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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 January to 31 March 1963

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Technical Report
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2. J. J. Muray, "Space-charge limit and confinement in particle acceleration with high-intensity light waves," SLAC Report No. 12 (January 1963).
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1. H. P. Noyes, "Neutron-proton scattering below 20 Mev," PUB-5 (January 1963).
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3. S. M. Berman and R. J. Oakes, "The vector theory of strong interactions and nucleon-antinucleon annihilation," PUB-8 (March 1963).
4. D. B. Lichtenberg, "A possible method to obtain evidence on the spins and parities of excited baryons," PUB-9 (February 1963).

I. INTRODUCTION

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

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

The terms of Contract AT(04-3)-400 provide for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision is made for an initial complement of general-use research equipment with which it will be possible to perform certain exploratory studies, such as measurement of the intensity and energy distribution of various secondary-particle beams. However, AT(04-3)-400 does not provide for the more specialized items of research equipment that will eventually be necessary for a full program of experimental physics with the machine. It is expected that a program of research-preparation work will have begun at SLAC by the summer of 1963. This work would be funded separately from Contract AT(04-3)-400, and its status would be reported in separate reports.

II. PLANT ENGINEERING

A. GENERAL

Considerable progress was made on the conventional facilities program during the quarter. The design effort continued and several new construction starts were made. Construction-contractor personnel at the Sand Hill site totaled 145 at the end of the period, as contrasted with 80 previously. The total ABA work force numbered 127 people in all categories, up from 123 in the last quarter.

Assistance is being provided the Heavy Electronics Group in their study of modulator rectifier characteristics. This consists of a circuit analysis and equipment test of starting transients, as well as an investigation of communications interference resulting from harmonic ac currents.

Plant Engineering will assume responsibility for operating the plant utility systems and for providing SLAC maintenance craft services as of April 1, 1963. This applies to the present facilities of the project on Campus Drive, and to the permanent facilities at the Sand Hill site as they are turned over to SLAC by the subcontractor. Information on maintenance practices and procedures at several major accelerator sites in the East has been obtained for planning purposes.

Engineering assistance was provided in connection with building and equipment alterations and space studies. The latter was particularly applicable to the Test Laboratory. This general area of service work will increase as project facilities are completed and put into operation.

Preliminary information was exchanged with the California State Division of Highways concerning the projected Junipero Serra Freeway crossing at the Sand Hill site, with emphasis on right-of-way problems and design of the accelerator overpass bridge. We have been informed that the FY 64 highway budget includes funds for construction of the overpass.

B. DESIGN STATUS

Criteria studies are underway for the Cafeteria and the Beam Switchyard structure. For the latter, the cognizant Plant Engineer is working directly with the SLAC Research Division in developing the necessary data. Preliminary designs are essentially complete for the Klystron Gallery Utilities and for the Main Receiving Substation, and are well along for the Control Building and for the initial phase of the landscaping program.

Final design (Title II) is in progress on a number of facilities. These facilities, together with their percentages of completion of design as of the end of March, are as follows: Central Laboratory (60); Heavy Assembly Building (30); Initial Accelerator Housing (92); Accelerator Housing and Earthwork (75); Klystron Gallery (7); Site Improvements (29); and Site Utilities (19).

A Furnace Building is to be added to the Shops Complex, adjacent to the Fabrication Building. Drawings and specifications are complete, and a quotation is being obtained from the construction contractor on site.

C. CONSTRUCTION STATUS

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

Facility	Percentage of Completion
Test Laboratory	90*
Alignment Survey Towers	82
Construction Office Building	45
Initial Site Utilities	42
Administration and Engineering Building	40
Initial Excavation (for Accelerator)	40
Utility Building "A"	15
Shops Complex	6

*The west portion of the High Bay was made available to SLAC on March 11th for the installation of test equipment, and this work is in progress. The 12 kv unit substation associated with the Test Laboratory is scheduled for completion in early April; the 60 kv substation and a temporary 12 kv overhead pole line should be available about May 1.

Figures 1 through 4 illustrate the present status of construction at the Sand Hill site.

D. UTILITY SERVICES

Negotiations were concluded for an electrical power contract between the Pacific Gas and Electric Company and the local area office of the Atomic Energy Commission, with Stanford personnel providing technical advice regarding project needs. The contract was executed January 10, 1963, and provides for 60 kv and 220 kv service for an initial term of ten years.

A correlated project is the proposed establishment of a 220 kv transmission line along the Skyline route, with a tie-in to the Sand Hill site. Stanford is cooperating with PG&E and the appropriate public agencies to obtain the necessary permits.

Negotiations for natural gas services have been continued, and it is expected that a contract will be signed shortly.

E. COOLING WATER SYSTEM

A corrosion test was run using samples of cleaned copper strips immersed in water in the Mark IV reduced-pressure boiling system. After 46 days' immersion at 113°F, the samples showed no corrosion film. This confirms that complete removal of oxygen will provide protection for copper and that protection can be achieved in a practical, working system.

Test runs planned for Mark IV on temperature control were not completed, as machine operation during the quarter was not stable enough to provide useful data.

The circulating water system in Building M-1 was enlarged by installing a second circulating pump. This enables the system to meet the rapidly growing cooling water needs and to maintain proper working pressure in the water mains.

FIGURE 1 - The initial accelerator excavation, viewed from the west end.

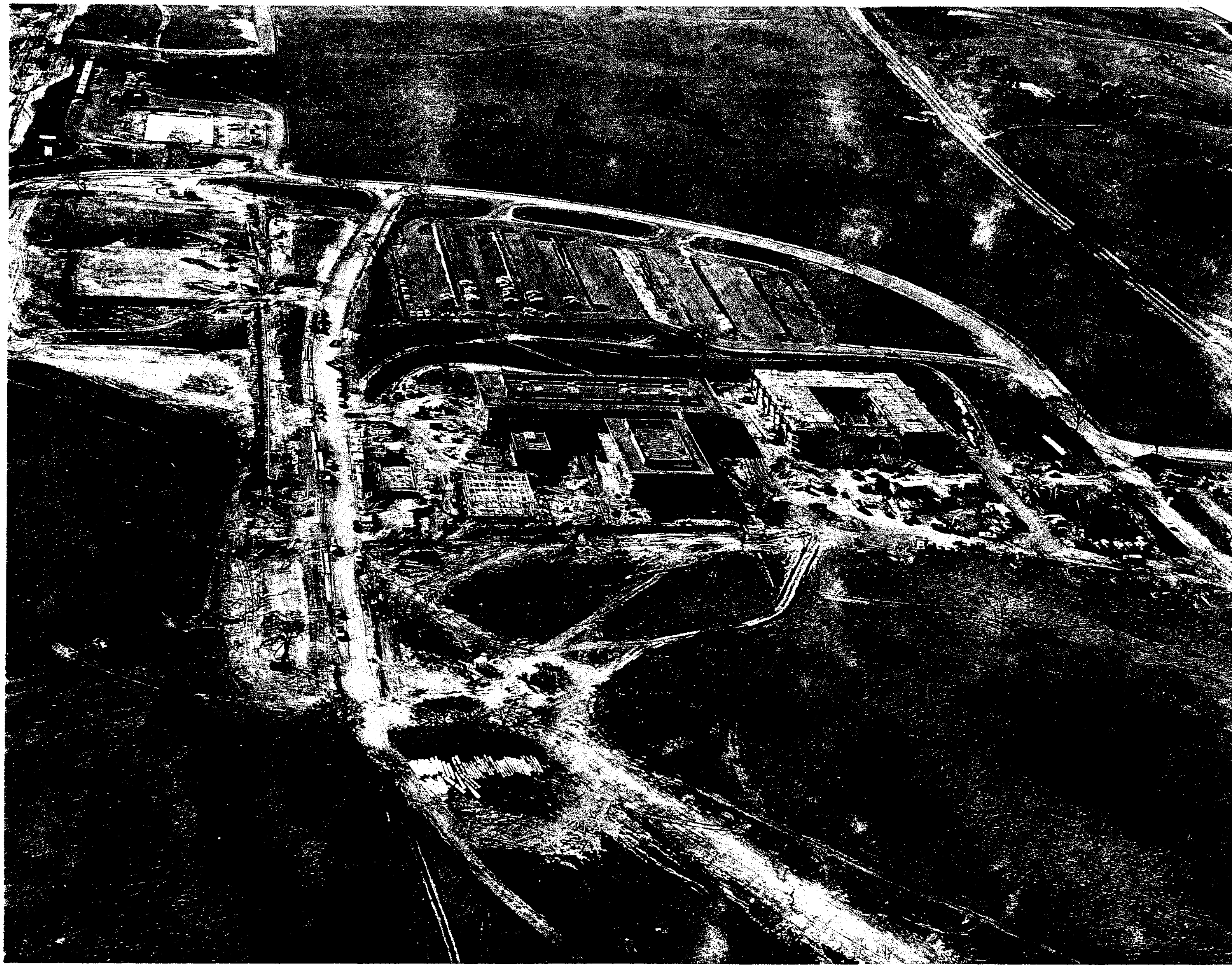

FIGURE 2 - The "campus" area at Sand Hill site.

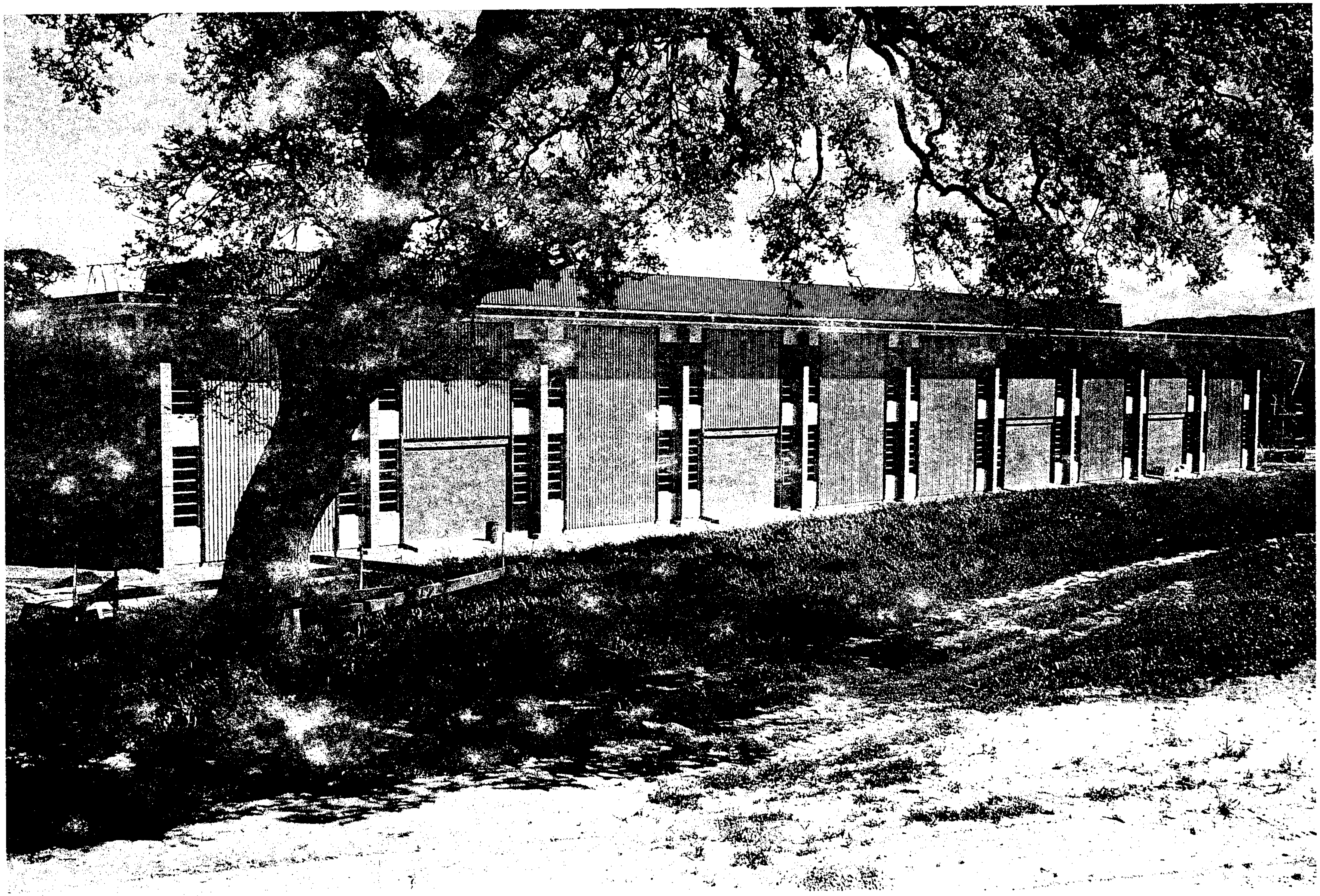

FIGURE 3 - Test Laboratory, viewed from the northwest.

FIGURE 4 - Administration and Engineering Building.

III. ACCELERATOR STRUCTURES

A. ACCELERATOR STRUCTURE

The seven accelerator sections mentioned in the previous quarterly status report have been made. They are being used for evaluation of modifications in dimensions and for study of rf processing and operating characteristics at the highest power levels presently available (approximately 13 megawatts at a 0.001 duty ratio). Four are being prepared for the "tree house" Test Tower.*

1. Accelerator Section Tuning and Phase Checking

The basic system design for structure phase measurements during production tuning has been largely completed. The status of various aspects of the system is:

(a) Electronic phase measuring equipment: A decision has been made to use a commercially available phase meter. Procurement of this device is underway.

(b) Control of dielectric constant during tuning: Evaluation of air and vacuum dielectric control systems continues. A vacuum system is being built with the primary objective of evaluating possible contamination difficulties.

(c) Precision phase standard: A high precision phase standard of the shorting plunger type is being made. It is to be used as a phase standard in the structure tuning operation.

(d) Automation of production tuning: A semi-automatic phase measuring and tuning system design is nearly completed.

2. Accelerator Structure Tuning Machine

A mechanism for semi-automatically tuning the cavities of ten-foot sections of accelerator pipe on a production line basis has been mechanically completed. The machine accepts the pipes in a suitable manner to enable the operator to select any cavity, to make phase

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*For technical description see "Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).

measurements, to determine the correction required, and then to indent the walls of the cavity at four points to effect the necessary cavity volume change.

Included in the mechanical aspects of the machine are the indenting mechanism, a shorting plunger, provision for evacuating the disk-loaded waveguide during tuning, and all control elements except those relating to rf measurement and recording. Cleanliness in the entire operation has been a primary consideration in the design and construction of the machine. Remaining portions of the control system will be added during testing of the machine.

3. High Power Tests of Accelerator Sections

The recently completed accelerator sections are being tested as rapidly as possible. The following consistent behavior at levels reaching 13 megawatts peak power has been obtained.

All sections were processed to the condition where operation at any power level was possible without outgassing, arcing, or changes in attenuation. Changes in pulse repetition rate and width did not affect operation.

Outgassing is more pronounced in a region from about 150 to 2000 kilowatts. After a section has passed through this region, prior to completion of the processing, it is possible to increase the pressure in the section by dropping the power to this range. This indicates the possibility of a multipactor discharge. Measurements of attenuation show no significant changes in the region; hence it appears that the discharge, if it exists, is a slight one. After processing to approximately 1×10^{-7} torr, no changes in pressure are observed at any power level.

Considerable work is being done in the High Power Test Stand No. 1 (purple coffin) area to improve the performance and equipment of the first test stand and to prepare for the installation of a second high power test stand. Concrete shielding constituting the second coffin has been cast, and the main control instrumentation rack has been placed in position.

A second accelerator section was provided for the Mark II machine where it has shown good correspondence between theoretical and measured electron energies. It has operated satisfactorily, bringing the energy of that machine close to the desired 60 Mev range.

4. Instrumentation for High Power Accelerator Station Tests

During this quarter preparations were initiated for providing the instrumentation that will be required to test the accelerator sections individually under high microwave power, prior to their installation in the SLAC machine. Early in this period, it was decided to provide instrumentation by which the following parameters can be measured and automatically recorded on an eight-channel strip recorder.

(a) X-Radiation – 2 Points

When electronic discharge occurs within the accelerator section, as it does in the initial processing under high microwave power, substantial amounts of X-radiation are emitted. The X-radiation will be monitored at two points near the ends of the section as a measure of electronic discharge.

(b) Gas Pressures – 2 Points

The gas pressure will be measured at two points near the ends of the accelerator section.

(c) RF Attenuation

The microwave attenuation of the accelerator section must not change appreciably over the full range of applied microwave power levels. Because of this, instrumentation will be provided by which the attenuation can be recorded during testing over this range of power levels. This measurement also will provide one indication of electronic discharge within the section.

(d) Input RF Power

The rf input power must be measured and recorded because the performance of each accelerator section must be assured over a wide range of power levels, and the parameters of section performance (that is, freedom from electronic discharge, rf attenuation, and rf phase shift), are all functions of the input rf power level. The average power will be measured, and the peak will be calculated from the average power and the duty factor.

(e) Phase Variation

The variation of phase shift through the accelerator sections must be measured and recorded over the required range of rf input power levels, since only a small variation in phase shift with input power level is permissible. This instrumentation will also provide an indication of electronic discharge within the section.

(f) Accelerator Section Temperature

The temperature of the accelerator section is an important factor in its performance, since both the attenuation and the phase shift through the section depend rather critically on its temperature. Instrumentation is being prepared by which the temperature of one point on the section will be continuously measured and recorded. Additional instrumentation will automatically measure and record temperatures at a number of other points on the section at periodic intervals.

5. Accelerator Water Jacket

(a) Heat Transfer Tests with RF

Temperature measurements were made on several constant gradient accelerator sections being processed in the rf test stand. The power input into the accelerator sections during these tests varied from 0 to 17 kw. The water jackets on these sections consisted of eight counterflowing tubes soft-soldered to the sections. Care was exercised during the soldering operation to obtain uniform contact between the cooling tubes and the accelerator.

On one accelerator section, the cooling tubes were brought as near to the accelerator ends as possible. This section was tested to 13 kw average input power. The average temperature of each cavity fell within a $0.9^{\circ}F$ band. On three other sections the cooling tubes were stopped approximately one inch short of the ends. The end cavity temperatures were observed to rise steeply, indicating that the entrance effects which were expected to depress the accelerator end temperatures are much smaller than predicted. Neglecting the end temperature rise, the temperature uniformity of these sections was within a $0.9^{\circ}F$ band. This uniformity was obtained at average input power levels up to 17 kw. The uniformity improved as the power level was decreased.

A temperature perturbation was observed at the points where the support structure attaches to the accelerator section. Approximately a 0.4°F temperature depression occurred because of the heat loss through the supports to the ambient air, which was about 30°F cooler than the accelerator section. Tests are planned in which the accelerator-to-ambient temperature difference will be reduced to simulate conditions expected during long term operation of the two-mile machine.

(b) Heat Transfer Analysis

The flux plotting work described in the previous quarterly status report was completed. For the reference water jacket design (eight counterflowing tubes brazed to the accelerator section, with a 3/16 inch wide braze, and with a 13 gpm water flow rate), the average temperature of each cavity was found to be within a 0.7°F band, neglecting entrance effects. The temperature peaked at the mid-point of the accelerator. Considering entrance effects, which yield improved heat transfer near the inlet end of the cooling tubes, the section temperature was predicted to drop off an additional 1.5°F at the ends. The entrance effect was predicted on the basis of data reported by Boelter.*

Doubling the number of cooling tubes and the water flow rate improved the temperature uniformity to within 0.5°F, neglecting entrance effects, and yielded a 0.8°F drop-off in temperature at the accelerator ends due to entrance effects. Increasing the number of cooling tubes and the water flow rate was not considered further because of the high cost of increasing the water flow.

Increasing the number of cooling tubes without increasing the water flow rate, increasing the tube wall thickness, and increasing the braze joint width all tended to lower the accelerator section temperature somewhat, but did not yield a more uniform temperature. Since any of these increases would increase the water jacket cost, it was not felt worthwhile to incorporate any of them.

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*L.M.K. Boelter, G. Young and H. W. Iversen, "An investigation of aircraft heaters XXVII--distribution of heat-transfer rate in the entrance section of a circular tube," Technical Note. No. 1451, National Advisory Committee for Aeronautics, Washington, D.C. (July 1948).

A slightly modified water jacket design, in which the basic flow arrangement is unchanged, but in which a spacer is placed between the cooling tubes and accelerator wall, was considered. The spacer would be shaped like an "I" beam, and one flange of the beam would be brazed to the accelerator while the cooling tube would be brazed to the other flange. The web thickness of such a spacer would vary in a predetermined manner to yield a constant accelerator temperature. A water jacket employing this concept would cost about 70% more than the reference water jacket. This design has been considered as a backup in the event that the reference design proved inadequate.

Indications from the temperature measurements made during rf testing have substantiated the flux plot results, and indicate that entrance effects are much smaller than predicted. It therefore appears that we can freeze on the design in which the cooling tubes are brazed directly to the accelerator section wall. The water jacket effort will now be concentrated on optimizing the water jacket fabrication and assembly methods and on working out the optimum manifold arrangement.

B. HIGH POWER WAVEGUIDE COMPONENTS

1. Waveguide Vacuum Valve

Six waveguide valves of the offset model-A design shown in Fig. 5 were brazed and tested during this quarter. These valves are denoted A_1, A_2, ...A_6 and were fabricated with various backseat arrangements, described below, to solve the problems experienced with arcing in the backseat region at very high power levels.

Valves A_1 and A_2 used an all stainless steel flexible backseat similar to that on earlier valves, and each exhibited intermittent arcing in the backseat when tested at 40 megawatts peak power level.

Valves A_3, A_4, and A_6 were copper-plated in the backseat region to lower the contact resistance. When high-power tested in a resonant ring at the 40 megawatt peak power and 30 kilowatt average power level, these valves showed no arcing in the backseat region. The high-power tests consisted of operation in the "on," or open, position, then cycling through the "off" (i.e., vacuum valve closed) position with

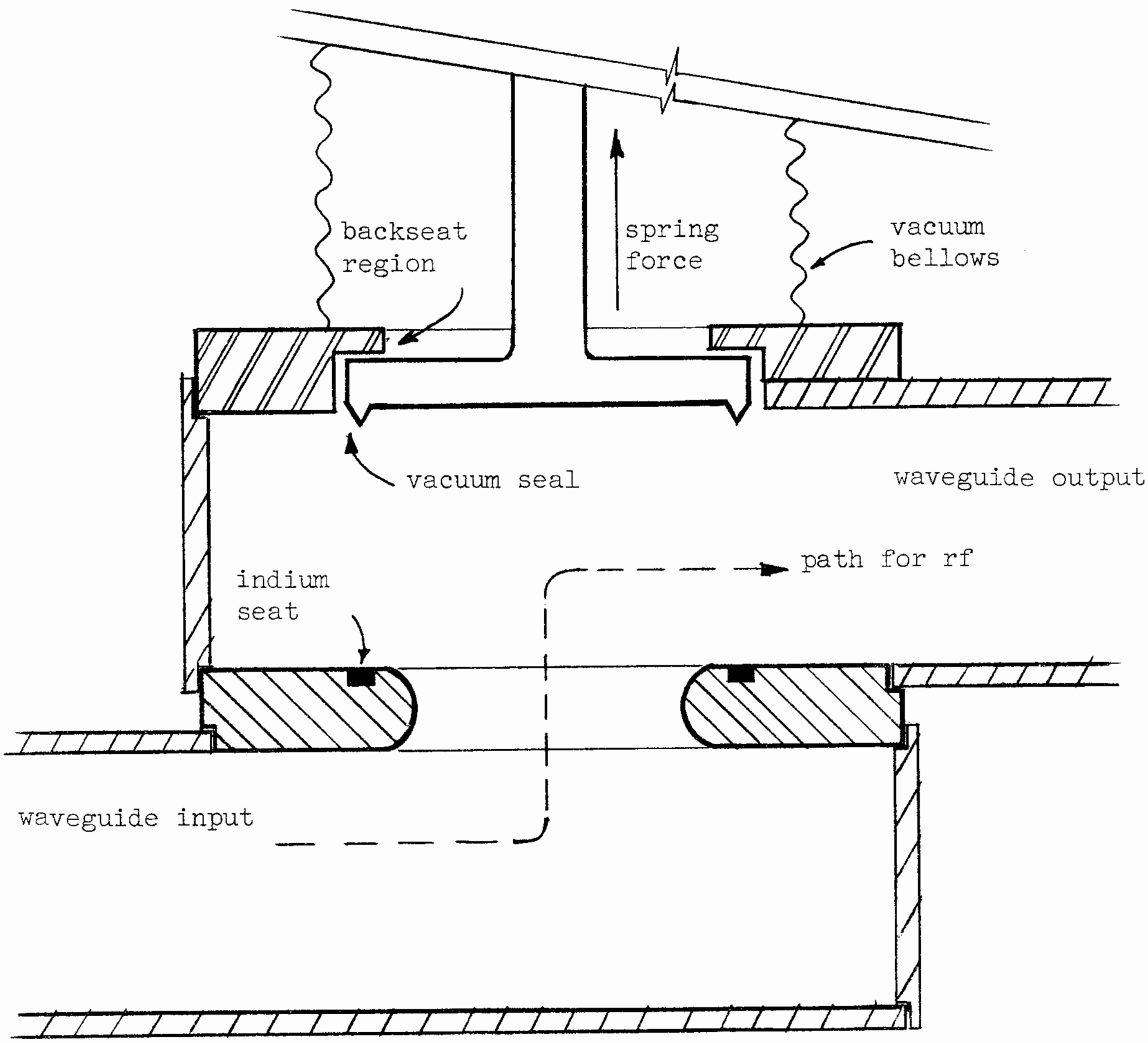

FIG. 5--Cross section of model-A offset vacuum valve.

rf off and then on again. This cycle was repeated 3 to 5 times for each valve. These valves are considered satisfactory.

An experiment was performed with valve A_5 to determine if an indium backseat might produce higher power transmission capability. This design is shown in Fig. 6. It was observed that the valve operated satisfactorily at 43 megawatts peak power after three successive open-close cycles of the indium backseat, but that average power was limited to 20 kw because of insertion loss. With an indium backseat, the bonnet temperature is 40°C higher at the 20 kw average power level than that measured for the copper-plated backseat. Since this differential temperature rise is sufficient to melt the indium backseat, we abandoned this approach in favor of the copper-plated backseat.

Three shapes for the vacuum seal were tried as illustrated in Figs. 7, 8 and 9. Shape 1 in Fig. 7 does not provide a low leak rate after several open-close cycles of the valve without re-melting the indium. Shape 2 in Fig. 8 has been successful in non-waveguide vacuum valves, but it was found to require excessive forces to close in the waveguide arrangement. Shape 3 in Fig. 9 was found to be successful. With this shape the leak rate was observed to be less than 0.1 liter per second at 10^{-6} torr after 2000 open-close cycles on one valve in a helium atmosphere. Vacuum tests on this shape are continuing in order to observe plastic flow when the valve is continuously closed.

Further electrical tests have been made on the valves. It was found that after assembly and brazing, six valves had measured VSWR of 1.22 to 1.28 prior to tuning. This indicates a reproducible and stable assembly procedure. The insertion loss on a matched valve, including two stainless steel flange pairs as terminals, was found to be 0.08 db ± 0.01 db. Additional transmission phase measurements on one valve, tested through 20 cycles, indicated that the phase deviations from one open-close cycle to the next are less than 0.1 degree.

One valve of the in-line Model B type, described in the last quarterly report,* was assembled and tested during this quarter. The valve was tested for more than 30 minutes at a peak power of 85 mw with an average

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*SLAC Report No. 10, <u>op. cit.</u>

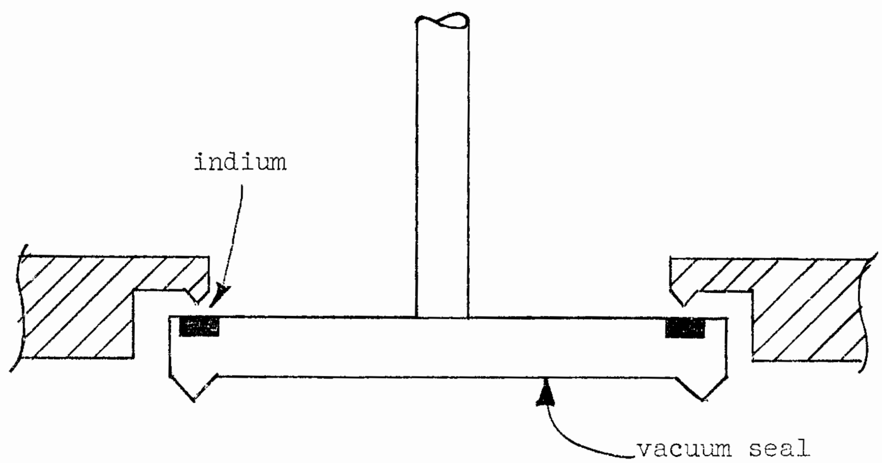

FIG. 6--Indium back-seat used on vacuum seal. (See Fig. 5.)

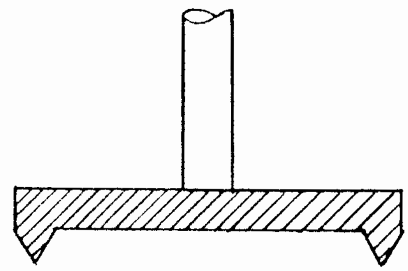

FIG. 7--Sharp-edge vacuum seal.

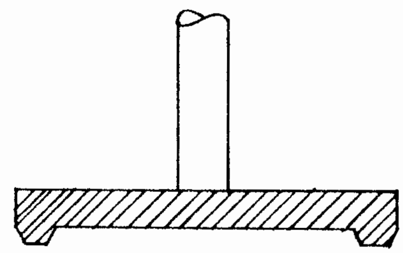

FIG. 8--Blunt-edge vacuum seal.

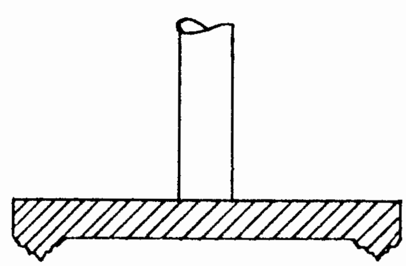

FIG. 9--Grooved-edge vacuum seal.

power of 40 kw with no arcing after the initial clean-up. The valve was opened and closed once with power off and then operated again at the same power as before without arcing. When the valve was closed, it was found to be vacuum tight on a leak detector. However, no further closings were attempted with this first assembly because of the awkwardness of the actuator used.

Parts are currently being made for four more valves and actuators. Some slight modifications in the valve and actuator have been made in order to simplify the opening and closing of these next valves, which, when finally assembled, will be subjected to rf and vacuum tests.

2. Waveguide Flanges

Extensive tests of both rf and vacuum characteristics of the waveguide flange designs have resulted in the selection of the design to be used for the SLAC machine rectangular waveguide flange couplings. The final choice is the stepped-type flange,* which will incorporate a 0.030" OFHC copper gasket of the geometry shown in Fig. 10.

The low power VSWR of this design is ≤ 1.02 at 2856 Mc/sec. Seven flanges of this design were successfully high-power tested in a resonant ring to levels on the order of 80 Mw peak and 40 kw average. The vacuum performance of the design has achieved the design goal, as the flanges have given a vacuum tight joint (10^{-7} torr) each time over a period of 20 closings with torque level at 15 ft lbs. The final specifications for procurement of 6500 pairs of these flanges are being prepared.

Further life testing of the design will be made on the various test stand and Test Tower (see tree house, SLAC Report No. 10)** installations where conversion to this type of flange is being made as quickly as possible. Future disk-loaded waveguide sections will incorporate this design.

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*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1962," SLAC Report No. 8, Stanford Linear Accelerator Center, Stanford University, Stanford, California; p. 13 (November 1962).

**SLAC Report No. 10, op. cit.

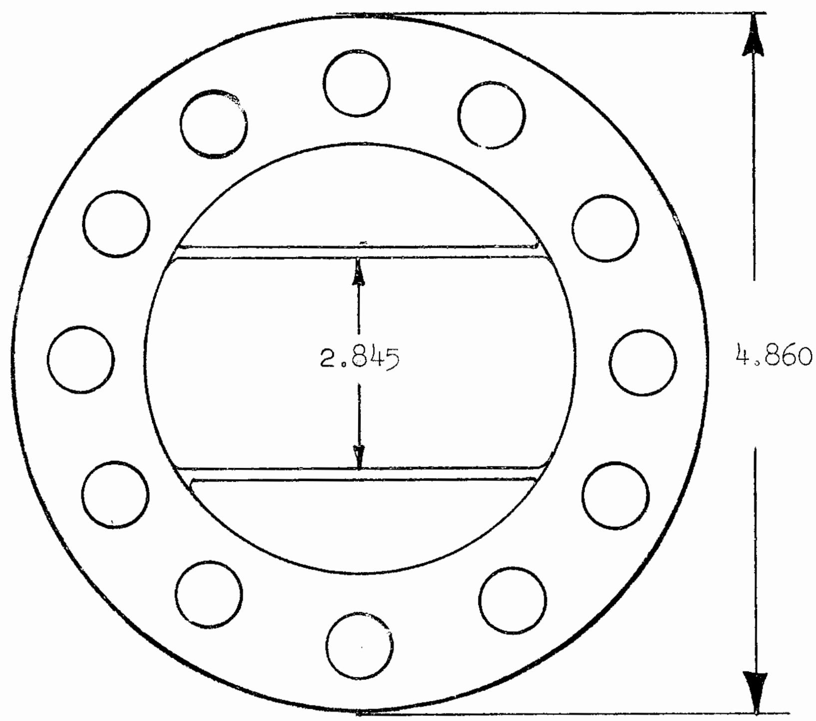

FIG. 10--Gasket used for rf flanges.

3. Magic Tee Power Divider

A magic tee power divider design, illustrated in Fig. 11, incorporating inductive irises in the series and shunt arms to provide a match at the design frequency of 2856 Mc/sec, has been developed. Three units of this design were fabricated for the Test Tower facility using techniques contemplated for the two-mile machine.

Tests on the three units showed that the VSWR was higher than expected, so it was shifted in frequency. With some alteration of the iris (slight bending toward the tee junction and reduction of the penetration of the iris into the waveguide), the tees were retuned to the following values of input VSWR.

Unit No.	E Plane Input	H. Plane Input
004	1.01	1.02
010	1.02	1.04
053	1.02	1.03

The data above was measured at 2856 Mc/sec. Measurements of the power split and isolation are not complete, but the initial tests show that the power split is 3.0 db ± 0.1 db and isolation is approximately 40 db. High power tests on these units will be made during the regular Test Tower rf tests.

A second design for the power dividers, in which no matching structures are required, has been prepared. An experimental version is being fabricated and will be tested during the next quarter. It is hoped that with this design higher power transmission capacity can be achieved, since resonant tuning elements are not required.

4. RF Loads

Porous ceramics were received and impregnated with various amounts of carbon to fabricate the lossy dielectric load discussed in previous reports. Ceramics of the same thickness and exposed to similar carbon concentrations gave very nearly the same rf attenuation when

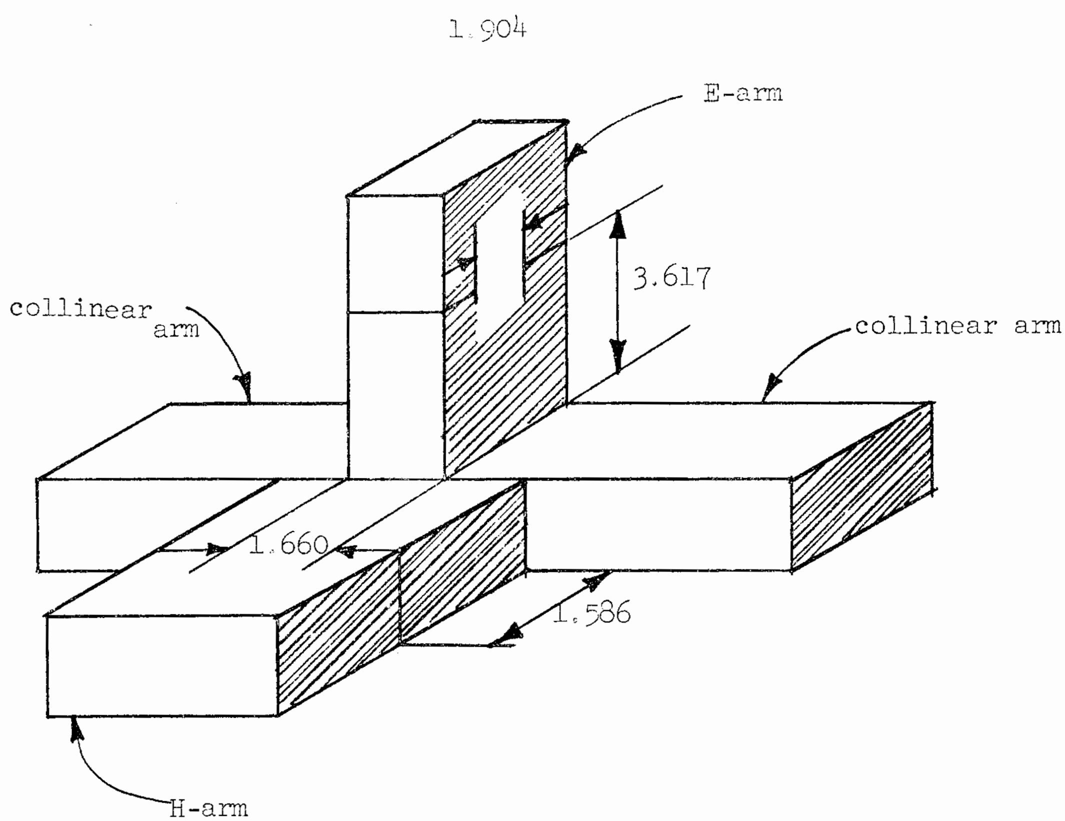

FIG. 11--Matched magic-tee power divider.
(Dimensions in inches to interior faces)

placed along the narrow wall of S-band waveguide. A preliminary load design, giving nearly uniform dissipation over an 18-inch length, is now being made.

A second type of load was investigated during the quarter in which a lossy-wall section was employed. The walls in this section were made lossy by spray-coating with Kanthal, a trade name for a substance with a surface resistivity at 3000 Mc, approximately 60 times as high as that of OFHC copper. Kanthal is extremely heat resistant (its principal application is in heating elements) and consists of 20 to 30 percent chromium, 5 percent aluminum, traces of manganese, and the balance of iron. It has a calculated attenuation constant of 0.35 db per foot at 2856 Mc/sec and a measured value of 0.6 db per foot.

This disk-loaded waveguide section employed seven cavities, including the input coupling section from a standard Model B accelerator pipe. The load exhibited an input VSWR of 1.1 over a 10 Mc bandwidth centered on 2856 Mc/sec. During the next quarter, high power tests will be made to evaluate more fully the performance of this design.

5. Test Tower

Structural work on the Test Tower (tree house) facility was completed during the quarter. A test stand modulator, with instrumentation and control racks, was installed and operated for 72 hours using a klystron diode as a load. This operation permitted an early evaluation of much of the instrumentation and control equipment and of the modulator itself. The vacuum system was installed and operates with a vacuum of 1×10^{-8} torr without the waveguides attached. The waveguide installation was 75 percent complete at the end of the quarter.

IV. KLYSTRONS

A. SUMMARY

During this quarter, procurement subcontracts for klystrons were signed with RCA, Electron Tube Division, Lancaster, Pennsylvania, and Sperry Gyroscope Company, Great Neck, Long Island, which became effective in January. Liaison work has progressed with these companies. Simultaneously, Stanford has continued work in fabricating and testing tubes to be used in SLAC sockets pending receipt of tubes purchased under the above subcontracts. In addition, work has been expended in the following areas: liaison with users of Stanford-built tubes; planning of test procedures and acceptance of tubes purchased under subcontract; planning of handling and installation; activation of a window life test system; and planning of testing and handling procedures for sub-booster klystrons.

B. SUBCONTRACTS

The subcontracts with Sperry and RCA provide for the delivery of 72 klystrons from each company at the rate of 3 per month, each beginning between July 1963 (early delivery) and November 1963 (late delivery). An additional 180 klystrons will be ordered by September 1964.

Liaison with the two companies during this quarter has resulted in mutually agreeable specifications concerning the outline drawing of the klystrons, which will insure that the tubes supplied by either company are physically interchangeable in the mounting being designed by Stanford University.

C. STANFORD FABRICATION AND TESTS

During the past quarter, Stanford has built, baked, activated, and tested 3 diodes and 18 klystrons. The diodes were built specifically to make possible the testing of modulators under a load which is equivalent to the klystron load under which they will have to perform in actual usage. The 3 diodes have been tested in our modulators and have been used by other groups without difficulties.

Six of the 18 klystrons built did not complete the test procedure because of punctured high-voltage seals, high-frequency oscillations which made the tubes unusable, or window failures. Some of the 12 tubes which were put in storage also showed oscillations, but were deemed usable since the oscillations could either be eliminated by proper focusing, or appeared over only a limited range of voltages and operating conditions. After being stored for a couple of months, we have found at least two of these 12 tubes down to air because of window failure. It is probable that one of these failures occurred during processing, but the other window looked as if it had failed due to mechanical stresses while in storage. The total number of spares available has fluctuated between two and six.

D. TUBE USAGE IN SLAC SOCKETS

Tubes are being used in sockets in the Mark IV accelerator, in the Accelerator Structures Group, the tree house, and the window test facility. Failures have occurred on all stations except the tree house, which was being activated at the end of the quarter. Vacuum failures in the rf output system caused five tube failures, while high-voltage seal puncture and insufficient cooling water in the collector each caused one tube to fail. In addition, oscillations necessitated the exchange of a tube on Mark IV. At this time it appears that the mean time to failure of tubes on these various sockets is between 300 and 500 hours of operation, with the exception of one tube on window life test which was removed early in the period but had approximately 5000 total operating hours.

E. KLYSTRON DEVELOPMENT

The original plans had been to continue the development of permanent-magnet focusing on Stanford klystrons; however, difficulties with the klystrons as built at Stanford have forced a postponement of this work. Unexpected oscillations have compelled us to re-evaluate the rf design and the gun design. We have observed at least three kinds of oscillations in the tubes. Those at a frequency close to the drive frequency were mentioned in the previous status report,* and appear to have been eliminated by careful adjustment of the resonant frequency of the first 3 cavities; these cavities are now tuned approximately 10 Mc from one another, and the amplitude modulation observed on the rf pulse envelope on a few of the previous tubes seems to have disappeared. Another oscillation which has been observed is at a frequency corresponding to a second mode of oscillation in the cavities, and approximating the second harmonic of the drive frequency. These oscillations have also been observed by both Sperry and RCA, and the solution appears to be in the use of asymmetrical cavities (that is, cavities where the nose lengths are not equal). Cavity redesign has been carried out to build tubes in which the 5700 Mc oscillations may be eliminated. A third type of oscillation which has been observed is a gun oscillation at approximately 3400 Mc. These oscillations are a function of cathode temperature and appear within a voltage range of approximately 175 to 225 kv. It is doubtful that these oscillations existed in the tubes built up to 6 months ago, when two changes were introduced in the cathode area: the corona ring was increased in length to eliminate cathode seal punctures, and a minor change in focusing ring structure was introduced to simplify the fabrication of the gun. Work will proceed in gradual modifications of the existing gun in an attempt to eliminate these oscillations. In addition, a new perveance-2 gun has been designed, and will be built and tested during the next quarter.

Another source of low yield of the tubes built during this period has been the failures of the output window. At the present time, most of the failures appear to be cracks of the windows, rather than the punctures which accounted for the majority of the klystron failures on the Mark III accelerator. Investigation of the mechanical design indicated that some stresses could be transmitted to the ceramic disk. Steps have been taken to correct the design, and we hope to eliminate this source of failure.

*"Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).

F. WINDOW LIFE-TEST FACILITY*

The window test facility, in which 6 windows can be operated in series and where reflected power and the general behavior of each window can be observed, was put into operation during this quarter, but a mechanical failure has resulted in a delay of approximately six weeks before tests can be resumed.

G. TEST EQUIPMENT PERFORMANCE

We have attempted to keep track of the amount of time spent in maintenance and trouble shooting of the test stations used by the group. Not counting the time spent installing tubes and loads on the station, approximately 665 hours were spent in maintenance and trouble shooting on 3 stations. The total operating hours for those 3 stations was approximately 1950; hence, due to station difficulties, they were available for tests only approximately 75% of the time.

In addition, there have been a number of failures of rf water loads within our own test stations and also in other locations. An rf water load failure results in vacuum system maintenance time which takes from 1 to 5 man days for an ion-getter pump system and up to 6 weeks for a diffusion pump system, and may result in the loss of a klystron if the load happens to fail while the tube is in operation. A program to complete the design of a dry load has been reactivated.

H. ACCEPTANCE AND LIFE TESTS

The tubes procured from RCA and Sperry will be tested on an acceptance test stand to insure that they meet the specifications as set forth in the contracts. Plans are being made to procure by either purchase or fabrication the special equipment needed to carry out these tests. A tube may be rejected if it fails to perform satisfactorily for 20 hours at full rated voltage and 20 hours at one-half peak power. Since we expect to receive an average of 6 tubes per month, we have to plan on a total testing time of between 250 and 300 hours per month, and special equipment to measure phase shifts, noise,

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*See Section IV.K for additional window development activities.

missing pulses, etc., must be procured during the next quarter.

I. KLYSTRON INSTALLATION

The problem of handling the klystrons, from receiving through acceptance tests to either life test or installation in the klystron gallery, is being studied at this time. Special jigs are being designed to insure that the mechanical tolerances of the outline drawing are met by the vendors. The method of supporting the klystron in the klystron gallery has been studied, and the general mounting scheme has been agreed upon. We expect to build samples of the support mechanism for operation in the test laboratory to insure that there will be no unexpected difficulties in the klystron gallery. The vehicles needed to handle the klystrons and move them in place in the gallery are in the design stage. We expect to be able to modify existing handling equipment to satisfy our needs.

J. SUB-BOOSTERS

During the quarter, the Klystron Group and the Microwave Engineering Group have collaborated in testing the first sub-booster klystrons procured under subcontract from Eimac. It is expected that the responsibility for accepting and following up the use of these sub-boosters will rest with the Klystron Group beginning next quarter.

K. HIGH-POWER KLYSTRON WINDOWS

1. Summary

On the resonant ring, tests have continued on grooved and coated windows and on smooth disks. Tests were also done of zirconia and magnesia disks. More valve and gasket tests were done for the Accelerator Structures Group. The all-metal cavity tests showed a striking difference between "polished" and "ground" disks. The all-metal ring has been completed and run successfully.

2. <u>All-Metal Cavity Tests</u>

Five disks were tested on this system during the quarter. Two of these were on AL 300 disks of standard roughness (60-80 μ inches); the other three were from a new batch of AL 300 with much smoother finish (20-30 μ inches). The rough disks gave loading curves very similar to those obtained last quarter;* two smoother disks did not show any significant loading variations as the vacuum is changed. In addition, the outgassing time before one can operate in the 10^{-8} region is shorter, the glow pattern is much less uniform, and the power levels at which breakdown is first observed are lower. One smooth disk punctured at 20 Mw before any data could be obtained.

3. <u>All-Metal Ring</u>

The all-metal ring has been completed and preliminary tests run without a window. Approximately two months delay was caused by trouble in assembly of the bellows in the phase shifter. After baking at 300°C the system pressure was 10^{-8} torr. It has operated at 120 Mw, 60 cps, and at 100 Mw, 85 kw, at 360 cps (the pressure was 5×10^{-8} torr). If higher average power than this is needed, additional cooling will have to be installed on the phase shifter's plungers. The cold gain was 14.2 db compared with 15.6 theoretical. The gain at 100 Mw, 85 Kw was 13.6 db. Some of this loss of gain is due to fm in the driver presently being used. The first window will be installed in April.

4. <u>Resonant Ring Testing</u>

(a) Heil Windows

Ring testing on windows designed by Dr. Oscar Heil of Eimac has continued with six additional windows as well as a retest of one of the eight processed last quarter.** Three of these windows were of grooved quartz, not coated; all were operated to full peak and average power capability of the ring under optimum conditions (i. e., low pressure, low temperature, low radiation intensity, high gain, and

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*SLAC Report No. 10, <u>op</u>. <u>cit</u>.; p. 47.

**SLAC Report No. 10, <u>op</u>. <u>cit</u>.; pp. 42-45.

little or no window glow). One window failed during a re-run under doubtful conditions. Two ungrooved quartz windows were tested, one of which was coated with titanium suboxide. The uncoated disk failed suddenly and spectacularly; the coated window failed at a very low power; the coating flowed together apparently as a result of surface arcing. One grooved Al_2O_3 window, coated with a combination of SiO_2 and SiO was tested. These tests are summarized in the table below:

TABLE I

Window No.	Material	Surface	Coating	Max Peak Power	Max Avg. Power (360)	Failure
7 (1)	Al_2O_3	Smooth	$Ti(O)_n$ (2)	87 Mw	———	None (5)
9	SiO_2	Grooved	None	84 Mw	41 kw	None
10	SiO_2	Smooth (3)	None	63 Mw	———	Destroyed
11	SiO_2	Grooved	None	88 Mw	44 kw	None
12	SiO_2	Smooth (4)	$Ti(O)_n$ (2)	10 Mw	———	Coating flowed together
13	SiO_2	Grooved	None	86 Mw	42 kw	None
13 (1)	SiO_2	Grooved	None	80 Mw	———	Destroyed
14	Al_2O_3	Grooved	SiO_2,SiO	80 Mw	43 kw	Punctures

(1) Re-test
(2) Spotted coating (through wire mesh)
(3) Sand-blasted to roughen surface slightly
(4) Polished
(5) No damage in addition to punctures during first run (last quarter)

The last status report did not state that the titanium suboxides used as coating provide a low secondary emission, thus eliminating the multipactor on the window.

(b) Magnesia and Zirconia Windows

A number of 1/8" × 3.00" diameter disks of magnesia and zirconia, supplied by courtesy of Norton Refractories, have been subjected to ring tests (see summary in Table II). Five MgO windows have been tested, all but one failing at relatively low power. Only one of the

ZrO_2 windows has been tested, cracking at 7 Mw. The temperature-dependent phase shift of this high dielectric material ($\epsilon' = 16$) makes testing in the model-A structure impracticable, and a broader bandwidth matching structure is being designed to use in testing the remaining ZrO_2 disks.

TABLE II

Window No.	Material	Max Pwr.	Nature of Failure
1M	MgO	58 Mw	No failure; superficial marks due to surface arcing
2M	MgO	7 Mw	Punctures
3M	MgO	2½Mw	Punctures and internal damage
4M	MgO	5 Mw	Punctures and internal damage
5M	MgO	3 Mw	Punctures and internal damage
1M	MgO	35 Mw	Internal damage, no visible punctures
6M	MgO	——	Cracked due to thermal shock, during handling before testing
1Z	ZrO_2	7 Mw	Cracked (crack almost perpendicular to E-field)

(c) Effect of Surface Finish

Two windows were run in the ring continuing the polished window sequence begun last Quarter.* Lucalox, (a vacuum-fired Al_2O_3 made by G. E.) is of interest for polished window testing because it should have fewer voids which could limit the uniformity of the surface finish obtainable by polishing. A 1/8" x 3.00" polished sample was operated to a peak power of 63 Mw at which time suspected internal damage was observed. No surface rupture could be found in the neighborhood of this apparent sub-surface lesion.

A recent shipment of AL-300 ceramics contained some samples which had surface finishes as good as those obtainable by diamond polishing (20μ inch rms). One disk (finish: 20μ inch on generator side and

*SLAC Report No. 10, op. cit.; pp. 41-42.

35μ inch on load side) was tested in a model-A structure. Initial testing resulted in window behavior similar to diamond-polished windows (high temperature, high radiation, and sporadic surface arcing) as well as an anomalous surface pattern similar to those observed in cavity tests of these glossy windows. However, following extensive testing during which 30 Mw was the effective ceiling of peak power, all operating parameters began to improve, characteristic glow patterns emerged in place of the anomalous ones, and the window eventually was operated to 80 Mw and 43 kw under nearly ideal conditions.

(d) Electron-Drilled Window

An Al-300 ceramic with six holes drilled into one surface was tested in the ring. The holes were drilled by 1, 2 and 3 second bombardments with an electron gun by the RCA Princeton Labs. While in the ring this window had a rather prolonged period of gradual clean-up. It was assumed that this behavior was due to extensive handling. Once clean-up was effected, the window was operated up to 80 Mw. Only above 70 Mw was activity occasionally observed in the two deepest holes. One additional puncture was discovered following high-power operation.

5. Electron Motion Calculations

Calculations have been started on the motion of electrons in the region near windows. Such electrons are involved in the single surface multipactor theory proposed by Priest and Talcott. This multipactor causes excessive heating and may be involved in the puncture mechanism. Initial work has been on a uniform running wave and will be extended to guided and standing waves, which are more representative of the window system.

V. MODULATOR STUDIES

A. IGNITRON

The ignitron, used as a switch tube in our modulators, has come under very close scrutiny during this period. Both its history on this project and its present performance were investigated. After consultation with tube experts, it was decided that the ignitron is not the best switch tube to use. Although years ago the ignitron was the only tube suitable for use in this power range, the high-power hydrogen and deuterium thyratrons now appear to be better switch tubes.

The main problem with the ignitron is its excessive kickout rate; that is, due to its inability to hold off voltage, the tube shorts over and remains shorted until the voltage on its anode is removed. This inability may be caused by a lack of the time necessary for complete de-ionization after the main pulse, or to secondary electrons being knocked out of grids, or because other tube parts find their way into the upper part of the tube and cause it to break down at the wrong time.

A tube expert at General Electric proposed the latter theory. A modulator expert with RCA's David Sarnoff Research Center in Princeton, New Jersey, agreed that this might be happening. A modulator engineer at Ling Electronics Company has observed that ignitrons which did not operate well in one of our modulators will operate better in a modulator which has a lower repetition rate. The modulator with the lower repetition rate has the same pulse line voltage as the type SLAC is using, but with 100 megawatt peak power and ten microsecond pulse length. On the other hand, this evidence may not be conclusive, as other ignitrons operate equally well or poorly in either modulator. It does seem logical, however, that a reduced repetition rate would lower the kickout rate, because the ignitron has mercury vapor in it which is slow to de-ionize as compared to other, much lighter gases.

The kickout rate which we have observed in our ignitrons averages about one every twenty to thirty minutes. On an accelerator with 240 modulators, other factors being equal, this means a drop in energy of about 0.4% every 5 to 7 seconds. For very accurate experiments, requiring electron energies of ±0.1%, this sort of kickout rate is intolerable.

Many engineers in various companies have attempted to solve the kickout problem by improving circuitry around the ignitron. Ling has worked on this problem, but was unable to devise any circuitry that would increase the time between kickouts by an order of magnitude adequate for our purposes. General Electric, which has two modulators running at our voltage and power level, one at Syracuse and one at Schenectady, was able to provide more time for the ignitron to de-ionize between pulses by the use of delayed charging. By the insertion of a small ignitron in the high voltage charging period, they were able to provide as much as 1500 microseconds of additional time to de-ionize. However, this system did not seem to provide a marked improvement in the kickout rate, and it had the added complication that the delayed charging ignitron rode at high voltage and required additional triggering circuits. RCA, which built three prototype modulators for SLAC about a year ago, has also been trying to perfect ignitron circuitry. Their circuits were improved at SLAC, and with some ignitrons we were able to achieve runs of several hours between kickouts, although this was the exception rather than the rule.

The main advantage of the ignitron appeared to be its long life, which resulted in a very low cost per hour for replacement of the tube. In rectifier service, ten or fifteen years is considered a normal life span for ignitrons of the type which we use. Economically, this great a life span would be ideal for SLAC, but in our experience the average life of our ignitrons has been more like a few hundred hours. In one or two isolated cases, 3000 or 3500 hours has been reported. Apparently, SLAC's use of these tubes is so different from rectifier service that the life of the ignitron is shortened considerably.

General Electric thinks this shortened life might be due to iron contamination of the ignitors as a result of arcing to the can or other iron parts within the tube during faulting. They pointed out to us that the FPS-7 radar, using a 5630 ignitron (which is smaller than our 6228), has been running five years on the same tube. However, that type of service is more like rectifier service, inasmuch as the prf is about 60 pps, and the PFN voltage is 20 kv with a 400 ampere peak current in the ignitron.

The high kickout rate, short life, and the added complexity of the ignitron (extra triggers required, close temperature control, extra water circuits, and 750 watts per tube of neck heaters), has caused us to consider replacing ignitrons with thyratrons as switch tubes.

B. THYRATRONS

There are a number of thyratrons which could be used as switch tubes at SLAC. Among them are: M.O. Valve E-2996, General Electric Z5212, Kuthe KU 274, Kuthe KU 275, General Electric GL-7890, Tung Sol 7890, E.G. and G's HY5, and the Tung Sol "phase 2 tube," which is due to arrive at SLAC next summer.

We obtained an HY5 and installed it in a new Ling modulator which was put into operation March 7. The tube would not run well at 21.5 kv, but at 17 kv, for example, the tube seemed to run much better. The kickout problem has been complicated by various breakdowns: (1) a shorted Pearson capacitive divider in the pulse transformer tank, (2) a defective pulse line capacitor which was replaced on April 5, (3) water load sparking, and (4) end-of-line clipper troubles. This tube is still operating at reduced voltages, and experiments are being performed on the modulator in an attempt to solve our problems of transients in the modulators and of ac line current harmonics. We have found that an LC filter is necessary in the modulators in order to reduce ac line harmonics, but the LC filters can cause voltage overshoots on our power supply output voltage which could cause other failures in klystrons and windows. At any rate, it would seem that the HY5 can be made to operate better by circuit improvements. If this is not sufficient, we can put two thyratrons in series, which would drop the anode voltage to about 21 kv (about half its rating). We intend to try this during the next period.

The next tube which was obtained was a General Electric Z5212. This tube was installed March 15, 1963, and at the end of March had run approximately 200 hours. At full voltage (21.5 kv) its longest run between kickouts was 31 hours. Several runs of 8 hours were turned in, but the average is about one hour between kickouts. The circuitry around this tube can be improved and will be in the near future.

End-of-line clipper operation can also be improved so that the tube will operate more efficiently.

In another Ling modulator, two thyratron tubes were set up in place of the ignitron. The pulse line was split into two halves and the impedance of each half doubled. A KU 274 was connected to each of the two pulse lines, and the two lines were then discharged in parallel into the load. The tubes were triggered from one source with 5 ohm resistors into each grid. Initial tests on this circuit revealed encouraging results. The pulse was smooth; the top of the pulse was easily flattened; and the time jitter was small (a few nanoseconds). These tubes were run up to full operating voltage, but one of the tubes for some unknown reason failed. There were troubles in this modulator which made switch tube evaluation uncertain, e.g., pulse line capacitors shorting, charging choke failure, and charging diodes shorting. A General Electric GL 7890 was installed in place of the KU 274 which had failed, and the system operated fairly well in spite of the above-mentioned troubles.

The M.O. Valve Company's E-2986 in the "purple coffin" modulator is still operating satisfactorily. The tube is not being operated at full power as the modulator must be operated at reduced power governed by what is being tested in the rf side of the klystron. This tube is the best and most conservatively operated tube on the project at the present time, and is free from kickout.*

The thyratron evaluation program is being continued. We will improve circuits wherever necessary to prove out one or more thyratrons. In spite of our poor initial results, we are confident that a thyratron or combination of thyratrons will be made to work.

The advantages of hydrogen and deuterium thryatrons are as follows:

1) they have been used in modulators for years
2) they have light gases in them which ionize and de-ionize rapidly
3) they are simpler to trigger as they require only one trigger
4) they do not require closely regulated water temperature nor necessarily pure water
5) some of them are air cooled, thus lowering the cost of the accelerator water system.

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*On page 57 of the "Quarterly Status Report, 1 July to 30 September 1962," SLAC-8, the dissipation or P_b factor of the E-2986 was incorrectly listed; this factor should properly have been shown as 80×10^9.

Their disadvantages are:

1) the rather high cost of operation (approximately one dollar per hour per tube)
2) heater power is required (although in most cases this is small)
3) a small amount of reservoir power and adjustment is required
4) they have a variable anode delay time, i.e., period between time of application of the trigger and the time of actual anode voltage drop. This effect is variable with anode voltage, repetition rate, and age of the tube, and will have to be dealt with as an additional adjustment in the triggering system. Its magnitude is approximately 0.4 microsecond, which is an appreciable variation when compared to our pulse width of 2.5 microseconds.

C. MAIN MODULATOR PROTOTYPE

A program was begun during this period to design and build a prototype of the main modulator which we feel will be the final modulator on the two-mile accelerator. A group of engineers met in study sessions and a design evolved. A circuit diagram was drawn up, parts were ordered, and a framework within which the unit will be constructed was ordered.

A second group of pulse transformers (improved versions of the originals) was obtained and evaluation tests were begun. The best of these transformers was put into a prototype transformer tank for evaluation tests.

D. SUB-BOOSTER MODULATOR

The sub-booster modulator was improved by: (1) the insertion of a bootstrapped cathode follower between the blocking grid oscillator and the main switching tubes, (2) improvements in the blocking oscillator, (3) Zener diode clipping of the drive pulse to the switching tubes, and (4) careful adjustment of the screen voltage on the switching tubes.

The cathode follower helped to take some of the load off the blocking grid oscillator, and because it was bootstrapped, less drive voltage was required. Thus better pulse shapes were obtained from it at a sacrifice of output voltage.

The Zener diode clipping helped to flatten the drive pulse to the switching tubes (four PR 1000's). These tubes have a gain of only 0.25 when bottomed, but, due to our tight specification on pulse flatness, we had to clip the top of the pulse to get the required flatness.

In order to speed the production of five of these units, we used commercial power supplies wherever possible, rather than designing and building our own.

The high voltage (26 kv) power supply is at present not regulated, but the design of a regulator for it is in progress. Such a regulator can later be added to the modulators already built.

Measuring the flatness of the pulse from this modulator is very difficult, as the specification calls for ±0.04%. Tektronix gave us a voltage divider designed especially for this type of work. When we perfected our circuits, we were able to approach, if not meet, the required specification. Microwave tests will now be made on the phase shift through the klystron as a function of modulator output voltage. These measurements will prove or invalidate our findings.

VI. MICROWAVE ENGINEERING

During the past quarter, following a reorganization of the project, the Microwave Engineering and Injection groups were merged. As a consequence, information concerning these two groups will in the future be listed under the single heading, Microwave Engineering.

A. INJECTION

1. Injection Test Stand

A schematic of the injection test stand which is presently being planned is shown in Fig. 13. This test stand will consist of an electron gun, a two-element buncher, and a two-foot accelerator section, followed by instruments to measure the bunching, the beam energy, and beam optics. During the past quarter, special emphasis has been placed on design and procurement of all the components necessary to obtain a beam by early summer, 1963.

The location of test racks, gun modulator, and rf structure was finalized and the routing of interconnecting wires has begun. The buncher and the two-foot accelerator section are in the machine shop. The cooling system for the structure is in the final design stage. It has been decided that the waveguide runs to the buncher and to the beam sweeper will be pressurized, permitting use of commercial waveguide phase shifters and power splitters to be supplied by Aircom Incorporated, Boston, Massachusetts. All associated flanges are presently in fabrication. To accomplish variable power splitting with no phase shift, the phase shifter will be electrically ganged to the power splitter. A coaxial phase shifter and attenuator prototype, fabricated for the Mark II linear accelerator in the Stanford High Energy Physics Laboratory, has been tested and is functioning properly. The equivalent unit for the test stand is now being fabricated in the Electronics shop.

Focusing and steering supplies have been purchased and are being installed. A focusing coil was designed and wound in-shop as an experimental unit, and final test stand focusing and steering coils will be fabricated in-house.

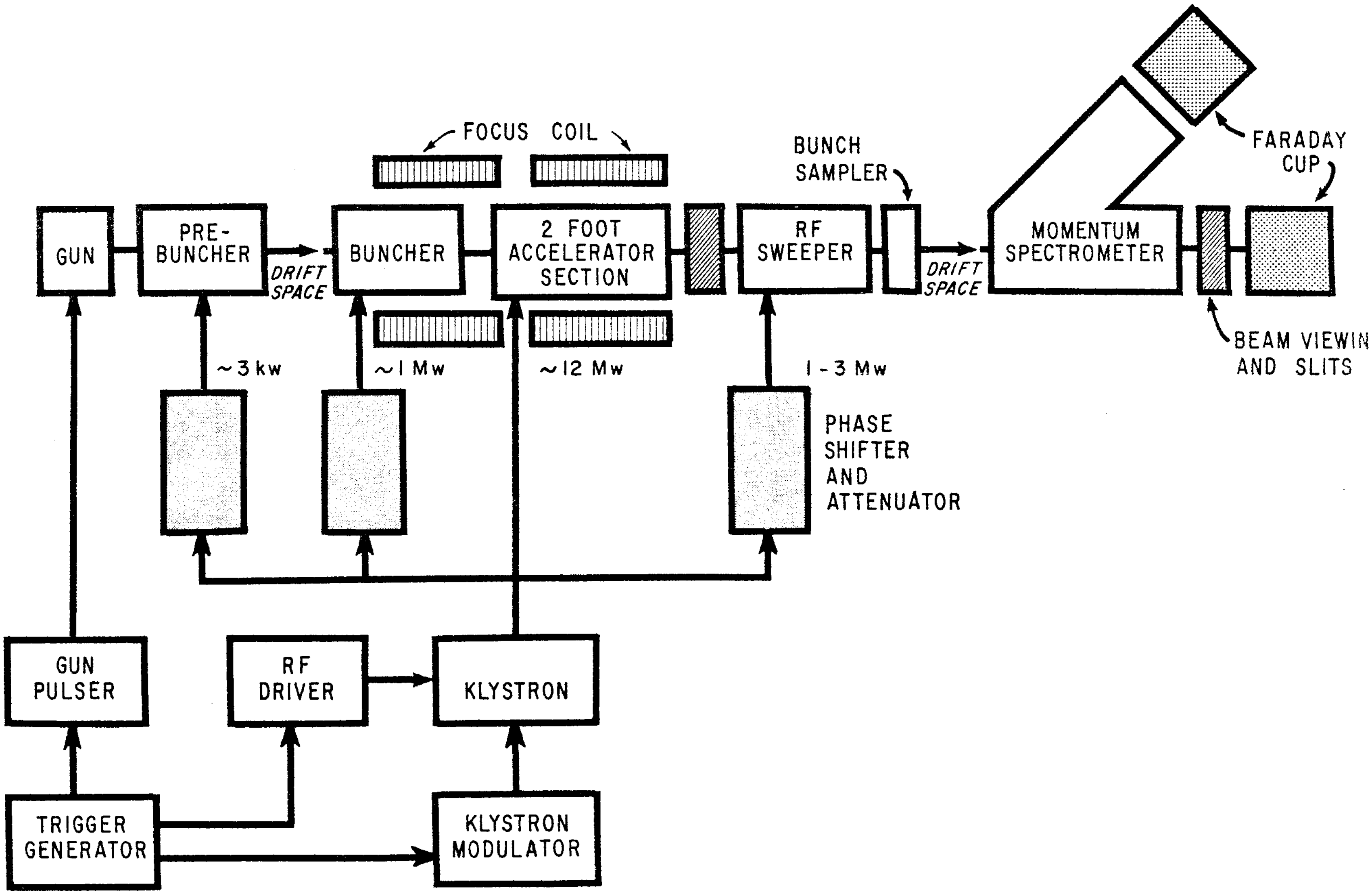

FIG. 13--Injector test stand layout.

Final design of the rf power monitoring system has been accomplished and associated components have been provided.

Preliminary investigation of radiation shielding requirements were completed, and a final design was scheduled to take place early in the next quarter.

The gun modulator bid package is essentially complete and should be sent out to prospective vendors by April 12. Bid openings are scheduled for May 13.

2. Gun Development and Testing

The Hughes electron gun, Model 3-1, was dc high-potted. The highest voltage obtained was 86 kv. Above this value, internal arc-overs took place which resulted in outgassing sufficient to limit gun testing. No external arcing or visible corona effect was observable. It appears most likely that the internal arcing is caused by severe corona effects around the pumpout holes existing in the sheet metal anode flange. These holes are in the area of highest fields, and it is difficult to provide them with large radii. This shortcoming will be remedied when the gun is modified and a bunching cavity is made an integral part of the anode flange.

Redesign of the all-metal beam analyzer has progressed during the past quarter, and purchasing of most parts is now complete. The vacuum station was built and is pumping down, awaiting final assembly of the analyzer. The associated instrumentation units have been designed and built.

Assistance has been given to the Mark IV accelerator group in an attempt to reduce radiated and conducted pulse-signal interference. Some success was achieved, but the final attempts to reduce the radial interference were postponed until installation of the 2 ampere electron gun purchased from Quantatron.

The production of all components to permit installation of the Quantatron electron gun, Model 2-2, has been completed.

3. 45° Inflection System

First and second order calculations have been carried out on the proposed inflection system. This system consists of the following elements, listed in the order in which they appear in the direction of beam travel.

1) Ten meter drift tube from the injector accelerator section.
2) 22.5° bending magnet. (H = 4.17 kGauss, radius of curvature = 20.4 cm, path in field = 8.0 cm.)
3) 11.7° rotated pole face for vertical focusing.
4) 93.6 cm drift space.
5) Ten-centimeter-long horizontal focusing quadrupole with 172 gauss/cm gradient.
6) 93.6 cm drift space.
7) 11.7° rotated pole face for vertical focusing.
8) 22.5° bending magnet. (H = 4.17 kGauss, radius of curvature = 20.4 cm, path in field = 8.0 cm.)

Except for the drift length, the system is symmetric about the center of the quadrupole.

The beam parameters which were assumed and the results obtained are tabulated below:

Parameter	Input	Output	
		1st Order	2nd Order
Energy	25.0 Mev	25.0 Mev	25.0 Mev
x (width)	± 0.5 cm	± 0.6 cm	± 0.66 cm
x' = dx/dz	± 1/3 milliradian	± 0.31 milliradian	± 0.7 milliradian
y (height)	± 0.5 cm	± 0.54 cm	± 0.55 cm
y' = dy/dz	± 1/3 milliradian	± 3.3 milliradian	± 3.3 milliradian
z (bunch length)	± 0.8 mm (~ 5° of phase)	± 0.8 mm	± 1.85 (~ 13°)
$\Delta p/p$ (momentum spread)	± 5%	± 5%	± 5%

The 13° phase spread, if not reduced, would account for about 0.6% of energy spread at the output of the two-mile accelerator. The contribution of this percentage by this single effect is presently considered too large. The prime cause of the debunching in second order is $(\Delta p/p)^2$. A number of approaches to minimize the second order debunching and to reduce the horizontal divergence are being considered. One approach to reduce the second order effect suggests itself as a result of the fact that there is essentially unit correlation between x and p in the center of the quadrupole. That is, all high energy rays have positive x at the plane of symmetry. This suggests that it is possible to correct for the second order debunching by using an asymetric quadrupole with the magnetic field gradient dB_y/dx larger for x positive than for x negative, or alternatively by rotating the faces of the quadrupole so that the path length through the quadrupole increases with increasing x. The angular divergence term due to $(\Delta p/p)^2$ can be reduced by placing the quadrupole off center. These and other modifications will be examined during the next quarter.

B. DRIVE SYSTEM

1. Over-all Design of the Drive System

The basic design of the drive system was frozen during the previous quarter.* Major emphasis during this quarter has been placed on testing the various components and prototypes to be used in the system. The results are discussed below.

2. Varactor Multipliers

Six harmonic generators were purchased from Syntax Corporation for evaluation. These units have an input frequency of 476 Mc/sec and an output frequency of 2856 Mc/sec, with a multiplication factor of six. For an input of 1 watt at 476 Mc/sec, the units deliver 150-200 mw at 2856 Mc/sec.

Phase stability measurements were made on all six units, with the following results:

a. Phase variation versus bias voltage: 20°/volt
b. Phase variation versus power input: 1°/0.1 db
c. Phase variation versus temperature: $1^\circ/^\circ C$
d. Phase variation versus frequency: Negligible for ± 100 kc tuning at S-band.

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*"Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).

These results are very encouraging and investigations on harmonic generators are now proceeding along the following lines:

a. Detailed mathematical analysis of phase shift in harmonic generators as a function of drive power.

b. Phase locking of the output of a harmonic generator to its input.

c. Performance of harmonic generators in a well controlled environment. For this purpose two small ovens are being purchased.

d. Microwave limiters for control of input power to harmonic generators.

e. Long term power stability of harmonic generators.

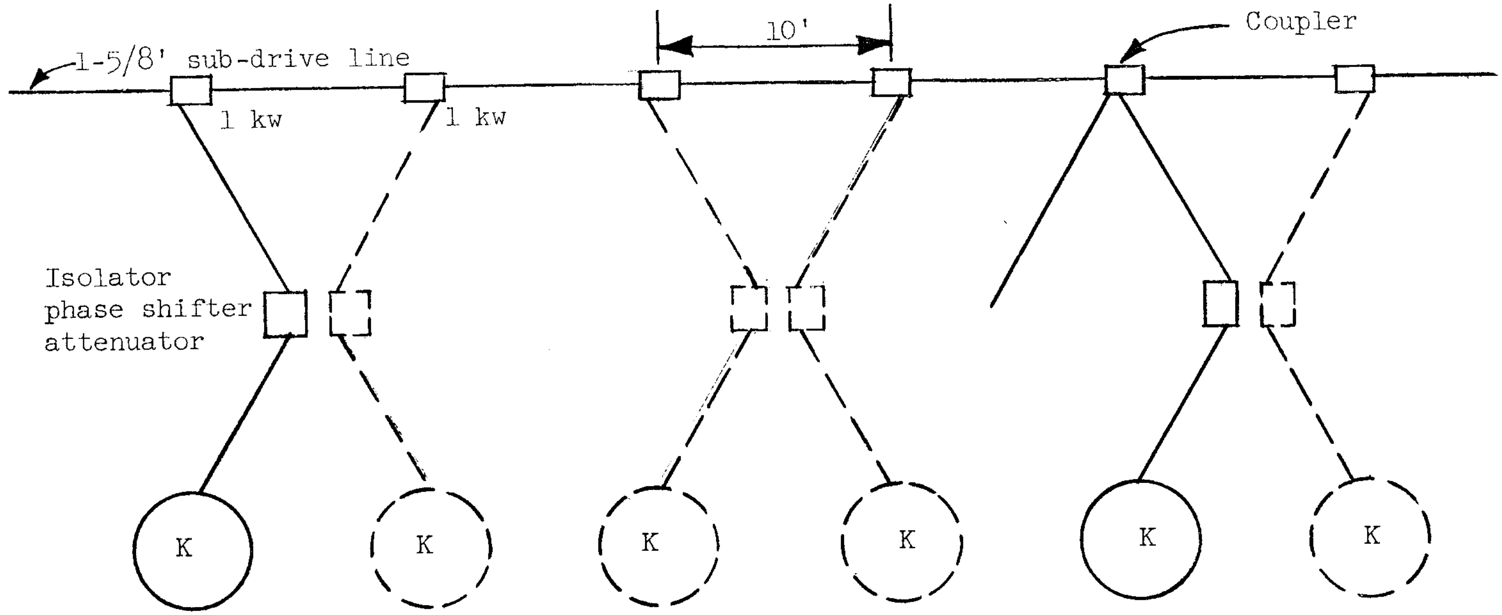
3. Main Booster Amplifier

During the past quarter, purchase specification PS-801-022-R0 was written and sent out for bids. It describes the 476 Mc/sec driver amplifier which will feed the main drive line. This amplifier will have a power output of 17.5 kilowatts and a long term stability of ± 0.1 db. Extensive reliability testing of this unit is required.

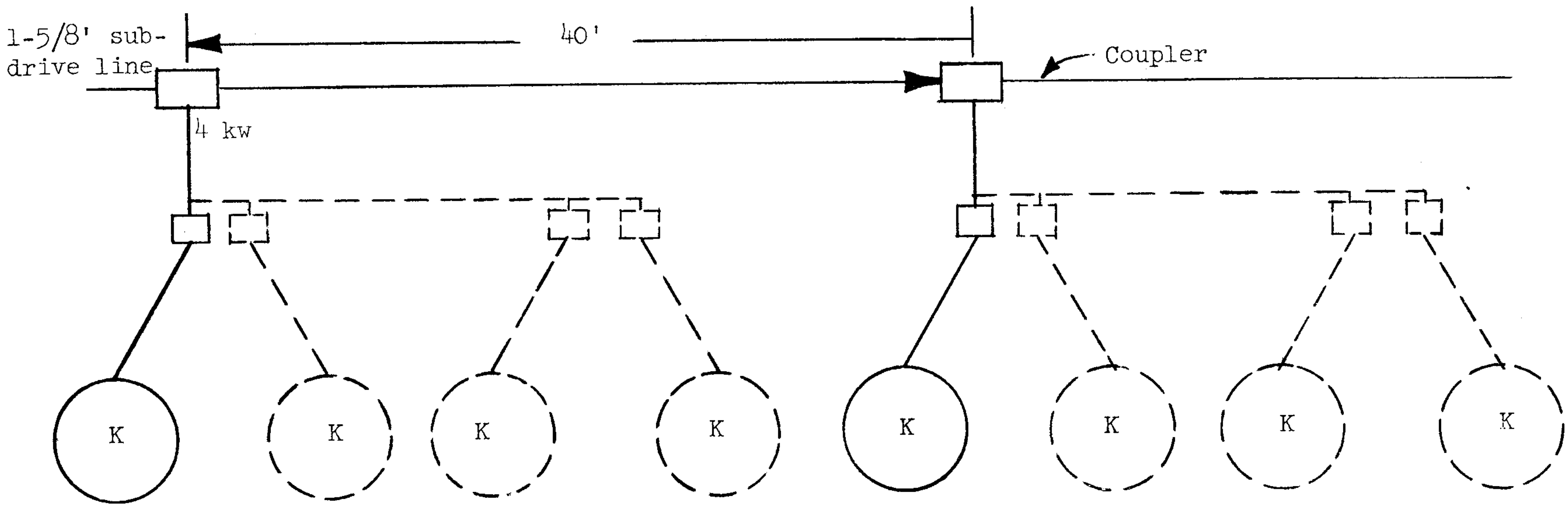
4. Drive Lines

The design and specifications of both the main and sub-drive lines are nearing completion. Experimental techniques have been developed to determine accurately the group velocity of experimental samples of both 3-1/8 inch and 1-5/8 inch coaxial lines. The measurement of this parameter, as well as that of the VSWR and reflections caused by periodically spaced obstacles in the lines, is indispensable to fully specify this equipment. One more series of experiments will be repeated during the early part of the next quarter, including the examination of coaxial lines, directional couplers and expansion sections.

A final decision has been made concerning the sub-drive line couplers. As shown in Fig. 14, two alternates in layout exist. One is to provide in Stage I the total number of couplers necessary for Stage II (i.e., 32 couplers per sector). However, this solution is costly. The other layout, with only 8 couplers in Stage I and an extra piece of line added in Stage II, is much more economical and it has been adopted as a final design. Hence, in Stage I, three-fourths of the available power at



(a) Original Stage I layout showing early installation of couplers for Stage II.



(b) Preferred Stage I layout.

FIG. 14--Sub-drive line coupler layouts.
Dotted lines indicate equipment
added for Stage II installation.

each coupler will be dissipated in the attenuator preceding the high power klystron. To complete Stage I installation, it would then be sufficient to add two inexpensive power splitters and an extra piece of 20-foot coaxial line. No interruption in operation for the change-over from Stage I to Stage II would be necessary.

5. Sub-Booster Klystrons

The first four sub-booster klystrons, supplied by the Eimac Company of San Carlos, California, were delivered during March, 1963. Testing of the tubes to the accuracy required by the specifications has been carried out using the equipment as shown in Fig. 15.

Figures 16 and 17 show results of saturation and bandwidth measurements for the third tube tested. The shape of the curves is typical of those obtained for the other three tubes. Some tube-to-tube variations in bandwidth and maximum output at saturation are apparently due to differences in cavity tuning and slight differences in design.

Measurements of phase shift as a function of beam voltage for the third tube gave a value of 0.04 degrees/volt. Some tube-to-tube variations were again noted.

Further evaluation of the results obtained and measurements of noise level are required before a detailed report on the sub-booster performance can be completed.

6. Test Stand Drive Systems

Directional couplers for the test stand drive distribution have been received and are being tested. All other components and coaxial lines have been ordered and received. Sub-booster modulators for the test stands are nearing completion and will be available as needed for the test stand installation and turn-on.

Two SAS-61 klystron modulators have been ordered from Manson Laboratories, Stamford, Connecticut, for the accelerator structure test stands. These units will be received, tested, and installed during the next quarter.

7. Isolator, Phase Shifter and Attenuator Units

Twenty complete units, each consisting of an isolator, phase shifter and attenuator, were delivered by the Sperry Microwave Corporation,

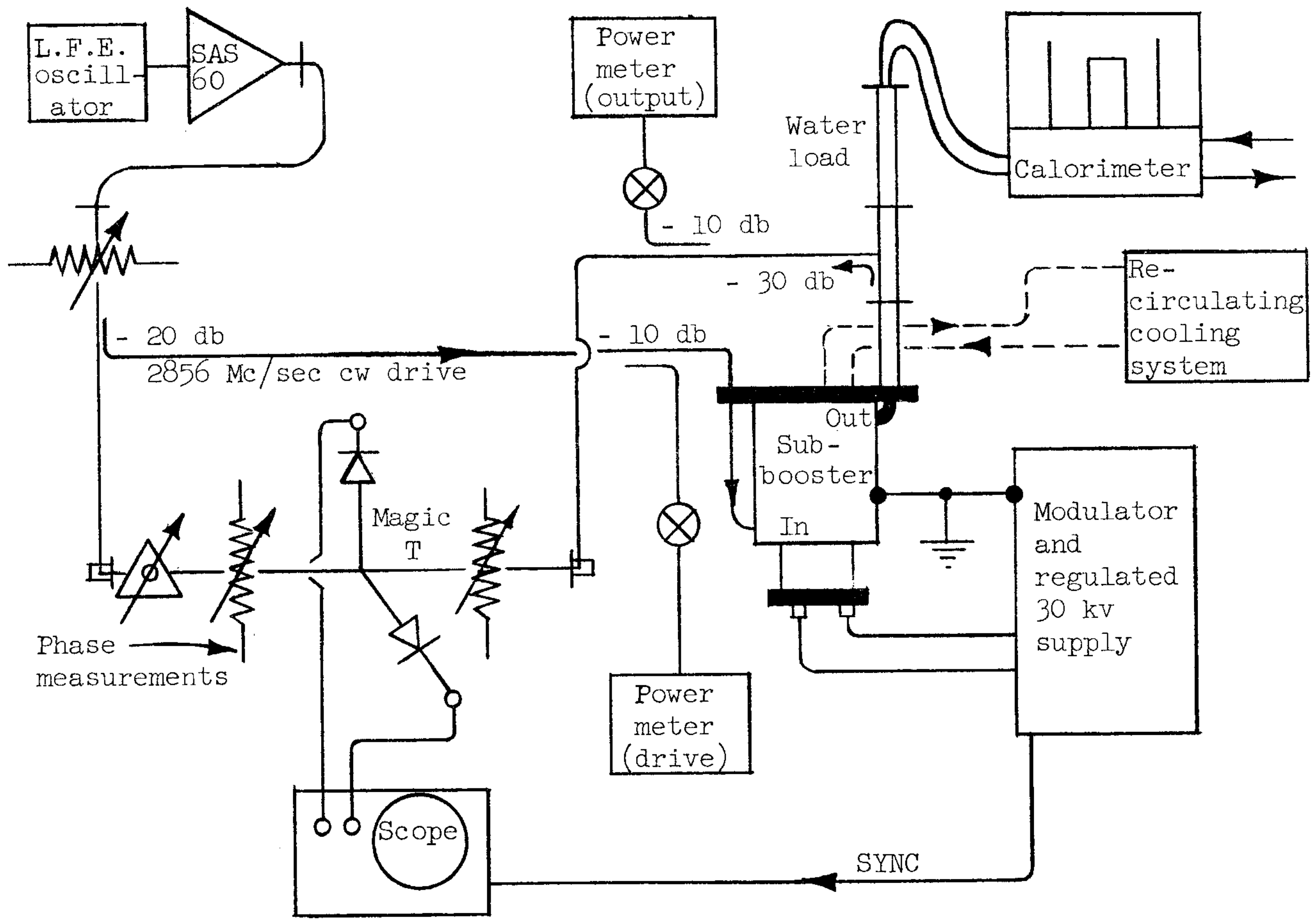


FIG. 15 --Equipment layout for sub-booster klystron tests.

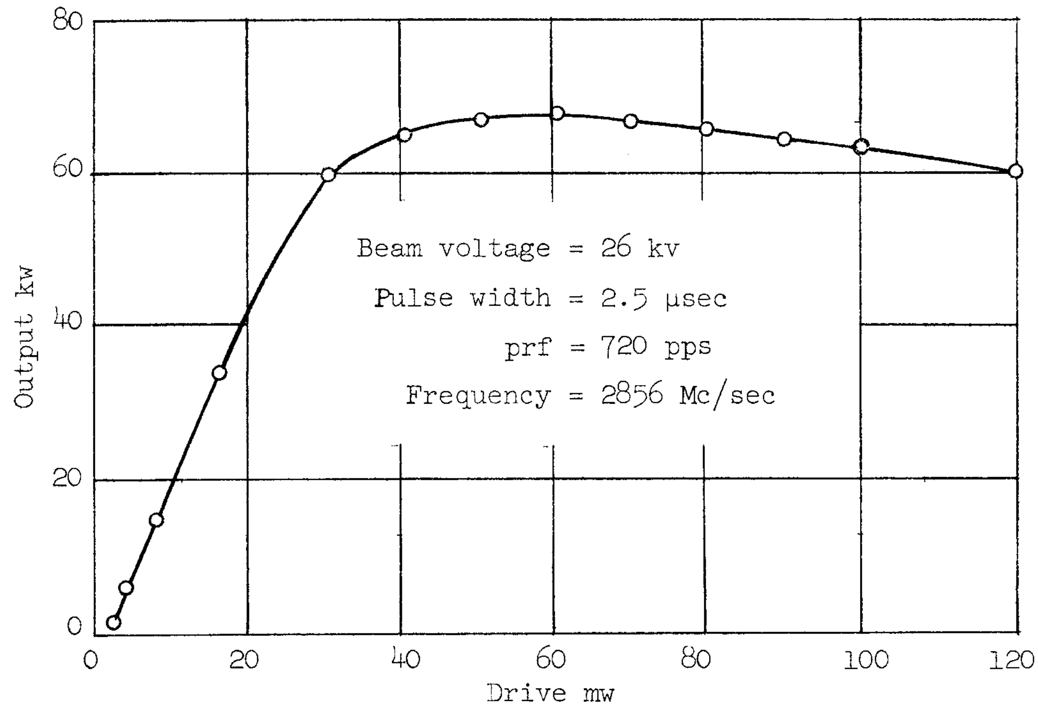


FIG. 16 --Sub-booster power output as a function of drive power.

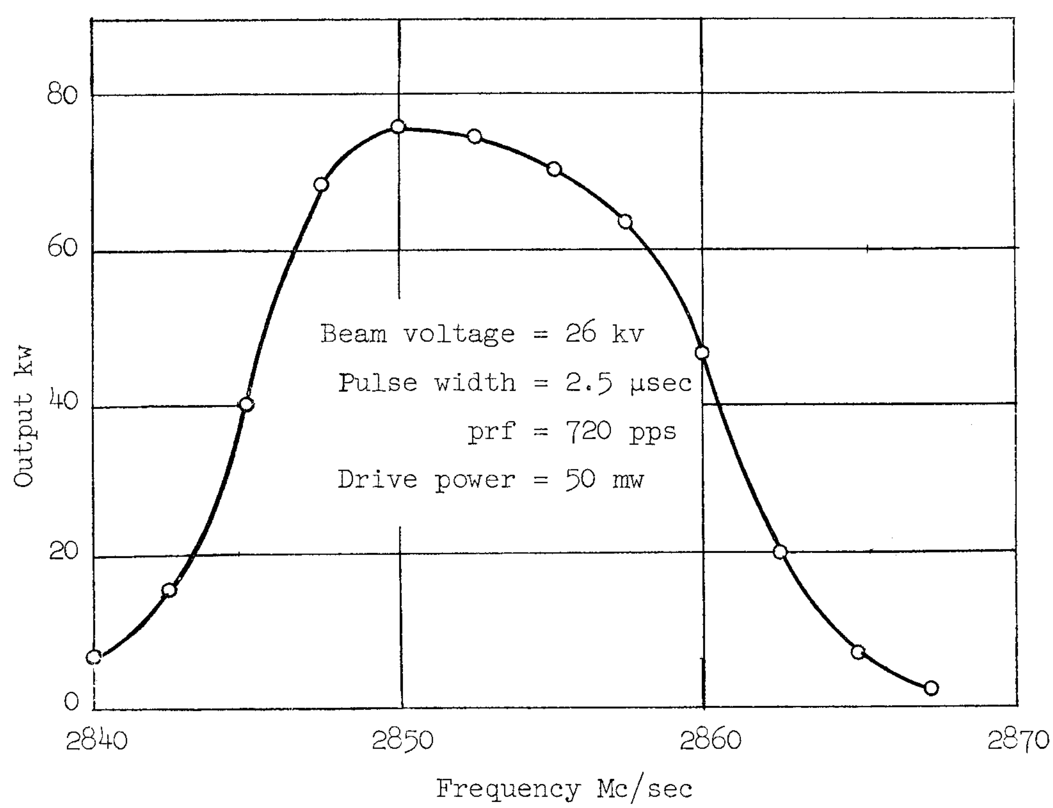


FIG. 17 --Sub-booster power output as a function of frequency.

Clearwater, Florida, during this quarter. Extensive tests have been carried out on these components and the units have been accepted by the project.

8. Stable Test Stand Drivers

Six stable drivers were ordered from Syntax Corporation during the previous quarter. Delivery took place in January and February, and all six units have now been accepted from the manufacturer.

9. Gombos S- and C-Band Pulse Oscillators

The Gombos S-band pulsed oscillator was returned from the manufacturer and is now operating satisfactorily, providing about 2 kw of power.

The C-band unit has also been received and works satisfactorily. This unit is to be used for the beam break-up experiments.

C. PHASING SYSTEM

1. Automatic Phasing System Using the Hybrid Method

The presently proposed hybrid method of phasing for the two-mile machine is undergoing extensive review. The problems of sector phasing and injection phasing are also under investigation. Discussions with the Instrumentation and Control Group and the Research Division are planned to determine permissible energy and current variations during the phasing operation. Because of the complicated requirements of the programmer, a decision was reached during this quarter to build the automatic phasing system in-house.

2. Sector Simulator

The sector phasing simulator based on the hybrid technique was put into operation during this quarter. Preliminary results indicate the practicability of such an automatic system. The simulator is being operated in an environment which resembles the expected operating environment as closely as can be obtained. The effect on the system of RFI and line transients, which were initially troublesome, has been significantly reduced. Work is presently continuing on refinements of the system. Modifications already incorporated include the design of a new relay stepping oscillator giving improved operation, increased reliability, and minor modifications to the programmer. The design of the servo system to operate on a dc basis is also being investigated.

3. 360° Continuous Phase Shifter

Because of the requirements of the servo system for the automatic system, a 360° continuous phase shifter is required. The required characteristics of this phase shifter are that it should be continuous in the range from 0 to 360° and exhibit no maxima nor minima within this range. In addition, one direction of rotation of the control motor shall always be associated with an increase in phase shift, and a contra direction of rotation shall always be associated with a decrease in phase shift. Because of these specialized requirements and the fact that it is a critical component of the automatic system, a survey letter has been distributed to a number of industrial concerns to determine if such a device could be built to our specifications. At the present time nine companies have replied indicating interest in producing such a device. Final specifications will be prepared during the next quarter. In addition, two designs using a strip-line approach are being investigated within the project.

4. Beam Induction Technique

An experimental re-evaluation of the beam induction technique of phasing will be undertaken on the Mark IV accelerator during the next quarter. The calibrated coupler required at the output of the second section is ready for installation and the remaining equipment is presently being calibrated.

5. Calculations of Beam Induced Power in a Constant-Gradient Accelerator Section

A calculation was carried out to evaluate the power induced by an electron beam in a constant gradient accelerator section. The expression is given by

$$P_{c.g.} = ri^2L \left(\frac{\tau^2}{e^{2\tau} - 1}\right)$$

where r is the shunt impedance, i is the peak beam current, L is the length of the section and τ is the attenuation parameter. For the design parameters of the two-mile accelerator, this power differs by only 1% from the corresponding power induced in a constant impedance section with the same parameters. This expression is needed to predict the power available for the hybrid method of phasing.

6. Phase Measuring Equipment

The phase measuring equipment described in SLAC-8* has been completed and an analysis of the double sideband suppressed-carrier modulator used in this equipment has been made.

7. Effect of Radiation on Phase Shift in Coaxial Cables

A calculation has been carried out on the effects of radiation on air-filled coaxial cables to estimate the phase shift causing by impinging ionizing radiation. The results show that for the radiation level expected to exist in the accelerator housing and for the presently anticipated exposed cable length, the phase shift is smaller than 0.1°.

D. GENERAL RF STUDIES

1. Constant-Gradient Accelerator Structure Design

The design of the constant-gradient accelerator structures was completed during the previous quarter. The more complicated design using ventilated disks, discussed in SLAC 10,** is in progress but no strong priority is being placed on this program at this point.

2. Design of Buncher

The constant velocity buncher using a value of $v_p/c = 0.75$ has been designed and drawings were turned over to the Fabrication Department.

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*"Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1962," SLAC Report No. 8, Stanford Linear Accelerator Center, Stanford University, Stanford, California (November 1962).

**SLAC Report No. 10, *op. cit.*

The main features of this design are:

	f	$= 2856$ Mc/sec
	r/Q	$= 36.9$ ohms/cm
	v_g/c	$= 0.0118$
disk aperture diameter	$2a$	$= 0.890"$
cavity inside diameter	$2b$	$= 3.2785"$
disk thickness	t	$= 0.230"$
periodic length	d	$= 0.803"$

3. Waveguide Vacuum Valve

The preliminary back-up design for a waveguide vacuum valve, discussed in the previous status report, has been completed. A VSWR of 1.05 has been obtained with a transmission loss of 0.1 db.

4. C-Band-to-S-Band Coupler

The C-band-to-S-band coupler discussed in the previous Status Reports was completely redesigned using a branch-coupler scheme. Final assembly of this model is underway, and it is planned that beam break-up experiments on the Mark IV accelerator will be carried out during the next quarter.

5. RF Particle Separators

This program is being carried out in cooperation with the Research Division. Considerable progress was made during the past quarter in the design of both the conventional TM_{11} structure and the modified TM_{11} structure, using mode suppressors to prevent rotation of the field patterns along the length of the separator. Table I outlines the obtained design parameters. Figure 18 shows the field configuration obtained in a cavity test cell for the TM_{11} mode. Figure 19 gives the ω-β diagrams for the standard structure and the structure with suppressor holes. It should be noticed how a 90° rotation of the axis of the suppressor holes causes the ω-β diagrams to be separated. Hence, mode rotation should be prevented with the orientation where the axis of the holes is at 90° with the rf coupler axis. Figure 20 shows a field plot obtained in the middle test cavity by means of a perturbation experiment using a one-centimeter-long sapphire rod. These perturbation measurements

TABLE I

RF SEPARATOR DESIGN DIMENSIONS

Design will be used at 2857.25 Mc, 113°F, 0% rh and E = 1,000,000 (Vacuum). This corresponds to a cold test frequency of 2857.12 Mc at 78°F and 42% rh.

Designation	Symbol	Standard Structure	Structure With Mode Suppressors
Total length (cavities)	ℓ	13 cavities + 2 couplers	13 cavities + 2 couplers
Outside diameter	OD	5.417"	5.417"
Inside diameter	2b	4.6670	4.6415
Disk aperture diameter	2a	1.600	1.600
Disk-edge rounding:			
Steel ball diameter	2r	1.7500	1.7500
Steel ball reading (with ρ = 0.1215; s = 0.031")	h	1.1376	1.1376
Disk thickness	t	0.230	0.230
Disk spacing	d	1.378	1.378
Suppressor holes:			
Diameter			3/4"
Radial distance			1.425
Orientation			at 90° x
Couplers:			
Inside diameter	2b(cpl)	4.590	4.590
Iris aperture		1.350	1.350
Thickness of cutoff-disk	tc	0.750	0.750
Disk hole of cutoff-disk	$2a_c$	1.000	1.000
Steel ball diameter for cutoff-disk	$2r_c$	1.1870	1.1870
Steel ball reading cutoff-disk	h_c	0.8296	0.8296

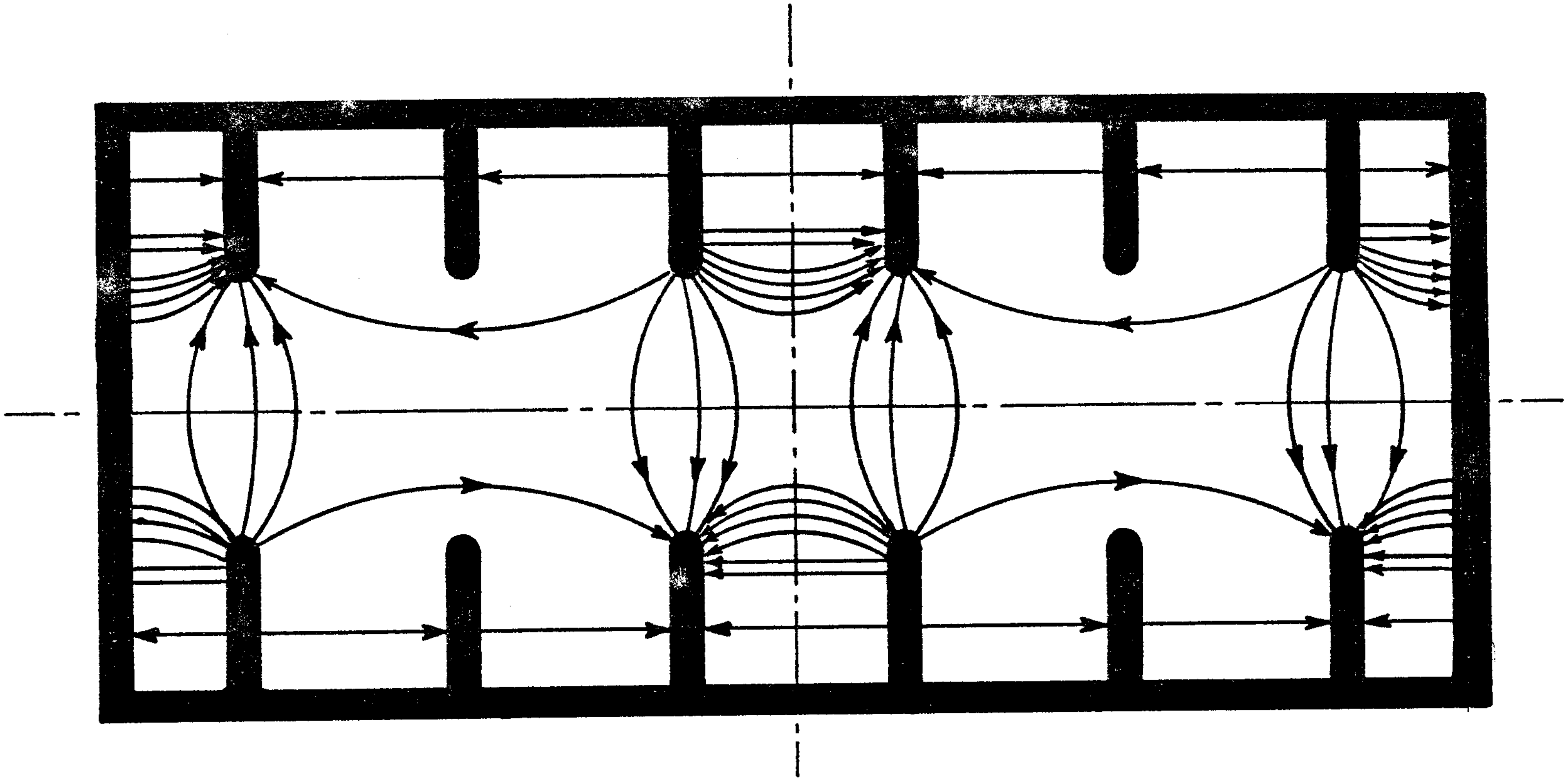

FIG. 18 --TM_{11}-like electric field configuration in rf separator test-cell.

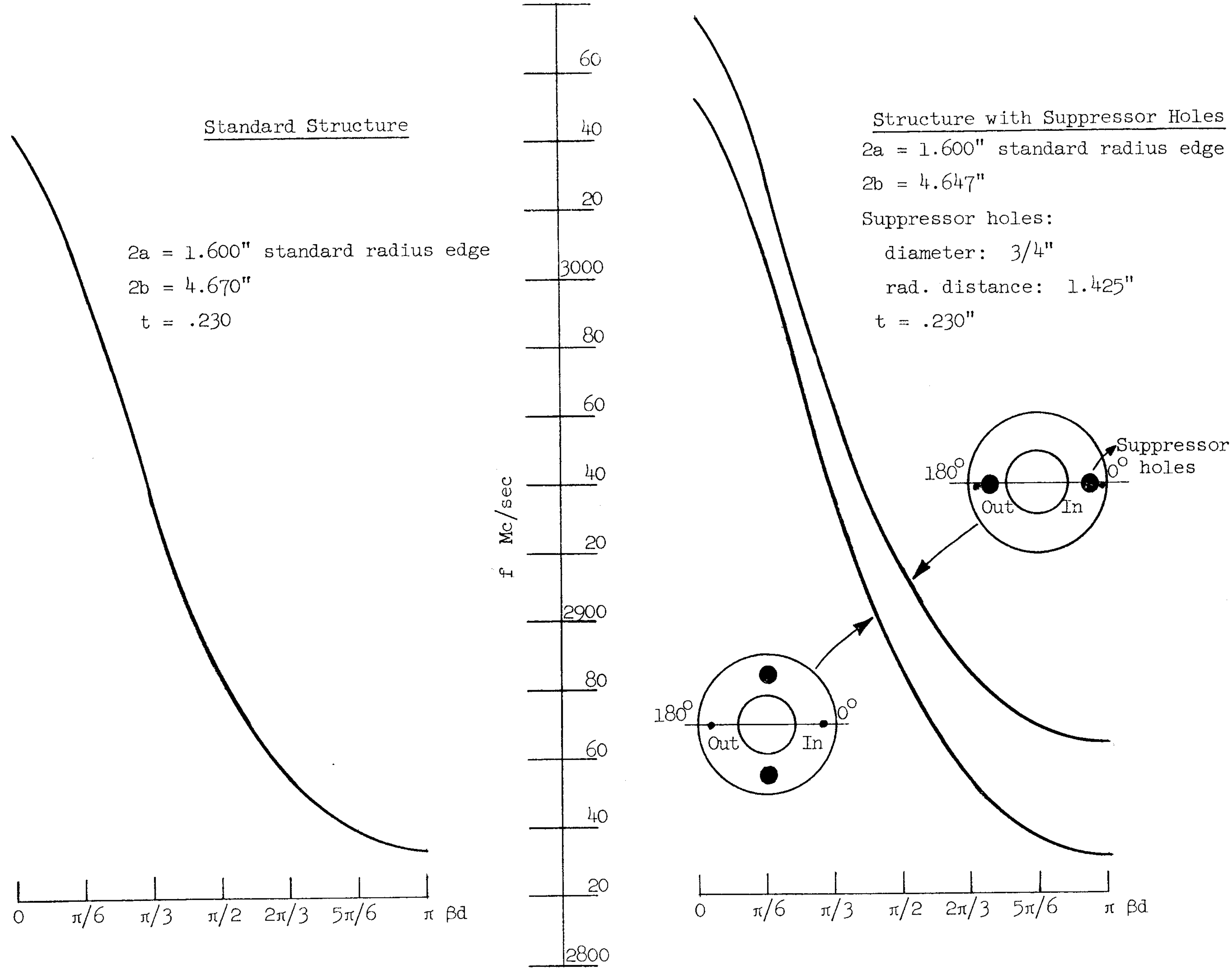

FIG. 19 --ω - β diagrams for two rf separator designs.

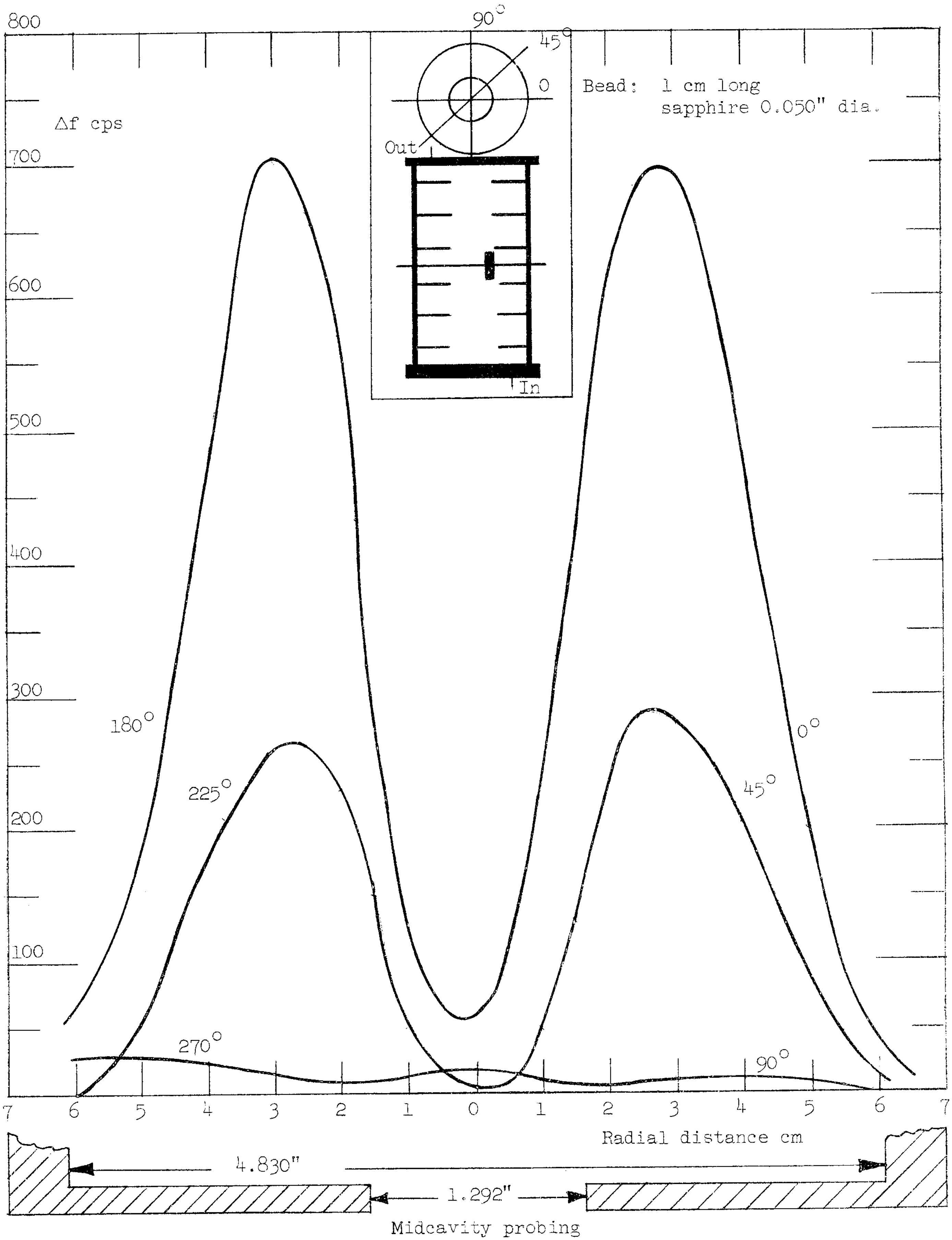

FIG. 20 --Square of electric field intensity in mid-cavity of test cell as a function of radial and angular position.

yield the square of the axial field intensity E_z^2 as a function of radial and angular position. Figure 21 shows the results of a perturbation experiment using a 1.8 centimeter sapphire rod moved along the z direction, close to the disk edge, and along the diameter of maximum field.

It should be noticed that both structures are of the backward-wave type. It is important to bear this fact in mind when performing the nodal shift experiments used to time the section and match the input and output couplers. This property causes the motion of the null in the slotted line as a function of the detuning plunger position to take place in the direction opposite to that obtained with a forward-wave structure. An increase in frequency here decreases the phase shift per cavity, whereas in a forward-wave structure an increase in frequency increases the phase shift per cavity. It is expected that the first separator structure will be fabricated during the next quarter and tested on the Mark IV accelerator.

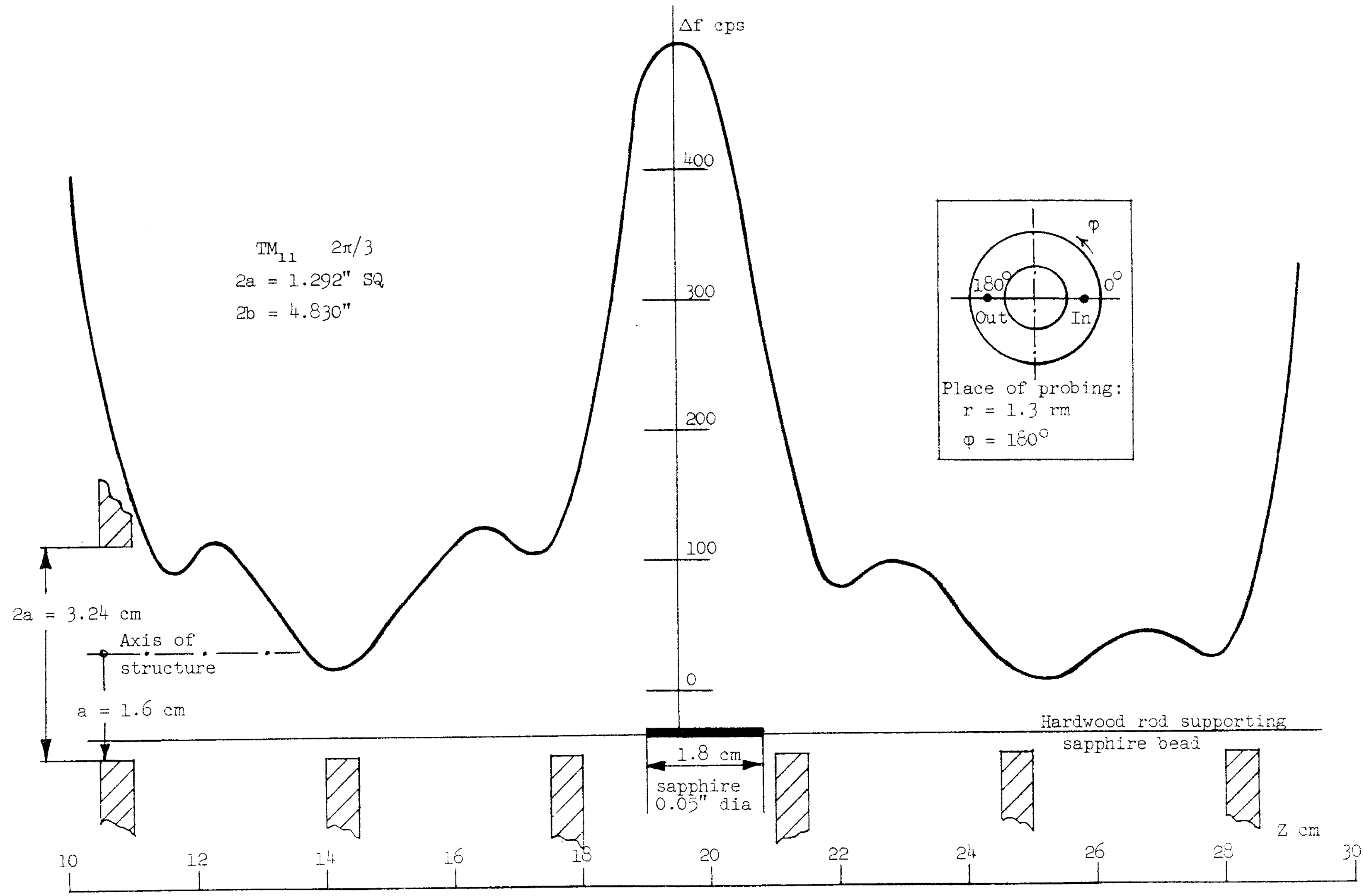

FIG. 21 --Square of electric field intensity as a function of Z in test-cell, with bead drawn close to disk edge ($\varphi = 180^{\circ}$).

VII. SYSTEMS ENGINEERING AND INSTALLATION

A. ACCELERATOR RESEARCH AND DEVELOPMENT

1. Vacuum System

a. Gauge Evaluation

Pressure measurements were made on a diffusion-pumped molecular sieve trapped system using a Hughes PG-7 cold cathode gauge and a Veeco Bayard-Alpert hot cathode gauge. There was close agreement between the two gauges over the pressure range 10^{-5} to 10^{-7} torr. An ion-pumped test system was designed which will be used to test commercially available cold and hot cathode gauges.

b. Valve Evaluation and Test Program

Commercially available bellows sealed valves are being investigated. A design for stainless steel valves (6 inch and 8 inch) with Viton O-ring seats has been prepared and submitted to vendors. An investigation of commercially available valves with removable operators for klystron roughing valves and gauge isolating valves is also underway. The Design and Fabrication Department is working on the design of an all-metal valve. Information is being compiled on Viton A with regard to the behavior of this elastomer in the environment to be encountered on the two-mile accelerator.

c. Roughing Systems Study

Investigations are in progress to determine the optimum system for rough pumpdown in combination with ion pumps. Under consideration are: (1) a diffusion pump-liquid nitrogen or molecular sieve trapped mechanical pump combination, (2) cryosorption pumping (with and without mechanical pump assistance), (3) a turbomolecular-mechanical backing pump combination, (4) an ion pump-titanium evaporation pump combination backed with liquid nitrogen trap, and (5) mechanical pump and liquid nitrogen trapped Roots blower-mechanical pump combination. Tests will be conducted on the Purple Coffin and Test Tower, and in the vacuum laboratory. Preliminary observations indicate that both cryosorption and turbomolecular pumping are applicable to the two-mile machine from the standpoint of eliminating the possibility of oil contamination in the vacuum system. A 140 L/S turbomolecular pump has been ordered from Welch and will be tested on the Test Tower.

d. Vacuum Piping

The possibility of substituting nickel-plated steel pipe for stainless was investigated in detail. Indicated cost savings did not compensate for potential difficulties of quality control, joining problems, and particularly the problem of cutting into the pipe subsequent to installation. Outgassing studies of stainless steel pipe and tubing are being conducted. A single outgassing measurement of the Test Tower vacuum system resulted in an average rate of 1.15×10^{-12} torr L/S cm^2 based on area of stainless in the system. An ion-pumped vacuum system is under design which will enable us to make outgassing studies and residual gas analyses of pipe after various cleaning and bakeout procedures.

e. Purple Coffin Vacuum Test

The vacuum system was completed and is ready for installation on the test stands. Measurements of pump speeds were made and curves were drawn for pump speed as a function of pressure.

f. Test Tower Vacuum Test

A vacuum system was installed, and work is proceeding on pump speed measurements, residual gas analyses, and approximate outgassing rates.

2. Supports

An accelerator truss was installed in the Test Tower. Accelerator truss seismic resistance test installation was started at the mockup. Negotiations are underway with John Blume for free vibration tests.

3. Alignment

Design work on experimental equipment for the optical-interference alignment system experiment at the Brisbane Tunnel was completed in early January. The traverse assembly, filament light source, light collimator, photomultiplier, and photomultiplier electronics were installed in February. Preliminary in-air observations were completed and preparation for evacuating the sight tube began (see Fig. 22).

4. Cooling Water

The Purple Coffin test unit was moved to Mark IV for conducting heat exchanger temperature control tests. Water treatment corrosion test circuit work commenced in February, preliminary design was completed, and final design was begun in March.

Test Tower cooling water piping and equipment design and procurement was completed in February, and installation is approximately 80 percent complete.

B. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. Design Coordination

This group assists in coordinating final design effort in all areas necessary to completion of installation drawing contract requirements. Design teams are assigned as required.

Work is progressing on klystron-waveguide vacuum manifold supports, main and off-axis injector area layouts, drift section layouts, and auxiliary machine shielding. Definitive drawings showing the latest general arrangement of all equipment have been issued for project review and approval.

A new, more comprehensive condensed model of the Klystron Gallery and Accelerator Housing is being constructed to reflect current design criteria changes.

2. Installation Drawings

A drawing control system was put into operation in February. Work, planned at a total of 2,790 drawings, has been organized into 31 sets, consisting of the main line injector station and 30 sector sets. The goal is to provide drawings which would permit advertising for lump sum installation contract bids for the complete two-mile machine in November 1963, in order that the award of installation contracts may be done on January 31, 1964. The present plan is that six sectors and the main in-line injector will include all information available. Final drawings are in progress for Sectors 1, 2, and 3, and for the Sector 4 variable

FIG. 22--Brisbane Tunnel alignment experiment.

voltage substation electrical. Release of drawings was deferred to permit the inclusion of the fourth cooling water circuit.

3. Vacuum

Layout drawings of the vacuum system for the SLAC machine are underway. A working decision was made to use getter-ion pumps for the primary pumping system, and design is proceeding on this basis.

4. Supports

Accelerator support trunions and end castings were designed. Jack design was under review. Inter-truss connections design is completed, and preliminary design has been started on injector supports.

5. Alignment

Accelerator alignment planning is proceeding on the basis of remote centralized controls using support jack stepping motor drives. Flip-up target enclosure design was incorporated into the support truss end casting detail. A review of space requirements for the alignment light source in the accelerator housing indicates that no special pits or alcoves will be required.

6. Special Material Handling Equipment

It has been determined that modified conventional equipment can be used for handling accelerator trusses, klystrons, and maintenance equipment.

7. Cooling Water

Work in all areas of design of the accelerator cooling water system is proceeding along the following lines:

(a) Analytical work on system transients.

(b) Development of final piping and instrument diagrams. Flow diagrams for the first three sectors will be issued in early April.

(c) Preparation of preliminary layout drawings. The ignitron and waveguide cooling water circuit was divided into two separate circuits to provide an interdependent cooling loop for the ignitrons.

(d) Preparation of piping standards and specifications.

(e) Revision and updating of the cooling water design criteria report.

8. Electrical

The scope of work has been increased to include variable voltage ac services to modulators. Preparation of specifications for a variable voltage regulating transformer which will supply 260- to 600-volt power to modulators is underway.

9. Auxiliary Machine Shielding

The need for auxiliary machine shielding for penetrations, injector stations, access shafts, etc., was explored and a cost estimate prepared, and preliminary studies are underway.

C. ACCELERATOR INSTALLATION

Design work has been completed on the test stands. Final as-built drawings should be available by December 1963. Installation subcontract specifications for electrical services, cooling water connections, and equipment installation were approved by the AEC in February, and installation subcontract work on Test Stands 09, 07, 05, and 03 is underway (see Fig. 23).

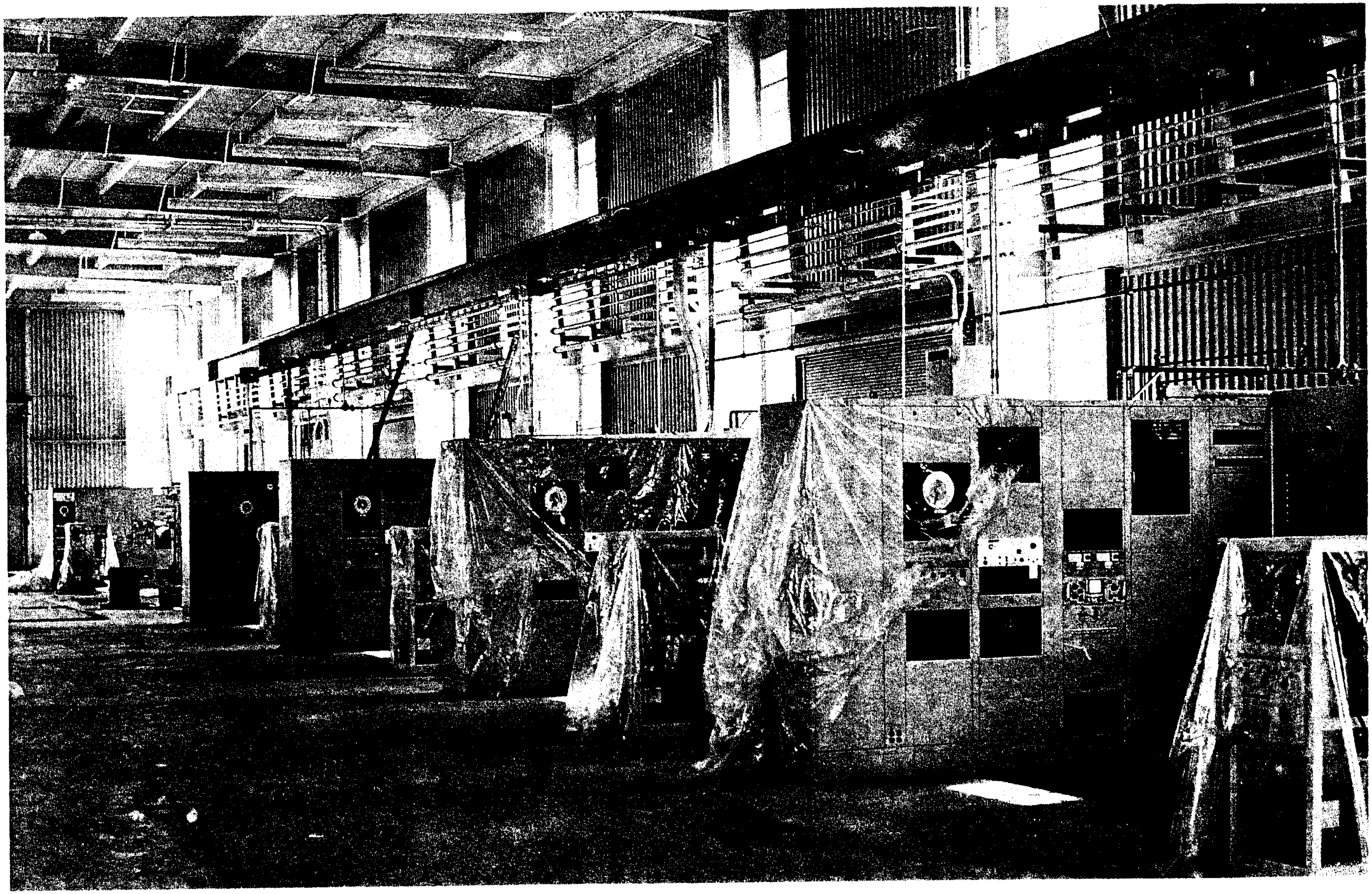

FIG. 23--Initial test stand installation at Test Laboratory.

VIII. INSTRUMENTATION AND CONTROL

A. MODULATOR INTERFACE REQUIREMENTS

An intensive study has been made of the interface equipment between the modulator and the control system. The control of the modulator serves three purposes: protection, maintenance, and operation.

Control of the modulator is accomplished through control of the HV supply voltage, the rf drive and the trigger. Protection is provided against: internal dc fault in the modulator; abnormal (high or low) pulse current in the pulse transformer or klystron; rf breakdown in the accelerator or poor vacuum. Window-protection requires that, after any interruption of one second or more, rf output be restored at a low level and then slowly raised to normal. Vacuum trouble or rf breakdown always initiates this slow reset cycle, thus providing a reasonable recovery time. DC or pulse faults within the modulator normally interrupt service for less than one second; service is then restored at normal level. Closely repeated faults will initiate the longer recovery cycle. If a predetermined number of faults occur in a limited time interval, the modulator is removed from service for maintenance.

The only operational control of the individual modulator is the selection between normal or delayed triggering. Delayed triggering occurs 20 to 40 microseconds after the beam pulse is past so that the klystron is "Off" with respect to beam acceleration, but "On" with respect to average power heating, pulse repetition rate, etc. HV level, trigger rate, trigger delay for beam loading correction, and rf phasing are adjusted for the sector as a whole. RF phasing of individual klystrons is a maintenance routine, not an operational adjustment.

B. RFI STUDIES

Transmission tests have been completed of the shielded balanced multi-paired cable proposed for use for instrumentation and control on the SLAC accelerator. These tests were made at two locations: (a) between the M-1 and M-2 Buildings, and (b) parallel to the Mark III accelerator between its end station control room and its accelerator control room. The measurements obtained indicate that a balanced-pair system is feasible and that the induced noise rejection is adequate. In both environments more than 85 db of isolation was observed.

Eighty percent completion has been reached on a "background" survey and on frequency analysis at six test locations on the SLAC accelerator site for all frequencies between 30 cycles/sec and 3000 Mc/sec. This survey is being made in conjunction with the SLAC Plant Engineering Group and the Space Science Department of Stanford.

C. DATA HANDLING

The evaluation of various data handling concepts being considered for use in the accelerator control system has progressed according to schedule. Different cable and wiring configurations have been tested for induced noise in the operational environment. These tests have been favorable in that they do not preclude use of any of the control techniques presently contemplated. They are not conclusive, however, because the accelerator environment cannot be completely duplicated in the tests. Multiplexing and transmission equipment has been ordered and will be evaluated in the near future.

As a result of the cable tests, it now seems probable that a design involving common sector equipment (sampling techniques) can be utilized for the handling of one-percent dc analog measurements between each sector and central control. This could result in a less costly and more versatile means for handling this type of signal.

An engineering design plan for the operational personnel communication system has been prepared during the quarter. It describes the proposed system from both technical and economic viewpoints.

D. TRIGGER SYSTEM

The amount of flexibility required for triggering the accelerator and the research equipment has been under continued review during the past quarter. The present philosophy is to develop the basic circuits which will be used regardless of the final trigger system design.

Most of the design effort during this quarter has been directed toward meeting test stand requirements. Two master trigger generators have been completed. VSWR monitors and fast protection circuits have been constructed. A trigger generator for the sub-booster modulator, which provides 360 double pulses per second (one normal pulse and one standby pulse after a variable delay), is under development.

E. BEAM GUIDANCE AND MONITORING

The principal effort during the past quarter has been directed toward the design, fabrication, and testing of a beam position measurement system based upon the four-winding sensor developed during the previous quarter. This system has been designed for use on the Mark IV test accelerator to provide data on the performance of the sensor and associated electronics in an accelerator environment consisting of radiation, electrical noise, and operation over long transmission lines (longer than 50 feet).

The above system was tested for two-channel (horizontal and vertical) operation in a laboratory shield box and precision positioning device. The isolation between the horizontal set of windings and the vertical set on the same sensor form is extremely good in the laboratory environment and indicates that four windings can be placed on one form, thus saving space in the drift section of the linac. Tests on the Mark IV accelerator are planned for the next quarter. In addition to the above effort on the beam position measurement system, a four-winding beam position sensor suitable for incorporation in the SLAC linac vacuum structure and radiation environment has been designed in cooperation with the Mechanical Design and Fabrication Group, and the principal parts — ceramic form and metalized ceramic tube — are in the process of fabrication. (The sensor to be used with Mark IV is fabricated of lucite.)

F. BEAM SWITCHYARD INSTRUMENTATION

1. Over-all Design

Most effort was concentrated on the over-all design of the control system for the beam switchyard. The essential beam switchyard equipment was shown in the previous status report.*

It was decided to operate the beam switchyard from the accelerator control room, since a separate control room for the beam switchyard, although economically very much preferred, is unacceptable from an operational point of view.

Layout drawings were made showing all components involved and including reasonably close estimates as to the number, nature, and precision of all quantities that will have to be controlled or observed.

About thirty electronic equipment racks will be needed in the Central Control Room for control and monitoring purposes and about fifteen racks for terminal and data handling equipment. An equal number will be needed in the buildings near the beam switchyard.

This information was used for a preliminary survey of the cost of the data transmission system and the cable plant.

2. The Beam Spectrum Analyzer

Some detailed engineering work has been done on the beam spectrum analyzer. The analyzer will be placed in front of the slit in the energy-analyzed beam.

The analyzer uses a number of secondary emission foils and a common secondary electron collector electrode. This principle was used by R. Helm in the spectrum analyzer for the Mark III accelerator.

The monitor is constructed in two half-sections that may be displaced to leave a gap, equal in width to the slit opening, through which the electrons may pass unscattered. Observing the spectrum edges intercepted by the foils aids the operator in optimizing the spectrum.

The display is essentially a fast electronic scanner displaying the signals from each foil, with the proper sequence, on an oscilloscope. The system is fast enough to display the spectrum on a pulse-to-pulse basis. It will be possible to display the spectrum over a short (gated) part of the electron beam pulse. This gating capability

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*"Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California; p. 61 (March 1963).

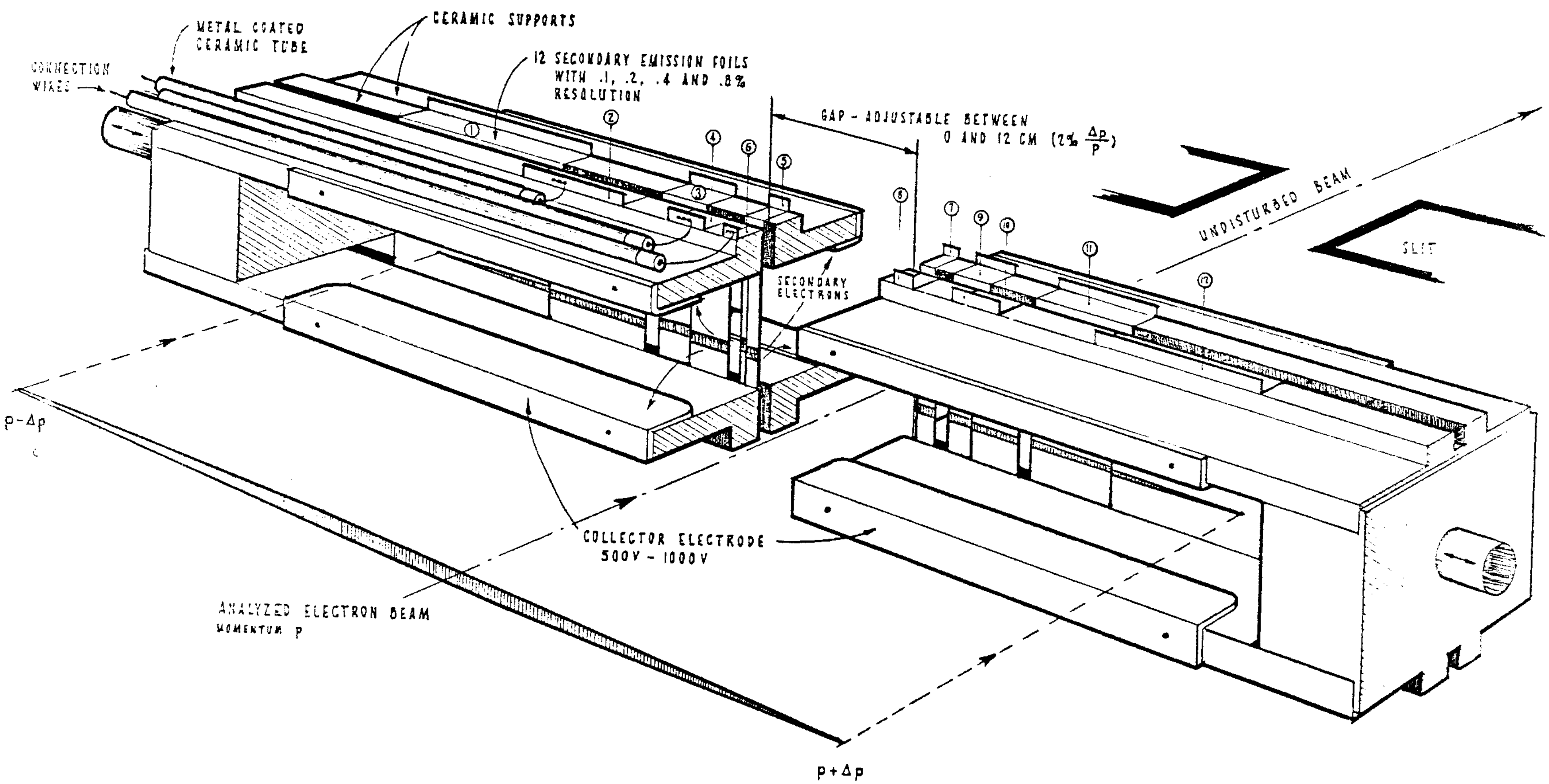

FIG. 24--Beam spectrum analyzer.

makes the analyzer a more useful research tool for the accelerator.

A prototype beam spectrum analyzer is being made and will be tested in the Mark IV accelerator.

G. MEASURING AND ACTIVATION DEVICES

1. Perveance Monitor

This instrument was developed to measure changes in klystron perveance during its 2.5-μsec pulse. The device permits detection of changes occurring over short intervals down to 0.5 μsec.

2. Alignment Electronics

A photomultiplier circuit measures position of interference fringes obtained from a xenon light passing through diffraction gratings. Position modulation enables the operator to locate light intensity peaks with accuracy using first and second harmonics of the modulation frequency. A preliminary experiment in a 1000-foot tunnel shows the signal-to-noise ratio to be more than adequate.

3. Electron Resonance Magnetometer

Design has started of an instrument to use electron spin resonance of DPPH for measurements of alternating magnetic fields to an accuracy of 0.1 percent.

H. TEST STANDS

The Instrumentation and Control racks for the Tree House were moved into place January 25, 1963, and interconnections to all other components for the test stand are essentially complete. Systems tests are now being performed, and as soon as a diode is available, modulator power testing will start.

Five sets of Instrumentation and Control racks were moved into the new Test Laboratory Building on March 18, and Systems tests will start April 18 on the first unit. Fabrication of six sub-booster modulators of SLAC design has been started.

IX. MARK IV PROGRAM

A. OPERATION

The Mark IV accelerator was operated during this quarter, and some experimental work was done. However, most of the effort was expended in shakedown operations, trouble-shooting, and improving the operating power level of the machine.

All operation this quarter was done with the SLAC-type, single output klystrons. In klystron socket No. 1, klystron E-8 was disabled by the beam's burning of a hole in the collector, and was replaced by F-6A. In socket No. 2, klystron E-3A developed a cracked window, and was replaced by E-9A, which had excessive oscillations. Klystron E-14C was then installed, but was put out of service by the breakage of an rf water load which was being used to check the klystron for oscillations. Klystron E-13C was installed and in service at the end of the quarter.

Although many difficulties with the modulators were encountered in running the machine, only one ignitron, in modulator No. 2, had to be replaced during the quarter. This tube was replaced due to internal arcing and excessive misfiring. By the end of the quarter, the comparative experience gained through the use of Ling and RCA modulators was great enough in favor of the Ling that it was recommended that Mark IV's RCA modulator ignitron firing electronic circuits be replaced by the Ling type. These circuits were removed from two Ling modulators, and replacement parts and chassis were ordered.

For protection of klystron windows from breakage caused by too rapid application of rf power output after a shutdown of even brief duration, automatically-operated, air-actuated waveguide flap attenuators were installed in the rf drive lines to the two Mark IV klystrons. These attenuators are nearly exact copies of the type used at the Stanford Mark III accelerator.

Additional klystron window protection was made possible by the fabrication and installation of waveguide elbow vacuum pumpout tees, using sidewall slots, which were placed at the waveguide output of each klystron. The pressure at the klystron window is estimated to have been reduced by at least a factor of four, which is of considerable help in attaining a normal operating pressure below 10^{-6} torr at the window.

During portions of this quarter, the vacuum on this machine was provided entirely by two getter-ion pumps, one at the klystrons and one in the accelerator trench. No particular difficulties were encountered when using diffusion pumps only, getter-ion pumps only, or when using both kinds of pumps together.

Water temperature control of the acceleration sections was provided by the reduced pressure boiling water system, and, later during the quarter, by a blended-water system furnished by the Systems Engineering and Installation Group. Although conclusive tests could not be run, the data obtained at Mark IV confirmed the results of tests run for other SLAC groups, i.e., that either temperature control system appears to be capable of meeting basic requirements for absolute temperature control at different power levels, and for stability of temperature at these levels.

The SLAC Research Division carried on experimentation at Mark IV with secondary emission monitor equipment. This group obtained useful data, and intends to make further use of the Mark IV accelerator as operating time becomes available.

B. FABRICATION OF NEW EQUIPMENT

New pieces of equipment under design and fabrication during this quarter were:

1. Two remotely-adjustable beam sampling collimators, designed for high power handling capability.
2. Three Faraday cups, also designed to handle high power. One cup is for the main undeflected beam, and two others are for use at the outputs of the two beam-bending magnets.
3. Support stands, for acceleration sections, collimators, and other components along the accelerator.
4. Hardware, including a light source, for use in accomplishing and checking accelerator alignment.
5. Vacuum components and mechanical accessories for use in several experiments to be performed at the output end of the accelerator.

C. PROGRAM FOR THE NEXT QUARTER

After completing at least part of the installation work given below, the machine will be turned on for checkout, trouble-shooting, and processing up to approximately full power. Then the investigations and experiments listed can be carried out alternately with the remaining installation work required to perform all of the experiments.

1. Continuation of the work started by the Research Division on secondary emission monitoring devices and on the effects of radiation on materials.

2. Energy spectrum determination by means of sets of secondary emission monitor plates.

3. RF phasing experiments.

4. Particle separation by rf deflection.

5. Beam breakup investigations.

6. Noise pickup on signal cable simulating that to be used on the two-mile machine.

7. Detailed data-taking of water temperature control system performance on acceleration sections.

8. Verification of expected overall beam loading performance characteristic of the accelerator.

9. Checking performance of vacuum systems.

10. Closer determination of rf power handling capability of the waveguides and acceleration sections, especially as influenced by gassing in these components due to both rf power and the presence of an electron beam.

11. Installation in the trench of new Faraday cups, beam sampling collimators, alignment equipment, and support stands.

12. Installation of retainers to prevent overhead shielding blocks from shifting and dropping into the trench during possible earthquake shock.

13. Installation of different electronic firing circuits for the ignitrons in the modulators.

14. Installation of improved water connections and valves for the cooling circuits associated with the klystrons, their focus coils, and the oil tanks. This work will improve the cooling of the klystron collectors, and will also enable a more flexible use of calorimetric

equipment to be made when checking heat balance relations during machine operation.

15. Investigation of beam steering methods, which, it is hoped, will form the basis for the development of routine techniques for establishing a properly steered beam from a completely new set of conditions.

16. Installation of a new injector gun, its associated accessories and electronic equipment, and modification of Mark IV trigger electronic circuitry.

17. Investigation of the performance of the new injector gun system.

18. Further specific improvements on the machine will be made, including:

a. Vacuum system, valves, electronics.

b. Personnel protection against radiation and high voltage hazards by additional interlocks and warning devices.

c. Machine protection against electrical overloads by additional interlocks.

d. Increased efficiency in trouble-shooting and repair, due to improved organization and storage of spare parts.

It is not expected that all of this work can be completed during the next quarter, but it is anticipated that the emergence of Mark IV as a reliably operating, high power machine has progressed far enough that this quarter will see the beginning of the full use of Mark IV as originally envisioned.

X. BEAM DYNAMICS

A study is being made of quadrupole multiplet combinations suitable for focusing the machine at sector intervals. It is expected that such systems will have less severe quadrupole alignment problems than the previously considered system of quadrupoles of alternating sign at 40-foot spacing.*

Four representative multiplet lenses have been chosen for consideration:

(1) Spaced Doublets, each consisting of two equal quadrupoles of opposite sign, separated as far as possible within the 9-foot drift space;

(2) Close Doublets, each consisting of two equal quadrupoles of opposite sign, placed end-to-end;

(3) Spaced Triplets, consisting of symmetrical triplets in which the elements are spaced as far as possible within the 9-foot drift space;

(4) Close Triplets, consisting of symmetrical triplets with the elements placed end-to-end.

The optical properties and space requirements of such systems are considered in SLAC-14.** As expected, these combinations all act very much like circularly symmetric lenses when conditions are compatible with periodic focusing at sector intervals. The space requirements are

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*R. H. Helm, "Discussion of focusing requirements for the Stanford two-mile accelerator," SLAC Report No. 2, Stanford Linear Accelerator Center, Stanford University, Stanford, California (August 1962).

"Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).

R. H. Helm, "Misalignment and quadrupole error effects in a focusing system for the two-mile accelerator," SLAC Report No. 11, Stanford Linear Accelerator Center, Stanford University, Stanford, California (January 1963).

**R. H. Helm, "Optical properties of quadrupole multiplets for sector focusing in the two-mile accelerator," SLAC Report No. 14, Stanford Linear Accelerator Center, Stanford University, Stanford, California (February 1963).

such as to allow adequate space for other proposed instrumentation in the 9-foot drift sections.

In SLAC-15,* some of the alignment and quadrupole-error problems associated with the multiplet systems are considered. Some of the more critical error components may be listed:

(1) Parallel displacement of the multiplet support relative to the accelerator axis. The tolerance for all the multiplets is typically ≈ 0.007 inch (7 mils) rms.

(2) For Doublets, skew, or rotation about a transverse axis, is critical. Typical rms tolerances for displacement of the ends of the doublet relative to the center are 0.73 mil (Spaced Doublet) and 0.52 mil (Close Doublet). (In terms of angular rotations, these numbers are equivalent to 1.8×10^{-5} radian and 3.5×10^{-5} radian, respectively.) For Triplets, the tolerances on this error are larger by two orders of magnitude.

(3) For Triplets, collinearity of the optical centers of the three elements is critical. In terms of transverse displacement of the center quadrupole relative to the outer pair, typical rms tolerances are 0.73 mil (Spaced Triplet) and 0.26 mil (Close Triplet).

Evaluation of these results in relation to operational and alignment problems should lead to a choice of the most favorable system for actual use.

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*R. H. Helm, "Misalignment and quadrupole error problems affecting the choice of multiplet type for sector focusing of the two-mile accelerator," SLAC Report No. 15, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).

XI. RESEARCH DIVISION

A. BEAM SWITCHYARD

1. General

Reports on the beam switchyard have been drawn up and submitted to ABA so that they may prepare a criteria report for submittal to the AEC. Work on general concepts of design has continued on several components of the switchyard, with the general layout remaining as outlined in the previous quarterly status report.* No final selection of criteria for any of the components has been made, but preliminary designs showing the feasibility of certain solutions have been completed. Tentative cost estimates of the total beam switchyard have been made using these preliminary designs.

2. Magnet Optic Systems

Following completion of the basic design of the beam transport systems for end stations A and B, a series of more detailed calculations was begun to study the systems in depth. The alignment tolerances are being recalculated to establish upper as well as lower limits on the errors. The results so far indicate that the strict tolerances on the level of the first quadrupole doublet are necessary, but that many of the other tolerances can be relaxed to varying degrees.

At the time the basic design was completed, not all of the matrix elements describing second-order aberrations were available. The complete array, including the horizontal-vertical coupling terms, has been derived and is being built into TRANSPORT, the computer program which performs the beam optics calculations. This will permit a definitive study of all second-order aberrations in the system.

The possibility of producing a gamma beam with a radiator (10^{-3} to 10^{-5} radiation lengths thick) placed between the second and third bending magnets in the first group was studied. By detuning the first quadrupole doublet it would be possible to obtain a 24 cm by 2 cm gamma beam in the vicinity of

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*"Two-mile accelerator project, Quarterly Status Report, 1 October to 30 December 1962," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).

end station A. The fourth bending magnet in the unit can be moved 7 or 8 meters toward the slit (to allow clearance for the gamma beam) without affecting the optics of the system.

3. Magnets

(a) 3° Bending Magnets

The design for a prototype bending magnet is finished. The water supply tubings to each coil are now based on rubber hoses which have an insufficient radiation resistance; an alternative method using ceramic tubing and metal bellows is out for bid.

(b) Field Lens and Beam Switchyard Quadrupoles

The calculation for the field lens is finished. This symmetric quadrupole has a new type of coil geometry to correct the superposition of the homogeneous field (coil), the quadrupole field, and boundary effects.

The coil insulation is based on glass-fiber tape impregnated with modified epoxy. This insulation was developed at SLAC and can stand an irradiation dose of $\approx 10^{13}$ ergs/gram. All water connections are based on ceramic tubing and metal bellows to give the structure the necessary flexibility.

Calculations for the quadrupoles to be used in the beam switchyard have also been completed; they possess basically the same features as the field lens quadrupole.

(c) Switching Magnets

Calculations have led to a design in which five magnets with laminated cold rolled iron cores of 80 cm are used. The five magnets together give a deflection angle of 0.5° at 25 Bev, and have a gap of 5 cm with a pole width of 12 cm. The poles are shaped to a form to reduce iron losses, and achieve a Q value higher than 100 at 1000 cps.

(d) Pulsed Circuit

The two inductances for the pulser were built and given a Q value of $\approx$ 100 at 1000 cps. The whole pulser has an efficiency of above 90 percent.

4. Steering Magnets

A set of four pulsed and four dc magnets will be placed in the space between the outlet of the accelerator and the switching magnet. The layout of the system is completed.

5. Radiation Problems

In a preliminary attempt to obtain some idea of the irradiation doses that will be hitting the coils, it has been shown that we can expect levels of $\approx 10^{14}$ to 10^{15} ergs/gram/10 years. No organic insulation can take this high an amount of radiation without being completely destroyed. We have built samples of ceramic impregnates and fiberglass tape, but this insulation is brittle and has an initial bonding strength much inferior to epoxy glass fiber.

Before a type of insulation can be decided upon, detailed calculations on how high a radiation level can be expected must be made, and the development of better insulation, either organic or inorganic, will be undertaken when these calculations are complete.

6. Pulsed Magnet

The prototype of the energy recovery coil has been designed and fabricated. Using this coil, which has a Q value of 100, the energy recovery has been measured, and it was found that 90 percent of the input energy can be recovered from each pulse. These measurements were taken with a pulse voltage of 5 kv and a pulsed energy of 100 joules. A program is presently underway to develop a driving circuit for the ignitrons which is capable of operating at a 360 pps repetition rate.

7. Beam Dump, Collimators, and Slits

Several methods of stopping the beam have been studied, and some have been shown to be definitely impossible. Analysis is proceeding on a beam dump composed only of forced-flow water in the high power density region, followed by water-cooled plates in the latter part of the shower.

8. Beam Switchyard Vacuum System

A preliminary design for the beam switchyard vacuum system has been carried out, including the differential pumping system required to make the transition from the 10^{-4} torr vacuum in the switchyard to the

10^{-7} torr region at the accelerator. Provisions have been incorporated to prevent contamination of the accelerator by diffusion pump oil and heavy hydrocarbons present in the switchyard system. Limited studies of the performance of ion pumps evacuating all-metal systems are being performed. The object is to provide quantitative data on the surface desorption of gases from various "good" vacuum structural materials under the action of electron bombardment and ultraviolet radiation. The results will have application to the proposed storage rings and to the beam switchyard vacuum system.

B. MAGNET RESEARCH

1. Quadrupole Program

A program which permits the calculation of exact quadrupole fields with higher harmonics has been tentatively worked out. This program considers the higher harmonics up to 22 and the superposition of homogeneous and quadrupole fields. By choosing an aperture diameter in the quadrupole where the field gradient should be constant within certain limits, the shape of the poletips will be plotted by the program automatically.

(a) Temperature Distribution in Coils

For composed coils, directly or indirectly cooled, a program was worked out to measure the temperature rise in any point of the coils, assuming uniform power distribution in the coil. The result of this program was favorable, and another program using non-uniform power distribution is underway.

(b) Shaping of the Poletips in Magnets

To achieve higher accuracy in determining the effective length of magnets, the iron in the poles has to be shaped in such a way as to avoid saturation effects. The three-dimensional field problem was worked out.

2. Pulsed and Cryogenic Magnets

The specifications for a 300 kj, 5 kv capacitor bank pulse generator have been written. This bank is composed of six units, allowing flexibility in working with short or long pulses. The specifications for a charging power supply of 5 kv and 5 amps have been written. An ADL-Collins Helium-Liquefier for $\approx$ 6 liters/hour of liquid helium is being considered for use in our super-conductive and cryogenic magnet program.

C. MAGNETIC MEASUREMENT INSTRUMENTATION

1. Quadrupole Harmonic Analyzer

A rotating search coil has been developed which can measure a large number of the harmonic coefficients in a quadrupole. This measuring device enables one to determine the contribution of each harmonic to the whole magnetic field. The coefficients of each term are determined by using a Radiometer Wave Analyzer. In a perfect quadrupole only the second harmonic should be present, and even in a poor quadrupole the second harmonic would be very large compared to other harmonics. Therefore, the coil is designed to minimize the second harmonic. If the poles are not equipotential surfaces, the higher harmonics will also contribute. The experiment has been successful thus far, and the harmonics have been plotted out directly on semilogarithmic graphs which show the contribution of each harmonic compared to the second harmonic (quadrupole field) which is constant throughout the aperture of the quadrupole. An important by-product of the work so far is the determination that by minimizing the dipole field, one can locate the magnetic center of the quadrupole to ±0.0005-inch.

Recently a new feed table has been added so that the coil can be positioned accurately in three dimensions in the quadrupole, and further studies of the harmonic content when the coil is positioned in the magnet in three dimensions are now planned.

2. Integrator for Magnetic Field Measurements

A prototype flux integrator for precision magnetic field measurements has been developed. The mechanical and electronic volt-second standards to calibrate the time constant of the integrator have been constructed.

3. Quadrupole Center Locator

An instrument designed to position a vial of suspended ferrite particles in the field of a quadrupole has been tested and modified in design, and improvements are now being fabricated. The entire alignment method, using an alignment telescope to observe the pattern, has been tried successfully. It has been found that the magnetic center of a quadrupole can be determined to within ±0.002-inch with present equipment; new equipment is expected to improve this figure.

4. Calibration of Magnetic Measuring Equipment

We now have equipment for calibration of any magnetic measuring equipment. Calibration equipment consists of a reference magnet with a homogeneous field that can be regulated to 0.001 percent between 1 and 23 kG. Standard measurement of field is made with Nuclear Magnetic Resonance Integrator. All of our magnetic measuring equipment has been calibrated.

D. THEORETICAL PHYSICS

Publications by Drs. Berman, Lichtenberg, and Noyes completed during this period are listed below. One of these (Ref. 1) shows that an optimum arrangement of stacked metal disks requires too large a spacing and hence too long a structure to be used as a practical beam stopper. Work has also been completed on two papers by Dr. Berman entitled, "Speculations on the production of vector mesons," and "Coherent production as a means of determining the spin and parity of bosons," which will be submitted for publication.

The analytic calculation of the differential cross section for the photoproduction of weak vector meson pairs, i.e., $\gamma + p \rightarrow W^{+} + W^{-} + p$, has been completed, and the very complicated expression is in complete agreement with an independent calculation made by Y. S. Tsai of Stanford University. The total cross section will be computed by numerical integration, and coding for this purpose is now in progress.

The question of the meaning of higher order effects in weak interactions investigated previously* has been reopened because of recent results obtained by Feinberg and Pais and is again under study.

*S. M. Berman, in Proceedings of the International Conference on Theoretical Aspects of Very High Energy Phenomena, CERN Report No. 61-22, Geneva, Switzerland (August 11, 1961).

Detailed comparison between the fits to p-p scattering data between 10 and 380 Mev obtained by Stapp, Moravcsik, and Noyes, and corresponding fits obtained by the Yale group using quite different techniques, is now in progress; it is hoped that this will isolate differences due to procedure from differences due to data selection, and also serve as a guide for proposing new nucleon-nucleon scattering experiments in those energy regions which remain ambiguous.

LIST OF THEORETICAL PHYSICS PUBLICATIONS

1. D. B. Lichtenberg, "Radiant heat transfer from parallel disks," TN-63-16, Stanford Linear Accelerator Center, Stanford University, Stanford, California (February 1963).
2. D. B. Lichtenberg, "Heavy mesons and excited baryons," SLAC Report No. 13, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1963).
3. S. M. Berman and R. J. Oakes, "The vector theory of strong interactions and nucleon-antinucleon annihilation," (submitted to Nuovo cimento).
4. D. B. Lichtenberg, "Classification of mesons in a compound model," Nuovo cimento 27, 860 (1963).
5. D. B. Lichtenberg, "A possible method to obtain evidence on the spins and parities of excited baryons," Phys. Letters 4, 73 (1963).
6. H. P. Noyes, "n-p scattering below 20 Mev," (to be published in Phys. Rev. June 1963).

E. SHIELDING AND HEALTH PHYSICS

We have begun a collaboration in a shielding experiment with Dr. C. Passow at DESY, Hamburg, Germany. Nuclear plates embedded in iron have been exposed to a beam at 20 Gev/c pions. Enough plates were exposed to trace the attenuation of the particles both laterally and in the beam direction. The exposures were excellent, and the scanning is proceeding well.

Instruments have been ordered that will permit complete neutron surveys in the fast and medium energy ranges. These will be used at present at the Mark IV accelerator.

The shielding necessary for the injector test station was calculated.

F. PHOTON AND ELECTRON EXPERIMENTAL AREA

It has been proposed that a low intensity photon beam be created by putting a very thin radiator in the path of the electrons on the way to experimental area A. This beam would be at a $6\text{-}1/2^{\circ}$ angle to the direction of the electrons in the accelerator.

It has also been proposed that two electron beams be created for area A, utilizing in part for the second beam the magnets that deflect the electrons to the beam dump.

Work is continuing to define the characteristics of these beams more specifically and to estimate their costs. If feasible, they would greatly enhance the experimental capabilities of the machine.

G. RF SEPARATORS

Preliminary cold-test measurements of a deflecting structure have been completed. Fabrication of a 1/2 meter by 4 cm structure has commenced. Closed circuit TV has been installed at Mark IV to view the deflection produced by the 1/2-meter structure. Evacuated drift tubes and other auxiliary equipment necessary for the performance testing of the deflector have been constructed and are ready for installation on the Mark IV accelerator.

H. MAGNETIC MOMENTUM SLIT

The experimental program of measurements on the magnetic momentum slit has been completed.

Dr. B. Hedin, visiting from CERN, has designed a model of a slit which does not require any pulsed currents and produces essentially the same shape of magnetic field as does the original slit.* This design eliminates the need for a very high current pulsed power supply.

The field in the neighborhood of the gap (2 cm width) is shown in Fig. 25 for the central plane and for 0.2-inch and 0.3-inch above this plane, respectively.

A comparison of the results for the current strip model and Hedin's magnet is shown in Figs. 26 and 27 for the symmetry plane and 0.2-inch above this plane, respectively. An examination of Fig. 27 shows that Hedin's magnet has a sharper slope but more pronounced "wings" or field reversals than does the current strip magnet. In terms of "practical" use the two magnets appear equivalent, but a calculation of the emerging beam has to be done before a final comparison can be made. The two would be made almost exactly equivalent by blocking out the electrons appearing in the transition region between constant field and zero field.

The use of Hedin's magnet as a slit is shown in Figs. 28, 29, 30, and 31, which give the field plots for slit widths of 0, 1, 3, and 4 cm, respectively.

Work remaining to be done on this slit is the computation of the orbits of the electrons after leaving the slits, and the calculation of a final system using magnetic momentum slits.

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*See for reference "Two-mile accelerator project, Quarterly Status Report, 1 July to 30 September 1962," SLAC Report No. 8, Stanford Linear Accelerator Center, Stanford University, Stanford, California (November 1962); and SLAC Report No. 10, op. cit.

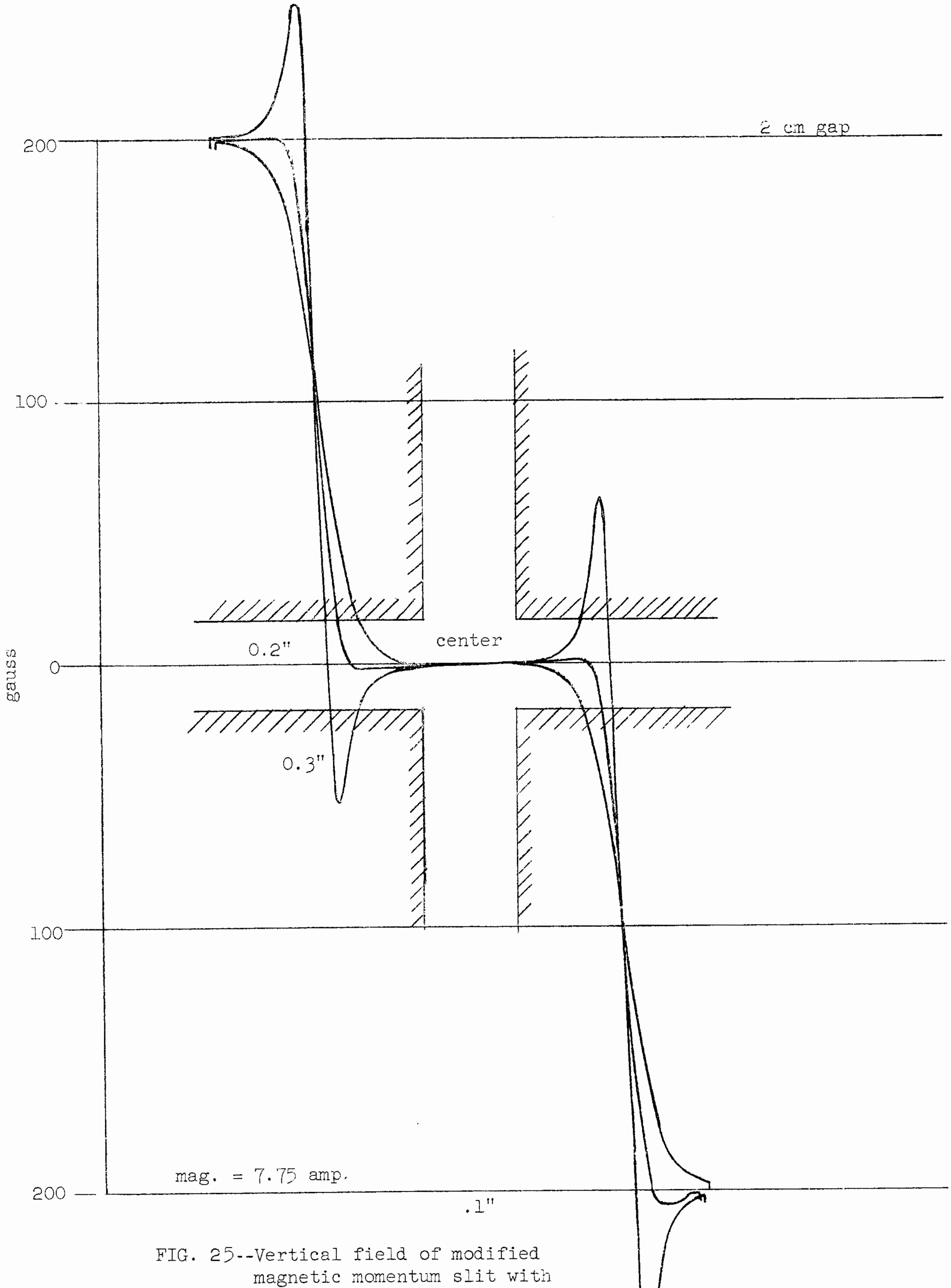

FIG. 25--Vertical field of modified magnetic momentum slit with a 2-cm gap.

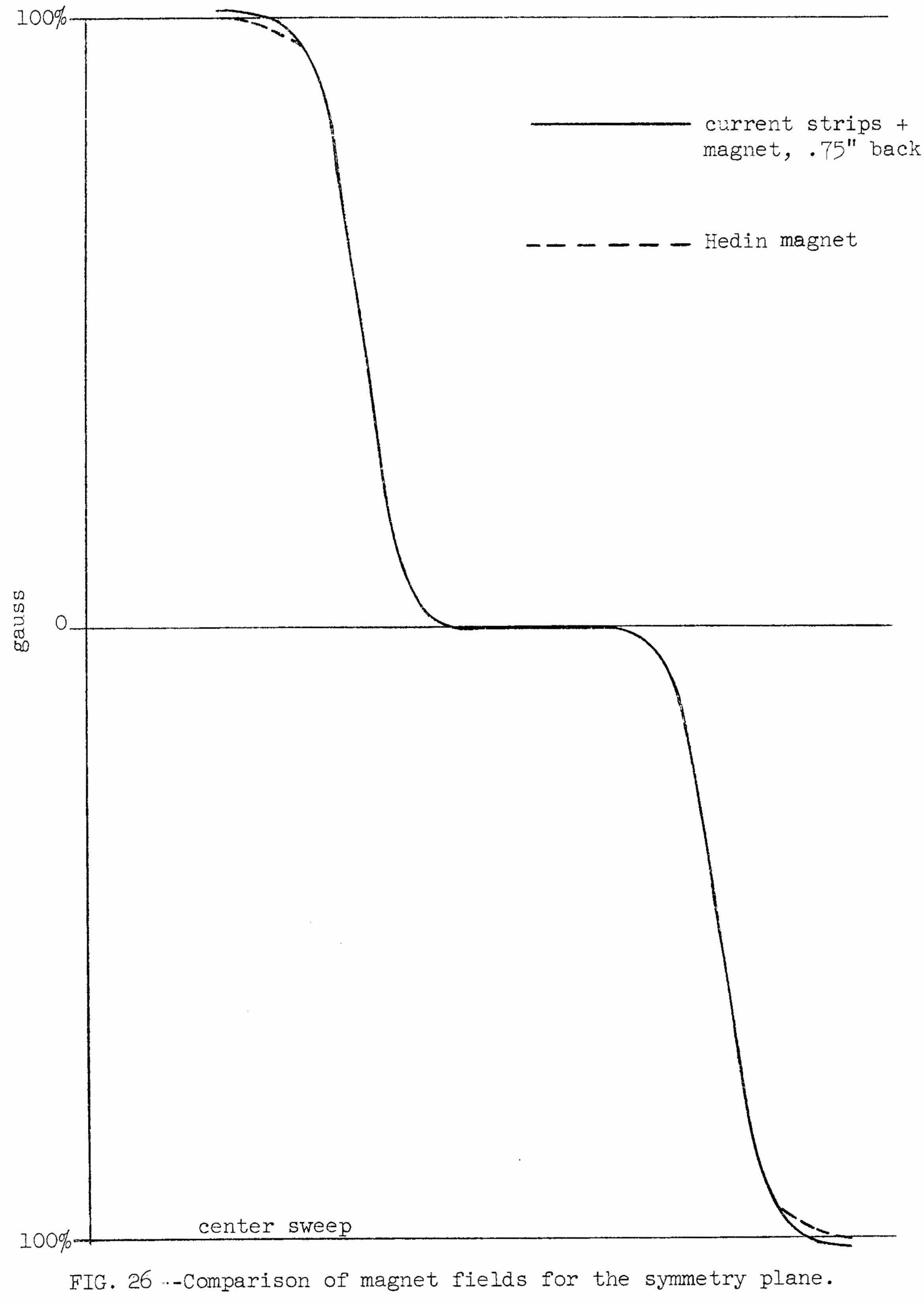

FIG. 26 --Comparison of magnet fields for the symmetry plane.

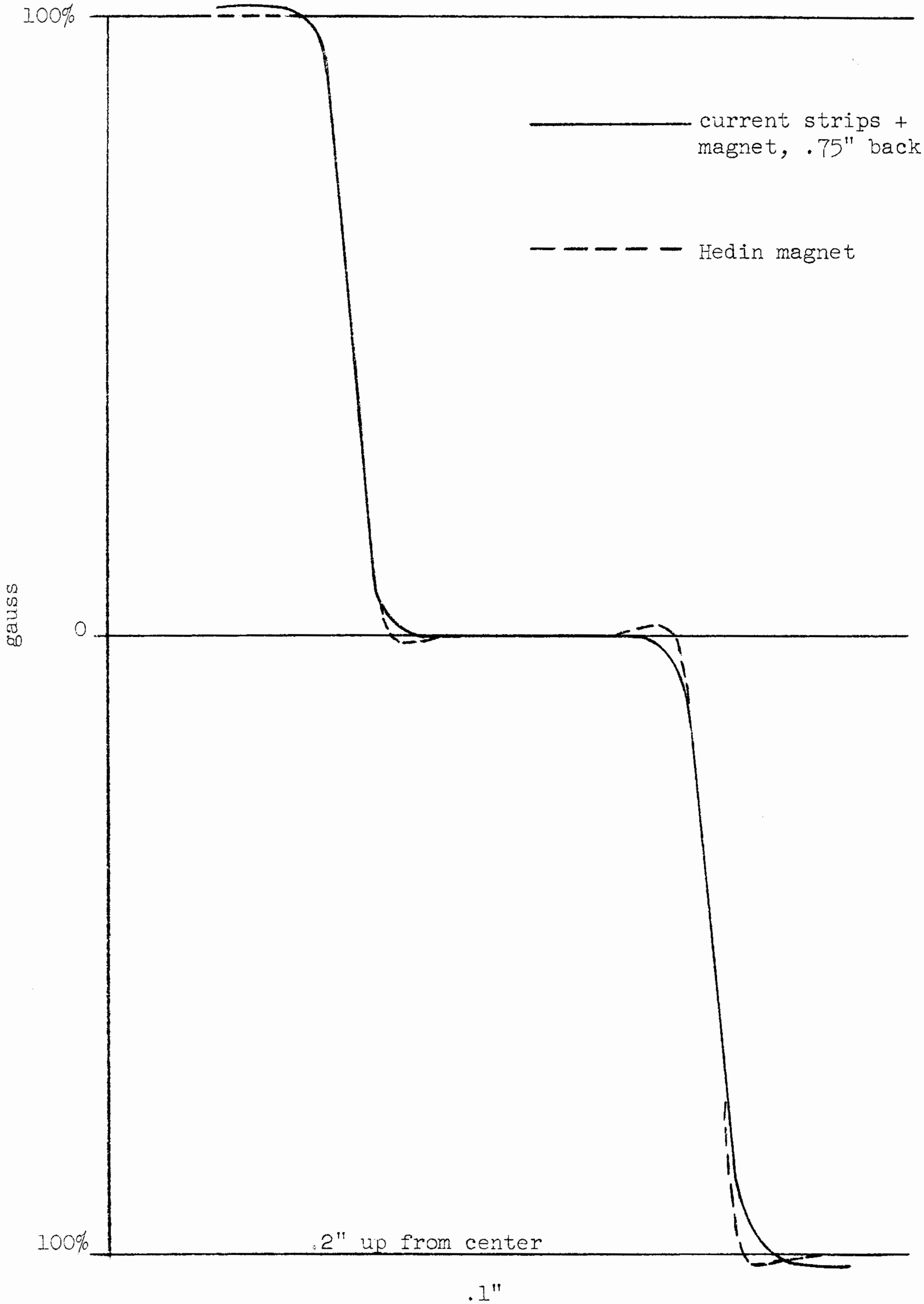

FIG. 27 --Comparison of magnet fields for 0.2 inch above the symmetry plane.

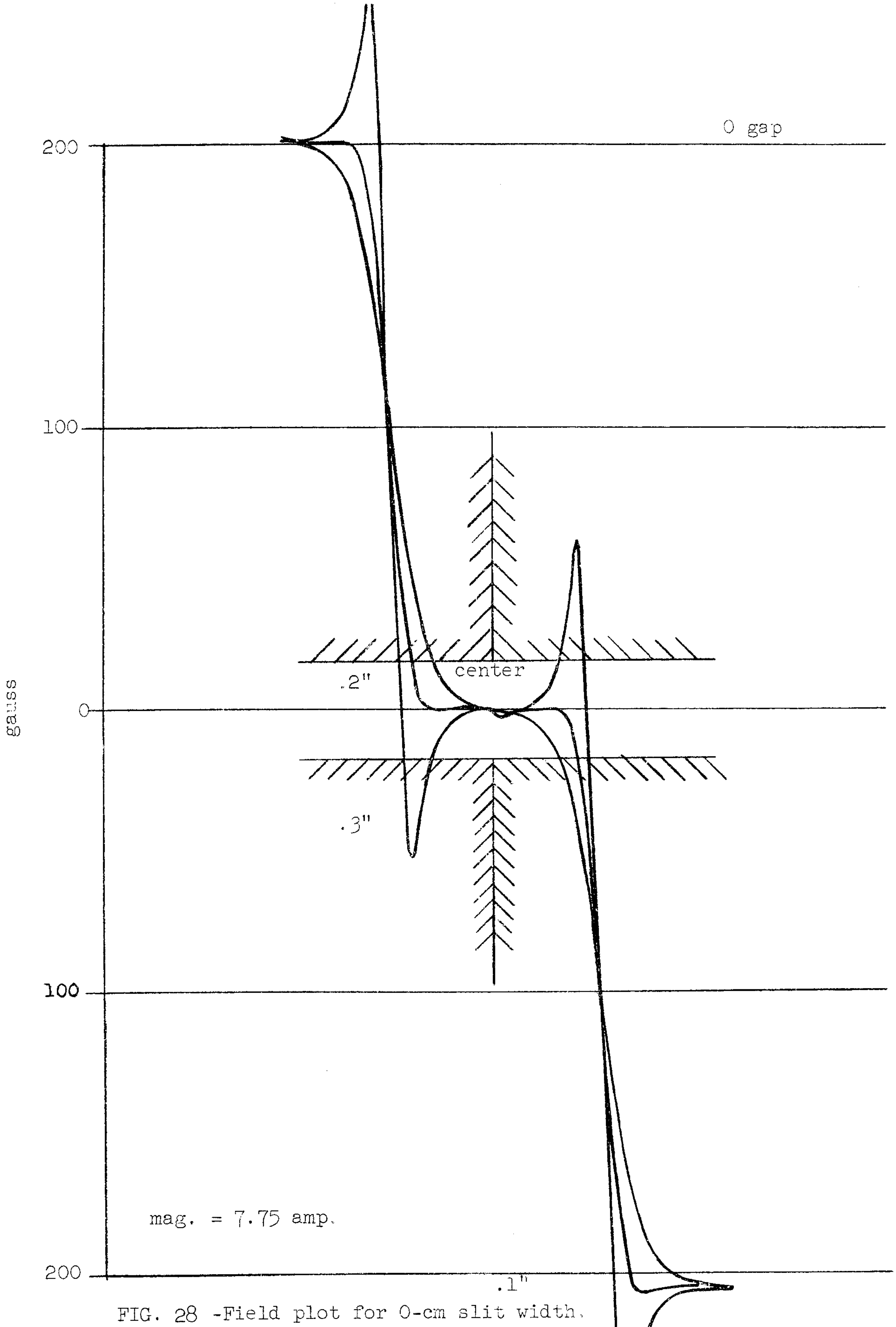

FIG. 28 -Field plot for 0-cm slit width.

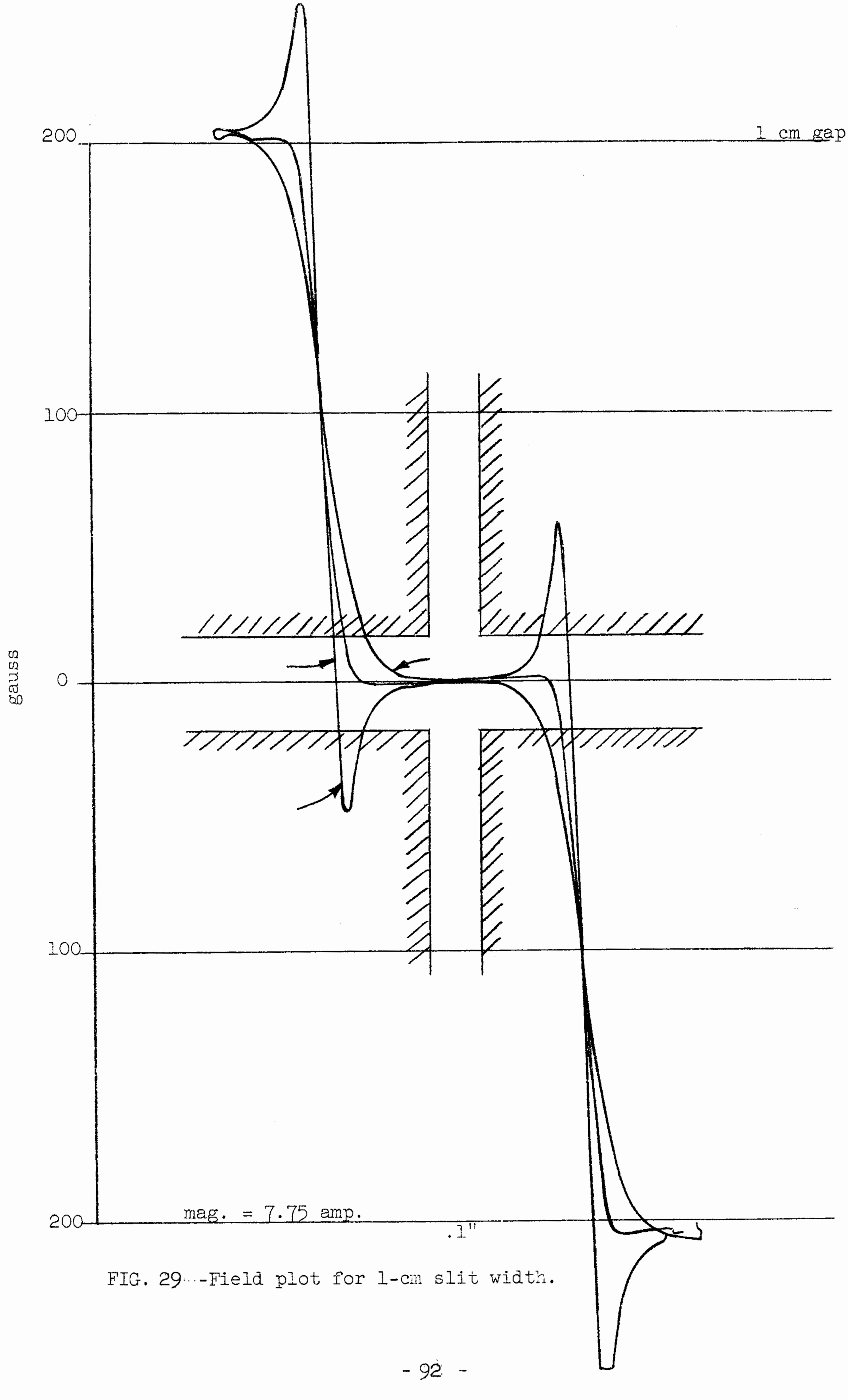

FIG. 29--Field plot for 1-cm slit width.

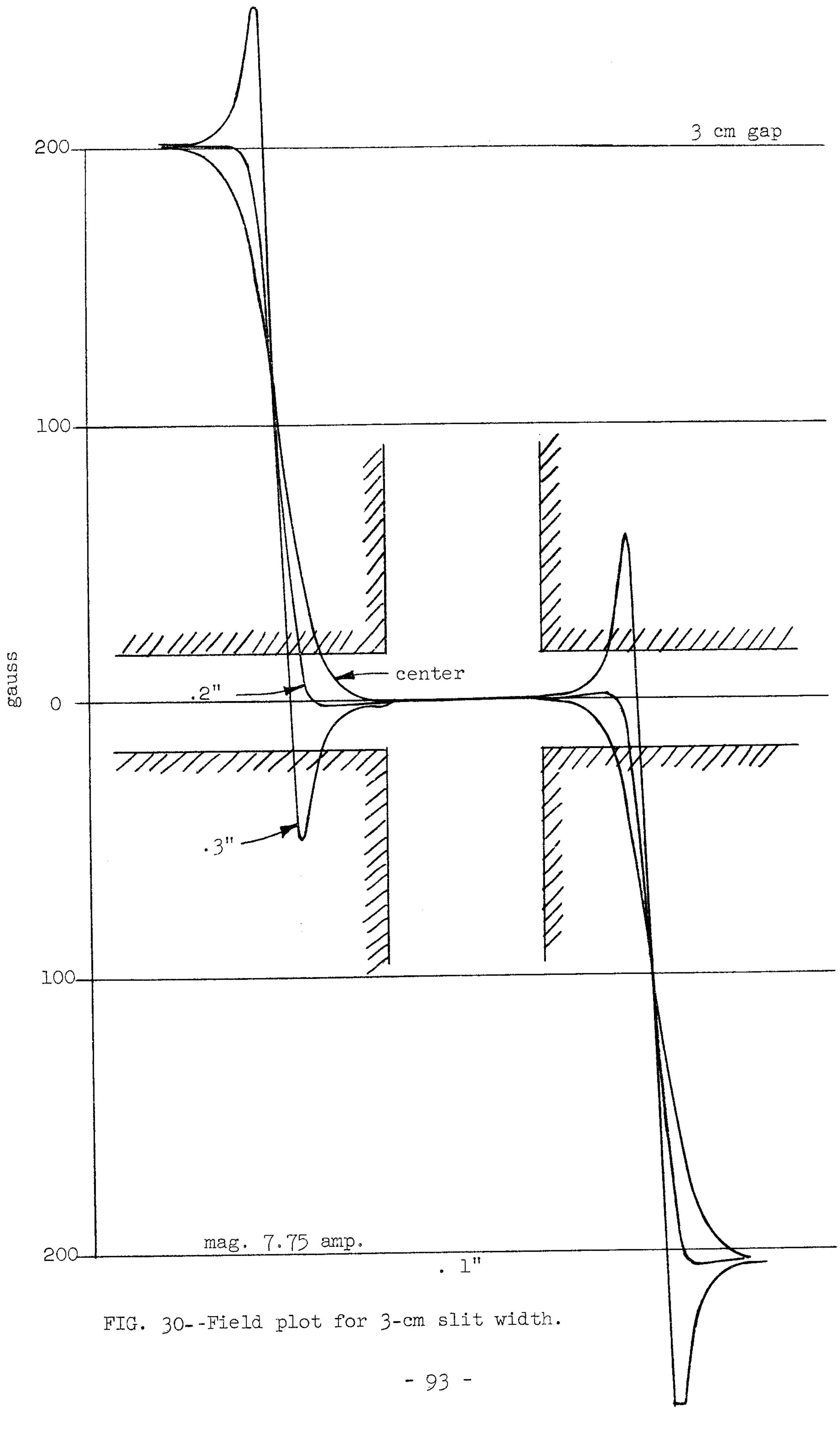

FIG. 30--Field plot for 3-cm slit width.

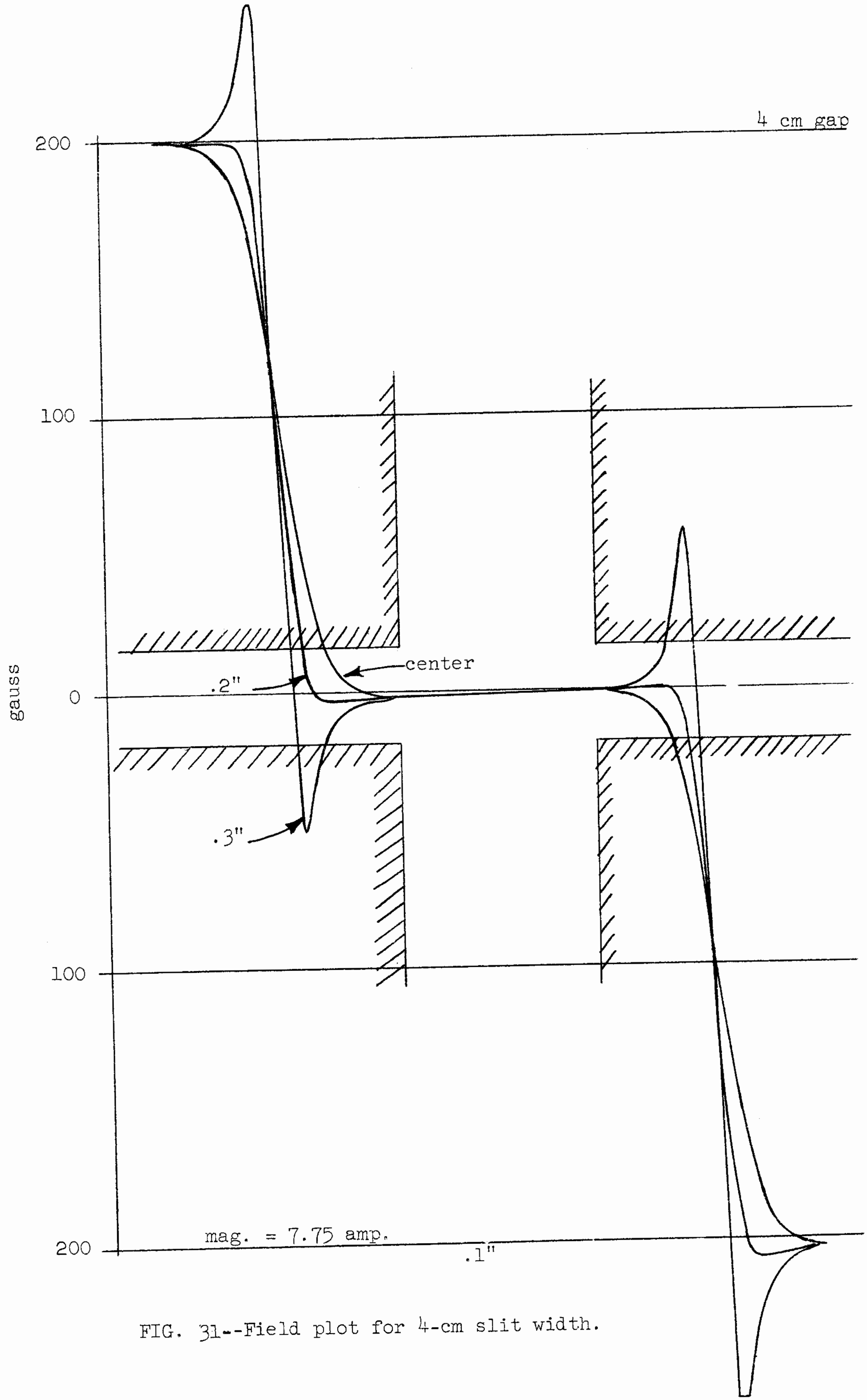

FIG. 31--Field plot for 4-cm slit width.