE_{21} ghost will be shifted to $\approx$ 2780 Mc.

It is possible that some of the window failures reported on klystrons could be caused by this ghost mode, because the mode undoubtedly shifts downward in frequency as the window temperature changes.

The window coating equipment has been overhauled, and a more compact, more reliable, and improved apparatus is being built for further window coating. Tests are also planned on water loads that will be coated in an attempt to further improve their life.

It has been decided to reactivate the window life test equipment, which is to be able to test six windows in series. The equipment is being rebuilt using an ion pump rather than a diffusion pump to better simulate the conditions that will exist in the accelerator waveguide vacuum system. One of the purposes of these tests is to acquire information on the minimum build-up time of the rf power through a window without degrading window life.

I. SUB-BOOSTER KLYSTRONS

Up to the end of December, Eimac had delivered 24 sub-booster klystrons. Of these, 6 were rejected for non-conformance to the specifications, and one had not been tested by the end of December. Accordingly, there were only 18 fully accepted tubes on hand, whereas the contract calls for a total of 26 acceptable tubes delivered by December 8.

In addition, of the 18 tubes accepted, 6 tubes failed by shelf life before any operating hours other than acceptance test hours had been accumulated.

It is planned to negotiate a new delivery schedule with Eimac, which will first request that the tubes which have been returned for end of life (shelf) shall be re-submitted to Stanford within the next two months, and that deliveries of additional acceptable tubes should begin in March 1964.

Two problems with the Eimac tubes have caused concern. The first one is the poor showing on shelf life; the second is that the percentage of acceptable tubes shipped to Stanford has dropped from better than 90% for tubes delivered through July to 50% for tubes delivered since September. We are keeping in close touch with the technical people at Eimac, who are at present working on the problems which have been pointed out by our findings.

On the other hand, tubes that are operated regularly appear to have good performance. Only one tube had to be rejected after 230 hours of operation because of indications of multipactor within the tube; two tubes have approximately 1000 and 2300 hours of operation, respectively. The other tubes have not been used sufficiently to be able to make definite statements about their probable life.

V. ELECTRONICS

A. GENERAL

The major accomplishments during the quarter were made by the Heavy Electronics (Modulator) group. Bids for the modulators have been received and recommendations for purchase have been made. Light Electronics and Instrumentation and Control groups have been finalizing layouts of chassis, cables, and control circuits for assembly of sectors 1 and 2.

B. MAIN MODULATOR

1. Prototype No. 2

Prototype No. 2 modulator was finished early in October. It was started up and operated satisfactorily except for difficulties with de-Q'ing circuits and a few other rather minor troubles.

The de-Q'ing circuit required an additional amplifier stage between the comparator circuit and the blocking oscillator that fires the SCR gate. This change improved the regulation of the modulator output pulse amplitude, and improved the operation of the circuit when it went in and out of de-Q'ing by making the transition much smoother. The main difficulty with de-Q'ing was that the silicon-controlled rectifiers would not last very long. Additional diodes were added in series with the SCR to reduce the inverse voltages, and the despiking circuit between the charging diodes and pulse forming network was optimized to reduce the inverse voltage spike across the SCR. Such changes have improved the overall circuit, but there is still uncertainty about the life of the SCR. In December, as a parallel effort, a search for other switching devices to replace the SCR was begun. A small ignitron is being experimented with, and preliminary tests are encouraging.

The end-of-line clipper relay was found to be not sensitive enough and was changed to a more sensitive one.

The airflow switches were relocated to a position that made them more positive in their operation.

The RFI line filters in the 260 to 600-volt incoming lines were found to have too small a current capacity, and higher capacity units were ordered.

RFI tests were performed on the modulator in order to determine how it performed in this respect, and if possible, to improve it. RFI radiation from the modulator was found to be low, but tests are continuing in an effort to reduce it further.

A time stability test (delay time between input trigger and output pulse) over the modulator's whole power operating range was performed and the total variation was 20 nanoseconds. This is excellent performance, due in a large part to the time stability of the GL 7890 switch tubes.

In summary, the modulator has performed well, with the exception of the short life of the SCR in the de-Q'ing circuitry. As of the middle of December this modulator had 960 plate hours and 1130 filament hours on it, most of the operation being at full power into a diode load.

2. Prototype No. 1

This modulator has been operated along with Prototype No. 2 almost continuously, 24 hours a day, in order to get reliability and life data, and as a test vehicle for pulse transformer tank components.

As of the middle of December it had approximately 1600 hours of plate operation on it. Very little trouble has been experienced with it, and it continues to be an excellent test vehicle. It will be used to test possible switching devices for de-Q'ing and other components.

3. Main Modulator Procurement

As Prototype No. 2 was being built, drawings and specifications were drawn up. Wherever possible the construction followed the drawings in order to check them. However, due to the tight time schedule, for the most part the drawings were drawn up after the construction of the applicable part in Prototype No. 2.

Performance specifications on about 24 custom made items which could not be purchased as catalog items were outlined. The bid packages, consisting of these drawings and specifications were sent to modulator manufacturers on October 12. A bidders' conference on the main modulator was held on October 23; the bid opening was on December 2. Ling Electronics Company was the apparent low bidder and was recommended by this department for the award of the contract.

4. Pulse Capacitors

Specifications for a separate procurement of the pulse capacitors to be used in our pulse forming networks were drawn up.

Polyethylene-silicon oil was recommended by most capacitor manufacturers for use at SLAC, because our size limitations would make paper-mineral oil units, which have a much higher dissipation factor, unreliable.

A set of Sangamo polyethylene-silicon oil units was obtained; the units were installed in Prototype No. 2 and have operated since the modulator was first turned on. No problems have arisen since they have been in service.

The bid package was sent to the capacitor manufacturers, and on September 26th bids were opened. Sangamo was low bidder, and was recommended by this department for award of the contract; the contract was signed early in December.

5. Switch Tube Procurement

The switch tube specifications, drawn up in September, consisted of two alternatives: one tube per modulator, or two per modulator, as in the present dual GL 7890 system. The manufacturers could bid on one system or both.

A bidders' conference was held early in October to acquaint the manufacturers with our problems and, if necessary, to modify our specifications.

Bids were opened on October 29th. The dual tubes naturally turned out to be more expensive than the single ones. However, the modulator design was made flexible enough to take either dual or single tubes, at least for the initial 20 modulators, in order to have some safety factor in switch tube types. The procurement was planned to be split evenly between two manufacturers; the lowest bidders were General Electric's 7004 tube (single) and Kuthe's KU274B (single). It was recommended that each company get an initial order of 50 tubes in order to fit out the initial number of production modulators (20) and to keep our test stands in operation.

Subcontracts for such tubes were in process of being negotiated in December 1963.

6. Pulse Cables

The search for a better cable to carry the pulse power from the main modulator to the pulse transformer tank has continued during this period.

The Anaconda "Special" cable with an extra shield pulled over it to make it triaxial continued to operate satisfactorily but two cables are required and it is not as flexible as is desirable. It has been operated on both Prototypes No. 1 and No. 2 with no trouble whatsoever. A single cable with a little more flexibility would be preferable, however, and in November many companies were contacted with regard to the problem.

Boston Insulated Wire Company proposed, and is submitting for testing, a sample quantity of a 14-ohm triaxial cable which appears to be a very good prospect for this job. The sample quantity is to be delivered late in December.

7. Pulse Transformer Procurement

Pulse transformer bids were opened on October 10, 1963.

This procurement included a provision for samples to be submitted for approval. Such samples were obtained from various companies and were tested in order to determine qualifications. All samples submitted failed either low voltage or high voltage tests except one. Pearson Electronics Company's transformer passed low voltage tests and has operated at high voltage with no trouble. Another unit of the same design has over 2000 hours on it with no trouble.

8. Pulse Transformer Tank Assembly

A change in design took place in the air expansion chamber in December. The old system, which used an air chamber with air in contact with the oil, has been dropped in favor of one with air inside a rubber tube that in turn is placed in the oil tank. This change was made because it was feared that air bubbles might find their way from the expansion chamber up to the ceramic seal at the bottom of the klystron and possibly cause an arc across the seal. This could happen if the oil tank, with its klystron in place, were tilted a little too much, thus allowing air to escape past the air chamber wall.

Specifications are being drawn up for other components in the pulse transformer tank, and procurement for such items is underway.

C. SUB-BOOSTER MODULATOR

It was decided during this period to obtain sub-booster modulators on a performance basis. Specifications were drawn up and were ready for the vendors late in December.

The design that has been worked out at SLAC, which does not quite meet specifications in some areas, was made available to the vendors in order to help them meet our tight specifications.

A high voltage power supply regulator was designed and built during this period. The regulation is close to 0.01%.

Additional parts for three more regulators are being ordered. When they are finished, the regulators will be incorporated in the present sub-booster modulators for test stand use.

D. SWITCH TUBE LIFE DATA

1. Type GL 7890

Two sets of GL 7890 tubes were received.

The first set lasted 1505 hours. This set was sent to General Electric to explore the possibility of rebuilding these tubes.

The second set of tubes failed after approximately 1700 hours, about 900 of which were on a diode load on Prototype No. 2.

2. Type KU-275

The first tube ran 1866 hours before failure.

The second KU-275 had 921 hours on it as of December 19. It is being operated by the Accelerator Structures group in a Ling modulator on a klystron load.

3. Type 7004

This tube was run 791 hours at SLAC. When the switch tube test program in the M-1 building terminated, there was no further use for it at SLAC. It was given to Sperry Gyroscope Company, where it was run another

750 hours before failure in their klystron aging modulator, giving a total of 1541 hours for that tube.

4. <u>Type 7005</u>

This tube ran 375 hours in Prototype No. 1 modulator before it failed due to inability to hold off high voltage. General Electric has since dissected this tube and found a manufacturing error in it. They are confident that this tube will prove to be one of our best switch tubes.

E. IONIZATION CHAMBER FOR ACCELERATOR PROTECTION

It has been proposed to place an ionization chamber, in the form of a coaxial line, in the housing parallel to the axis of the accelerator. The objectives are: (a) to provide a shut-off signal in case of excessive beam loss, and (b) to furnish diagnostic aid in beam operation.

The sensitivity of such a cable to a radiation-loss event was estimated by W. Panofsky and also by H. DeStaebler. Their results have been normalized to a 1-5/8-inch diameter, 75-ohm coaxial cable filled to 1 atmosphere absolute with a 90% argon, 10% carbon dioxide gas mixture. The estimated sensitivity parameter, $K = VD/Jd^2$, ranged from 0.4 to 10 volts/joule-cm, where V is signal voltage, D is distance from accelerator axis, J is intercepted beam energy, and d is the diameter of the cable.

A 10-foot length of a similar 7/8-inch diameter cable was tested at the Mark III accelerator. The beam was reduced in amplitude and duration to about 1.4×10^{10} epp, 0.2 μsec, and scattered by inserting the downstream gate valve in the second halfway station. The gate valve was brass, about 0.5-inch thick ($\approx$ 1 radiation length) and scattered the beam by about 0.1 radian, rms. The beam energy was about 250 MeV. The cable was positioned just downstream of the valve at a distance of about 10 inches from the accelerator center line. The bulk of the shower particles probably emerged well within this region. In the experiment, V was about 3 volts, J about 0.6 joule. The experimental K was determined to be 2.0 volts/joule-cm.

The propagation of the signal will be affected by the presence of electrons in the gas. Using the propagation parameter given by Rose and

Clark* for a signal traveling through a plasma, it is found that the attenuation will be of the order of 20% with a uniform beam energy loss of 100 joules in 10,000 feet of the above cable. If three joules (approximately 0.1% of the beam energy) are intercepted by a beam scraper, and the shower emerges in a region one meter long, a discontinuity will be produced that reflects about 0.7% of the signal amplitude, which could give rise to signal distortions of the order of 10%. These numbers are based on a small signal theory which probably overestimates the magnitude of the effects.

The measured sensitivity of the devices is great enough that a 3-joule beam loss event will produce a signal magnitude of 0.5 volt, even when the cable is spaced 10 feet from the accelerator pipe. This extra distance would reduce any plasma effect by a factor of 10. The noise is expected to be 10 millivolts or less.

F. DATA TRANSMISSION

Criteria Reports were issued on the Analog Measurement, Beam Monitoring, and Beam Shut-Off sub-systems. Present designs use a pair of wires assigned to handle each analog measurement, a PAM-FM transmission system for beam monitoring measurements, and a cascaded arrangement of amplifier-switches for equipment protection (beam shut-off).

Quotes were received from vendors bidding on equipment required for the public address and paging portion of the Personnel Communications System. Bid packages are being prepared for Battery Plant equipment according to technical specifications prepared by this section.

Evaluation of data transmission equipment and techniques in the accelerator environment was continued throughout the quarter. Prototype status monitoring and analog measurement equipment has performed satisfactorily in testing to date.

G. MEASUREMENT AND ACTUATION DEVICES

The technical requirements of the modulator-klystron protection equipment have been modified as a result of continuing changes in the design of the modulator and additional changes based on economic considerations

*D. J. Rose and M. Clark, Plasmas and Controlled Fusion (MIT Press, Cambridge, Massachusetts, 1961); p. 184.

and technical simplifications. The principal changes can be summarized as follows:

1. Elimination of an overvoltage protective device based on measuring the voltage at the pulse forming network.
2. Change of the sector-reference voltage supply from 600 volts to 120 volts.
3. Elimination of the possibility of having short (less than 1 second) interruptions of klystron operation.
4. Reduction of the input trigger level to the modulator from 100 volts to 50 volts.
5. Substitution of an overcurrent fault detector and an overvoltage fault detector for the klystron impedance fault detector.

Adoption of the de-Q'ing circuit for regulation of the modulator output level eliminated the need for an overvoltage protective device based on measuring the voltage at the pulse-forming network. However, the requirements on the voltage reference source were made more exacting to achieve noise immunity. A brute force solution of the noise problem substituted a 260 to 600-volt supply for the 26 to 60-volt supply. However, because the noise pulses due to the modulator operation do not occur until <u>after</u> triggering occurs, it appeared possible to eliminate interference using simple low-pass filtering. A reference power supply of 52 to 120 volts was then adopted.

Elimination of the possibility of having short (less than 1 second) interruptions led to the need for redesign of the low speed logic circuitry. Present design is based upon inhibiting triggers for approximately 2.5 seconds after any fault. For faults persisting longer than 3.5 seconds or for repetitive faults, in a 3.5-second interval, attenuation is inserted to reduce rf drive to a minimum.

Reduction of the input trigger level to 50 volts was made to achieve improved reliability and circuit simplification. Similarly, elimination of the impedance fault sensor was implemented to achieve a significant simplification and a slight increase in reliability while sacrificing only insignificantly in performance.

Although breadboards for the circuitry for protection and control of the modulator had been completed, further development is now under way to implement changes dictated by new requirements.

H. BEAM GUIDANCE

A number of design decisions were made concerning the beam guidance system. It has been decided that no servo system will be provided for degaussing or steering.

The degaussing system consists of 8 current-carrying wires running the full length of each sector. The currents will be adjusted only at the sector, not from Central Control.

A quadrupole triplet will be provided in the drift space after each sector. The quadrupole currents will be adjustable from Central Control.

Magnetic shielding will be used to reduce the accuracy with which the dc degaussing currents must be maintained and to reduce the magnetic fields at the accelerator axis. The shielding factor will be about 30, reduced to an effective value of about 10 due to the unavoidable gaps in the shielding.

Dipole steering coils will be provided in the drift space after each sector. The dipoles will have remotely controlled dc supplies. The dipole design will allow pulsed dc or superimposed ac to be applied at a later time, if required for multiple beam operation.

In order to protect the accelerator structure from stray electron beams, a beam scraper will be designed and will be used at selected positions along the accelerator length. Space will be reserved in each drift section for this purpose. The beam scraper will be of a fixed aperture, non-retractable type.

VI. MICROWAVE ENGINEERING AND INJECTION

A. INJECTION

1. Injection Test Stand

During the past quarter, the injection test stand (station No. 13) was activated. A beam of about 2.8 amps peak current was obtained with close to 100% transmission through the accelerator. The following other significant events took place.

a. Radiation

Upon achieving 2.8 amps peak beam current, it was found that the radiation considerably exceeded the safety levels; up to two roentgens/hour were found at certain locations. Following a complete radiation survey, two and one-half tons of lead bricks were stacked inside the Accelerator Housing around the Faraday cups and the momentum spectrometer. This reduced the radiation to safe levels.

b. Vacuum System

In checking out the momentum spectrometer, it was found that heating caused by the beam produced a crack near a weld of the spectrometer vacuum envelope. The resulting loss of vacuum poisoned the gun. The gun was rebuilt and the spectrometer vacuum envelope was rewelded. Air cooling was installed on both the momentum spectrometer and the output windows.

c. Accelerator Magnetic Focusing

The axial fields created by the focusing coils were measured and the data were compiled in a table. With the aid of this table, focusing coil currents can be translated into axial field strength as a function of position along the accelerator axis.

d. Momentum Spectrometer

The controls for the momentum spectrometer were revised to provide automatic plotting of current on an x-y recorder. The circuitry for degaussing the spectrometer magnet was also installed.

e. Beam Sweeper

The beam sweeper was finished and checked on the Mark IV accelerator. Fabrication of the sweep tank and associated hardware has started.

f. Beam Analysis Subassembly

Fabrication of the beam analysis subassembly consisting of the beam viewer, the adjustable slits, and the current monitoring toroid is almost complete.

g. Bunch Monitor

The bunch monitor is being fabricated as a separate subassembly. Models of both cavities have been fabricated and are undergoing tests.

During the next quarter, the injection test stand will be used to study the effects of the pre-buncher, the buncher, and focusing on beam transmission and spectrum. During the available maintenance periods, the sweeper and sweep tank as well as the beam analysis subassembly will be installed.

2. Electron Guns and Modulators

The injection test stand modulator (Model 4-1) delivery date from Manson Laboratories, Stamford, Connecticut, has slipped. Provided a satisfactory arrangement can be worked out with the manufacturer, an attempt will be made to revise the design of the second modulator to include two channels capable of giving double beam operation. This should be the first step to test multiple beam operation. Fast changes in both the grid pulser and the bias supply will permit changing the pulse length and pulse height from pulse to pulse on a 360 pps basis.

In November 1963, a rebuilt Stanford gun, type Model 1, which has also been used on the medical accelerators, was installed on the Mark IV accelerator. It has been emitting up to 275 mA peak. A second Model 1 gun was constructed in December and is available as a replacement.

Electron gun Model 2-2, originally built by Quantatron, required two new filaments this quarter. One of the failures resulted from a vacuum failure in the test stand, which also destroyed the cathode button support structure. Gun Model 2-1 (also from Quantatron), which was already inoperative because of a leaky vacuum envelope, was taken apart and its cathode was installed on gun 2-2. The spherical radii of the two cathodes differed by a factor of 2, but computer studies indicated that the electron orbits were not altered significantly. The gun was then installed on the injection test stand.

Gun 3-1 (from Hughes) was let down to air to replace a faulty thin valve; it emitted up to 1.8 amps peak after reassembly, following several hours of outgassing. The gun was then installed on the beam analyzer for analysis early next quarter.

3. Off-Axis Inflection System

The construction of the inflection magnet system for the off-axis injector has started. Mechanical design for all magnetic components is complete and support and alignment design is about to begin. Some parts for the magnets, such as the coils, have been ordered, and the iron parts will be built in-house as soon as materials become available.

4. SLAC Gun Design Program

The computer program for electron gun design announced in the previous Status Report* has been brought to a useful level of completion. The program has been used to predict trajectories for both the injector and klystron guns. It accurately predicts gun perveance for those designs which have actually been constructed. The accuracy is tested by a test problem consisting of a spherical diode for which the perveance is known theoretically. Agreement with theory is within 1 to 5% depending on certain assumptions on the starting boundary conditions. Recent innovations included automating the input so that only end points of straight line segments of the boundaries need be punched on data cards. This represents approximately an 80% time saving in program preparation. Another modification allows very thin surfaces to be placed in the field, thus making it possible to calculate the effect of grids on the trajectories.

5. Magnetic Shielding and Degaussing

A system of eight degaussing wires derived from a design proposed by Dr. Richard Helm has been built in a ten-foot-long mock-up. Tests of the system have been made both with and without metallic shielding. Preliminary results confirm all the original design assumptions. Specifically, ac shielding factors of from 10 to 30 have been measured using 14-mil-thick cylindrical shells of different materials. DC shielding (cancellation of the earth's magnetic field) has been successful down to 5 to 10

*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1963," SLAC Report No. 23, Stanford Linear Accelerator Center, Stanford University, Stanford, California (October 1963).

gammas. (One gamma is equivalent to 10^{-5} gauss.) The combination of shielding material and degaussing wires yields peak fields of 10^{-4} gauss if the shielding material is properly demagnetized. Presumably, very well annealed material would not need demagnetizing, but such material has not been found and probably does not exist. If the material has been demagnetized and has not been abused, it can be demagnetized again by applying an ac field from a third set of 4 wires, producing a field of about 10 times the earth's magnetic field. However, if the material is highly magnetized, best results have been obtained by demagnetizing with an internal concentric cylinder conducting the demagnetizing currents.

Design work to obtain an acceptable layout for the wires and shielding material has started. It is expected that satisfactory results will be obtained if the shielding is well demagnetized after assembly by means of an auxiliary ac current. However, it should be pointed out that the dc current necessary to cancel the earth's magnetic field must be applied during demagnetizing. If this is not done, the shield becomes magnetized to the earth's magnetic field. This result would only be acceptable as long as the material is not moved and the field remains unchanged.

6. Injection System Reports

Two basic Design Reports were published during the past quarter, one on the injection system as a whole and one describing a proposal for a beam knockout system.

B. DRIVE SYSTEM

1. Overall Design of the Drive System

All basic design parameters for the drive system have been determined and most of the procurement contracts are now in effect. They are briefly described below.

a. Bids for the Main and Sub-Drive Lines were received and the contract has been let to Dielectric Engineering Products, Raymond, Maine. Delivery of sectors 1 and 2 is scheduled for early April 1964.

b. The Varactor Frequency Multiplier bids were evaluated and the contract was awarded to Remanco Incorporated, Santa Monica, California. Delivery is scheduled to begin in early February.

c. The contract for the Main Booster Amplifier approached completion during the last quarter. Delivery is scheduled for late January 1964. While this delivery will be somewhat behind schedule, the contract has progressed satisfactorily from the technical point of view.

d. The Sub-Booster Klystron Tube contract remains in force and klystrons have been received periodically. Some production problems were encountered by the Eimac Company and several tubes had to be rejected. Further tests are forthcoming during the next quarter.

e. The Sub-Booster Modulator program is now being handled by the Heavy Electronics Group. However, during the last quarter, the Microwave Engineering and Injection Group participated actively in writing the design report and in preparing the specifications and bid package for procurement of the 31 required units.

2. Master Oscillator

A preliminary specification for the master oscillator was completed and sent to prospective bidders for comments and suggestions. Answers to our questions were received and indicated that there should be no major difficulty in obtaining the required equipment. The final bid cycle is scheduled to start in late January 1964.

3. Testing of the Main Booster Amplifier

Preparations are being made in the Test Laboratory building to test the main booster amplifiers upon delivery to SLAC. A 4.5-watt, 476-Mc/sec driver has been obtained from Microwave Associates in Burlington, Massachusetts for use as an rf source. Upon testing of the amplifiers at Energy Systems, it was found that the WL-120 Eimac water load originally purchased for use with the main booster amplifier was inadequate. A WL-130 model was obtained and it is suitable for use with tap water but not with distilled water. The WL-130 load is to be returned and a WL-140 will be obtained for use at SLAC. The latter model is dimensionally longer and has a lower VSWR than the other loads.

4. Testing of Varactor Frequency Multipliers

The waveguide phase bridge mentioned in the previous Status Report has been completed and is capable of measuring phase stability with an accuracy of ± 0.1° per week. This bridge will be a major tool in the acceptance testing of the frequency multipliers. Experiments have been conducted with new varactor diodes manufactured by Sylvania, and it is now possible to obtain 750 milliwatts output for 4.5 watts input with the six prototype multipliers provided by Syntax Corporation. A theory is being developed to explain phase shift as a function of drive power, and several promising ways of minimizing phase shift as a function of drive power have been discovered. These methods are under investigation.

5. Microwave Test Stand Operation

During the past quarter tests were conducted on the sub-booster modulator associated with the test stand. The experiments concerned phase delay, phase stability, and general operation, in preparation for observing the phase characteristics of the main 24 MW klystron. The rf water load furnished with the test stand was inadequate to absorb the power and the quartz tube fractured. The load has been repaired but will only be used as a temporary low-power load. A new type of rf load has been ordered and will be available next quarter.

A six-foot-long section of 7/8-inch coaxial cable was tested at high power using the sub-booster klystron as a power source. The cable is a sample of the type proposed for the accelerator phasing system in which the anticipated peak power is approximately 60 kilowatts maximum. The tests indicated so far that peak powers of 80 kilowatts can be transmitted without problems.

6. Group Velocity Measurements

In order to test the main and sub-drive lines, equipment has been built, particularly to verify the group velocity specifications. A synchronizer-adapter has been constructed that controls the difference frequency between two klystrons or any voltage-controlled oscillators. The unit is capable of maintaining a 500 kc difference frequency with a stability of one part in 10^7. Constant difference frequency signals were obtained both at 2856 Mc/sec and at 476 Mc/sec. Thus, group velocity measurements can be performed with the required accuracy of one part in 10^4 or better.

C. PHASING SYSTEM

1. Beam Induction Technique

The final design report on the Automatic Phasing System for High Power Klystrons was published during this quarter and has received project approval.

2. Programmer Design

The final design of the phasing system programmer is under active review, and the design of the appliqué panels that will be associated with the sector programmer is being undertaken. These appliqué panels will enable the system to accommodate up to 32 klystrons per sector and will readily be adapted to sectors 1 and 11, which already in Stage I have more than the standard complement of eight klystrons.

3. RF Head

The final design of the rf head was completed during this quarter and a prototype unit has been constructed. Evaluation of the unit is presently being undertaken, and procurement of all components for the first two sectors is complete.

4. Sector Simulator

The sector simulator has been further modified in order to raise the section input power levels to values comparable to those anticipated for the machine. The prototype rf head and system programmer have been incorporated into the simulator, and tests show that the system operates over a range of signal levels of 50 db with an output voltage of less than 4-1. The time required to phase eight channels is normally one minute.

5. 360° Continuous Phase Shifter

The design of the 360° continuous phase shifter is still in process. The unit is being designed to meet the stringent requirements of the Isolator-Phase Shifter-Attenuator assembly and the Control Phase Shifter specifications. At the present time emphasis is being placed on the design of the direct coaxial to circular waveguide transition to reduce reflections. It is anticipated that the phase shifter will be ready for testing early in the next quarter and will serve as a design backup in the event that the units procured from industry should fail to meet specifications.

6. Procurement of Isolator-Phase Shifter-Attenuator Assembly

Bids for the procurement of the Isolator-Phase Shifter-Attenuator Assembly and the Control Phase Shifter Assembly were received during this quarter. These units will be produced ty the Sperry Microwave Corporation, Clearwater, Flcrida. Delivery of the pre-production run is scheduled for March 1964.

7. Momentum Spectrometers

The design of the momentum spectrometers which form a part of the beam analyzing stations in sectors 1 and 11 has been completed by the Research Division. Detailed drawings should be ready next quarter. Preliminary calculations for the secondary emission monitor and beam dump, also to be associated with the beam analyzing stations, were started. These will be completed in the next quarter together with the design of the magnets.

8. RF Cavity for Drift Section

The design of the rf cavity for the drift section has been completed. This cavity will be used as a sector phase monitor. Cold tests on the cavity will start next quarter; in addition, a series of tests are scheduled to take place on the Mark IV accelerator.

9. Beam Position Monitors

The possibility of using microwave beam position monitors in the drift sections is being considered. Experimental results from the two types tested on the Mark IV accelerator, the three particle separator type and the TM_{012} rectangular resonator, indicated that monitors of this type could provide high-sensitivity and low noise operation. In addition to the above models, four other types of monitors are being studied: a resonant ring, a traveling-wave ring, and two types of short-circuited waveguides.

Calculations of the induced power as a function of beam current for these monitors have been completed and some preliminary experiments have been carried out on the injection test stand. Good correlation between signal level and position was obtained. Experiments on the Mark IV accelerator are planned for the beginning of the next quarter.

10. Linear Detector Design

An essential component in the automatic phasing system and possibly in the microwave position monitor system is the linear detector. To provide a source of these detectors in addition to the outside suppliers, a design has been completed at SLAC. Two prototypes have been produced and life tests are being undertaken.

VII. SYSTEMS ENGINEERING AND INSTALLATIONS

A. ACCELERATOR RESEARCH AND DEVELOPMENT

1. Vacuum System

(a) Gauge Evaluation

The four-channel cold cathode gauge power supply was installed and connected to two Vactek gauges, one prototype General Electric gauge, and one prototype CVC gauge. Observations indicate that the Vactek gauges operate more satisfactorily than the others; gauge tests will be continued during the next quarter.

(b) Valve Evaluation Program

An all metal Cryo-lab valve was cycled and leak tested cold several times. No leaks were found, and the valve generally appears to be satisfactory.

(c) Roughing Systems

Linde prototype cryosorption pumps were installed in the Test Tower. The system was let up to N_2 and pumped with three-stage cryopumping. A pressure of 4.0×10^{-4} torr was reached in 2 hours, 25 minutes. In a second test with N_2, the system was pre-pumped with a mechanical pump to 85 microns and the cryopump was then valved in sequentially. Pressure of 2.6×10^{-4} torr was reached in four hours. The lowest pressure attained with sequential cryopumping, starting from atmospheric pressure and a system filled with N_2, was 4.2×10^{-5} torr after 24 hours. With pre-evacuation by mechanical pumping, the lowest pressure reached was 2.7×10^{-5} torr after seven hours.

The pump was then modified, with three-inch tubulation replacing the one-inch tubulation, and a pressure of 2×10^{-7} torr was reached in less than four hours, starting from dry nitrogen let-up.

(d) Test Tower

The Klystron Gallery floor of the Test Tower was raised and lowered one inch without damage to the vacuum system. Typical system pressures without rf were:

Pump	Klystron Pumpout	Accelerator
2.5×10^{-7} torr	1.5×10^{-7} torr	1.6×10^{-7} torr

with an average outgassing rate of 2×10^{-11} torr-liters/sec/cm^2. Typical pressures during rf phase tests were as follows:

	Ion Pump	8-inch Manifold	Klystron Window	Accelerator
RF Off	8.9×10^{-9}	3.4×10^{-8}	4.6×10^{-8}	5.7×10^{-8}
RF On (4 kW average power)		1.4×10^{-7}	1.8×10^{-7}	2.4×10^{-7}

2. Supports

Support girder bellows were received and will be installed in January. Klystron frame vibration tests indicated that a stiffer column-column base arrangement was necessary. The test frame was modified, and the results of the retest of the frame were satisfactory.

The horizontal support girder jack and jack hardware were tested in December. The application of a ±100-pound load parallel to the axis of the accelerator applied to the jack clevis in the extended position produced a motion of ±0.004 inches, or 40% of the allowable motion.

3. Alignment

The sensitivity of the relationship between accuracy of alignment target manufacture and position along the light pipe has required the making of more precise targets. Triple Fresnel zone plate targets were purchased for evaluation.

4. Cooling Water

Corrosion testing of the cooling water system is continuing at the Test Laboratory setup.

B. ACCELERATOR ENGINEERING, DESIGN, AND INSPECTION

1. General Design

(a) Design Coordination

Penetration details were substantially completed and the latest changes were incorporated in the vacuum, electrical, and cooling water installation subcontracts. Updated definitive layout drawings were issued to project groups for reference and comments (except the waveguide layout, which is being revised to reflect latest design requirements). An evaluation of the positron source alcove requirements has been initiated. Coordination of the full scale drift section mockup is continuing, and Beam Dynamics Committee assistance toward this end was provided during the quarter.

(b) Model Shop

One-eighth-scale models of short sections of the Klystron Gallery and Accelerator Housing were substantially completed. A 1/32-scale model of Sector 14 was completed for the Klystron Gallery level and work was begun on the Accelerator Housing portion. These models have been used to advantage in arriving at a final layout, and subsequently at pre-bidding conferences relating to the vacuum, water, and electrical installation subcontracts.

2. Installation Drawings

Drawings for the electrical services and high vacuum system bid packages were completed. Cooling water drawings are being revised to incorporate major changes in the klystron circuit involving connections to klystron water jackets and the addition of automatic temperature control.

3. Vacuum System

The contract was awarded for getter ion pumps. An invitation for bids was issued for vacuum system installation and for three-inch and six-inch valve assemblies. Proposals were received on cold cathode gauges, and negotiations with three proposers are underway. Specifications for the all-metal valves used to isolate vacuum gauges and for roughing valves to be installed on the three-inch and six-inch valves are being prepared.

4. Supports

Fabrication of the 24-inch girder assemblies to unite the target housing, girder pipe, intermediate support brackets, and end plates was completed. Drift support prototype fabrication is underway. The klystron support frame fabrication specification is under review. The jack specification bid package has been completed and is now under review. The support girder pipe contract was awarded to Kaiser. Preparations for support girder bellows, connection pins, and jack life tests are underway.

5. Alignment

The support girder mockup target support hardware and actuator were fabricated and installed. The monument support hardware design was completed. Final design of the jack actuators to be operated on the airplane control cable system basis was reviewed. Target actuators will be operated pneumatically. The laser to be used in the alignment system of the SLAC machine was purchased. Requirements for anticipated life tests for the target hardware and actuator were established. The target bid package is approximately 90% complete.

6. Cooling Water

The cooling water installation specification was submitted to the AEC for 90% review in November. Revisions of subcontract drawings and technical specifications were made during December, with the bid package scheduled to go out to bidders in mid-January.

7. Electrical Services

Installation specifications and drawings for electrical services were reviewed, approved by the AEC, and the invitation for bids was issued. Variable voltage substation shop drawing approval was in process during the quarter.

8. Auxiliary Machine Shielding

Services penetration shield studies concentrated on alternate materials which, at low cost, might reduce the depth of the plug from 4 feet to 2 feet. Local ores or borax look promising. Treatment of the air seal extending through the shields was reviewed.

9. Electronic Systems

Final layout and installation drawings for electronic systems and rack program design work were initiated during this quarter. Criteria, some inspection, some procurement, and all test labor after installation are to be furnished by the Electronics Department. SE&I is to receive criteria, furnish layout and installation drawings, procure certain items, and supervise subcontractors during the installation work period. During this quarter, cable trays, phase monitoring cable installation, miscellaneous instrumentation and control conduits, and modulator installation work was added to the electrical services subcontract package. The specification for electronic equipment rack frame components was issued for bids.

C. ACCELERATOR INSTALLATION

1. Installation Coordination

Work continued in updating of schedules for installation subcontracts in accordance with actual progress. Procurement subcontract dates are being checked for compatibility with installation subcontracts.

Updated critical path networks for this department's installation subcontracts will be available for review in January 1964.

The preparation of forms and supporting procedures for field installation was started, together with a three-year installation bar chart.

VIII. MARK IV PROGRAM

A. OPERATION

Very effective use of available machine time was made by experimenters during this quarter. Improvements in the machine itself resulted in higher power operation under much more stable conditions. Experimental schedules were maintained on a regular, routine basis.

Groups of experimenters performed extensive work on secondary emission materials for beam energy spectrum analyzers, and on insulating and supporting materials for magnet coil windings. The instrumentation and control and microwave groups also used the machine in continuation of their experimental programs.

The machine has continued to run reliably with the original thyratrons installed as switch tubes in the modulators.

With the changes reported below in the vacuum system, initial pumpdown is fast, and the base pressure is considerably improved. As an example, a before-and-after comparison can be made for the conditions at each of the klystron window pumpouts, whose vacuum arrangements were not changed. The base pressure prior to change was in the vicinity of 4×10^{-7} torr, while it is now in the 10^{-8} torr range. It now takes up to 30 seconds, compared with a few seconds formerly, to pump down after a heavy burst of gas in the accelerator, but this is a minor disadvantage and has become very infrequent. This is probably the only deleterious effect of the reduction in volume of the vacuum system.

In the latter part of the quarter, the machine was run up to full power, without an electron beam, to check the system capability. The modulators, klystrons, and waveguide and accelerator system ran without difficulty at 360 pulses per second. The high voltage dc power supply provided current at its full rated output of 7.2 amperes, and it appeared that the voltage applied to the klystrons was well above 250 kv.

B. MACHINE MODIFICATIONS

The major improvement in the machine during this quarter was the installation of new acceleration sections, along with transmission waveguide components. Except for some mechanical mounting and alignment features, the acceleration sections are of the type to be used on the two-mile machine. These sections were fabricated and installed by the SLAC accelerator structures group.

Major changes and improvements in the vacuum system were also made during this changeover. The 12-inch-diameter vacuum manifold running the length of the accelerator was completely removed, and the accelerator is now pumped entirely by getter-ion pumps. One 125 liter/sec pump is on the straight-ahead output arm of the end beam bending magnet. A 280 liter/sec pump is located upstairs at the klystrons, with two arms going to the waveguide pumpout connections near the klystron output windows. At the injector, a 50 liter/sec and a 5 liter/sec pump are connected, the small pump being used for standby or to keep the injector gun under vacuum when it is removed from the accelerator.

The accelerator beam components were carefully aligned mechanically, which apparently effected an improvement, as the steering of the electron beam seemed to be much easier when the machine was started up again. Floating wire calibrations of the two beam bending magnets were made, using a new air-bearing pulley (developed by SLAC Research) for the wire.

Water system flow and pressure were improved by adjustment of the new pump, which is driven by a 15 hp electric motor. Limited water flow through one klystron was due to a defect in the klystron, and it was replaced.

The lower control room was put into use as an experimenter's position. Although shielded for radiation, it was not designed for the high power levels expected from the present Mark IV machine, and care is exercised to control machine operation to prevent excessive radiation when experimenters are in the room. The use of this room during those experiments for which it can be used has greatly relieved the serious congestion in the main control room.

High voltage power supply No. 2 has been equipped with new solid state diode rectifier stacks, but resumption of the use of this supply is delayed pending receipt and installation of line reactors. These reactors are designed to prevent destruction of the diodes during load faults.

The major part of the wiring installation for local telephone equipment was completed during the quarter. The equipment itself is on order and is expected to arrive in January.

An order was placed for a radiation resistant closed circuit television camera and accompanying system. This camera and system are also expected to arrive in January.

The eight vacuum gauge amplifiers were modified for Mark IV, but their installation was delayed until early in the next quarter.

C. PROGRAM FOR THE NEXT QUARTER

During the next quarter it is planned to continue operating the Mark IV accelerator two shifts per day, five days per week. However, it is tentatively planned to reduce operations to one shift per day at the beginning of the following quarter.

The experimental work performed during this quarter will be continued at a heavy rate.

The design of an acceleration section with an axial magnetic field produced by solenoid coils was delayed. It is hoped that the design will be started early in the next quarter, with fabrication and installation to be accomplished during the following quarter.

It is expected that waveguide vacuum valves will be installed, and that the high power beam collimators can be completely checked out and installed during the next quarter.

has to be interrupted, however, by a fast-acting interlock system. The interlock system being studied uses a number of radiation detectors and simple beam monitors strategically located along the vacuum chambers in the switchyard. Signals from this system may interrupt the beam on a pulse-to-pulse basis and will help locate the origin of incorrect deflection.

4. Beam Switchyard Magnets

a. 3° Bending Magnets

The prototype magnet contract has been awarded. After some preliminary clarification, copper, steel and other insulation parts have been ordered by the manufacturer, and studies concerning tolerances in the gap and manufacturing of the insulation have been started.

The coil samples received from the manufacturer were not satisfactory due to the poor quality of impregnation, and these samples have been rejected. It was pointed out in the previous Quarterly Status Report* that the minimum amount of integrated radiation dose on the insulation, calculated over a period of 10 years, is about 10^{13} ergs/gram. The epoxies that have been developed at SLAC are capable of withstanding this dose, but manufacturing of these materials has caused some difficulties. SLAC is working closely with the manufacturer to solve this problem. New samples were received from the manufacturer and have been subjected to radiation tests at the Mark IV accelerator, with excellent results. As soon as the impregnation quality is satisfactory to SLAC, permission for coil manufacturing will be given.

b. Symmetry Quadrupole

After receiving the bids from a number of companies, it was found that the price asked for the manufacture of a prototype magnet was much higher than anticipated. Modifications have now been incorporated in the design, and a new invitation to bid will be prepared in January 1964.

c. Double Eight-cm Quadrupoles

The prototype of the magnet has been ordered. The status of this magnet and the problems regarding tolerances and insulation quality are the same as mentioned above for the 3° bending magnets.

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*Ibid., p. 74.

d. 0.1° Pulsed Magnet

The prototype of the pulsed magnet has been ordered. The water-cooled, multi-stranded cable that will be used in the pulsed magnets had to be modified from our original design, and an order for the water-cooled cable has now been awarded.

e. Steering Magnets

The gap height of the dc and pulsed steering magnets has been changed from 1.2 to 2 inches. This increase in gap was designed primarily for safety reasons, and it will affect the magnet design completely. The magnets are being recalculated with the new gap, but detailed design has not yet started.

f. Dump Magnets

A group of four C-magnets, located in the A beam in front of the beam dump, is to be used to bend the 25 BeV electron beam a maximum of 12° down. The magnets have a gap of 8 cm, an effective length of 3 meters, a physical length of 3.7 meters, and a total weight of 15 tons each.

These magnets are in the design stage. They do not require tight tolerances, but their insulation has to comply with the requirements of the high radiation dose mentioned in (a) above.

5. Accelerator Magnets

a. Quadrupole Triplets Along the Accelerator

The prototype of a quadrupole triplet has been built and tests conducted. A number of measurements have been made, as follows:

(1) Effective length measurement as a function of position inside the gap and of the excitation current. Due to the peculiar shape of the poletips, the deviation between calculated and measured values of the effective length has been less than 1%.

(2) Higher harmonics. Due to the symmetric arrangement of the poles, no dipole and sextupole field components could be measured.

(3) Temperature gradient. The magnet coils are wound and impregnated on the poles and yokes, and the heat transfer from the coils to the iron parts of the magnet is very efficient. The magnet current for normal operation is 6 amps, but tests have shown that it can operate up to 15 amps.

(4) Magnetic center. The deviation of the magnetic center from the physical center is less than 0.001 inch.

A rack to be used for the alignment of a quadrupole triplet is in the construction stage, and tests of the alignment of a triplet will be started in February 1964.

The quadrupole-triplet contract has been awarded.

b. Steering Magnets Along the Accelerator

A set of magnets, shown in Fig. 20, is foreseen in each drift section of the accelerator to steer the beam in either the horizontal or vertical direction up to 5×10^{-5} radians. The magnets are designed in such a way that they can be used either for continuous operation (dc) or as a pulsed magnet with up to 360 pulses/sec. The magnets are air-cooled, and are designed for minimum length. A prototype of a steering magnet is now in construction.

6. Injector Magnets

a. Quadrupole With Sextupole Correction

The design of the magnets has been finished and the parts are ordered. The magnet will be built partly at SLAC and partly by an outside manufacturer.

b. Bending Magnets

The design of these magnets for a 22.5° deflection* is finished, and a prototype magnet which allows an easy change of shimming is under construction at SLAC.

c. In-Line Injection Spectrometer

For a maximum energy of 205 MeV and a 0.2% energy resolution, two spectrometers are designed which will bend the beam 30° each. The magnets are water-cooled and require about 4 kW of power each. The design of the magnets has been finished and the specifications written.

B. END STATIONS

The criteria reports for End Stations A and B have been completed and approved by SLAC. The accompanying drawings (Figs. 21 and 22) show

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*Ibid., p. 73.

a plan view of each of the end stations. ABA has started Title I work on End Station A. Title I work on End Station B is scheduled to begin by the middle of January 1964.

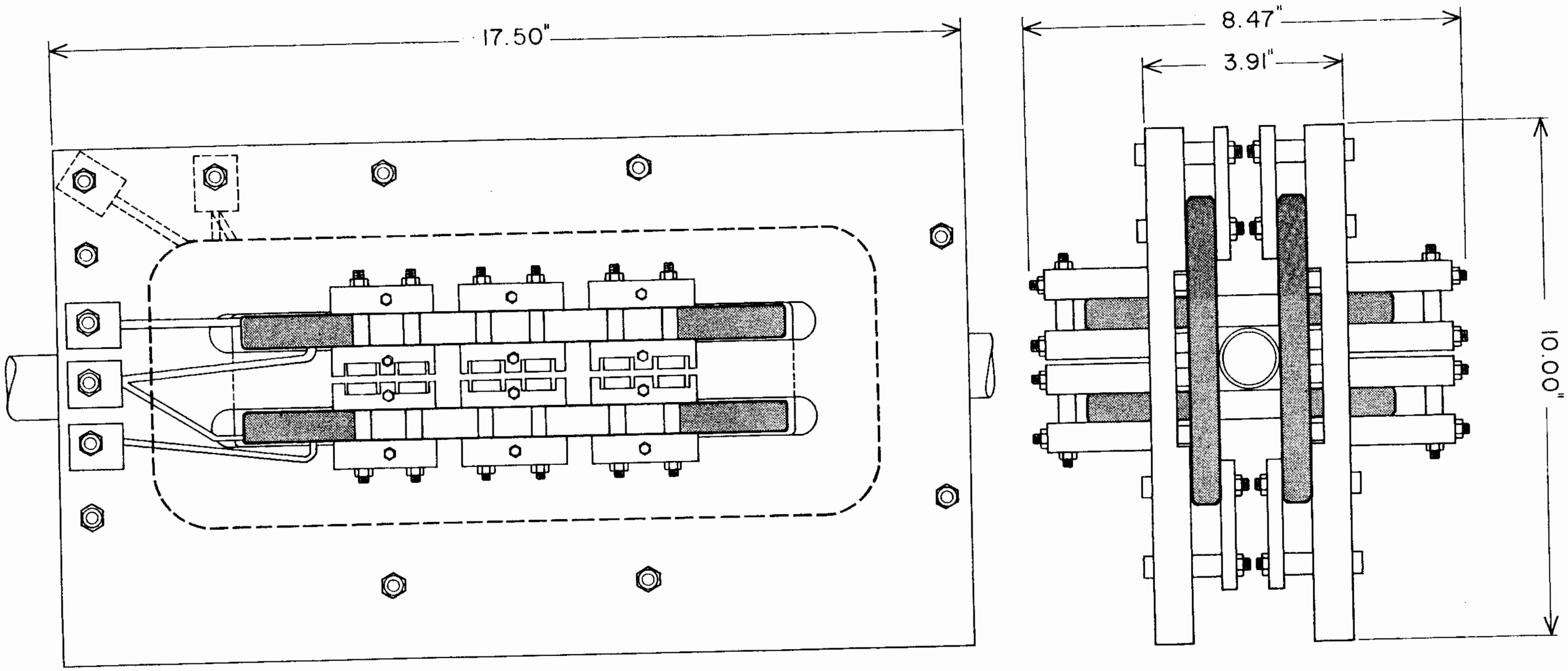

FIG. 20--ACCELERATOR STEERING MAGNET

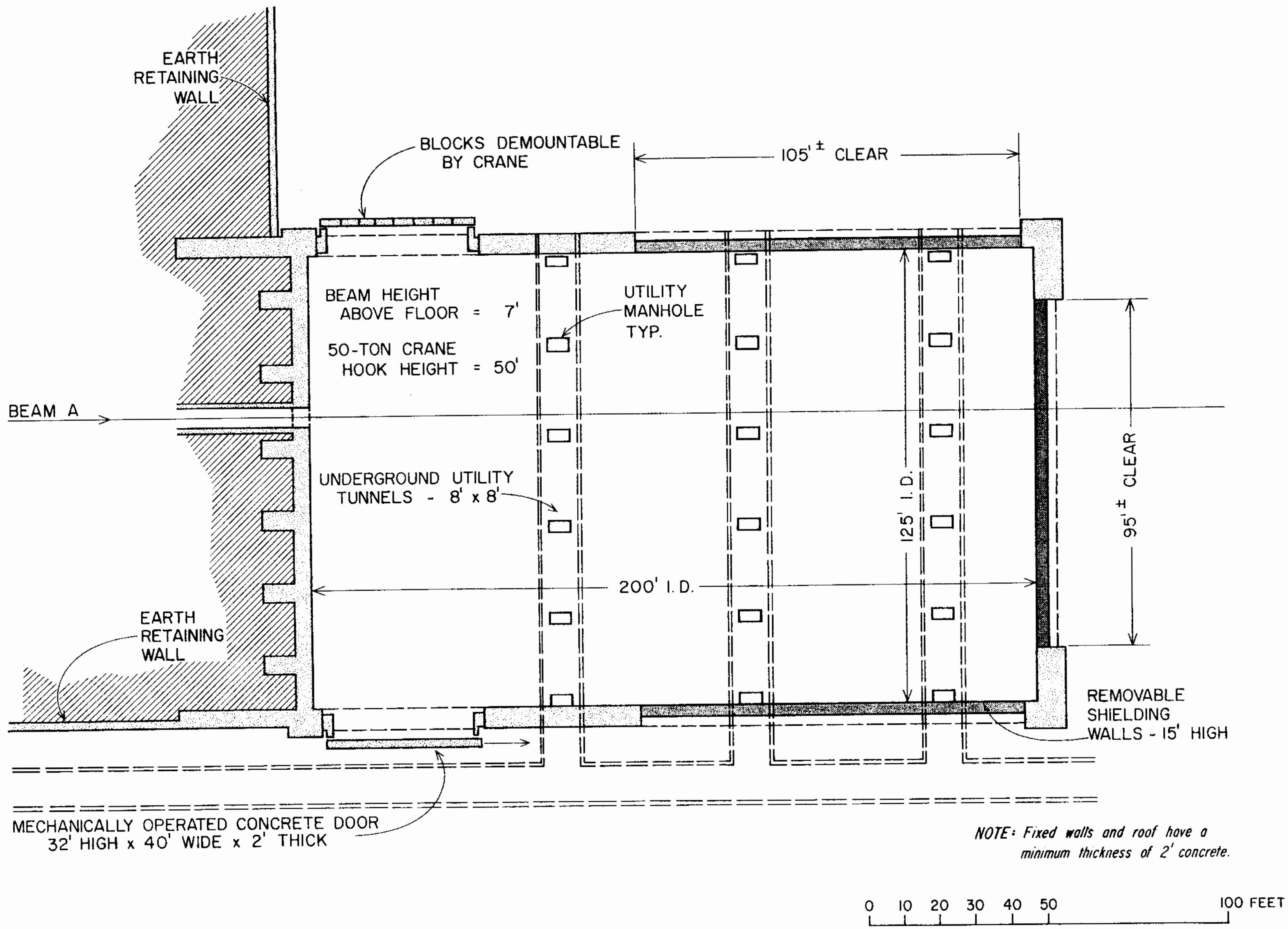

FIG. 21--END STATION A - GROUND FLOOR PLAN

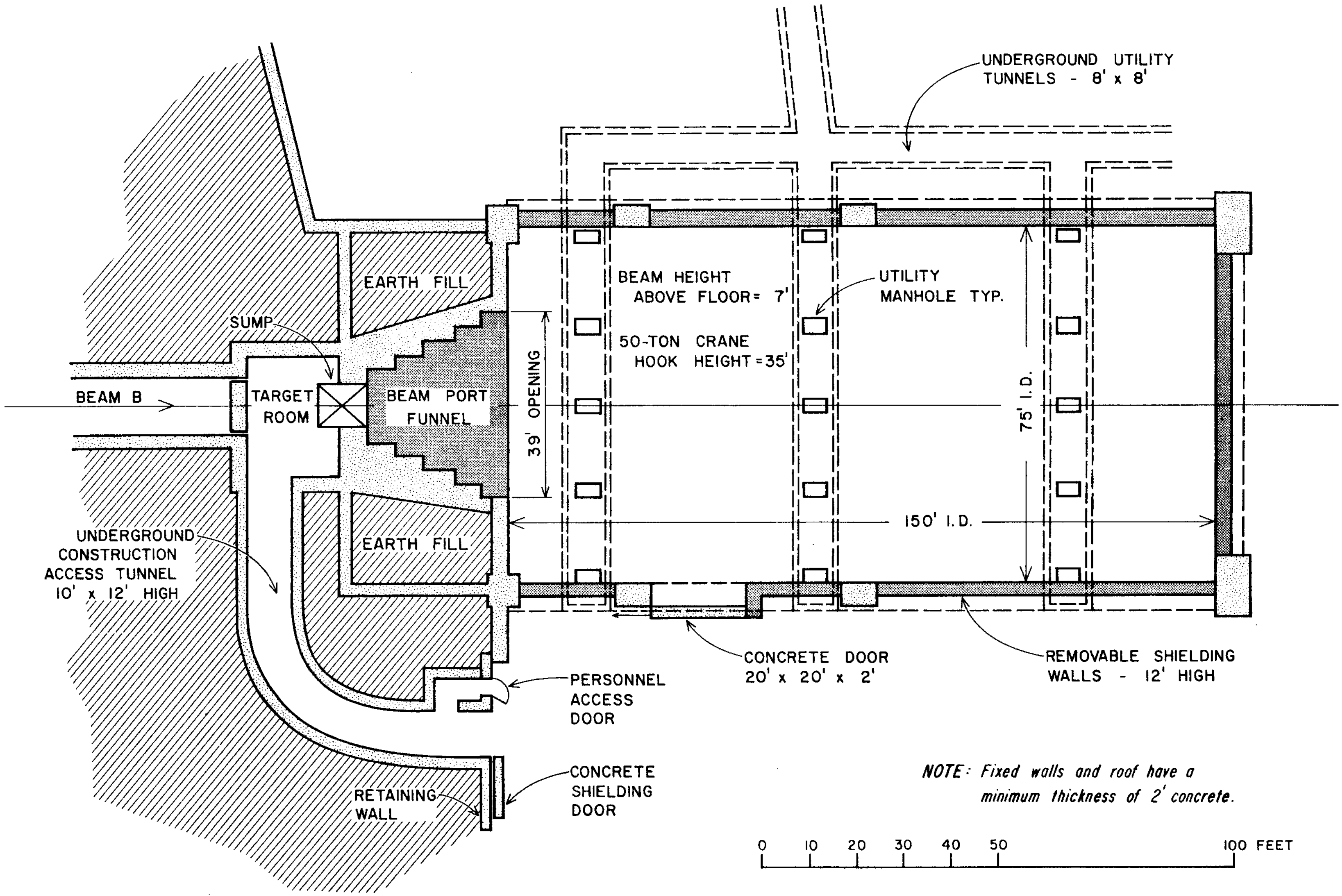

FIG. 22--END STATION B - GROUND FLOOR PLAN

16-2-B

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

A. THEORETICAL PHYSICS

1. Pion, Muon, Neutrino, and Electron Fluxes

Detailed calculations of the pion yield predicted by the Drell-Ballam mechanism have been carried through in a form which allows comparison with the CEA experiments, and predictions at the energies to be available at SLAC.[1] These calculations include a discussion of modifications due to thick-target bremsstrahlung, nuclear attenuation of pions, nuclear Fermi motion, and nuclear recoil. Comparison with the experimental results at CEA[2,3] shows that the order of magnitude predicted is correct, but that substantially more pions are produced at small angles than the prediction gives. General theoretical studies at SLAC of the peripheral production of particles[4,5] indicate that this may well be due to the production of vector boson resonances, particularly the ρ. Detailed investigation of this possibility is now in progress.

Comparison of these predicted pion yields with the Cocconi-formula estimate of AGS pion yields in the forward direction,[6] and with recent unpublished experimental results from the CERN proton synchrotron, reveals that the pion yield from 3×10^{14} electrons/sec at 20 BeV will be roughly the same in both magnitude and energy spectrum as the forward-pion yields currently achieved with the 30 BeV proton machines. If this predicted spectrum is used to compute the neutrino event rate above 1 BeV in a 50-ton detector, taking accurate account of geometrical effects,[7] then the rates predicted agree well with those achieved in the CERN neutrino experiment.

Calculations of muon yields, including finite mass effects and experimental form factors, have been formulated and a computer program successfully developed. Although adequate for muon-yield calculations,

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*Contract AT(04-3)-515 goes into effect on January 1, 1964. The work reported in this section was actually performed under Contract AT(04-3)-476 which was a preliminary interim contract to provide for this work prior to execution of the permanent Contract AT(04-3)-515.

[1]References for the "Theoretical Physics" section of the Quarterly Status Report will be listed at the end of the section.

this still contains cancellations which make it unreliable for electron-positron yields due to roundoff errors. For μ-e decay neutrino yields, the Bethe-Heitler yield (if thick-target corrections are applied) is adequate. This gives an optimized event rate of only two to four per day in 50 tons assuming a 10 radiation length target and 3×10^{14} electrons/sec. Since this is again comparable to the CERN event rate from Ke_3 decay neutrinos, we conclude that SLAC could do existing types of neutrino physics at about the same level of achievement as the proton machines.

If the weak interactions are mediated by a charged vector boson, it can be photoproduced, and the production rates offer a means of determining its magnetic moment.[8] As the CERN neutrino experiment shows that the mass of such a particle must be in excess of 1.3 BeV/c, this is not a feasible experiment at CEA, but could be done at SLAC.

A program for the calculation of electron and positron yields from liquid hydrogen has been developed, and tables useful for both CEA and SLAC experiments were prepared.[9] This code has been used to calculate yields for the specific requirements of Douglas Stairs at CEA. Calculations of production in the electron-positron converter for use with the storage rings, and of beam loss within the e^+e^- beams due to bremsstrahlung, have also been carried out. A general method for the calculation of radiative corrections to electron scattering has been developed.[10]

2. Other Particle Production and Interaction Studies

Investigation of all possible correlations in the two-body final states of processes such as $\pi p \to K\Lambda$, $Kp \to \omega\Lambda$, $Kp \to \varphi\Lambda$, $Kp \to p\Lambda$, $\pi p \to \pi n^*$, $\pi p \to pn^*$, $\pi p \to \omega n^*$, $Kp \to Kn^*$, $Kp \to K^*n^*$, etc., has been carried through.[11] These correlations depend on the spin of the final bodies and give many different kinds of tests for the various models. For example, in $Kp \to \omega\Lambda$ there are 12 independent correlations, of which 11 should vanish if the process is due to pure K exchange. The problem of a covariant method for correlating photoproduction and electroproduction has been solved and is being prepared for publication.

Detailed comparison of the Amati-Fubini-Stanghellini multiperipheral model with experiment has been carried out. It is shown that the energy independence of the average inelasticity parameter K predicted by the model is not changed by including pionic form factors or more than one class of particles, and is in disagreement with experiment. Analysis of n-p charge exchange is being carried out in terms of the ρ trajectory for comparison with that used in the pion-photoproduction calculation.

Analysis of the recent Los Alamos experiment on p-p scattering near the interference minimum at 0.3825 MeV, and differential cross sections between 1.4 and 3 MeV, taking due account of vacuum polarization, confirms the predicted value of the $^1S_0$ shape parameter and provides the first evidence for one-pion exchange in the $^1S_0$ state.[12] The analysis also yields the average ^3P wave behavior at low energy, which is at first sight peculiar, but can also be shown to agree with the multiboson exchange interpretation of the two-nucleon interactions. Calculation of the multiple scattering corrections in the capture process $\pi^- + d \rightarrow 2n + \gamma$ have been carried through, and it is shown that an experiment now in progress could yield the n-n scattering length with only a ± 1 fermi uncertainty due to the theoretical analysis.

3. Other Theoretical Studies

An N/D calculation of π-π scattering with Regge asymptotic behavior has been completed and the ρ trajectory and its residue computed. General investigation of the accuracy of the N/D method under various approximations is in progress.

Investigation of the Γ-limiting process of Lee for the calculation of the interaction of vector bosons with photons shows it to be adequate for the calculation of the Lamb shift due to the photon self-energy induced by the weak vector boson W.

A general investigation of the shrinkage and rotation of the polarization vector for electron and positron due to Møller, Bhaba, and nuclear scatterings has been carried through and is being prepared for publication.

A lecture series on "Weak Interactions" has been written up for publication,[13] and lecture notes for lectures on "Relativistic Quantum Mechanics"[14] and "SU-3 Symmetry"[15] being given at SLAC are being prepared.

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9. M.L. Thiebaux, "Electron production from bremsstrahlung passing through liquid hydrogen," SLAC Internal Document (May 1963).
10. Y.S. Tsai, "Radiative corrections to electron scattering" reported at the International Conference on Nucleon Structure held at Stanford University, June 24-27, 1963.
11. S.M. Berman, "Angular correlations in production processes," reported at the ZGS inaugural meeting December 4-5, 1963.
12. H.P. Noyes, "Determination of the $^1S_0$ shape parameter" (Submitted to Phys. Rev. Letters).
13. S.M. Berman, "Lectures on weak interactions," Proc. of the Ettare Majorana International School of Physics May 26 - June 7, 1963 (to be published).

14. S.D. Drell (with J.B. Bjorken), "Relativistic quantum mechanics" (to be published).

15. S.M. Berman (notes by M.L. Thiebaux), "Lectures on SU-3 Symmetry."

B. EXPERIMENTAL PHYSICS

1. Multipion and Pion-Nucleon Resonances in 3.9 and 4.2 BeV π^--p Interactions — Z. Guiragossian and M. Whitehead (in collaboration with R. Birge and R. Ely at the Lawrence Radiation Laboratory, Berkeley, California)

Since May 1963 an experimental run has been performed, using the LRL 72-inch hydrogen bubble chamber exposed to 3.95 and 4.17 BeV/c π^- beams from the Berkeley Bevatron. About 60,000 pictures are taken at each momentum setting. The scanning and measurement effort is concentrated on the candidates to the following reactions:

1. $\pi^- + p \rightarrow \pi^- + \pi^+ + n$
2. $\rightarrow \pi^- + \pi^0 + p$
3. $\rightarrow \pi^- + \pi^+ + \pi^- + p$
4. $\rightarrow \pi^- + \pi^+ + \pi^0 + \pi^- + p$
5. $\rightarrow \pi^- + \pi^+ + \pi^- + \pi^+ + n$

The major part of the above effort has been conducted at Berkeley, using the fast FSD data reduction system. So far, approximately 7000 two-prong and 3000 four-prong events have been analyzed.

Reactions 1 and 2 are used to study the ρ^0, f^0 and ρ resonances, with respect to their production mechanism and decay angular distributions. The four-prong events are used in the study of ω^0-π and ρ^0-π resonances. Further, all of the reactions are examined for N^* production.

Scanning and measurement effort at SLAC will begin in February 1964, upon arrival of data-reduction equipment.

2. Almost Monochromatic Photon Beams for a Hydrogen Bubble Chamber
Z. Guiragossian

A method of obtaining almost monochromatic photon beams from well-collimated positrons has been investigated, taking advantage of the expected high positron beam intensity at SLAC ($\approx 10^{10}$ e^+/pulse). With a liquid hydrogen target of thickness $t \approx 0.5$ gm-cm^{-2}, the angular dependence of annihilation radiation as compared with that of positron bremsstrahlung was examined for positron beams of energy $E_0 = 5$ to 15 BeV. At angles $\theta \approx 200(m_e/E_0)$, and after one radiation length of LiH photon hardener, the total number of bremsstrahlung photons is about three times that of annihilation photons of fixed energy.

It was found that such beams are naturally suitable for a hydrogen bubble chamber having a beam window dimension of 30×90 cm. Work is in progress to optimize the angular and energy settings, and to better estimate the positron bremsstrahlung contribution.

3. Bent-Crystal-Spectrometer Measurement of Mesic X-Ray Energies

R.E. Taylor (in collaboration with K.H. Crowe, A. Astbury, and R.E. Schaeffer at Lawrence Radiation Laboratory)

During the last quarter of 1963, the energy of γ-rays from π mesons stopping in an aluminum target have successfully been measured. The data is presently being analyzed.

4. Pion Beta Decay — W. Johnson, R. Larsen

The present status of this experiment can be summarized with the following facts:

1. Maximum π^+ stopping rate under present conditions is $\approx 2.5 \times 10^4$ sec^{-1}.
2. One trigger (picture) every $\approx 10^6$ stopped π's.
3. With an estimated efficiency of $\approx 5\%$, we have one event every 2×10^3 pictures.
4. The background is no greater than the effect.

It is hoped that an extensive run can be concluded in the first quarter of 1964.

C. DEVELOPMENT PROGRAMS

1. Magnet Research

a. Cryogenic and Superconductive Magnet Research

The magnet group was fortunate in being able to acquire some of the equipment of the superconductive laboratory at the Lawrence Radiation Laboratory. This acquisition will enable SLAC to accelerate the research program foreseen for superconductive magnets.

The Collins-A.D. Little cryostat and purifier for liquid helium is now installed and can produce a maximum of about 8 liters of liquid helium per hour. The liquefier is now used constantly, and preliminary tests and experiments are being conducted with small superconductive coils. Tests with superconductive materials and superconductive joints are also being carried out.

A superconductive magnet has been designed for 100 kG maximum field inside a 1.5-inch bore.

Preliminary studies for a cryogenic bubble-chamber magnet have been started. During the next quarter a model of a 10-inch bubble-chamber magnet with liquid hydrogen cooling may be built and tested at the National Bureau of Standards in Boulder, Colorado.

b. Pulsed Magnet Research

The capacitors for a pulsed generator with a total energy of 300 kilojoules have been received. The cabinets, busbars, and auxiliary parts are pending. The power supply to be used in connection with this capacitor bank, with a power of 25 kW (5 kV and 5 amps), has been tested at the manufacturer's plant and will arrive at SLAC soon.

2. RF Particle Separator

Since publication of the report on rf particle separators,* work has been actively pursued to optimize the design of the traveling-wave structure to be used as a particle separator. A model called LOLA III with a relative group velocity of 0.007 and a Q of 10,000 was constructed and tested on the Mark IV accelerator. Its attenuation factor $I\ell$ was 0.119 for a length of 28 centimeters. An experiment carried out on the Mark IV accelerator yielded a relationship between the deflecting field strength and the rf power as shown below:

$$E_{eq.}\ (10^6 \text{ volt/meter}) = 1.7\ \sqrt{P(\text{megawatts})}.$$

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

Although this equivalent field appeared to be greater than that obtained for models LOLA I and II, it was found in fact that the transverse shunt impedance had dropped severely for this design. A new prototype is presently being designed with a relative group velocity of 0.0180. This value should yield a deflecting field very close to the maximum obtainable value. At the same time, cold-test experiments are being conducted to measure the transverse shunt impedance directly with a series of dielectric and metallic beads.