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TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 July to 30 September 1962

November 1962

Technical Report
Prepared Under
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for the USAEC
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1. K. G. Dedrick, "Kinematics of high-energy particles," Rev. Mod. Phys. 34, 429 (1962).

I. INTRODUCTION

This is the second 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 elctron 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. MARK IV PROGRAM

A. GENERAL

The experimental program of the last quarter on the Mark IV test accelerator was continued for one month into this quarter. Enough experimental data were collected to satisfy the immediate needs of the technical groups, and the machine was shut down to make the changeover to the RCA modulators. During the succeeding two months the old modulator and power supply were removed, and the new equipment was brought in and installed. It is expected that the machine will be in operation again early in November.

B. SYSTEM PERFORMANCE

As stated in the previous Status Report,[1] the klystrons were reconnected to the accelerator to permit resumption of the experimental work referred to above. The amount of power increase achieved was substantial, but other than showing the ability of the constant-gradient accelerator structure to handle up to about 16 Mw peak rf power, no great additions to experimental knowledge were gained by the increase in power. Otherwise, the machine was operated under the same conditions as before the power increase.

The Microwave Engineering Group set up for and ran experiments on the current-variation-detection method of phasing. Semiconductor Hall-effect magnetic-field detectors were studied by the Beam Switchyard Group as the output electron beam of the machine was passed through the detectors. A monitor of beam-induced pulse voltage was installed by the Instrumentation and Control Group, and observations were made. A brief experiment was run, which indicated a considerable increase in capture of injected beam current because of the use of the prebunching cavity previously installed.

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[1]Status Report, SLAC Report No. 1, Stanford Linear Accelerator Center, Stanford University, Stanford, California, July 1962.

C. INSTALLATION OF NEW EQUIPMENT, AND GENERAL MACHINE WORK

The major pieces of new equipment are the two RCA modulators, each accompanied by a high-voltage dc power supply, an induction variable-voltage regulator, and a power control cabinet. Two tanks, one for each of the two klystrons, were designed and fabricated. The klystrons previously used were removed, and focus-coil and waveguide arrangements were made to accommodate the use of RCA klystrons delivered to the project under the klystron developmental contract. The RCA klystrons are double-output types, but the waveguide connections were designed to permit a simple changeover to the SLAC single-output klystrons under development and construction.

The Faraday-cup reduced-pressure boiling-water system was fabricated and partially installed, awaiting delivery of the Faraday cup itself (probably early in December).

The recording-type ac line voltmeter was received. It was connected to a 120-volt circuit, and so far it has indicated very good constancy of the 120 volts over several weeks of continuous running.

Temperature recorders and sensing elements for water-system use were received but have not as yet been installed.

Actual installation work has required heavy wiring runs for 480-volt three-phase circuits; 208/120-volt ducts; cable trays and cable for control, interlock, and instrumentation; interlock placement; fabrication of support brackets and high-voltage barriers; console wiring, etc. A backlog of control, interlock, and instrumentation work had accumulated up until the shutdown, and this was substantially reduced during the quarter.

D. PLANS FOR NEXT QUARTER

During the next quarter it is expected that the machine will be operated primarily for the purpose of obtaining high-power performance data on these major components: the modulators, the accelerator structures, and the klystrons. Other experiments are also expected, such as further runs on the Hall-effect magnetic-field detectors, rf phasing, beam-location and beam-induction devices, and injection studies.

As the beam hardware is completed it will be installed as operating schedules permit, and these components will make possible the use of the machine for obtaining basic data on beam performance under many different controlled conditions.

III. ACCELERATOR STRUCTURE

A. DISK-LOADED WAVEGUIDE

The decision has been made to freeze the rf design of the disk-loaded waveguide. The structure is to be constant-gradient, operating in the $2\pi/3$ mode, with a disk thickness of .230 inch. The attenuation parameter has been set at 0.57 neper, and the phase velocity is to be equal to c.

The constant-gradient electric field is achieved by varying the group velocity in a prescribed manner. However, "true" constant-gradient operation is only possible at one specific value of electron beam current. It has, therefore, been decided to set the group velocity variation such that constant-gradient operation occurs at 25 milliamps peak current for Stage I and at 50 milliamps peak for Stage II. This corresponds to a v_g/c for a 10-foot section of approximately .0204 at the input and approximately .0065 at the output.

While the thin-disk (.120 inch thick) constant-gradient design gave an energy improvement approaching 5% over the selected design, it was rejected because of the smaller minimum beam aperture of the disk. The minimum hole size in the thin-disk design is approximately .67 inch, as compared to a minimum hole size of approximately .77 inch in the .230-inch thick-disk design. The smaller beam aperture for the thin-disk was deemed less desirable than the slight improvement in energy obtained from it.

It is possible to make a modified thin-disk structure that would have an essentially uniform beam aperture in each disk. However, these results cannot be obtained unless the disk has a variable contoured thickness in the region of the hole. Such a disk design lends great complexity to the structure and results in a design for which there has been no previous high-power or heat-transfer experience. It has therefore been judged undesirable to pursue the contoured disk idea.

1. Accelerator Structure Tuning

A design for a vertical tuning mechanism has been completed, and procurement of components is under way. When complete, it appears that the unit will make it possible to tune a 10-foot accelerator length in four hours or less.

A decision has been made to tune the accelerator section at the operating temperature. Hence a constant-temperature water source for use during tuning has been completed. The unit is capable of controlling temperature to within 0.1° F anywhere in the range from 80° F to 130° F.

2. High-Power Testing of Accelerator Sections

The test stand was placed in operation during this report period. Preliminary tests have been run on two 10-foot accelerator sections, one a uniform section, and the other a constant-gradient section. A peak power of 15 megawatts at full duty cycle (360 pulses per second) was applied to both sections. In addition to testing the modulator and other components in the test setup, these preliminary tests have demonstrated that it is possible to achieve satisfactory operating pressure after only 4 to 8 hours of rf processing on an "as fabricated" section of disk-loaded waveguide. These results, while inconclusive, tend to confirm the expectation that it will be unnecessary to vacuum-bake the disk-loaded waveguide.

When complete, the high-power tests will provide data on the "gas burst" behavior and the type of gas evolved, as well as on the rf behavior of the disk-loaded waveguide. Further, the test will be used to check water-jacket design.

3. Water Jacket

The full-scale constant-gradient accelerator section mockup was re-instrumented, and water-jacket heat-transfer and water-flow tests were continued on the counterflow arrangement. The tests indicated that two effects were largely responsible for the temperature non-uniformities observed. The first of these was the non-uniform contact between the cooling tubes and the accelerator mockup. The second was the unequal flow distribution through the cooling tubes. A new accelerator mockup, in which the contact between cooling tubes and accelerator section is much more uniform and in which the cooling-tube flows will be balanced, is currently being readied for test.

A small-scale test, in which a single tube of the longitudinal-cooling-tube type of water jacket can be tested, was set up, and several test sections tested. The tests were set up to determine the magnitude of the thermal-entry length of a cooling tube and its effect on the accelerator wall temperature. The temperature was found to drop off about 1° F at the inlet end of the cooling tube. Ways of eliminating this temperature drop, such as by tube tapering or by continuously interrupting the boundary layer, are being considered and will be tested in the small-scale test rig. Test results from the small-scale test sections were also used to help verify the suspicion that the temperature non-uniformities observed in the full-scale tests were due, at least in part, to non-uniform contact.

B. HIGH-POWER WAVEGUIDE COMPONENTS

1. Waveguide Vacuum Valve

Effort in the past quarter has been primarily on evaluation of the high-power performance of the waveguide-valve structure. The first test was conducted with a valve body that was operated as a resonant cavity, and this test indicated that the valve structure could handle at least 50 megawatts (based on a very conservative estimate of R/Q) with no visible breakdown in the drive line. The power limit was taken as the power level coinciding with the onset of a high X-ray field, which was measured externally.

The second test was performed on the SLAC high-power ring with a complete valve assembly. Problems were encountered with arcing between the moveable valve head and its open-position seat. The arcing was intermittent, and with no seat-arcing the valve handled up to 40 megawatts. Work is proceeding to correct this arcing problem.

Facilities for processing indium and experimenting with the vacuum seat for the valve are essentially complete.

2. Phase Measurements

In Stage I the output power of each klystron will be divided into four equal parts to feed four successive 10-foot sections of disk-loaded waveguide. It is important that the electrical phase length of these paths be identical within ± 1°, or some multiple of a guide wavelength. To achieve this goal, plans have been made to test each component to be incorporated in the waveguide runs prior to installation. Studies have shown that slight deviations in one waveguide bend as compared to another will cause large phase changes, particularly with H-plane bends. These deviations must be compensated for by mechanical adjustments of the bends. As the various bends, power dividers, and waveguide lines are fabricated together, electrical phase measurements will be used as a quality-control test for acceptance. These production tests by themselves will not insure that the path lengths mentioned above are within ± 1°, however, because variations in tightening the waveguide flanges or the stresses caused by slight misalignment will cause a greater error than this. Accordingly, phase tests and final adjustment must be made with the waveguide lines in place between the klystrons and the disk-loaded waveguide.

The proposed technique for these tests allows phase measurements to be made at the operating frequency. This is desirable since most of the waveguide components will be narrow-band, and the reflection phase variation between one accelerator pipe and the next cannot be held to better than a few degrees outside the pass-band. Phase measurements and subsequent adjustments will be made in three steps over each 40-foot subsector. The first step will consist of feeding a test pulse signal at the klystron input to the first power divider and then monitoring the pulse returns from shorts placed in the other two power dividers fed from the co-linear arms of the first power divider. The return signal at the first power divider, as viewed on a sampling scope, will then be adjusted to be below a specified amplitude by appropriate phase change (probably by squeezing) of either one of the co-linear feed arms of the first power divider.

Adjustment of the two pairs of paths from the second and third power dividers to the accelerator pipes will then proceed as follows. The test pulse will again be fed into the first power divider; however, the return signals from the accelerator pipe will be monitored, in turn, at the load ports of the second and third power dividers. By adjusting the length of the appropriate co-linear arm of the second power divider, the phase length of the first path pair will be corrected by obtaining a specified minimum signal on the scope. Similar measurements and adjustments will be made at the third power divider to adjust the second path pair. The adjustments will be achieved by tuning the waveguide by permanent slight deformations in the waveguide wall.

In order to obtain a sufficient return amplitude from the accelerator sections at their design frequency, a pulsed test signal that is short compared to the filling time will be required. The proposed technique will use a cw signal source whose output is amplitude-modulated by a diode modulator. The resultant test pulse will have a 10-nanosecond rise time and a duration of 100 nanoseconds at approximately 200 pulses per second.

A simulated system has been set up to obtain a preliminary evaluation of this technique. The setup consisted of using a single hybrid with its co-linear arms feeding two constant-attenuation pipes. By the use of phase shifters in both arms, a null was achieved. A precision phase shifter in one of the arms was then adjusted until the display on a sampling scope just gave a noticeable indication on either side of the null. This incremental phase change was measured to be 2.18°.

3. Waveguide Flanges

The techniques of "cover-cover" or "cover-choke" flange connections used in pressurized waveguide systems are not applicable in high-power vacuum systems. In the SLAC system a vacuum of 10^{-7} torr is to be maintained. No organic seals may be used because they deteriorate rapidly in the presence of radiation. These restrictions in turn create another problem in maintaining electrical continuity across a flange interface at the high peak and average power levels required. The criteria for the flanges are that they use a replaceable metal gasket, provide a reliable vacuum seal, and provide electrical continuity at the rf power levels under consideration.

At present, a so-called "Merdinian flange" is in use. This flange, shown in Fig. 1, is of the crush-and-shear type and (as with all others to be considered) is made from 304 LC stainless steel and uses an OFHC copper replaceable gasket. The advantages of this flange are:

(1) It provides an rf seal around the circumference of the mating waveguides.

(2) It is a compact design.

(3) Since it is already in use on the project, performance and life data are available.

Among the disadvantages are:

(1) The broad wall of the male flange tends to bow and to take a permanent set, thus limiting the number of seals one can obtain from each flange set.

(2) Because of its configuration the flange must be made by milling in order to maintain sharp, clear edges; this milling operation characteristically puts tool marks normal to the shear edge, thus providing vacuum leak paths.

(3) The operation of eliminating the tool marks in (2), by blowing glass beads against the surface, also dulls the important shear edges.

(4) The pressure exerted on the copper gasket is not uniform throughout its circumference.

(5) The flange is a complex design and is costly to produce.

Some modifications to the basic Merdinian flange were made to eliminate some of the disadvantages, and a straightforward simplification led to the flange shown in Fig. 2. The advantages of the modified flange are: (a) the shear edge is exposed and can be lapped to improve surface finish while simultaneously sharpening the shear edge; (b) the bowing of the broad wall of the male flange is reduced; and (c) the design is less expensive.

Vacuum tests on flanges modified as above were made with 20 annealed and 20 non-annealed copper gaskets. The annealed gaskets provided a better vacuum seal at lower torques than the non-annealed, while the reverse was true at higher torque levels. The annealed gaskets tended

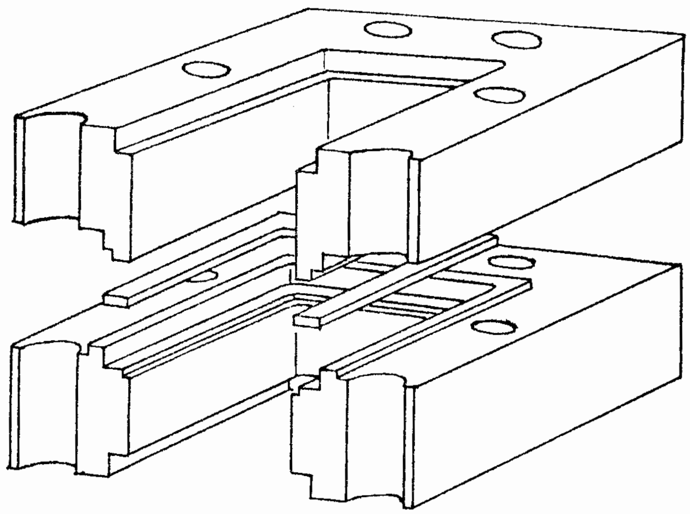

FIG. 1--The Merdinian flange.

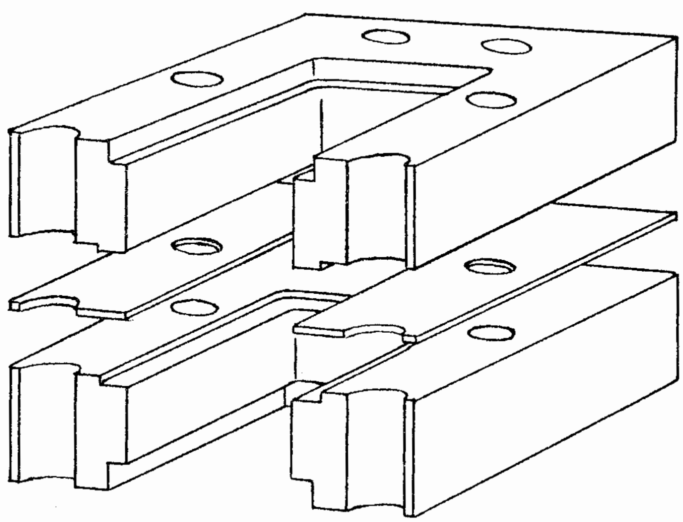

FIG. 2--Modified Merdinian flange.

to open up at the higher torques when used in these flanges.

A second approach is shown in Fig. 3. This circular flange incorporates a simplified shear edge and also provides: (a) a more uniform pressure along the shear edge by making it circular in shape; (b) a further reduction in bow of the broad wall; and (c) a simpler design throughout. This design is undergoing tests at the present time.

The third approach is a circular flange, as shown in Fig. 4. The circular shear edge bites into the soft copper gasket, providing the vacuum seal. The copper gasket also provides rf continuity. Several gasket configurations (shown in Fig. 5) are under consideration from an rf point of view.

Pertinent test data for these gasket configurations in Fig. 5 are given in Table I.

TABLE I

GASKET CONFIGURATIONS

Configuration	Low Power	Vacuum Test	High-Power Test	Remarks
(A)	1.02 VSWR (f_o ± 100 Mc)	10^{-6}mm Hg	No breakdown up to maximum level of recirculator: 85 Mw peak and 35 kw average	Used in flange shown in Fig. 3
(B)	1.02 VSWR (f_o ± 100 Mc)	10^{-6}mm Hg	Test to be made	Used in flange shown in Fig. 3
(C)	1.02 VSWR (f_o ± 100 Mc)	10^{-5}mm Hg	No breakdown at 85 Mw peak	Gasket placed between O-ring flanges in resonant ring

Note: Present upper power limit of resonant ring is approximately 85-90 megawatts peak.

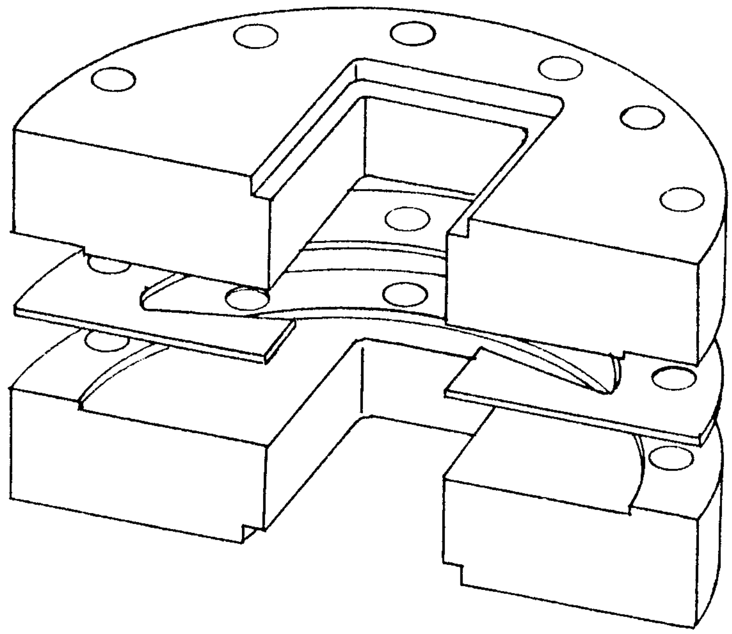

FIG. 3--A stepped-type waveguide flange.

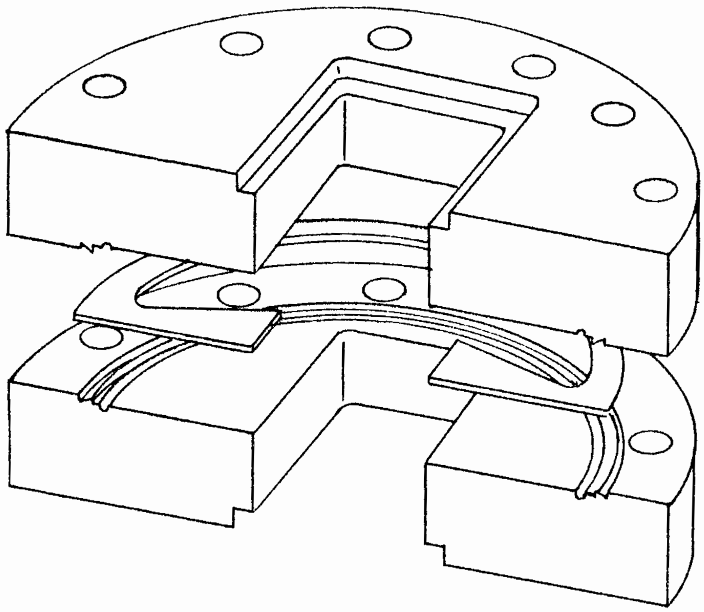

FIG. 4--Conflat-type waveguide flange.

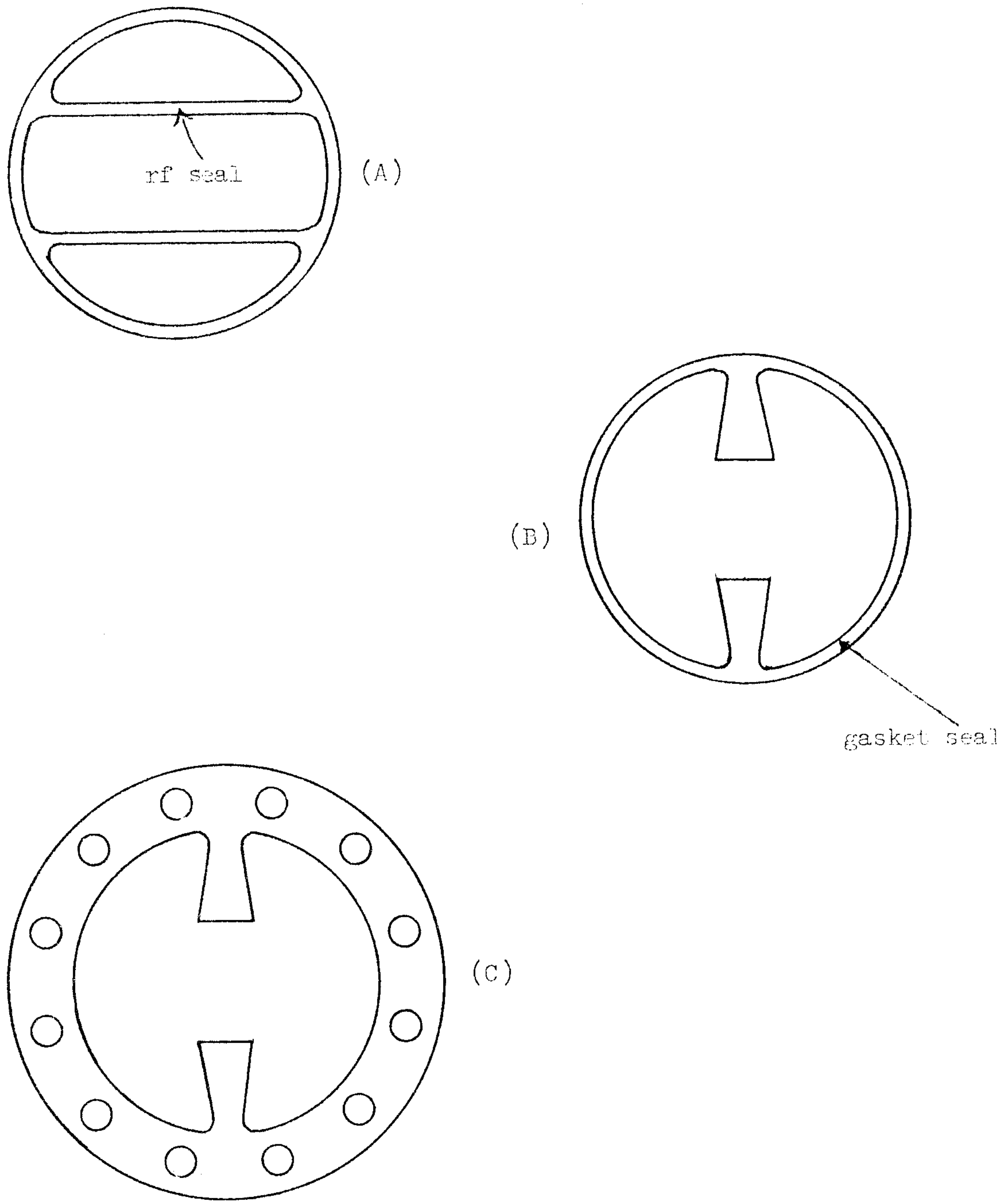

FIG. 5--RF vacuum gaskets.

4. Dummy Loads

Ceramics are on order for the load mentioned in the last Status Report[2] but have not yet been received. A hydrogen bell jar for processing carbon-loaded ceramics has been set up ready for use. Several other dummy-load approaches are also being studied. One of these uses a transition from the TE_{10} rectangular to the TM_{01} circular mode to take advantage of the higher wall attenuation per unit length provided by some higher order modes. The circular waveguide wall will be fabricated of 410 magnetic stainless steel in bellows form to provide as much surface area in as short length as practical.

Another dummy load, designed by Professor Sonkin, utilizes a TE_{10} rectangular to TE_{11} circular mode transducer. Within the circular guide region a hollow copper cone, metal-sprayed with a thin coating of Kanthal, is brazed in place. The hollow interior permits convenient water cooling of the cone. Initial tests on a model of this load gave a high VSWR. The load is now being reworked to locate the apex of the cone far from the transition section. In its present form the apex is located in the transition.

5. Rectangular Waveguide Cooling

The possibility of cooling the accelerator section, dummy load, and waveguide in series, and in that order, using a water-flow rate of 13 gpm, has been considered. For Stage I operation the series-flow arrangement yields satisfactory waveguide temperature control. For Stage II operation the waveguide temperature control, using a series-flow arrangement, would be marginal in that the entire temperature allowance would be taken up by the variations in water temperature to the waveguide, and no safety margin would remain. The suitability of the series-flow arrangement must be verified by testing. Full-power tests of the ac-

[2]SLAC Report No. 1, op. cit.

celerator, load, and waveguide system are planned for the next calendar year.

IV. BEAM DYNAMICS

A report has been prepared on focusing requirements for the two-mile accelerator.[3] Two specific types of systems were considered: (1) a "minimal" system consisting of rather weak and widely spaced quadrupole multiplets and just capable of transporting an electron beam having fairly small phase-space; and (2) a moderately strong focusing system consisting of alternating-gradient, thin-lens quadrupoles spaced fairly close together and designed to transport a reasonable fraction of the phase-space admittance of the end station transport system. Perturbing effects, such as misalignments, stray magnetic fields, aberrations and coupler asymmetries, were not discussed but will be treated in later reports.

The main conclusions of this report may be summed up briefly.

1. Transmission of the electron beam from the end of the injector to the end of the machine could be accomplished with something like one to three lenses (e.g., quadrupole doublets) of moderate strength.

2. There are a number of reasons for wanting focusing somewhat stronger than the minimal requirement for electron transmission; for example, to reduce the beam size, to allow for possible nonconservation of transverse phase space, to take advantage of the beam-guiding properties of strong focusing, or to increase the yield in the positron beam. The number of focusing elements then becomes appreciable, and the system takes on the properties of periodic focusing. Alternating-gradient quadrupole focusing is the obvious expedient.

3. The phase-space admittance, $\int dx dp_x$, for an alternating-gradient quadrupole system is proportional to the quadrupole strength $|Q|$. For admittances of the order of $(0.1 \text{ to } 0.4)\pi$ mc-cm, which corresponds to a beam diameter of one centimeter and an angular divergence of $\pm (1 \text{ to } 4) \times 10^{-5}$ at 10 Bev, the quadrupole strength comes out to be about 1000 to 4000 gauss.

4. Because of the low-energy cutoff in a periodic system, the spacing of the quadrupoles must be closest where low beam energies are present. In regions following injectors and positron converters, the spacing generally will be less than the nominal 40 feet allowed for small-aperture quadrupoles; hence some "special" or large-aperture quadrupoles will be required.

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[3] 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, October 1962.

5. In a hypothetical positron-beam situation it is found, for example, that about 10 special quadrupoles would be required to conduct the beam from the 38 Mev point up to the beginning of 40-foot spacing (the desired admittance is taken as $\approx 0.1\pi$ mc-cm). The number of special quadrupoles is essentially proportional to the design admittance.

6. A typical "special" quadrupole for 5000 gauss strength is found to be about 16 to 18 inches maximum outside diameter and 12 inches in length, with a weight of 400 to 500 lbs and a power requirement about 500 watts. About 10 to 50 of these "special" quadrupoles will be required.

7. A typical "standard" quadrupole for 5000 gauss strength might be on the order of 6 to 8 inches maximum outside diameter, 3 to 6 inches long, weigh < 50 lbs, and require < 100 watts. Two-hundred and forty (nominal 40-foot spacing) of these would be required.

8. All the above numbers are based only on focusing requirements. Other considerations may eventually change the size and number of quadrupoles somewhat.

The moderate-focusing system consisting of equally spaced alternating-gradient quadrupoles may prove impractical because of the rather tight tolerance or short-range alignment. Hence an alternate moderate-focusing system consisting of quadrupole multiplets may be desirable; such a system is less efficient in terms of total weight and power in the quadrupoles, but requires fewer lenses per unit length.

Reports on alignment, degaussing, and other perturbations, and on the alternative (quadrupole multiplet) moderate-focusing system, are now in preparation.

V. INJECTION SYSTEM

A. MARK II ACCELERATOR

A prebuncher cavity was designed, built and installed on the Mark II linear accelerator. The phase-shifter attenuator unit has not yet been completed because of procurement time, but the components are now on hand and the unit will be assembled in the first part of next quarter. It consists of a symmetrical bridge formed of two coaxial trombone line-stretchers and two hybrid rings, as shown schematically in Fig. 6. The trombones will be driven synchronously by two Slo-Syn stepping motors in the same or opposite directions to produce phase shift or attenuation, respectively. This design is being used to try to achieve a variable attenuator that does not introduce phase shift. If the design proves satisfactory it will be used on the SLAC injectors, and a waveguide equivalent will be built and tested for the high-power (order of one megawatt) drive to the second component of the SLAC buncher.

B. MARK IV ACCELERATOR

The two high-current guns purchased from Quantatron for the Mark IV accelerator were received. Thin valves and 5-liter ion pumps were mounted on the guns. The guns were baked to $400^{\circ}C$ and converted using an oven and oil-diffusion pump vacuum station belonging to the Microwave Laboratory tube shop. The guns were tested and found to deliver in excess of 2 amperes peak beam current with a 70-kv cathode pulse and a 700-volt grid pulse. The guns require a negative grid bias of about 300 volts for cutoff.

The higher beam current from these guns necessitates focusing in the drift space between the prebuncher and the accelerator. A magnetic lens has been designed and built for this function. Two prebunchers (one for each gun) have been built and installed between the guns and the gun thin valves so that the prebuncher gap occurs at the beam minimum, thus minimizing the effect of the radial variation of the fields.

The Mark IV gun modulator has been modified to make it usable with the new guns and has been tested at a repetition rate of 360 pps.

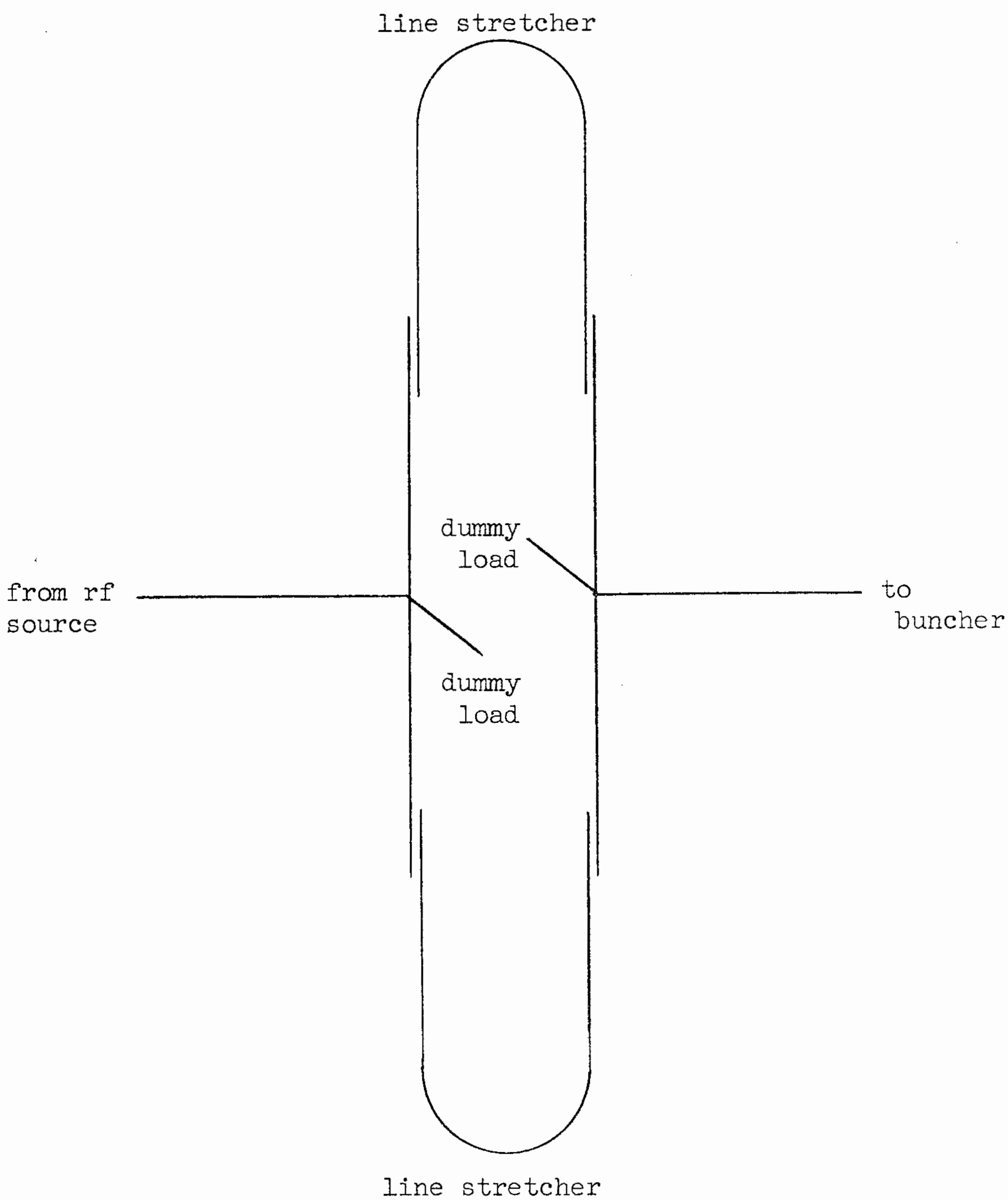

FIG. 6--Phase shifter attenuator.

C. THIN VALVE DEVELOPMENT

Considerable effort has been expended during the quarter on improvement of the thin valves used on the electron guns. These valves are of the same basic design as the valves used on Mark IV accelerator. The valve shafts were increased in size because the Mark IV valves all failed as the result of the shafts bending. This modification and a change in brazing procedure weakened the valve disks and caused valve failure due to the disk bending after a few closures. Increasing the disk thickness and brazing with copper-silver eutectic instead of Nicoro eliminated this difficulty. In addition, the new seal configuration shown in Fig. 7 seems to give more reliable seals than the original copper knife-edge.

D. INJECTION TEST STAND

Detailed design of the waveguide and vacuum manifolding for the injection test stand was begun during the quarter, and will continue with high priority during the coming quarter.

Use of a traveling-wave structure to produce rf beam-sweeping for bunch analysis is being investigated in cooperation with the Microwave Engineering Group, which began an experimental study of such structures during the quarter.

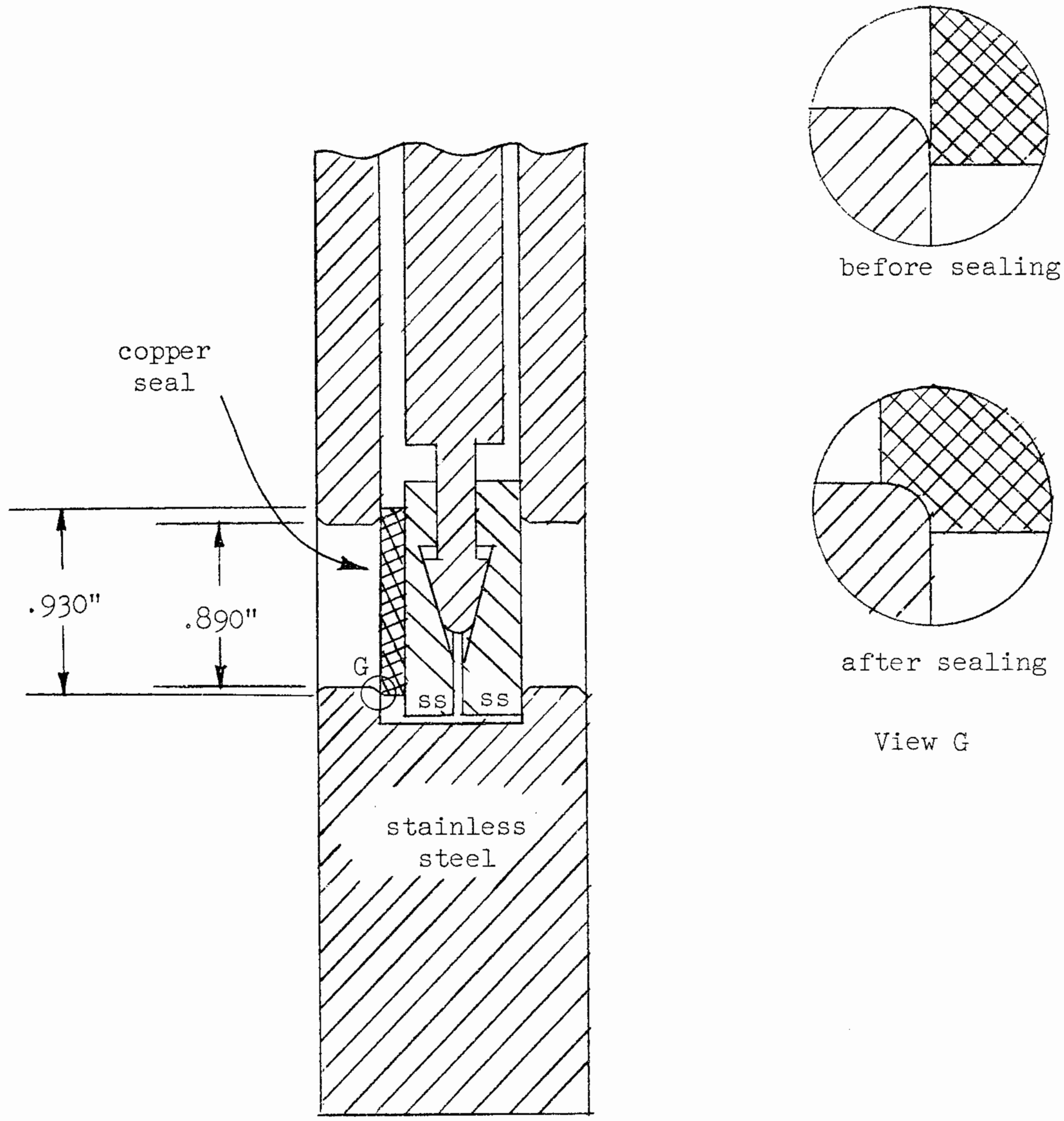

FIG. 7--Thin valve.

VI. MICROWAVE ENGINEERING

A. GENERAL MICROWAVE STUDIES

1. Constant-Gradient Accelerator Structure Design

During the past quarter the constant-gradient structure designs were once more modified as a result of a reduction in the final length of the individual accelerator sections. This length has now been frozen at 86 cavities (including couplers). For the attenuation parameter, $\tau = 0.57$ neper, the group velocity must decrease linearly between the following intervals:

$$\text{input end:} \quad v_g/c = 0.0204$$

$$\text{output end:} \quad v_g/c = 0.0065$$

Using the same conventions as given in the previous Status Report,[4] structure designs were obtained for both thick disks (0.230 in.) and thin disks (0.120 in.). Figure 8 and Table I show the variations, as a function of cavity number, of the cavity diameter 2b, the disk aperture diameter 2a, and the steel-ball height h for the thick disk (disk-edge radius $\rho = .1215$ in.). Figure 9 and Table II give the same variations for the thin-disk design ($\rho = .0625$ in.). These results were obtained by programming the experimental points in a Burroughs 220 Computer. The data for the two disk thicknesses were smoothed by using, respectively, 4th- and 6th-order polynominals and by minimizing least-square dimensions.

Work is also proceeding on the design of a constant-gradient structure with $\tau = 0.40$. Although it is not planned at this point to use this design on the two-mile accelerator, this information may be useful for experimental sections at a later date.

2. Tuning and Matching Theory

As noted in the previous Status Report,[5] an effort is being made to understand better the interaction between coupler matching and accelerator

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[4]Status Report, SLAC Report No. 1, Stanford Linear Accelerator Center, Stanford University, Stanford, California, July 1962, p. 24.

[5]SLAC Report No. 1, *op. cit.*

tuning for sections operating in the $2\pi/3$ mode. In connection with this work, one 10-ft section that had been tuned by the Microwave Engineering Group was examined. It was found to have a built-in stop band between 2846.9 Mc/sec and 2847.9 Mc/sec. This conclusion was drawn from the appearance of a slight irregularity around the $\pi/2$ point in the pass-band. This pass-band was obtained by resonating the structure with a reflecting plunger and plotting 87 points.

Work is being continued on the experimental demountable coupler and stack of cavities with micrometer-mounted tuners (as described in the previous Status Report[6]) in order to explore further the suggestions received from R. L. Kyhl of M.I.T.[7]

3. Q Measurements

Recently acquired highly stable signal generators now permit performing Q measurements by the 3 db-down technique with better accuracy than before. For this reason a new series of Q measurements is being made on the accelerator test-cells.

4. Shunt-Impedance Measurements for Disk-Loaded Waveguide Structures

Recent interest in disk-loaded waveguide structures having phase velocities between 0.5 and 1.0c has prompted a series of cold-tests to obtain the shunt impedances, corrected for the fundamental space harmonic, as a function of phase velocity. Table III and Fig. 10 outline the results of these measurements.

5. Ventilated-Disk Accelerator Structure

The present constant-gradient characteristic of SLAC accelerator structures is being obtained by tapering both the cavity diameter and the disk-aperture diameter. It has been suggested recently that the same result could be achieved by holding the disk aperture constant over a full 10-ft section and by obtaining the variation in group velocity by means of so-called ventilating holes drilled on the periphery of the main disk aperture. The farther out these holes are placed, the more magnetic coupling is obtained from cavity to cavity, and the narrower the pass-band becomes. Hence the same decrease in group velocity can be achieved by simply tapering the distance of these holes away from the center of the

[6]SLAC Report No. 1, op. cit.

[7]Private Communication.

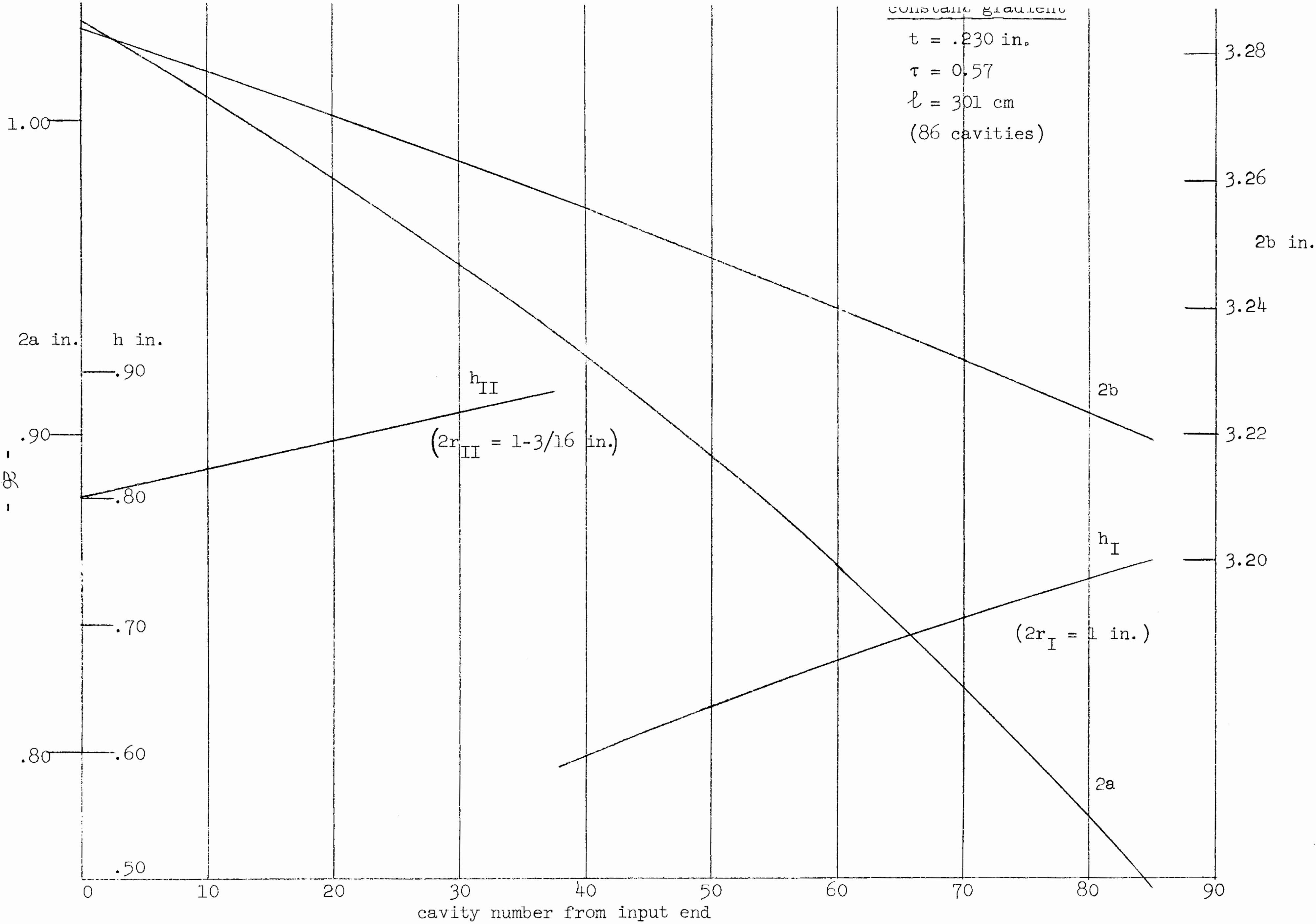

FIG. 8--Variations of 2b, 2a and h as a function of cavity number.

TABLE I

DIMENSIONS OF CONSTANT-GRADIENT ACCELERATOR SECTION

(t = 0.230 in.)

$2\pi/3$ MODE, 86 CAVITIES, τ = 0.57, ρ = 0.1215 in.

Note: The dimensions of the coupler cavities (Nos. 0 and 85) are given assuming no coupling-iris aperture. To correct for this perturbation, reduce:

2b of cavity No. 0 by approximately 0.050 in.
2b of cavity No. 85 by approximately 0.040 in.
DISK THICKNESS = 0.230 in.

CAVITY	2A	2B	H	GROUP VEL. v_g/c		CAVITY	2A	2B	H	GROUP VEL. v_g/c
0	1.0314	3.2843	.80105	.0202383		43	.91505	3.2533	.60939	.0132883
1	1.0290	3.2836	.80331	.0200767		44	.91192	3.2526	.61326	.0131267
2	1.0266	3.2829	.80557	.0199151		45	.90877	3.2518	.61708	.0129651
3	1.0242	3.2822	.80783	.0197534		46	.90560	3.2510	.62087	.0128034
4	1.0218	3.2815	.81008	.0195918		47	.90239	3.2502	.62461	.0126418
5	1.0194	3.2809	.81232	.0194302		48	.89917	3.2495	.62832	.0124802
6	1.0170	3.2802	.81457	.0192686		49	.89592	3.2487	.63199	.0123186
7	1.0145	3.2795	.81681	.0191069		50	.89264	3.2479	.63563	.0121569
8	1.0121	3.2788	.81904	.0189453		51	.88934	3.2471	.63923	.0119953
9	1.0096	3.2781	.82127	.0187837		52	.88601	3.2463	.64280	.0118337
10	1.0071	3.2774	.82349	.0186220		53	.88265	3.2455	.64635	.0116720
11	1.0046	3.2767	.82571	.0184604		54	.87926	3.2447	.64987	.0115104
12	1.0020	3.2760	.82793	.0182988		55	.87584	3.2439	.65336	.0113488
13	.99955	3.2753	.83014	.0181372		56	.87240	3.2431	.65682	.0111872
14	.99698	3.2746	.83235	.0179755		57	.86892	3.2423	.66027	.0110255
15	.99441	3.2739	.83455	.0178139		58	.86542	3.2415	.66369	.0108639
16	.99181	3.2731	.83675	.0176523		59	.86188	3.2407	.66708	.0107023
17	.98920	3.2724	.83895	.0174906		60	.85831	3.2399	.67046	.0105406
18	.98658	3.2717	.84114	.0173290		61	.85471	3.2391	.67382	.0103790
19	.98393	3.2710	.84332	.0171674		62	.85108	3.2383	.67716	.0102174
20	.98127	3.2703	.84551	.0170058		63	.84741	3.2374	.68049	.0100558
21	.97860	3.2696	.84768	.0168441		64	.84370	3.2366	.68379	.0098941
22	.97590	3.2689	.84986	.0166825		65	.83997	3.2358	.68708	.0097325
23	.97319	3.2681	.85203	.0165209		66	.83619	3.2350	.69036	.0095709
24	.97047	3.2674	.85420	.0163593		67	.83238	3.2341	.69362	.0094093
25	.96772	3.2667	.85636	.0161976		68	.82854	3.2333	.69687	.0092476
26	.96496	3.2660	.85852	.0160360		69	.82465	3.2325	.70010	.0090860
27	.96218	3.2652	.86068	.0158744		70	.82073	3.2317	.70332	.0089244
28	.95938	3.2645	.86284	.0157127		71	.81676	3.2308	.70654	.0087627
29	.95656	3.2638	.86499	.0155511		72	.81276	3.2300	.70974	.0086011
30	.95373	3.2631	.86714	.0153895		73	.80871	3.2292	.71293	.0084395
31	.95087	3.2623	.86928	.0152279		74	.80462	3.2283	.71610	.0082779
32	.94800	3.2616	.87143	.0150662		75	.80049	3.2275	.71928	.0081162
33	.94511	3.2608	.87357	.0149046	↑	76	.79632	3.2267	.72244	.0079546
34	.94220	3.2601	.87571	.0147430		77	.79210	3.2258	.72559	.0077930
35	.93926	3.2594	.87785	.0145813		78	.78784	3.2250	.72874	.0076313
36	.93631	3.2586	.87998	.0144197	h_{II}	79	.78353	3.2242	.73187	.0074697
37	.93334	3.2579	.88212	.0142581		80	.77917	3.2233	.73500	.0073081
38	.93035	3.2571	.58927	.0140965	h_I	81	.77477	3.2225	.73813	.0071465
39	.92733	3.2564	.59341	.0139348		82	.77032	3.2217	.74124	.0069848
40	.92429	3.2556	.59748	.0137732		83	.76582	3.2209	.74436	.0068232
41	.92124	3.2548	.60150	.0136116		84	.76126	3.2201	.74746	.0066616
42	.91815	3.2541	.60547	.0134500	↓	85	.75666	3.2193	.75056	.0065000

All dimensions in inches, fifth significant figure to be disregarded.

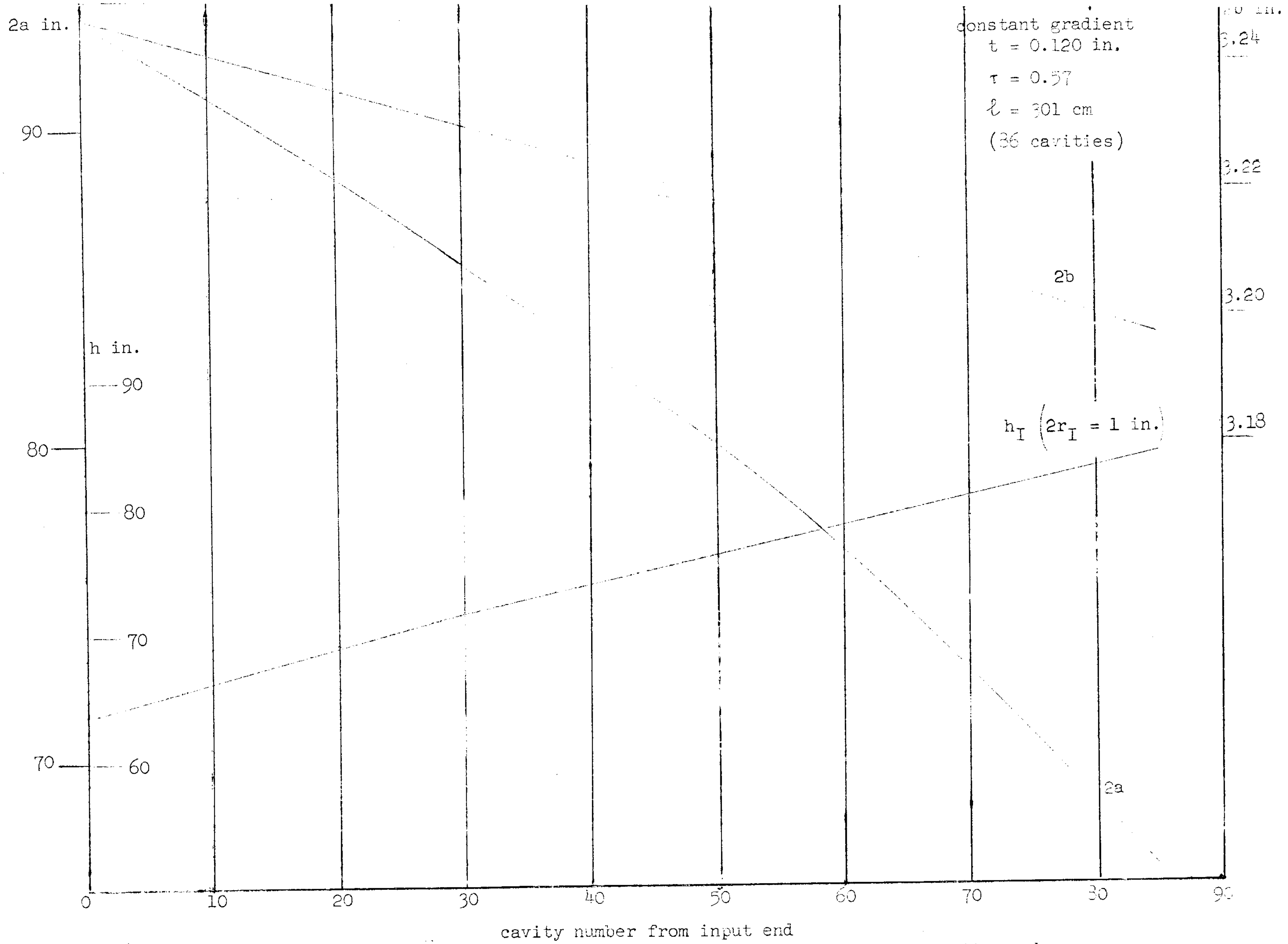

FIG. 9--Variations of 2b, 2a and h as a function of cavity number.

TABLE II

DIMENSIONS OF CONSTANT GRADIENT ACCELERATOR SECTION

(t = 0.120 in.)

$2\pi/3$ MODE, 86 CAVITIES, τ = 0.57, ρ = 0.0625 in.

Note: The dimensions of the coupler cavities (Nos. 0 and 85) are given assuming no coupling-iris aperture. To correct for this perturbation, reduce:
2b of cavity No. 0 by approximately 0.040 in.
2b of cavity No. 85 by approximately 0.030 in.

DISK THICKNESS = 0.120 in.

CAVITY	2A	2B	H	GROUP VEL. v_g/c	CAVITY	2A	2B	H	GROUP VEL. v_g/c
0	.93315	3.2475	.63569	.0202383	43	.81994	3.2229	.74681	.0132883
1	.93081	3.2469	.63876	.0200767	44	.81702	3.2223	.74901	.0131267
2	.92846	3.2464	.64181	.0199151	45	.81409	3.2217	.75120	.0129651
3	.92609	3.2458	.64482	.0197534	46	.81113	3.2212	.75339	.0128034
4	.92370	3.2453	.64781	.0195918	47	.80814	3.2206	.75558	.0126418
5	.92129	3.2447	.65077	.0194302	48	.80512	3.2200	.75777	.0124802
6	.91887	3.2442	.65370	.0192686	49	.80208	3.2194	.75996	.0123186
7	.91642	3.2436	.65661	.0191069	50	.79900	3.2188	.76215	.0121569
8	.91396	3.2431	.65950	.0189453	51	.79588	3.2182	.76434	.0119953
9	.91149	3.2425	.66236	.0187837	52	.79273	3.2176	.76654	.0118337
10	.90899	3.2419	.66520	.0186220	53	.78954	3.2170	.76874	.0116720
11	.90648	3.2414	.66802	.0184604	54	.78632	3.2164	.77094	.0115104
12	.90395	3.2408	.67082	.0182988	55	.78304	3.2158	.77315	.0113488
13	.90140	3.2402	.67359	.0181372	56	.77973	3.2152	.77537	.0111872
14	.89884	3.2396	.67634	.0179755	57	.77637	3.2146	.77759	.0110255
15	.89626	3.2391	.67907	.0178139	58	.77297	3.2140	.77982	.0108639
16	.89367	3.2385	.68177	.0176523	59	.76951	3.2133	.78206	.0107023
17	.89107	3.2379	.68445	.0174906	60	.76601	3.2127	.78431	.0105406
18	.88846	3.2373	.68711	.0173290	61	.76246	3.2121	.78657	.0103790
19	.88583	3.2368	.68974	.0171674	62	.75885	3.2115	.78883	.0102174
20	.88319	3.2362	.69236	.0170058	63	.75520	3.2108	.79111	.0100558
21	.88054	3.2356	.69494	.0168441	64	.75149	3.2102	.79339	.0098941
22	.87789	3.2350	.69751	.0166825	65	.74773	3.2095	.79568	.0097325
23	.87522	3.2344	.70005	.0165209	66	.74392	3.2089	.79797	.0095709
24	.87254	3.2339	.70257	.0163593	67	.74006	3.2082	.80027	.0094093
25	.86986	3.2333	.70507	.0161976	68	.73615	3.2076	.80257	.0092476
26	.86717	3.2327	.70754	.0160360	69	.73219	3.2069	.80488	.0090860
27	.86447	3.2321	.70999	.0158744	70	.72819	3.2063	.80719	.0089244
28	.86176	3.2315	.71242	.0157127	71	.72414	3.2056	.80950	.0087627
29	.85905	3.2310	.71483	.0155511	72	.72004	3.2049	.81181	.0086011
30	.85632	3.2304	.71722	.0153895	73	.71591	3.2043	.81411	.0084395
31	.85359	3.2298	.71959	.0152279	74	.71175	3.2036	.81641	.0082779
32	.85085	3.2292	.72194	.0150662	75	.70756	3.2030	.81870	.0081162
33	.84811	3.2287	.72427	.0149046	76	.70333	3.2023	.82097	.0079546
34	.84535	3.2281	.72659	.0147430	77	.69910	3.2016	.82324	.0077930
35	.84258	3.2275	.72888	.0145813	78	.69484	3.2010	.82548	.0076313
36	.83980	3.2269	.73117	.0144197	79	.69058	3.2003	.82770	.0074697
37	.83701	3.2264	.73343	.0142581	80	.68633	3.1997	.82990	.0073081
38	.83420	3.2258	.73569	.0140965	81	.68208	3.1991	.83207	.0071465
39	.83138	3.2252	.73793	.0139348	82	.67785	3.1984	.83421	.0069848
40	.82855	3.2246	.74016	.0137732	83	.67365	3.1978	.83631	.0068232
41	.82570	3.2241	.74239	.0136116	84	.66949	3.1972	.83836	.0066616
42	.82283	3.2235	.74460	.0134500	85	.66539	3.1966	.84037	.0065000

All dimensions in inches, fifth significant figure to be disregarded.

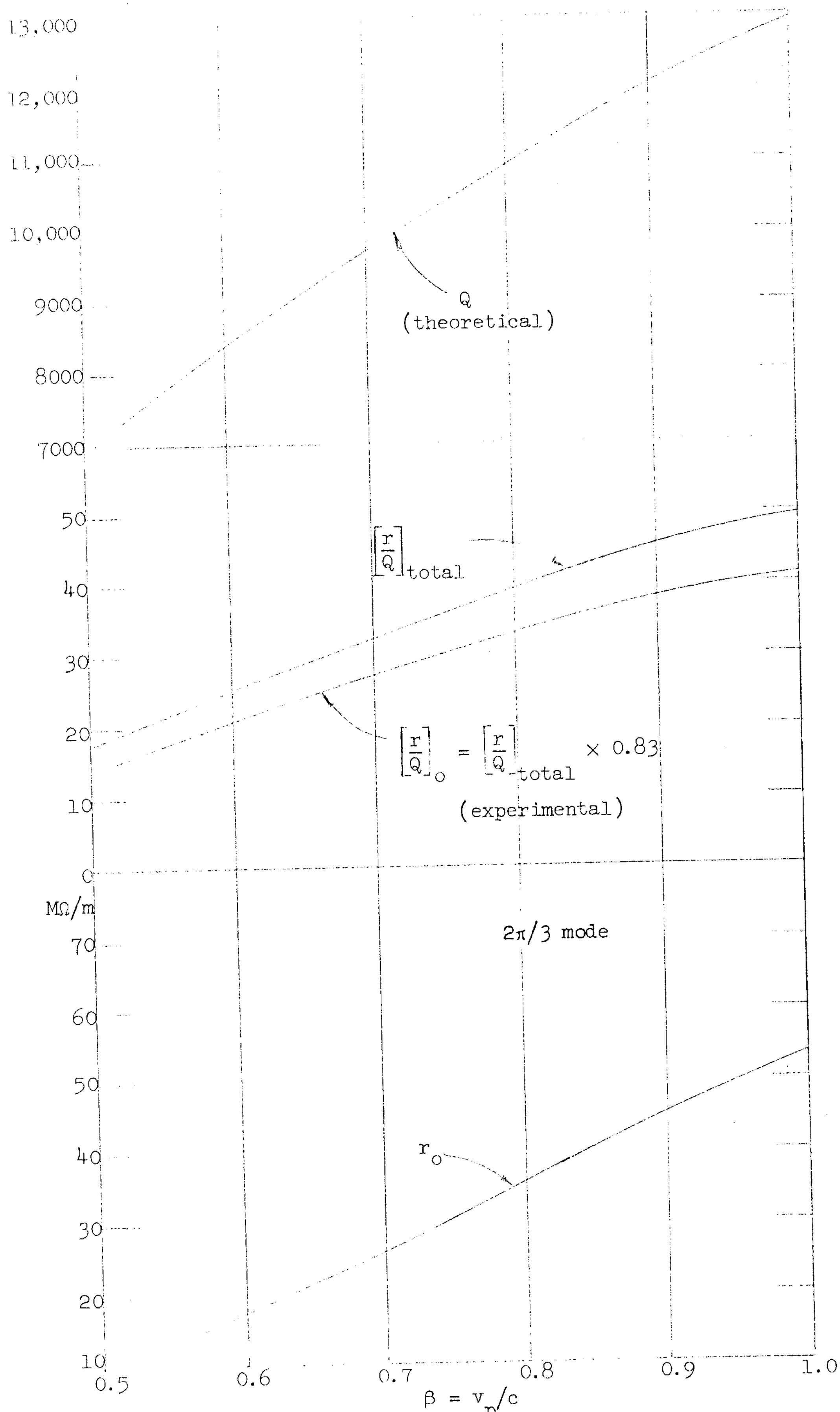

FIG. 10--Plots of Q_{Th}, $(r/Q)_T$, $(r/Q)_o$ and r_o as a function of $\beta = v_p/c$ for disk-loaded waveguide.

TABLE III

SHUNT IMPEDANCE MEASUREMENTS FOR DISK-LOADED WAVEGUIDE, $0.5 \leqslant \frac{v_p}{c} \leqslant 1.0$ ($2\pi/3$ mode)

$\beta = v_p/c$	0.5	0.6	0.7	0.8	0.9	1.0
Disk spacing d (in.)*	0.689	0.827	0.965	1.102	1.240	1.378
Diameter 2b (in.)	3.339	3.307	3.287	3.270	3.254	3.245
v_g/c	0.0097	0.0110	0.0116	0.0116	0.0120	0.0116
$(r/Q)_{total}$	17.3	25.8	31.8	39.3	45.1	49.8
$a_o^2/\Sigma a_n^2$	0.89	0.850	0.834	0.847	0.860	0.850
$(r/Q)_o$**	14.35	21.41	26.4	32.65	37.5	41.4
$Q_{theoretical}$***	6950	8480	9770	10980	12030	13000
$r_o = \left(\frac{r}{Q}\right)_o Q_{th} \left(\frac{M\Omega}{m}\right)$	9.98	18.19	25.80	35.80	45.2	53.8

*Disk thickness t = 0.230 in.

**Based on an average value of $\frac{a_o^2}{\Sigma a_n^2} = 0.83$

***Based on $\frac{Q\delta}{\lambda_o} = \frac{\beta(1 - \eta)}{n + 2.61\beta(1 - \eta)}$ where $\eta = t/d$, $n = 3$ and δ = skin depth.

disk as a function of cavity number. It has been found experimentally that eight holes, 5/16 in. in diameter, are sufficient to obtain the complete group velocity variation. Work is in progress to produce a complete constant-gradient design based on this idea.

6. RF Particle Separators

During the past quarter a new activity has been started on rf particle separators in cooperation with the SLAC Research Division. The present objectives of this activity are as follows:

(a) Defining the specifications of an rf particle separator and then the criteria that a slow-wave structure must comply with to meet these specifications. It is believed that the slow-wave structure must be a backward-wave circuit, that it must have a large transverse shunt impedance, and that the acceptance must be as large as possible. Several structures that may be able to meet these conditions are presently under study.

(b) Planning the construction of one or two prototypes.

(c) Installing and testing these prototypes in the deflected, analyzed beam of the Mark IV accelerator.

The microwave equipment needed to power these separators is already in place in the Mark IV accelerator, where it had been installed for use with the current-variation detection technique of phasing.

7. RF Transient Effects in Accelerator Structures

Because of the band-pass-filter characteristics of an accelerator structure an impressed rf wave envelope of finite rise time results in amplitude and phase oscillations of the traveling wave.[8]

During the last quarter these transient effects were examined experimentally on constant-gradient as well as constant-impedance accelerator structures. A simultaneous program of theoretical calculations has been completed for SLAC at the National Bureau of Standards. At this point the principal results can be outlined in the following two statements.

(a) The transient effects are more quickly damped in the constant-gradient structure than in the constant-impedance structure.

(b) The resulting increase in the energy-spectrum width of the electron beam is predicted to amount to less than 1/2 a percent. In practice this effect can be further reduced by staggering the timing of

[8]J. E. Leiss and R. A. Schrack, "Transient and Beam-Loading Phemomena in Linear Electron Accelerators," National Bureau of Standards, Washington, D. C., October 30, 1962.

successive sectors.

8. Waveguide Pumpout

The waveguide pumpout described in the previous Status Report[9] was tested and used during phasing experiments on the Mark IV accelerator. Tests were carried out at power levels up to 2 megawatts peak, and performance was entirely satisfactory.

9. Waveguide Vacuum Valve

Tests are in progress on the waveguide vacuum valve using successive transitions of rectangular, circular, and rectangular waveguide. A model using a configuration approximating the sealing plunger and seat has been constructed and will be tested.

10. High Power RF Loads

The silicon carbide high-power rf load noted in the previous Status Report[10] was found to contain certain undersirable materials. A cleaner sample is expected soon.

11. Mark IV Waveguide Recombiners

The RCA klystrons that are being installed in the Mark IV accelerator have two vertical extended output arms, as compared to the original klystrons with horizontally extended arms. Hence the old power recombiners had to be modified for use with the RCA klystrons. These klystrons will eventually be replaced with single-output tubes. The present recombiners have been designed in such a manner that they can easily be adapted to the single-output tubes. The hybrids have been rematched and now have the following standing-wave ratios at 2857 Mc/sec:

	VSWR	
	E Arm	H Arm
Hybrid A	1.03	1.08
Hybrid B	1.06	1.02

For a frequency range of 2856 to 2860 Mc/sec, the isolation between the colinear arms of both hybrids stays above 36 db. In order to achieve equal electrical length in both arms of the recombiners, the waveguides

[9]SLAC Report No. 1, op. cit.

[10]SLAC Report No. 1, op. cit.

were "tuned" by denting the narrow walls with a special C-clamp. In addition, directional couplers have been added in the fourth arm of the magic-T's, before the dummy load to permit examination of any mismatch caused by unbalance of the arms of the recombiner during klystron operation.

A Bethe-hole coupler with a coupling of 36 db and a directivity of 17 db at 2857 Mc/sec is also being installed at the output of the second accelerator section. This low coupling ratio should facilitate measurements of beam-induced rf signals.

12. Beam Break-Up Studies

The two-kilowatt (peak power) C-band generator to be used in studies of the beam break-up phenomenon in the Mark IV accelerator has been received. The waveguide runs are installed, and a C-band to S-band coupler is presently being constructed. In addition, two extra Bethe-hole couplers of the type mentioned in the previous paragraph have also been installed at the input and output of Section 1 of the Mark IV accelerator. These couplers have been calibrated for both S- and C-band, and their coupling ratios are such that any signal generated in the accelerator section by the beam between 4 and 4.4 kMc should be easily detectable through them.

A preliminary experiment to study the phenomenon of beam break-up was performed on the Mark III accelerator operating at an energy of about 800 Mev, and at a peak current of about 50 milliamps (at the beginning of the machine). It is generally believed that at this current level the phenomenon of beam break-up does not normally take place. To attempt to induce it, the second klystron was misphased. The electron bunches were thereby placed approximately 90° ahead of crest, where the transverse defocusing forces are strongest. The cross section of the electron beam was thereby increased considerably, and the current pulse, observed at the 98-foot toroid, appeared to break up in the second half of the one-microsecond pulse. Since no amount of resteering permitted recovery of this latter part of the pulse, it is believed that its disappearance could not be explained by energy changes. Another observation, which tended to confirm that the pulse break-up was real, was that when the current was decreased by reducing the grid voltage of the gun the late part of the current pulse reappeared. Although these experiments were quite preliminary and could not be performed under optimum conditions, they were interesting because they seemed to show that the beam break-up phenomenon can occur at relatively low currents as the electron bunches are driven into the region where longitudinal interaction with, and build-up of, the TM_{11} mode, presumably responsible for beam break-up, is strong.

B. DRIVE SYSTEM

1. Over-all Design of the Drive System

In the previous Status Report[11] it was stated that the main drive line of the two-mile accelerator would transmit either a pulsed signal at 2856 Mc/sec or a cw signal at 119 Mc/sec. The reasoning, both pro and con, on these alternatives was presented. Since that time the rising interest in rf particle separators and the possible need for subharmonic frequencies, both along the machine and in the end station, have pointed to the desirability of having a cw system. For these reasons the pulsed system at 2856 Mc/sec has been discarded. The two alternatives are described below.

(1) A low-frequency system without series boosters but with varactor multipliers at each sector coupling point. Such a system would use a 3-1/8 in. rigid coaxial line (less lossy than the 1-5/8 in. line) and some submultiple of 2856 Mc/sec. The higher the frequency, the fewer stages of varactor multiplication one needs. Since these multipliers can introduce phase errors as a function of time, temperature and drive power, it is advantageous to reduce the stages, and klystrons to the smallest possible number. Results concerning specific tests on varactor multipliers are given in a subsequent paragraph.

(2) A 2856 Mc/sec system using cw boosters. This system would use a 1-5/8 in. rigid coaxial line. To reduce the number of boosters to three tubes, a cw klystron of at least 1 kw must be used. One of these tubes is presently available commercially, its performance has already been examined by SLAC, and its operation appears satisfactory. With the availability of the cw 2856 Mc/sec signal, the subharmonic frequency could be obtained anywhere along the line by generating a local signal at

[11] SLAC Report No. 1, op. cit.

119 Mc, multiplying it through the proper stages up to 2856 Mc/sec, and phase-locking the output with the drive signal from the drive line. Hence the desired subharmonic would also be indirectly locked to the main drive signal.

A decision to adopt one or the other of these two systems is due during the next quarter.

The sub-drive lines will all carry pulsed signals at 2856 Mc/sec and use 1-5/8 in. rigid coaxial line. Both the main and sub-drive lines will be insulated and their temperature stabilized as a group with the ignitron water supply.

2. Stable RF Sources

A stable S-band source was purchased from the Syntax Corporation, Oakland, California. It has been evaluated and meets all specifications for the stable test-stand drivers. Presently it is being used as a test vehicle, and it is proving to be particularly satisfactory with regard to frequency and power stability. Four more identical units have been ordered for use in the test stands. Four tunable test-stand drivers are being constructed by the SLAC Instrumentation and Control Group. These units use triode oscillators and should be ready by November 15.

Modification of an existing crystal chain was completed. By replacement of the tripler and output cavities, power output has been increased to 1 watt, with a long-term amplitude stability of better than ± 0.2 db.

3. Mark IV Drive System

Operating conditions of the 6442 triodes in the Granger driver were altered, increasing tube life from 50 to 1300 hours. Although 1300 hours is a reasonable life for these tubes, it is still an inconveniently short period (8 weeks). Therefore, it was decided to replace these tubes with solid-state multipliers. These have been ordered and will be installed during the next quarter.

The complete drive system, including isolator, phase shifter, attenuator and couplers, has been rebuilt. Except for the isolators, all ferrite components were eliminated becuase of undersirable performance. The present components can be remotely controlled from the control panel.

4. Varactor Multiplier Evaluation

The interest in a drive system propagating a VHF signal in the main drive line, with local frequency multiplication at each sector to 2856 Mc/sec, makes it imperative that the phase stability of each multiplier be thoroughly studied. For this purpose three multiplier chains were purchased and evaluated. All three chains are identical and consist of a 119 Mc/sec to 476 Mc/sec quadrupler, a 476 Mc/sec to 952 Mc/sec doubler, and a 952 Mc/sec to 2856 Mc/sec tripler. A summary of the results follows.

Power input (119 Mc)	2 watts
Power output (2856 Mc)	170 mw
Efficiency	8.5%
Phase stability versus bias voltage change	15.0°/0.1 volt (250 volt bias supply)
Phase stability versus temperature change	1°-$2^\circ/^\circ$F
Power stability	Better than 0.2 db/48 hours

It can be concluded that bias should be supplied locally by bias cells and that oven control of the ambient temperature will be required.

One important question remains to be answered: What is the phase stability as a function of input drive power? Indications are that a change in drive of 0.1 db can cause several degrees of phase shift. However, the differential phase shift among multipliers should be substantially less, and the input drive power can probably be very closely controlled.

5. Drive Line Studies

The phase velocity and dispersion of a commercial 1-5/8 in. coaxial transmission line were examined once more, both theoretically and experimentally. The following conclusions were reached.

a. Dispersion is negligibly small.

b. Copper losses cause a negligibly small phase velocity deviation from the velocity of light.

c. Dielectric supports and other small discontinuities will alter the phase velocity from c to approximately 0.997c.

The rf phase-shift change of the rf wave between accelerator inputs, as the frequency is changed by Δf, should be nearly identical to the phase-shift change between the centers of the electron bunches at the same points. It has been shown theoretically that the change in the rf phase shift between accelerator inputs for a small change in frequency can be determined, and further that it can be made nearly equal to the phase-shift change of the electron bunch centers between corresponding inputs. Practically, this is achieved by inserting an extra length of rf line in the first parallel path between the sub-drive line and the first klystron input and by progressively inserting shorter lengths of rf line in the subsequent parallel paths; alternately, the drive line can be made shorter than the accelerator pipe.

6. Sub-Boosters

The sub-booster tube contract has been signed with Eitel-McCullough, Inc., San Carlos, California, and the first four tubes are due for delivery on March 15, 1963. These tubes will use periodic focusing with permanent magnets. A parallel approach is being carried out using unidirectional permanent-magnet-focusing to provide a back-up design.

The sub-booster modulator program is in progress.

7. Isolators, Phase Shifters, and Attenuators

During the past quarter a contract was signed with the Sperry Microwave, Electronic Division of Sperry-Rand Corp., Clearwater, Florida, for the manufacture of 20 modular units, each including an isolator, phase shifter, and two attenuators. The first attenuator is continuously variable; the second provides 0 or 20 db of attenuation and is designed to protect the klystron output window from abrupt spurts of high rf power. This protective attenuation may be inserted automatically upon command of a given input signal. Delivery of these 20 packages is scheduled to take place before the end of November, 1962.

C. PHASING SYSTEM

1. Current-Variation Detection Technique of Phasing

An experiment to simulate the effect that adjusting one klystron out of 240 klystrons would have on accelerator output current was carried out on the Mark IV accelerator. The results showed that it would be extremely difficult to use this technique unless the contribution of the source being phased represented at least 1% of the total energy. Below this level, the current variations caused by amplitude and phase modulation of the input power are hard to distinguish from those caused by the inherent instabilities of the machine. Hence phasing to better than $\pm 30^{\circ}$ was not possible. This experiment will be repeated when the new klystron and modulator are installed on the Mark IV accelerator.

While performing this current-variation experiment it was observed that the pulse reflected by the cavity exhibited two triangular notches at the beginning and end of the 2.5 μsec rf pulse. In order to understand this irregular shape of the reflected pulse, which appears both in the presence and the absence of the beam, a theoretical calculation was made for three cases: (a) a rectangular pulse envelope; (b) a trapezoidal pulse envelope; and (c) a rectangular pulse envelope containing frequency modulation. Cases (a) and (b) do not agree with the experimental results; case (c) does. In order to verify this, an attempt will be made to examine the frequency modulation present in the actual klystron pulse when this experiment is repeated on the Mark IV accelerator.

2. <u>The Hybrid Method of Phasing</u>

The experiments on the Mark III accelerator (described in the previous Status Report[12]) designed to measure the phase stability of long cable runs from accelerator section outputs to the control panel, were completed. It was found that over a period of one week the differential phase shift between these cable runs never amounted to more than 6°. Hence it appears that reasonable phase stability can be expected of the hybrid system and that calibration would not be required more than perhaps once a week.

Progress was made during the past quarter on the microwave and electronic circuitry necessary for the hybrid system. Figures 11 and 12 illustrate two possible systems. Figure 11 shows a manual system, and Fig. 12 shows a more sophisticated automatic system. Both systems have low-loss cable runs, which permit comparing the phase of all sections at sector control.

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[12]SLAC Report No. 1, <u>op. cit</u>.

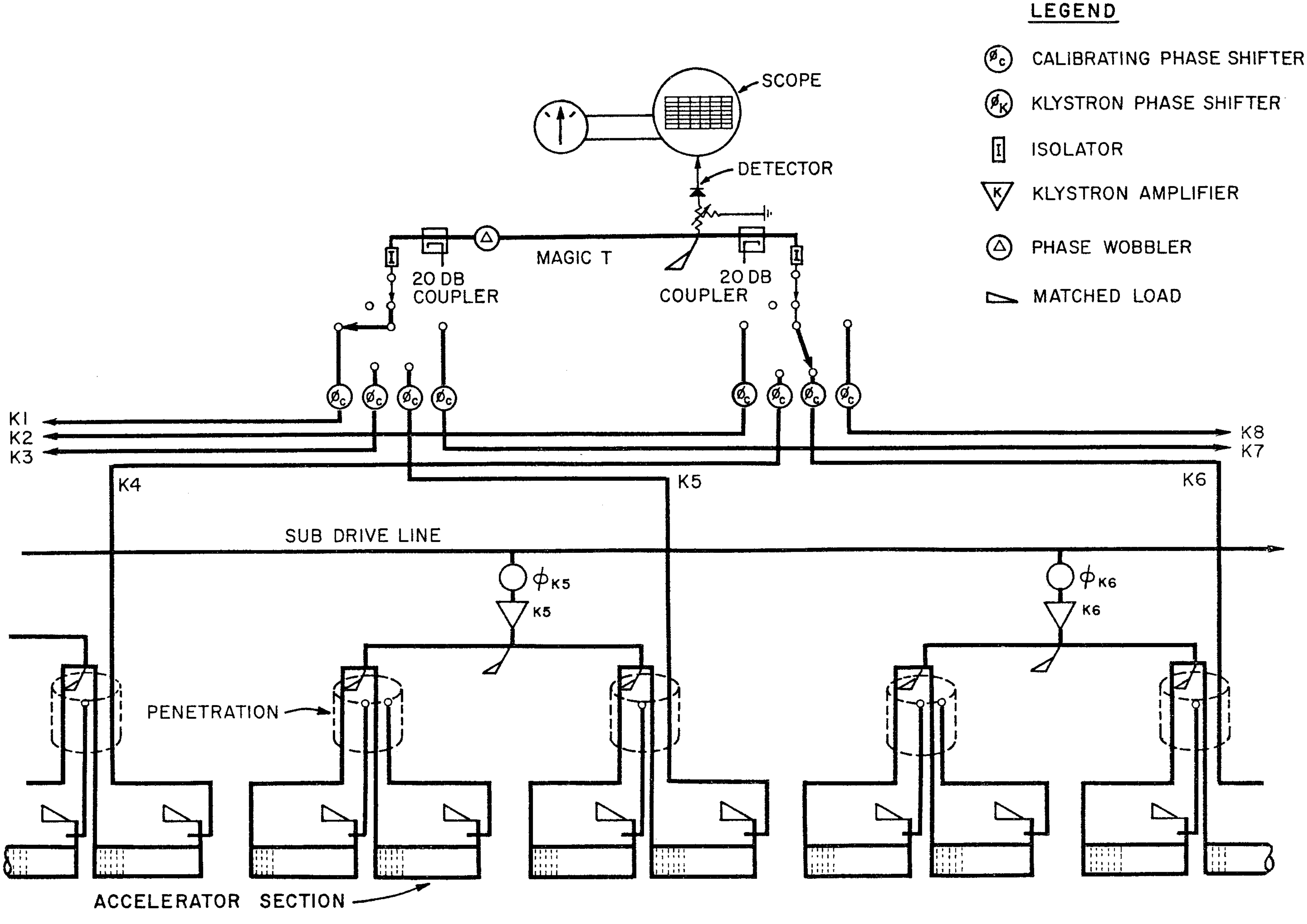

FIG. 11--Principle of the hybrid method of phasing applied to one sector (manual system).

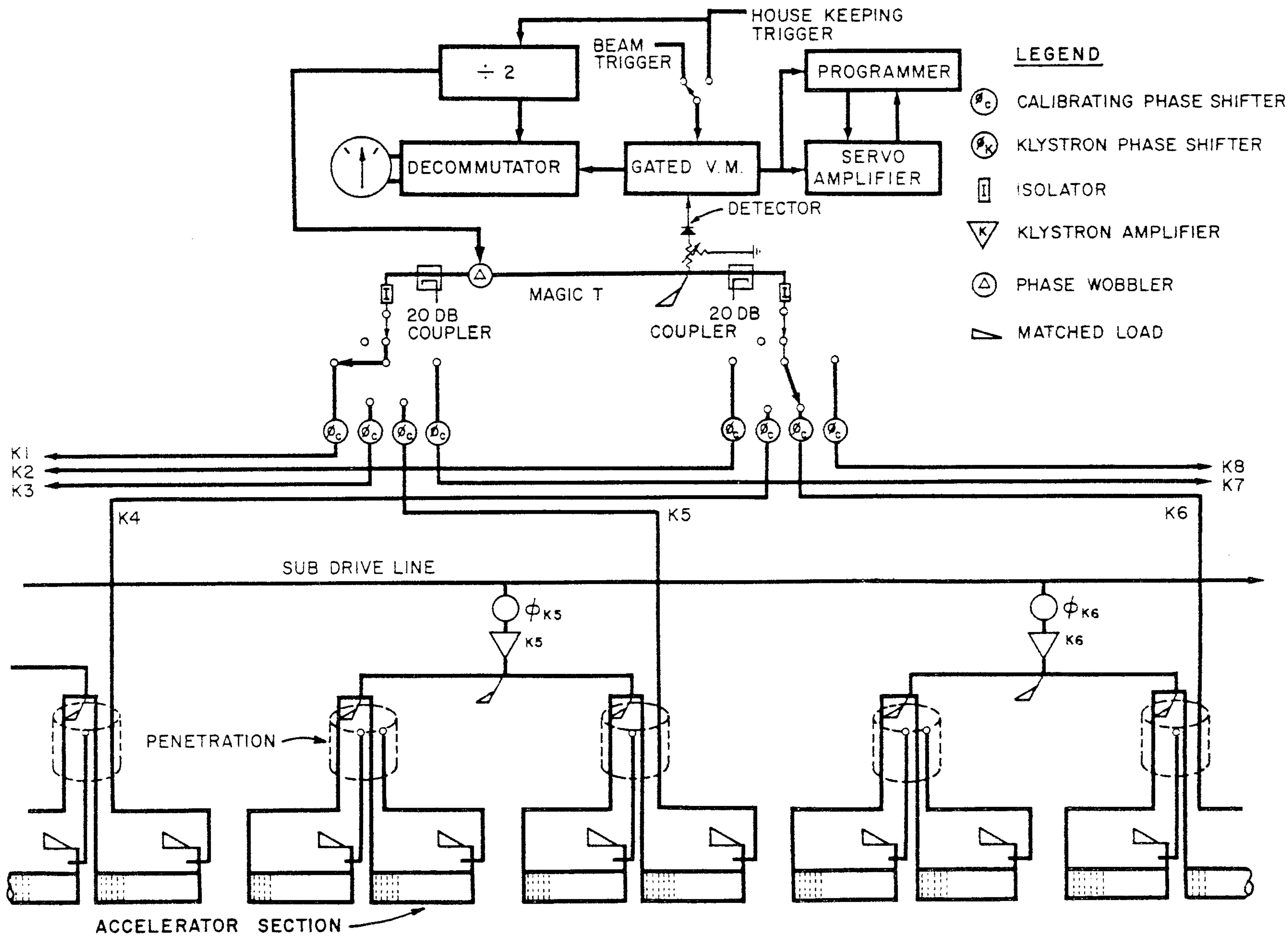

FIG. 12--Principle of the hybrid method of phasing applied to one sector (automatic system).

The components labeled φ_c are the calibrating phase shifters which serve as memories. The components labeled φ_k are the klystron phase shifters. The automatic system shown in Fig. 12 includes a gated voltmeter, a programmer to automatically perform sequential phasing of all sections in the sector, and a servo-amplifier to seek the minimum. The phase shifter Δ is a phase wobbler capable of modulating the phase by $\pm 90^{\circ}$ around the phase set by φ_c and φ_k. The "divide-by-two network" permits readout alternately of + and - 90° around the phase set by the system. Only when a minimum is attained does the gated voltmeter yield equal outputs that correspond to a zero output for the servo-amplifier.

The manual and automatic systems are presently being examined on both their technical and economic merits. An experiment is planned to simulate a complete sector phasing system. Further details of this experiment will be presented in the next Status Report.

3. Beam-Induction Technique of Phasing

The phase detector unit to be used on the Mark IV for the beam-induction technique of phasing has been completed. Figure 13 shows a complete circuit diagram of the unit. This phase detector permits comparison of two signals, 30 db apart in power level, by means of the switching arrangement, the AT2 attenuator, and the CR1 circulator. The microwave switch RFS1 is used to protect crystals CR2 and CR3 when the large klystron signal is on.

4. Phase Measurements of RF Components

A model of a phase-measuring set has been completed. Preliminary measurements indicate that measurements can be made with an accuracy of 0.1°. Presently, a Hewlett-Packard ratio-meter is being used for the readout of the phase angle. This leads to some ambiguity in the measurements. A resolver is being built to remove this ambiguity by allowing direct readout of the phase angle. A precision trombone and a 3-db hybrid for this application are also being designed.

A number of other microwave components were also examined for phase stability as a function of termperature, mechanical setting, and input power. These included a Sperry power limiter (model D-1351-1) and a tri-plate variable directional coupler (model MVDG2).

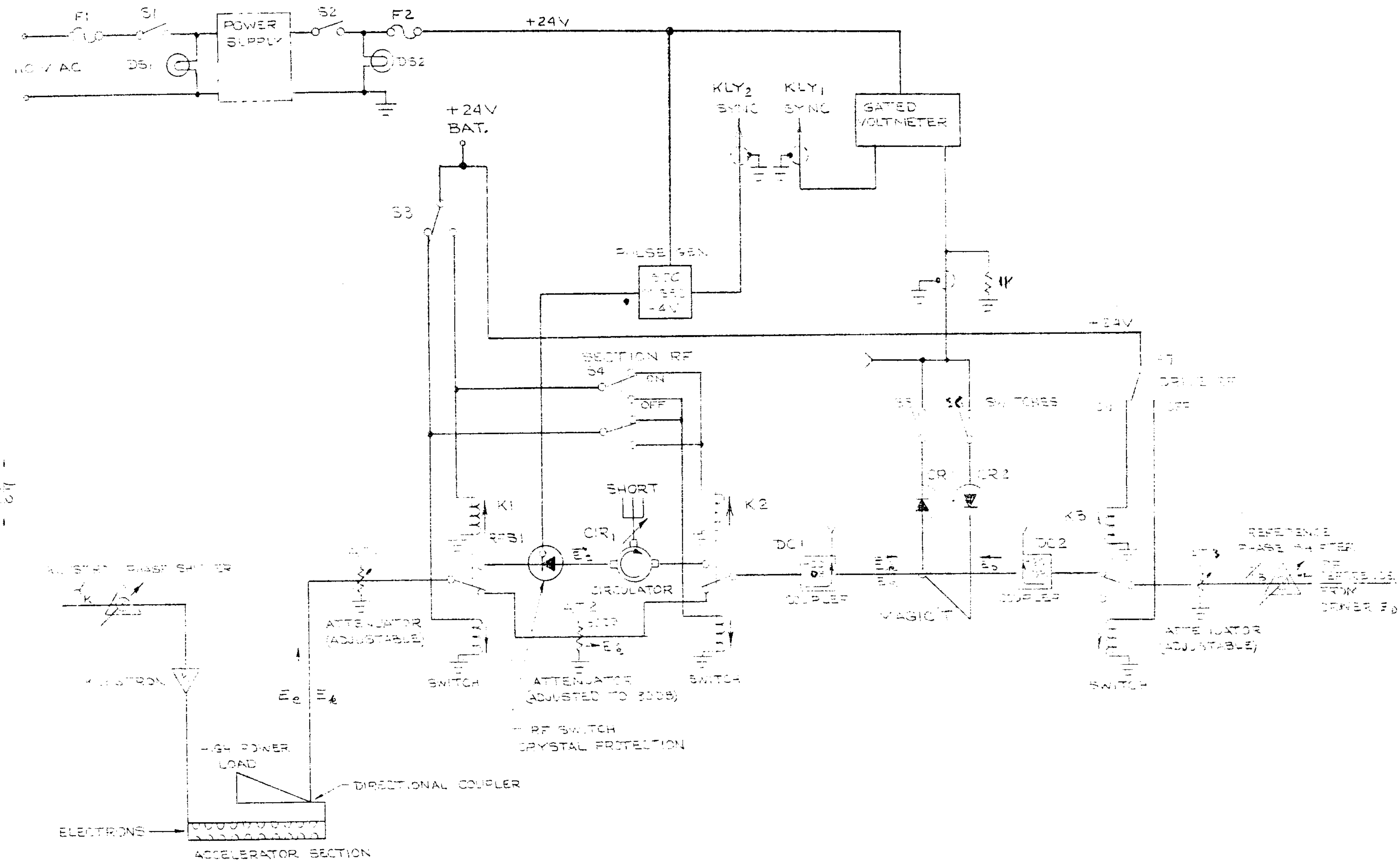

FIG. 13--Phase-detector beam-induction technique.

For the limiter it was found that the relative phase shift varied over a range of 40° for a 30-db relative input power range. For the directional coupler the relative phase shift was found to be about 20° over the same range of input power. A Caswell Isolator (model 101-G) was examined for phase shift as a function of temperature. It was found that for a temperature change from 60 to 120°F. the phase change across the unit was less than 4°. A similar test is now being performed on a circulator.

VII. KLYSTRON STUDIES

A. SUMMARY

During the past quarter, besides the continuing work on permanent-magnet-focused klystrons, extensive analysis has been made of the proposals by the vacuum tube industry to build power klystrons for the two-mile accelerator. Substantial experience has been gained in the use of a diffusion and ionic pump combination vacuum system. A cold-wall vacuum bakeout station is under construction and is 80% complete. Fourteen klystrons have been tested, seven of which are of the experimental type. The window life test station was transferred to the Klystron Group, and the decision was made that the Klystron Group would build two klystrons per week to fill the needs of the different SLAC Groups.

B. KLYSTRON PROCUREMENT

After analyzing submitted proposals by six different companies, it was concluded that the prices for the permanent-magnet-focused klystrons were lower than those of the electromagnet-focused klystrons and that, in addition, the permanent-magnet klystrons are more reliable. It is expected that a decision will be made during the next quarter as to which of the competing companies will be selected, and the procurement contracts will then be signed.

C. NEW FACILITIES

The second bake station, which consists of diffusion and ionic pumps, has been changed to diffusion pump only. The system using diffusion and ionic pumps requires separate valves for each pump; otherwise, any mishap or slight contamination of the ionic pumps by oil results in loss of these pumps. On the other hand, the pressures that have been achieved with the diffusion-pump system are in the region of 4×10^{-8} torr, which are considered to be adequate at the present time. The bakeout cycle for a klystron using a diffusion pump is in the vicinity of 48 hours; that is, 3 days are required to process a klystron, including installation, pinch-off and dressing-up.

With increased demand for the klystrons and the desire to achieve better vacuum, a cold-wall bakeout station (vacuum external to the klystron, rather than air as in the previous bake station) was designed and, at the present time, is 80% complete.

Work is also proceeding on the components for the additional window-test facilities. The vacuum-system bakeout oven and controls for the above are completed and have been checked out. A set of windows and interconnecting rf and vacuum plumbing is near ccompletion. Some monitoring instruments and recorders are due in November, 1962.

D. EXPERIMENTAL TUBES AND NEW DESIGNS

Five experimental klystrons were built and tested during this quarter: two with 1 inch drift tube diameter, and three with 1-1/8 inch drift tube diameter. The klystrons with larger diameter require less magnetic field but, at the same time, the gain is reduced by approximately 8 to 10 db. However, the gain of these latter klystrons is still 50 db, which is the required gain. Power and efficiency obtained from these klystrons are around 19 Mw peak and 35% efficiency at 250 kv beam voltage. (See Fig. 14) It is believed that better efficiency and power could be obtained with higher Q_e of the output cavity. Beam interception in the klystrons with large drift-tube diameter is around 3% at full beam. The drive power remains essentially constant within 3 db throughout the range of beam voltage of 150 to 250 kv. (See Fig. 15)

With increased drift-tube diameter, oscillations occur only with a reduced magnetic field; none have been observed with normal or higher fields. Further experiments are planned to determine the source of oscillations. Cold tests and shaping of the magnetic field (in the cathode region) on the permanent magnet to fit the gun requirements are near completion. In addition, a klystron with a special gun shield to meet the permanent-magnet requirements is under construction.

Because of the decision to use a single output window and the desirability of reduction in price of parts, a cold test was started to design a simple cavity with symmetrical rf field distribution in the gap region.

Simplified gun and dismountable window construction was designed and will be incorporated into the klystrons during the next quarter.

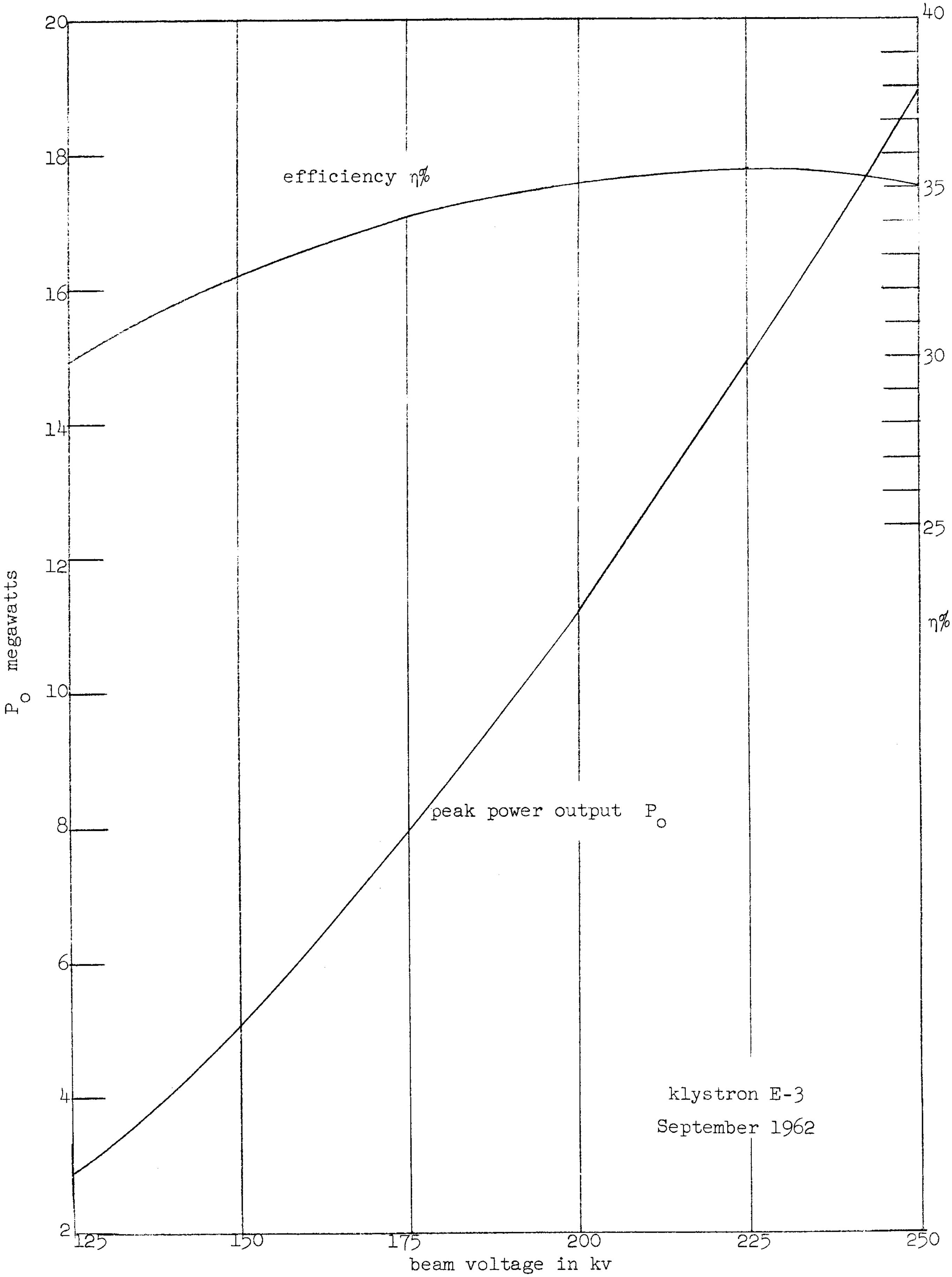

FIG. 14--Power output and efficiency vs beam voltage.

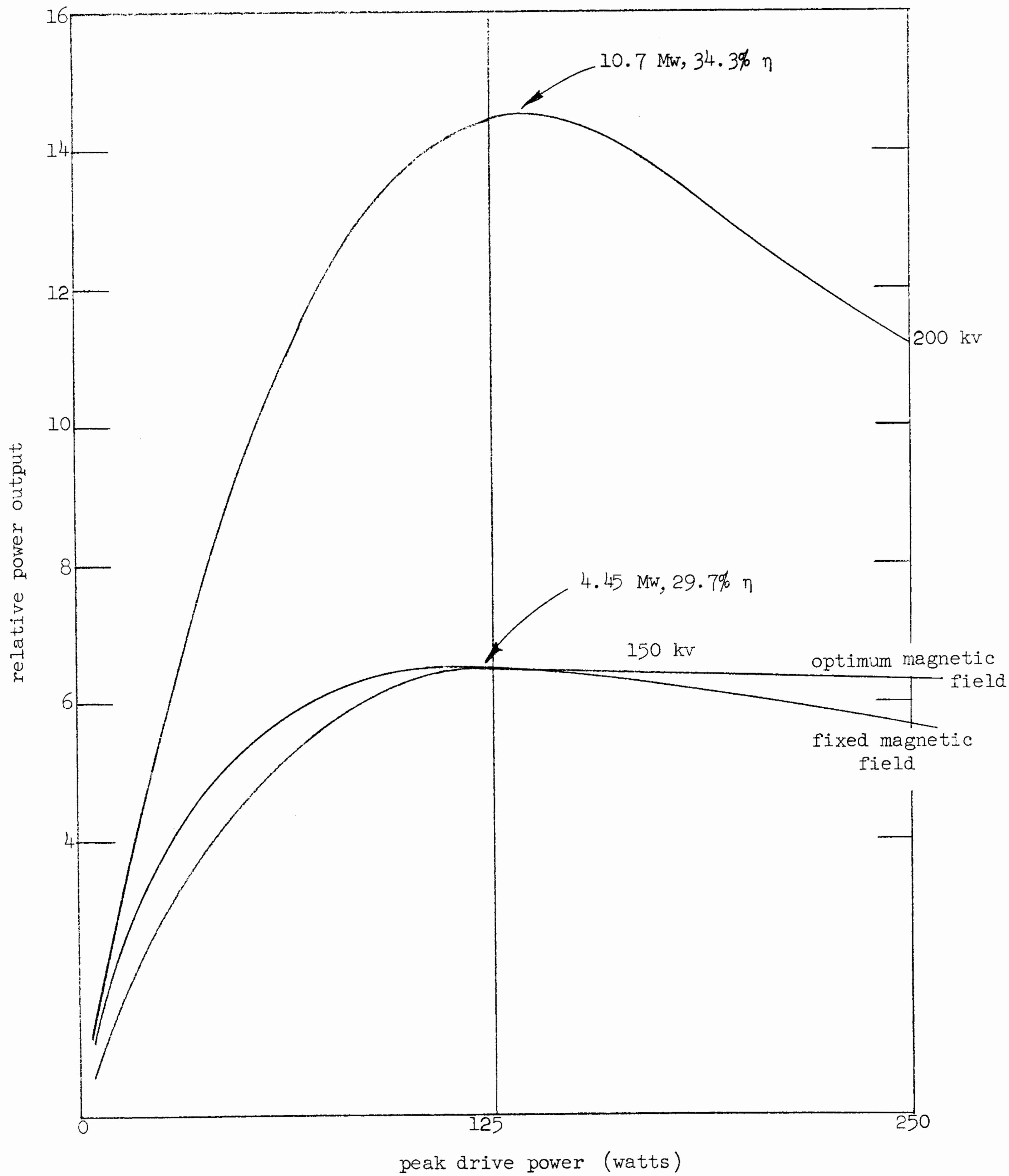

FIG. 15--Relative power output vs peak drive power.

E. WINDOW-LIFE TEST STAND

The window-life test stand is now being operated by the Klystron Group. It was operated 917 hours during the last quarter, during which time one window failed at 2750 hours. This window was not replaced, since a new type of window will be introduced shortly. A considerable amount of down time has occurred because of trouble with the modulator. The ignitron had to be replaced after 3211 hours service, the heat exchanger was changed, several other components failed, and the main bushing on the pulse transformer tank again developed an oil leak.

The first of the new life-test units is almost complete. The vacuum system is operating, and most of the instrumentation is available. Some difficulty was experienced with the all-metal vacuum valves, but this has now been remedied. It is planned to add this unit of six windows in series with the present system during the next quarter.

VIII. HIGH-POWER KLYSTRON WINDOWS

A. SUMMARY

The window-life test facility has been transferred to the Klystron Group and is discussed in Section VII of this report. Tests have continued on the resonant ring and the resonant cavities. Most of the cavity work has been done with the new all-metal system, where the vacuum conditions are better by more than a factor of ten. Tests with this system indicate so far that the better vacuum increases the ability to resist breakdown by about a factor of two in power, if initial outgassing is done slowly. Tests on alumina with deliberately introduced voids have shown that such disks fail at nearly the same power. Normal material of the same composition shows a wide spread in breakdown levels.

B. RECIRCULATOR WINDOW TESTS

Except for some time lost because of water and power modifications in the building, the resonant ring has been in continuous use this quarter. Below is a summary of the 22 windows tested.

1. Sperry Beryllia Window

One Sperry beryllia window, which had been previously tested to 26 Mw, was re-run to 37 Mw. It failed at this level at the metal-to-ceramic seal.

2. RCA Frenchtown Alumina Windows

Two RCA alumina windows made with Frenchtown alumina were retested to higher peak powers than previously available. One, using a compression seal, failed at 15 Mw, although it had been previously tested to 28 Mw. This window had slight damage from the previous test,[13] which may have contributed to failure at such low power. The second window,[14] with a pressed seal, failed near the seal at top and bottom at 35 Mw. This rather unusual type of failure is believed due to the large gap between the metal and ceramic in the pressed seal.

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[13] Status Report, M Report No. 280, Stanford Linear Accelerator Center, Stanford University, Stanford, California, October 1961, p. 28.

[14] Status Report, M Report No. 272, Stanford Linear Accelerator Center, Stanford University, Stanford, California, July 1961, p. 15.

3. Boron Nitride Window

A $2\frac{1}{2}$-inch diameter disk was tested in a symmetrical structure to a peak power of 70 Mw. Damage was similar to the previous tests,[15] except that some punctures also occurred through the surface "layers" of the material. This sample had a much smoother surface than those previously tested. As in the other disks most of the damage occurred between the natural layers of the material. Although this material can handle reasonably high powers, it does not seem to be superior to alumina and, once breakdown has started, is much more easily damaged.

4. Half-Wave Windows

Two half-wave thick windows were tested. One, of Coors AD-96, failed at 40 Mw peak, and one, of Wesgo AL300, failed at 60 Mw. The Coors disk, after initial breakdown, was operated to 50 Mw before extensive breakdown occurred. The failure of the Wesgo disk may have been partly caused by contamination found at the metal-to-ceramic interface where most of the arcing occurred.

5. Quartz Window

A 1/16 inch-thick quartz disk was tested in the Model A geometry, primarily to compare it with results obtained in cavity tests.[16] The disk failed at 32 Mw peak, 12 kw average power, with a pair of vertically orientated punctures at the center of the window. It had previously operated at 50 Mw peak power. During operation the disk became red hot in the center, with dark tracks at locations where previous surface arcing had occurred. We believe that the arcing removed the surface contamination that is responsible for the visual glow. This would leave the dark streaks, since the visual emissivity of quartz alone is very low.

6. Effect of Voids

A series of tests were made on a dozen Wesgo AL300 disks, 1/8-inch thick, in the model A geometry. Half of the samples contained artificially

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[15] Status Report, SLAC Report No. 1, Stanford Linear Accelerator Center, Stanford University, Stanford, California, July 1962, p. 47.

[16] SLAC Report No. 1, op. cit., p. 52.

introduced voids approximately 5 mils in diameter, which occupied 21% of the volume. The samples were made from the same isostatically pressed batch of material and were processed identically by the manufacturer. The tests were run as identically as possible. During operation the windows with voids showed a characteristic mottled glow pattern. The data from these tests, together with some data from three tests on moulded material, is shown in the following table.

POWER AT FAILURE OF AL300 ALUMINA DISKS, WITH AND WITHOUT ARTIFICIAL VOIDS

Sample	Isostatically Pressed		Moulded
	Controls	Material with voids	
1	35 Mw	48 Mw	35 Mw
2	70	44[a]	80
3	67	50	54
4	30	30	---
5	65	40	---
6	80[b]	-[c]	---

[a]Did not fail.
[b]Punctures doubtful.
[c]Damaged in mounting.

The most remarkable feature of these data is the much closer grouping of the windows with voids. It is obvious that the voids limited the power-handling capability of the ceramic. It is not clear why some of the controls should fail at a lower power.

C. RESONANT CAVITY TESTS

During this quarter the new all-metal cavity was put into operation after some difficulty with the modified Veeco vacuum valves. The cavity is one wavelength long and is similar to the "O-ring" cavity. A double resonance in the cavity (probably because of out-of-round parts) has been suppressed by rotating the feed guide to excite only one mode. Since the completion of the all-metal cavity, most of the tests have been done by using it primarily to test the effect of the better vacuum conditions. These tests, and those using the O-ring cavity, are described briefly below.

1. O-ring Cavity

Six 1/16-inch-thick, AL300 windows were tested in the O-ring cavity. The only variation from the 1/8-inch thick disks previously tested in this cavity has been radial cracking from the center toward the edge in some thin disks. This was caused by sudden excessive heating at the center of the disk, which made it buckle since it was tightly restrained at the edge. Other failures had the familiar punctures and internal destruction.

Three 1/16-inch-thick quartz disks were also tested. All ran incandescent at the center at full power, and although none was damaged one shattered when removed. Another had a strong stress pattern in the center when viewed by polarized light.

2. All-Metal Cavity

Seven 1/8-inch-thick AL300 alumina disks were tested in this system. Although some difficulty has been experienced in accurately measuring the power in the system, these tests indicate that alumina will withstand about twice the effective power (100 Mw)* with this system than the alumina will in the O-ring cavity. The pressure is more than an order of magnitude better in the all-metal cavity. It is not yet known whether this improved power handling is due to the lower pressure or to the absence of contaminents in the system. Several of the samples that had power applied quickly (with resultant increase in gas) failed very quickly at low power, indicating that any contaminents come from the alumina itself.

It was noticed that the rf loading was less in the all-metal cavity than in the O-ring type, and attempts were made to study this effect. Two tests showed the effect, one very clearly (see Fig. 16). Data taken without the disk (the length was adjusted to give the same resonant frequency) did not show any change of Q with change of pressure. Studies of this effect are continuing.

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*A running wave of this power will give the same gradient as exists at the window in the cavity.

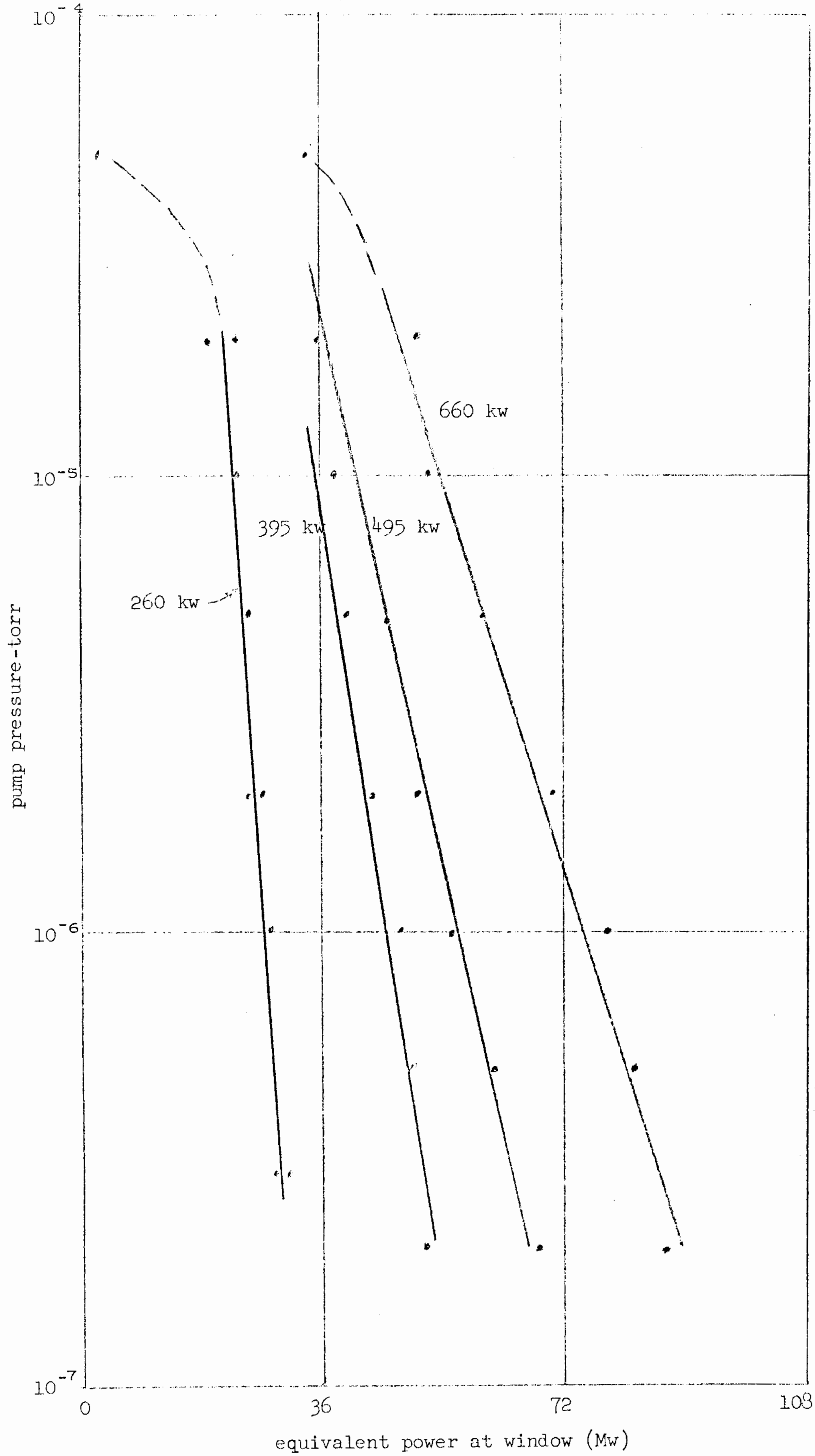

FIG. 16--Effect of vacuum on power in all-metal cavity, with window disk.

D. OTHER WINDOW WORK

1. New Equipment

The all-metal ring still lacks the phase shifter, which is now being machined. All other parts are nearly complete, and the vacuum manifold is almost ready for testing.

2. New Material

Samples of Zirconia and polycrystalline magnesium oxide have been received from Norton Refractories for evaluation. It has not yet been possible to get good measurements of the electrical properties of the small samples of single-crystal MnO mentioned in the last Status Report.[17]

3. Mark III Accelerator Windows

A punctured window was removed during the quarter. It had 2600 hours of life. It now appears that the window failure rate on this machine will be about four per year, or about 1/20th of the rate before slow turn-on was started. This would give (by linear extrapolation) about three per month for the SLAC accelerator when operating at 60 cps and at powers below 15 Mw. It is believed that the better vacuum conditions in the SLAC accelerator may give even better results than this.

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[17] SLAC Report No. 1, op. cit.

IX. MODULATOR STUDIES

The work started earlier on the RCA modulators has continued throughout this period. The first two modulators were brought up to the full output level, where severe transients in the de-Q'ing circuits became uncontrollable. It was decided to continue the high-level tests without employing the de-Q'ing circuit since the circuit would be worked out separately. Following removal of the de-Q'ing circuit, the first two modulators were moved to Mark IV where the tests will be continued.

The third RCA modulator is being used to complete the testing of modulator circuits. A multi-channel tape recorder operating in the loop mode in conjunction with a memory oscilliscope has made it possible to study the operation of the various circuits and components.

A test modulator, employing equipment removed from Mark IV, has been constructed and is being used for ignitron testing. The General Electric Company has supplied several modified ignitrons, which have been tested under pulsed conditions. Westinghouse has also supplied an ignitron for test purposes.

It was decided to conduct a survey of switching devices other than ignitrons. This would provide a basis for consideration of a back-up program for the ignitron. A British deuterium thyratron (Type E2886) has been observed in operation at Lancaster, Pennyslvania. Other developmental work with high-power ceramic thyratrons has also been noted. Table I provides a summary of the different tube ratings and the project requirements. These data are based on a modulator discharge efficiency of 85% and a matched-impedance condition. The efficiency figure is based on previous RCA tests. The operating parameters obtained should be adequate for project purposes.

There are three alternate possibilities for back-up tubes for ignitrons. These are:

1. The deuterium thyratron, Type No. E2986, manufactured by the M. O. Valve Company, London, England.
2. The new high-power ceramic thyratron, GE Type Z-5212, or Kuthe Type KU-275.

TABLE I

SUMMARY OF SWITCHING TUBE RATINGS

Description	SLAC	GE Z5212	Kuthe KU-275 (8301)	MO valve E-2986	Kuthe KU-274	GE GL-7890
Dissipation factor ($\times 10^9$)[a]	56	400	400	40	55	55
Peak power output in Mw	66 (to load)	—	100	—	60	48
Forward anode voltage, kv	44	50	50	40	50	40
Peak cathode current, amps	3,520	2,000[b]	4,000	10,000	2,400	2,400
Average cathode current, amps	4.05	8.0	8.0	15	4.0	4.0
RMS cathode current, amps	120	120 to 140	125	—	90	75

[a]The dissipation factor rating is a number arrived at by multiplying the peak charging voltage by the peak anode current by the pulse repetition frequency; it is commonly called the P_b factor.

[b]No upper limit has been established for this rating. This represents only a test parameter.

3. The lower power ceramic thyratrons, GE Type CL-7890, or Kuthe Type KU-274. (Two of these tubes would be required to handle the power requirements.)

The modulator contract with Ling Electronics, Anaheim, California, is proceeding on schedule. Ling has set up its first unit to evaluate the modulator circuits. The new modulator design employing a delayed-charging arrangement and a new de-Q'ing system seems promising. A study of these circuits is planned at SLAC in order to determine if they should be incorporated in the main modulators for the accelerator.

The hard-tube modulator for the sub-booster amplifier has been under construction for some time. The high-voltage regulation systems are being evaluated, and it is hoped that a solid-state regulated power supply, exclusive of the high-vacuum series tube, can be designed. Several power-supply manufacturers intend to send to SLAC modified versions of existing equipment that may be capable of meeting our requirements. There appear to be several possibilities of obtaining the degree of voltage regulation required under the modulator specifications.

X. MECHNICAL ENGINEERING

A. TECHNICAL DIVISION SUPPORT ENGINEERING

1. Plant Engineering

Work included study of the expected rate of electrical power demand rise for the SLAC accelerator and for research facilities to January 1966; model work for the Accelerator Housing; a reinforcing-bar study and modifications to SLAC site models; drafting for Central Laboratory layouts, trailer complex and M Building modifications; technical review of ABA document submittals relating to the Administration and Engineering Building, the Construction Office, the Electronic, Stores, and Fabrication Buildings, and the early-cut Accelerator Housing excavation; and evaluation of trailers for use at the Mark IV accelerator.

2. Microwave Engineering

Work included study of the shaft-indicator limit stops; design of an experimental phase-shifter drive; preparation of illustrative material for reports; and drafting for phase detectors, packaging, oscillator schematics, and a quarter wave transformer.

3. Injector Systems

Work included (a) assessing the equipment requirements and flow-plans for the sections at the west-end in-line gun station and at the off-axis gun stations at the Klystron Gallery and Accelerator Housing levels; (b) furnishing two 4-inch vacuum valves; and (c) drafting for thin-valve modification, gun-testing manifold, and injection-studies sketches.

4. Accelerator Structures

Work included (a) preparation of a scale model of the shop-equipment layout in the Heavy Assembly Building; (b) drafting for the accelerator fabrication shop layout and the accelerator tube tuner; and (c) maintenance of a 4-inch vacuum pumping station.

5. Klystrons

Work included studying the electrical power supply requirements for klystron electromagnets and drafting for klystron assembly details, a klystron model, an ion-pump power supply, a UHF optical baffle, test and storage equipment, and a window-bakeout oven diagram.

6. Window Group

Work included redesign and drafting for phase shifters and furnishing a vacuum pumping system and table for the rf ring test stand.

7. Modulator Group

Work included drafting for schematics of modulator networks, a pulse transformer tank for the klystron models and the rf-shielded modulator cage.

8. Instrumentation and Control

Work included advance planning of cable-tray requirements, preparation of material and cable identification lists, drafting for chassis purchase orders, and the working drawings for the instrumentation and control work on the test-stand project.

9. Mark IV Operations

Work included design and furnishing of beam-sampling collimators, Faraday cups, and pulse-transformer oil tanks; rearrangement of klystrons and waveguides; upgrading of equipment supports; and drafting for as-built revisions of Mark IV installation drawings.

10. Electronics Engineering

Work included drafting for the 119 Mc amplifier.

11. Technical Division Staff

Work included assistance in (a) studies related to the requirements of the dc modulator service, the Klystron Gallery structure, the Accelerator Housing structure, and magnetic shielding of the accelerator; and (b) drafting for critical paths, construction-cost charts, and status and personnel charts and graphs.

B. RESEARCH DIVISION SUPPORT ENGINEERING

1. Review of Requirements

Present and future requirements of the Research Division were studied by interested project groups and reviewed by project management. It was decided that the mechanical engineering staff would be expanded so that an adequate support staff of machine designers will be available for research projects.

2. Research Facilities

Work included the furnishing of a full-time draftsman for preparation of preliminary sketches of future research facilities.

3. Magnets

Work included design of magnetic field analyzers. Work on a small unit is well along and is just starting on a large unit. Also included was the design, substantially completed in September, 1962, of a quadrupole-magnet center-locator.

4. Positron Source Radiator

Work of preparing calculations of heat transfer for the positron source radiator is just starting.

C. TEST-STAND PROJECT

1. Temporary Test-Stand Locations

Over-all SLAC test stand schedule requirements were reviewed during the third quarter, with particular emphasis on the requirements of the Accelerator Structures Group. Advancement of beneficial occupancy dates of certain site facilities resulted in the decision that the two new test-stands, ultimately to be installed in the Fabrication Building, will first be located in the M Buildings. These test stands are scheduled to be available in January, 1963, and will be relocated to the site after other test-stand work at the Test Laboratory is complete.

2. Work on Test-Stand Design and Procurement

Purchase orders were issued for water manifold equipment. Test-stand-arrangement drawings were revised to accommodate component group review comments. A drawing showing the Test Laboratory rf drive lines was issued. Vendor prints were received from the test-stand vacuum-pump supplier. Fabrication Building test-stand-arrangement drawings were issued. Temporary test-stand-arrangement drawings were issued for project review.

3. Test-Stand Project Progress

At the end of the quarter mechanical engineering design was 85% complete, advance procurement of material was 53% complete, installation work had not started, and over-all test-stand mechanical engineering work was 39% complete. Manpower and purchase commitments were within budget allocations.

D. TWO-MILE ACCELERATOR PROJECT

1. Planning

a. Design Coordination

The Accelerator Housing arrangement was completed with the accelerator and beam-takeoff laterals located to the north. A full-scale model of the Accelerator Housing cross section was constructed. Cost estimates of vertical-access ladders, hatchways, and substation arrangements were made. Schematic layouts of injector stations were completed. Accelerator Housing dimensions were reviewed and reaffirmed at 10 feet high and 11 feet wide.

b. Installation Drawings

As-built requirements for 30 sectors, together with the physical dimensions involved, resulted in drawing schedules to be issued on the basis of F-sized drawings. Klystron Gallery and Accelerator Housing blanket drawings were started. Work proceeded at a slow rate because of the need to correlate the work with the needs of SLAC accelerator component groups and the unavailability of the structural-frame design of the Klystron Gallery. At the end of the quarter installation drawings were 2% complete.

c. Installation Management

Preparation of a report, which is to be a complete documentation of operations planning for the installation of the SLAC accelerator and its appurtenant auxiliaries and service subsystems, was started. The report will cover schedules, manpower requirements, sequences of installation work, numbers of installation and labor subcontracts needed, and recommendations of what work can and should be done by SLAC personnel. It will also outline the various work-item procedures that will be applicable to this work and who will be responsible for each item. This report takes as its point of departure the over-all project's critical path, and it will make available for review and approval, well in advance of start of the work, a detailed description of how the machine will be installed.

2. Vacuum

The SLAC accelerator vacuum requirements were reviewed and specified at a normal operating pressure in the accelerator tube centers of 5×10^{-7} torr. Various alternate vacuum systems were intensively reviewed.

Two systems were selected for further study, and a design report was issued covering these schemes. Scheme 1 requires two 10-inch diffusion pumps per sector separated from the accelerator hardware by Zeolite traps, a 10-inch manifold in the Klystron Gallery, and 6-inch fingers extending down each of the 510 accelerator services shafts. Rectangular-waveguide pumpouts for the accelerator are located close to the accelerator tube sections, the rectangular-waveguide entrypoint to the accelerator services shafts, and the klystron and waveguide windows or valves.

Scheme 2 requires one 10-inch diffusion pump per sector separated from accelerator hardware by a liquid nitrogen trap. The pump unit will be used for occasional roughing of the system down to less than 10^{-5} torr. Then four 6-inch ion pumps per sector can be started using minimum size power supplies with an 8-inch manifold in the Klystron Gallery.

Most other items of the two schemes are identical. The conclusion of the report was that the over-all costs of Scheme 1 and Scheme 2 are similar but, that Scheme 2 appears preferable because of a lower possibility of contaminating the accelerator section with vacuum-pump oil. Project review of the report and correlary investigations are in progress. The vacuum R & D program was revised to accommodate review of specific SLAC accelerator requirements as established during the quarter.

3. Alignment

SLAC accelerator alignment requirements were intensively reviewed by interested project groups, particularly in relation to the problems of beam transport, and were specified at ± 1 millimeter over the two-mile length. An optical alignment system is under investigation in collaboration with the Theoretical and Special Studies Group. If the optical alignment system does not work, then an alternate system using gamma rays will be developed. Both systems require a source at one or both ends of the machine, flip-up interferometer grids or collimating targets located at each section between accelerator support trusses, and detection devices at one or both ends of the machine. As further backup, the SLAC accelerator can be initially aligned using established survey techniques, and may be kept in alignment through programmed study and utilization of data available from the beam-position monitoring devices now under development. Each of the two hundred and forty 40-1/2-foot accelerator support trusses (each carrying four accelerator tube sections) will have mechanical provision for an alignment check (within sector distances) by an optical auto-collimation procedure. It was decided that the ability to align using beam-position information, as well as a sight tube for light or gamma rays, will be incorporated into the final design. The sight tube will be 12-inch pipe and will be evacuated by mechanical vacuum pumps. Provision will be made for the addition of remote actuation of the flip-up targets.

4. Supports

During this quarter the mechanical supports work was devoted to establishing the requirements of the accelerator structures and in-line quadrupole magnets. Various systems of support were reviewed, all based on the use of aluminum and/or stainless steel as the nonmagnetic materials suitable for location close to the electron beam. All of the designs under serious consideration at the end of the quarter incorporate the use of a 12-inch sight tube for alignment purposes, which will also contribute to torsional and flexural rigidity as part of the support truss. The adjustable bases for supporting the ends of the accelerator support trusses are likely to incorporate the use of three jacks. One jack will be used for horizontal positioning of the ends of each truss, while the other two will be used for vertical positioning. Provision will be made for operation of the vertical jacks simultaneously for rectilinear adjustment, and in opposition for angular adjustment. Quick relocation travels are to be limited to less than the movement capability of the rectangular waveguide as established by the Accelerator Structures Group. A design was prepared for a prototype truss, which will be acquired for testing during the next quarter.

5. Special Handling Equipment

It was proposed that equipment-handling within the Accelerator Housing be done by means of a 3-foot gage railroad. Track will be sized for medium-heavy duty in anticipation of the heavy loads that will be imposed by research equipment. Initial rolling stock will not be heavy duty, but it will be designed to meet the requirements of installing and maintaining the accelerator. The use of diesel engines having oxy-catalyst scrubbers as motive power (as used in mines) is under investigation.

6. Cooling Water

A design study covering the detailed requirements of the three cooling-water systems for the accelerator was prepared and issued for project review. These three systems are designed to: (1) remove heat from the accelerator tube sections, output dummy loads, and then the rectangular waveguides; (2) cool some modulator components and the pulse transformers and then the klystrons; and (3) trace rf drive lines to maintain them at a constant temperature and then to remove heat from the modulator ignitrons. Specific data included was in accordance with the specifications outlined in the last Status Report.[18]

Basic requirements for the second and third systems are established, and final design can proceed. The first system which is to maintain a constant accelerator-tube metal temperature poses unusual technical problems. Intensive review was started to determine experimentally whether or not standard water-to-water heat exchangers can be used. If tests show that these heat exchangers are not applicable, then the use of reduced-pressure boiling-type heat exchangers will merit consideration. Research work is under way on both types of heat-exchanger equipment; they will be tested on Mark IV during the next quarter.

During this quarter the feasibility of cooling accelerator tubes, dummy loads, and rectangular waveguides, in series and in that order, was reviewed by interested project groups and found to be adequate. Work was started on a review of corrosion-control requirements for distilled, demineralized, low-conductivity all-copper and stainless-steel systems. A study of corrosion-control requirements will be made to determine the specific oxygen and carbon dioxide content limitation criteria.

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[18]Status Report, SLAC Report No. 1, Stanford Linear Accelerator Center, Stanford University, Stanford, California, July 1962.

7. Electrical Work

During the quarter work was substantially completed on a design report which will stipulate the requirements of the various SLAC accelerator subsystems. Electrical power needs of the machine in various conditions of service, and service outage and service duties, are well developed and clearly defined. Studies in the area of radiofrequency interference were started in collaboration with the Plant Engineering and the Instrumentation and Control Group.

E. TECHNICAL SERVICES

1. Project Standards

Work of preparation, submittal for review, and incorporation of approved standards has continued. Current work was in the areas of inspection requirements of incoming material, general drafting instructions, safety, and of standards for painting, corrosion-protective plating, light intensity values, quality control, electrical drawing symbols, piping, concrete, and resistance welding.

2. Parts Catalog

Work of expanding the parts catalog to meet the needs of the component groups has continued. A VSMF microfilm file and reader were installed and made available for project use.

3. Specification Service

A military specifications and standards library was initiated, and it now contains 400 documents. This is available for project reference. Inspection and rejection forms were ordered for project quality-control use.

4. Document Control

The document-control system installed in the last quarter is now in full use. Logging of ABA Title II drawings and specifications was started, and a system for filing and distribution of standards was initiated.

XI. CONTROL SYSTEM STUDIES

A. STATUS OF DATA-HANDLING SYSTEM

The control concept adopted for operation of the accelerator provides for beam operations and maintenance operations separately supervised from one central location. In order to implement this plan, an economical means must first be found for reliable transmission of the data required at the Central Control area despite possible high electromagnetic interference levels. Second, a means should be devised for reducing the volume of data so that efficient operations can be achieved by a minimum number of human operators. These two requirements are strongly interrelated and are integrated in the system outlined below.

Physical wire-lines are proposed as the basic communication facility for accelerator control. The alternative, radio communication, is susceptible to possible radiofrequency interference from the accelerator components. The use of an individual transmission facility (wire pair) per signal has been considered but has been discarded in favor of multiplexing, which is the sharing of a transmission facility among several signals. There is statistical evidence that multiplex equipment is more reliable and gives less total outage time than the associated cable plant. Other arguments favoring multiplexing are that significant cost savings are available at the communication distances involved in the SLAC accelerator; that the cross-sectional space required for cable runs is considerably reduced; and, most important, that multiplexing provides the data system with flexibility for system modification and expansion by simply changing the terminal equipment without altering the cable plant.

Balanced circuitry, carrier transmission, and careful shielding and grounding are the principal technical provisions that are included in wire-line communications to mitigate the adverse effects of both induced noise and environmental variations. System-wide coordination of communication signal levels and frequencies will allow the many diverse control functions to be carried on without mutual interference. Such coordination of signal characteristics will also accommodate any change and expansion of the system without major disruption of service or expensive modifications.

Data will, for the most part, be assembled by sectors for transmission to and from Central Control. Signals within a given sector will be distributed by shielded cables or wire pairs in conduit, duct, or wall-mounted tray. The signals exchanged between a sector and Central Control will be via shielded cables run in trays mounted on the Klystron Gallery wall.

1. Two-State Status Measurements

These measurements form the greatest volume of signals to be handled for accelerator control. They include such indicators as operational go/no-go or alarms for accelerator components and operational availability of components and subsystems. For these signals the most economical of the available multiplexing schemes is to time-share a single wire-pair among all status signals within a sector. By adding FM transmission of the composite signal, communication performance in the noisy environment would be improved at little extra cost.

At communication distances of less than one-half mile the individual wire-pair method for handling status signals might be less expensive. Since there are advantages to be gained by having a standard sector configuration, it is proposed that the time-division multiplexing method be applied for communicating status signals to Central Control from all sectors.

2. DC Absolute Value Measurements

These measurements are needed where go/no-go status information is not sufficient. In many cases they are read-outs, or reactive measurements of remote-control actuations. From the communication viewpoint it is preferable to convert the absolute dc value to a form relatively insensitive to level variations. Voltage-to-frequency and voltage-to-digital conversion are both technically acceptable in the accelerator application. For accuracies up to 1 part in 100, voltage-to-frequency conversion is to be preferred as this method presents the dc value in analog form ready for display at Central Control and is normally less expensive than digital conversions. For operational accuracies greater than 1 part in 100, a digital (pulse code) conversion is mandatory.

Either frequency or digital conversion allows multiplexing of more than one signal per wire-pair. The frequency conversion requires no common equipment other than the wire pair. About five such signals can share one wire-pair.

3. On-Off Remote Control

On-off remote control of accelerator components from a central control location can be accomplished by using individual wire pairs, but multiplexing of such signals is to be preferred for the reasons discussed above. There is a good possibility that the same time-division multiplexing equipment that is used for acquiring two-state measurements can also be used for on-off remote-control functions.

4. Remote Angular Positioning

Remote angular positioning of accelerator components from Central Control by servo-systems that are amplitude or phase sensitive is considered impractical at the distances and in the environment encountered in the accelerator application. Remote positioning by incremental (stepping motor or switch) servo-systems is to be preferred from a communication viewpoint. Any degree of positioning accuracy can be obtained at any distance with this method, with high immunity to noise in the communication facility. Moreover, position can be retained during any power interruptions. Multiplexing of these signals is also feasible and will be applied in some form.

5. Protection

Protection of the accelerator from self-damage requires a communication network that causes the beam to shut off under certain circumstances. The network and the measuring devices must have a fast-enough reaction time to perform the shut-off function between individual accelerator pulses. A series arrangement of unity-gain amplifiers, one at each sector, that interrupt a carrier tone whenever a protection device trips, is contemplated for this beam shut-off purpose. In addition to this special network, the measured status of all personnel- and equipment-protection devices, including those not involved in beam shut-off, would be continuously transmitted to Central Control for monitoring purposes. It is proposed that the tunnel-access door release also be controlled from the Central Control Building.

B. Progress During the Past Quarter

1. Cable and Data System

Electromagnetic interference measurements have been made at a 220 kv substation and on transmission lines to correlate interference problems with the instrumentation and control network. More tests are being planned. Preliminary studies seem to indicate that the substation should not cause serious interference with the control system. More studies will have to be made before the over-all effect of the 220-kv transmission line on the control network can be determined.

Plans to install a test facility for the control system between Buildings M-1 and M-2 have been made. When this facility is installed, it will be possible to test various subsystems of the instrumentation and control system from a remote control center. Sector control is being simulated in the M-1 Building, and central control in the M-2 Building. Several types of signal cabling, as well as a variety of shielding and grounding arrangements, will be installed to test transmission of measurement and control signals. Control, communication, and data-handling equipment will be subjected to performance and life tests to determine their suitability for the generator application. Known or suspected sources of interference will be duplicated or simulated to provide as nearly as practicable the actual conditions to be encountered in the Klystron Gallery.

2. Beam Monitoring and Guidance

Tests have been conducted on a commercially obtained current-pulse transformer to be used as an accelerator beam-intensity monitor. This device was used in conjunction with balanced transformers, the tests being of the following two types.

In the first tests known pulse currents were fed through a wire passing through the pulse transformer core, and the output-voltage waveforms were compared with the known input current waveform. The results obtained agreed with the manufacturer's performance figures for both sensitivity and pulse rise-time. These tests were carried out with 125 ft of screened cable, this being the length of the cable in the Mark IV accelerator between the trench and the display console, thus simulating the second type of test described below.

The second tests were carried out by using the Mark IV accelerator beam. Considerable amounts of noise, starting several microseconds before the beam current pulse, were picked up and traced to the injector system. However, it was found that the waveform induced in the beam-intensity-monitor coil was very similar to that developed by the beam current collected in the Faraday cup. Moreover, the output amplitudes were in close agreement. Further work is being carried out on beam-position-monitor coils.

3. Trigger System Developments

Trigger systems have been laid out in detail for two different sets of requirements. Digital and analog versions of one system have been worked out. Both systems provide interlaced triggers at 60 and 360 pps, three independent bubble-chamber pulses occurring at a rate between 0.5 to 2.0 pps, and data pulses at 3 pps. Although one system is considerably more flexible than the other, the cost of the two systems is comparable. A 360 pps trigger generator for Mark IV has been built and tested. It will furnish 60, 120, 180, and 360 pps rates. The existing Mark IV trigger booster has been modified to mate with the new trigger generator and the RCA modulators. A more sophisticated trigger generator, similar to the eventual SLAC trigger generator, will be breadboarded soon and will be installed in Mark IV in the next month or two.

One of the Mark IV ion-gage power supplies is being redesigned for greater power output, better electron-current regulation, and less ion-current drift. Electron-current regulation has been improved by about an order of magnitude, with a high-gain, reference-type, solid-state system. This has been breadboarded, and the power supply is being modified accordingly. An ion-current feedback amplifier is under development.

4. Electronics Shop

Prototype and fabrication work is being carried out for the Instrumentation and Control, Klystron, and Microwave Groups, for the Research Division, and for the Mark IV accelerator. Repair of and calibration service for the commercially-built test equipment belonging to the project is now available.

5. Test Stands

Test-stand instrumentation is proceeding on schedule.

XII. RESEARCH DIVISION

A. MAGNET AND BEAM STUDIES

1. Beam-Transport Design

Design work was completed for the tunnel to house the low-energy (5-10 Bev) transport system that has been proposed at the one-third point along the accelerator. The actual transport system, patterned after the Brown design,[19,20] bends a total of 45°, can pass a $\pm$ 1% momentum spread or provide $\pm$ 0.05% momentum resolution, is achromatic and nearly isochronous, and can produce small (1 mm square) image spots over a wide range of positions in the end station.

The design of a tunnel penetration for the suggested 3-Bev storage ring at the two-thirds point along the accelerator is finished. The tunnel has a total bend of 45° up to the end station.

Design work on the 25-Bev beam-transport system for end station A is in the final stages. The first-order design of the first half of the system (up to the slit) has also been finished, subject to the results from second-order optics calculations and mechanical-tolerance calculations. Computer programs for these calculations have been completed.

The final magnet configuration for the second half of the system is still under study but should be frozen shortly. The total bend of the system will probably be 24°. Angles much larger than this increase the non-isochronicity of the beam prohibitively, while angles less than this lead to excessive tunnel costs. Final review and approval of the design is expected next quarter.

Various bending-magnet designs for this system have been proposed, and evaluation of the designs is proceeding.

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[19] S. Penner, "Electron Beam Deflection Systems for the Monster," M Report No. 200-13, Stanford Linear Accelerator Center, Stanford University, Stanford, California, August 1960.

[20] H. S. Butler and J. J. Muray, "Deflection Magnet Systems for the Primary Beam," Internal Memo., M Report No. 297, Stanford University, Stanford, California, April 1962.

2. Pulsed Magnet

Several circuits have been tested on a small scale using both thyratrons and hard tubes. Although hard-tube circuits are necessary if the field is to be regulated during the pulse, they dissipate a large amount of power. It has been decided to use a circuit which uses ignitrons to pulse the magnet and which operates at the resonant frequency of the magnet and the storage capacitor. The circuit chosen also provides for recovery of part of the energy stored in the magnet. An attempt is being made to control the peak flux density in the magnet by pulsing it from a constant-voltage source and by degaussing the magnet between pulses, thereby eliminating the need to regulate the current during the pulse with a feedback technique. One possible scheme for degaussing is to place a small capacitor across the magnet that will cause a decaying sinusoidal current after each pulse. Construction of a model pulse magnet using ignitrons is in process.

3. Quadrupole-Magnet-Center Locator

The magnetic center of a quadrupole can be observed visually when a beam of polarized light passes through a colloidal solution of iron-oxide and the polarized beam is analyzed. The zero-field point appears as a dark cross in a reddish background.[21] To make use of this effect, an instrument will be designed to position a vial of colloidally suspended ferrite particles in the field of a quadrupole. Movement of the vial, with the polarizing plates parallel to and centered between the pole faces, will be controlled by a graduated hand crank. The instrument is to be designed to fit magnets up to one meter long; it will be useable with magnet bore sizes between 3-1/2 and 8 inches.

4. Positioning Device for Magnetic-Field Probes

A table with mechanical components having three degrees of freedom of motion has been designed for precision location of magnetic-field probes. The magnet-mounting surface area is 1 meter square, and it should be able to support 10,000 lbs. The machine is portable enough to permit relocation

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[21] R. M. Johnson, "Method of Locating the Center of a Quadrupole Field Using Magneto-Optics," Bev-687, Lawrence Radiation Laboratory, University of California, Berkeley, California, October 6, 1961.

by shop personnel and has provision for wheel retraction. The probe movement will be a 3-axis movement, motor driven. Its accuracy will be .001-inch, with the probe approaching from one direction only. The movement indicators will be electronic Veeder root counters with digital readout on Nixie indicator lights.

5. Hall-Probe Irradiation

After a long search a radiation-insensitive Hall probe was found, which is constructed from InSb instead of InAs. In addition, a single crystal of semiconductor is replaced by a film deposit on glass. The Hall voltage from this generator changes only a few percent when bombarded by 10^6 40-Mev electrons. After this initial change the Hall voltage seems to stay constant.

6. Coil Design for the Harmonic Analyzer for Quadrupole Measurements

An asymmetric coil has been designed for the harmonic analyzer in order to measure the higher harmonic contribution to the field. A computation program has been started to find different coil designs so as to minimize certain harmonics and to maximize others.

B. RADIATION STUDIES

1. Transverse Shielding

A report describing the transverse-shielding calculations is in process and will probably be issued during the coming quarter.

2. Effects of Penetrations and Passages Through the Transverse Shielding

Preliminary calculations indicate that significant amounts of radiation will come through the waveguide penetrations unless they are plugged or capped-off with several feet of concrete shielding. Similarly, the access ways for personnel and material will probably also have to be shielded. The access ways for personnel only may not have to be shielded.

3. Target-Area Shielding

A preliminary calculation for a shielding wall perpendicular to the direction of the incident electron beam confirms that the μ-mesons can be a serious radiation problem. For reasonable decay distances (on the order of 10 feet), the decay muons from the photoproduction of pions via the statistical model or via γ + nucleon $\rightarrow \pi$ + nucleon are important at large angles. At small angles the muons from direct μ-pair production dominate. Decay muons and pions produced via direct electromagnetic pair production or via the Drell process are negligible, because they have about the same angular distribution as the μ-pairs and are less abundant.

4. Radiation Levels Inside the Accelerator Housing After the Machine is Turned Off

A preliminary calculation is underway to estimate the induced activity in the copper of the accelerator and in the concrete of the walls of the Accelerator Housing.

5. Radiation Levels Inside the Accelerator Housing While the Machine Is On

When a high-energy electron hits the accelerator structure, an electromagnetic cascade develops. Some of the initial energy then scatters out of the machine and causes radiation in the tunnel. Negotiations are under way with the shielding group at Oak Ridge for a calculation that will assist in estimating the distribution of this energy in angle, in energy, in determining whether it is carried by electrons or photons.

6. Shielding for a Positron Source

It is expected that a radiator about 5-radiation-lengths thick will occasionally be put into the machine to act as a positron source. It will also act as a strong, localized source of high-energy penetrating radiation, which will give rise to high radiation levels in the Klystron Gallery unless extra shielding is put above it. For an incident electron beam power of 2.5 Mw, preliminary calculations indicate that if the part of the earth shield closest to the radiator is replaced by a slab of iron about 10 feet thick, 15 feet wide and 20 feet long (about 700 tons total), then the radiation levels in the Klystron Gallery will be safe for continuous occupancy.

7. Shielding Experiment

SLAC will cooperate in the analysis of a shielding experiment organized by CERN and the Rutherford Laboratory. Nuclear emulsions will be buried at various depths in a steel absorber that will be irradiated with 9 Bev/c and 20 Bev/c protons from the CERN proton synchrotron. SLAC will scan some of the emulsions.

C. THEORETICAL PHYSICS

1. CEA Experiment

Since planning of the experimental areas depends heavily on how accurately the secondary-particle intensities can be computed from the peripheral mechanism proposed by Drell and Ballam, an attempt to confirm this prediction experimentally will be made at the Cambridge Electron Accelerator. In order to plan this experiment it is necessary to know at what energies and angles it will be possible to discriminate the pions from the electron background. These electron-to-pion ratios have been computed for liquid hydrogen assuming a point charge (which gives a safe upper limit for the electrons) and are given for a 1 cm target in Fig. 17. The ratio for a target L cm long is given by $fL + 1 - f$, where f is given in the figure at different points along the constant-ratio contours. A code that includes the finite size of the charge distribution and that can also be used to compute muon production is nearly complete.

2. Secondary-Yield Calculations

It is conceivable that if virtual particles behave like "Regge poles," then the cross sections computed for the Drell mechanism would be an overestimate. It can be shown that for pions this reduction is unimportant, but that it could reduce the predicted kaon and anti-proton yields considerably; a reliable calculation of this reduction cannot be made without a better understanding of the Regge mechanism than is currently available. Another mechanism for the production of pions and kaons is via the processes

$$\gamma + p \to \rho \to 2\pi + n$$

and

$$\gamma + p \to K^{*} \to K + \pi + \Lambda$$

The absolute rate and spectrum have been computed from a peripheral model, which indicates that the first process will be a major contributor to the high-energy pion beam. The calculation also shows that the second process would provide by far the most important source of kaons. Calculation of the photoproduction of charged vector bosons is being completed.

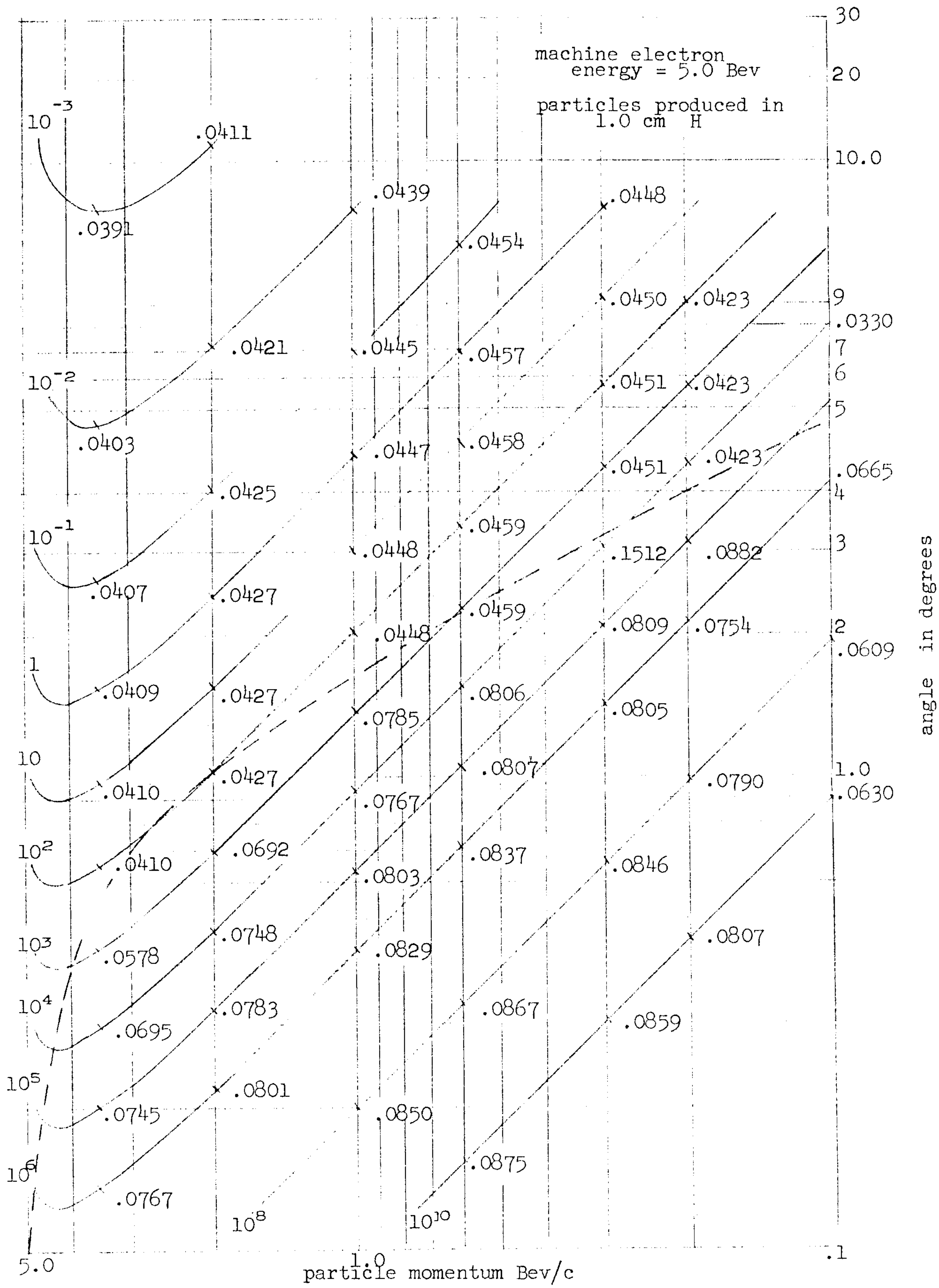

FIG. 17--Contours of constant ratios of electron-to-pion yields.

3. Colliding Beams

The radiative correction to the colliding-beam process, $e^+ + e^- \rightarrow$ (strongly interacting particles), has been calculated. The results show that for good energy resolution in detecting two-body final states the radiative corrections are nearly 50%. This large effect is attributable, in the first place, to the fact that the center-of-mass energy is large compared to the electron mass, and secondly because the radiation is emitted mostly along the direction of the electrons and hence escapes detection.

4. Model for Mesons

If mesons are taken to be bound states of baryons and anti-baryons, the bound states with the lowest quantum numbers correspond to the observed mesons. According to this model there should also exist low-lying states with the quantum numbers $T = 0$, $J = 0$, $P = +$, $G = +$ (ABC state ?), and $T = 1$, $J = 0$, $P = +$, $G = -$ (zeta meson ?). The model also allows mesons of zero strangeness that are not eigenstates of G parity. Examination of the experiments pertaining to the zeta meson show that the evidence for its existence is not good; but if the experiments are believed, they slightly favor the quantum numbers predicted by the model.

5. n-p Scattering

By a combination of theoretical arguments and data analysis it has proved possible to extract some information about the energy variation of the $^1S_0$ neutron-proton scattering amplitude in the energy range 0-20 Mev. Preliminary results indicate that the long-range part of the interaction in this state is consistent with the prediction of one-pion-exchange, thus strengthening the belief that most of the features of the nuclear force can be quantitatively understood from pion theory. Examination of current experiments reveals that more quantitative information cannot be obtained by simply refining existing techniques, and the feasibility of spin-correlation experiments in this energy range (which would give information about the interaction not otherwise obtainable) is being explored with an experimental group at Los Alamos.

D. EXPERIMENTAL PHYSICS

1. Experimental Program at the Cambridge Electron Accelerator

A joint program with Professor Frank Pipkin of Harvard has been set up to measure the photo Drell effect using photons from the bremsstrahlung of 6-Bev electrons. Plans for this program have been worked out in detail during this reporting period. At present the experiment is expected to provide information on the energy and angular distribution of π's and K's at small angles (1 to 8 degrees) with respect to the external photon beam at the CEA.

The experimental set up will be as follows. The photons will strike a 1/10-radiation-length Be target located just in front of a large bending magnet. Following this is a $1/2^{\circ}$ quadrupole magnet to provide momentum resolution, and then a $d\beta/\beta$ gas Cerenkov counter (to distinguish K's from π's) and electron momentum-defining counters. Finally there is a gas threshold-counter to anti-out electrons or electrons plus pions, followed by a shower detector and μ-meson detector. The whole assembly is mounted on a truck that can be rotated around a point, which is essentially the virtual image given by the first bending magnet.

Most of the equipment is already finished or under construction at Harvard. The differential counter will be provided by Professor R. Schluter of Argonne, and some optics for this counter will be built at SLAC. It is hoped that measurements will be under way by the first of the year.

2. Magnetic Momentum Slit

The model of this slit, described in two previous Status Reports,[22,23] is now under construction, and delivery is scheduled in a matter of weeks. Preparations for making the magnetic measurements are almost complete. This will be the Hall probe described earlier in this section. An assembly drawing of the model magnet is shown in Fig. 18.

An array of current strips which are to be glued to the pole faces has been fabricated. These are being mounted. Power supplies for the magnet and current sheets have already been delivered.

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[22]Status Report, M Report No. 298, Stanford Linear Accelerator Center, Stanford University, Stanford, California, April 1962, p. 50.

[23]Status Report, SLAC Report No. 1, Stanford Linear Accelerator Center, Stanford University, Stanford, California, July 1962, p. 67.

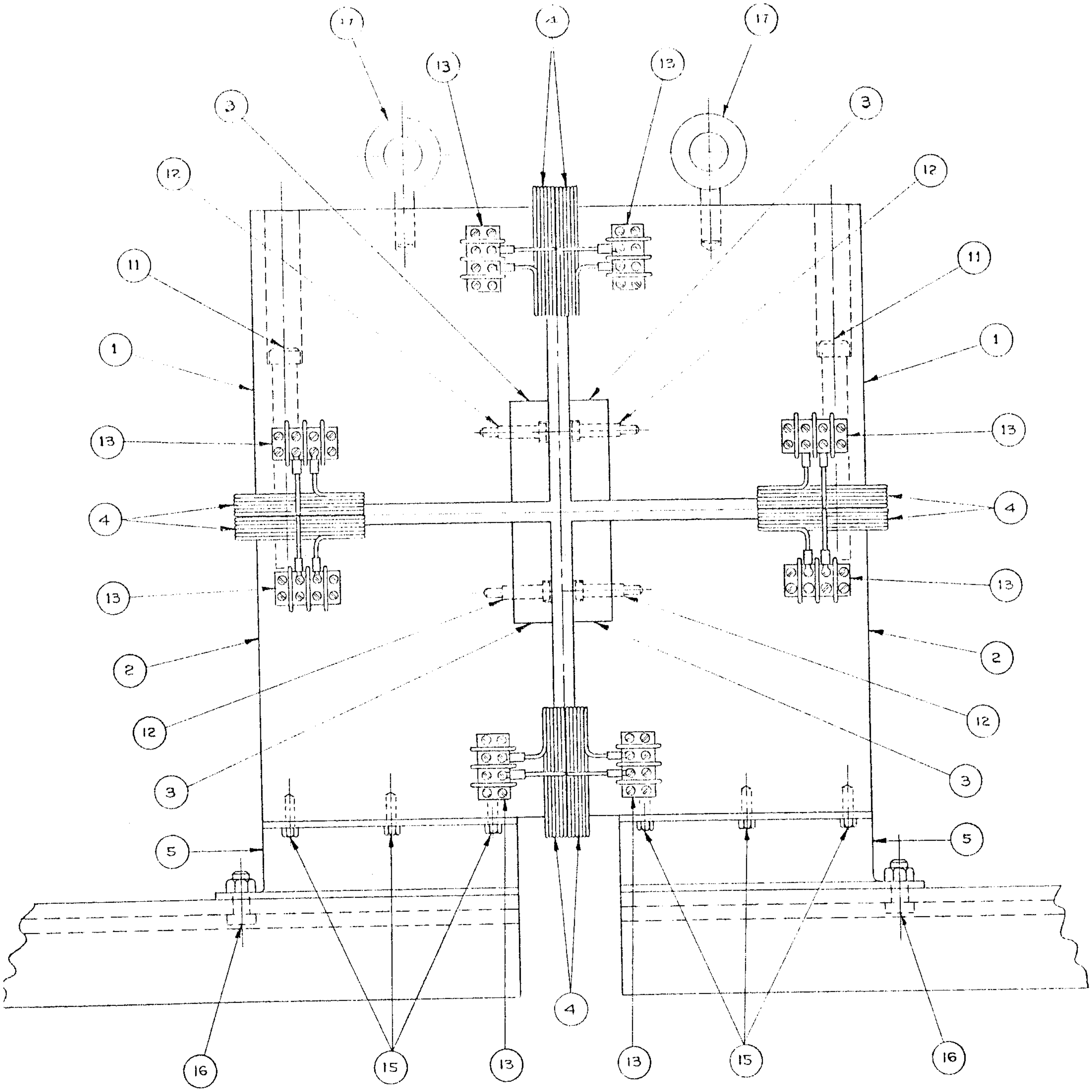

FIG. 18--Assembly of magnetic collimator (Sheet 1 of 2).

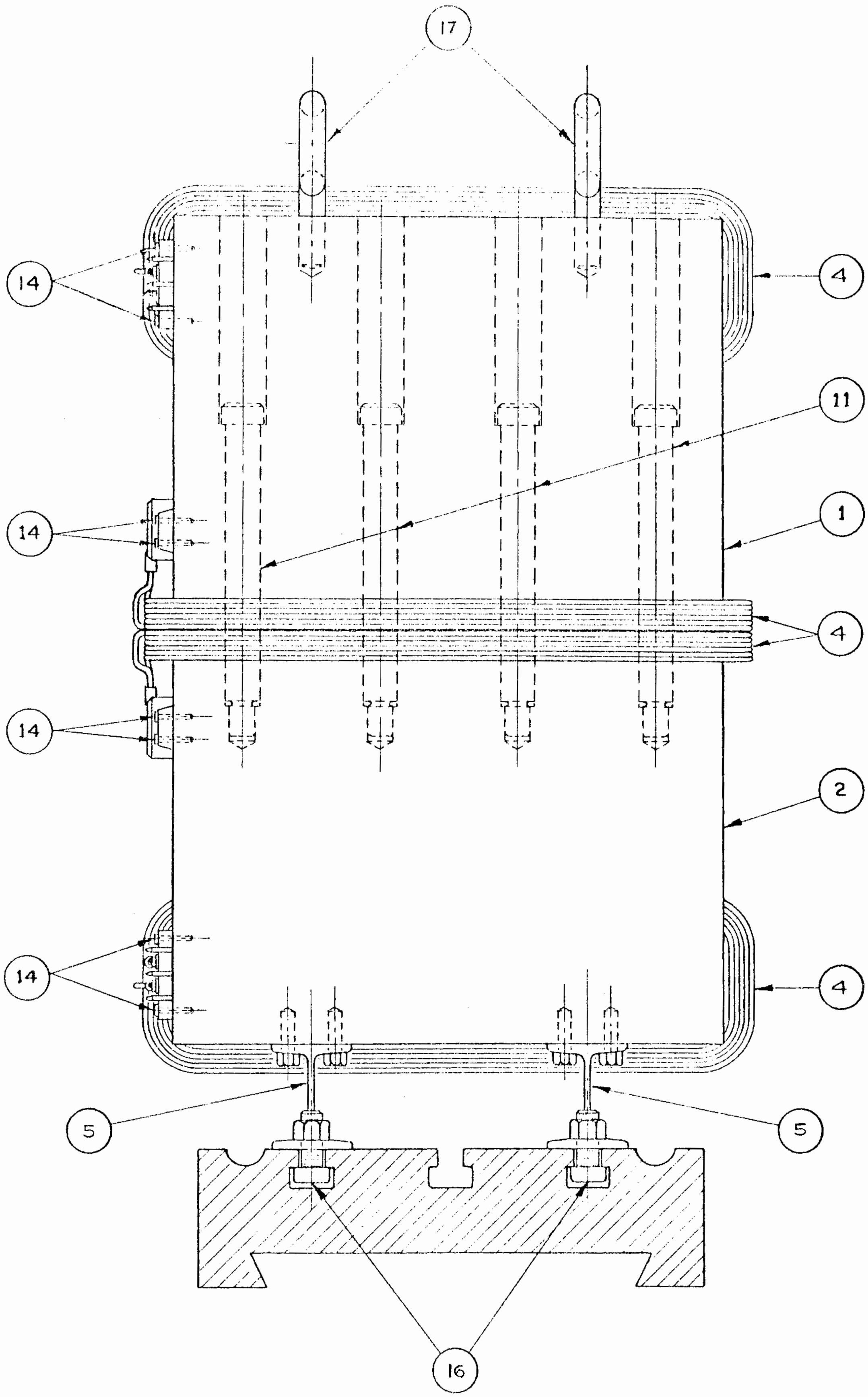

FIG. 18--Assembly of magnetic collimator (Sheet 2 of 2).

3. Experimental Program at Mark III

a. Beam angular divergence

Preliminary measurements confirm the earlier estimates of a beam phase volume of the Mark III accelerator of approximately 10^{-8} steradian-cm^2. Higher resolution measuring equipment is being constructed to make these measurements more accurate.

b. Longitudinal shower development

The calculations of Zerby and Moran[24] have given a longitudinal shower development considerably different from that calculated earlier by Wilson,[25] but in reasonably good agreement with the work of Butcher and Messel.[26] An error has been found in the Wilson calculations, but Zerby's calculations disagree with the measurements of Kantz and Hofstadter.[27] The calculation indicates a smaller build up in the transition curve than that measured. This build up is a function of the minimum energy considered and could be affected by the fact that recombination effects are not taken into account. However, it seems unlikely that such effects could account for the difference. Very preliminary new measurements indicate a value between the Kantz-Hofstadter measurements and the calculated values, but in disagreement with both. More accurate measurements will be required.

E. SUMMER STUDY PROGRAM

A number of visitors studied problems related to the experimental uses of the accelerator during the summer.

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[24] C. D. Zerby and H. S. Moran, "Studies of the Longitudinal Development of High-Energy Electron-Photon Cascade Showers in Copper," ORNL-3329, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 2, 1962.

[25] R. R. Wilson, Phys. Rev. 86, 261, (1952).

[26] S. Butcher and H. Messel, Nucl. Phys. 20, 15, (1960).

[27] A. D. Kantz and R. Hofstadter, Nucleonics 12, 36, (March 1954).

A list of these visitors, and the subjects studied, is given below. Most of these studies will be issued as a report at a later date.

William Chinowsky	Some considerations on bubble chamber experiments with M
J. W. DeWire	Photon beam from Project M accelerator
D. B. Lichtenberg	Conjectures on the effects of Regge poles on Drell processes
Stewart Marcowitz	A suggested beam layout for the switchyard of the Stanford Linear Accelerator
George Masek	μ-beams with M and their application to μ-p elastic scattering experiments
M. L. Perl	Detection systems for the 3-Bev electron-positron colliding-beam storage ring
M. L. Perl	Strong-interaction physics with spark chambers
Melvin Schwartz	A proposed method to search for intermediate bosons and heavy leptons
John Tinlot	A storage ring for 10-Bev mu mesons
George Trilling	Kinematic calculations to determine yields of particles arising from the decays of short-lived intermediate states
George Trilling	The use of hydrogen bubble chambers at SLAC
J. Murray	RF separators
W. Wenzel	Multiple targets
K. Crowe	Plans for the CEA photo-Drell experiments
R. Kenney	Spectrometer studies
J. Mathews	Peripheral model studies of K* and ρ production

F. RF SEPARATORS

A program to develop an rf particle separator has been undertaken. Cold-tests will be conducted on two structures that look promising (the TM_{01} mode in a structure with an off-center aperture, and the TM_{11} mode in a symmetrical structure) from the standpoint of producing backward waves.

It is anticipated that a structure will be developed within three months and can then be hot-tested in the Mark IV beam.

XIII. PLANT ENGINEERING

A. GENERAL

Considerable progress was made on the conventional-facilities program during the quarter. The design effort was continued, and construction was started. Initial ground-breaking took place on July 9. Inclusive of field personnel, ABA now totals 120 people in all categories. Construction-contractor personnel at the Sand Hill site totaled 55 at the end of the period, and this number is increasing.

New schedules were developed in July, using the critical path method, and work is moving along generally on schedule. The requirements are tight, and a continuing effort is necessary to meet key dates.

The concept of "occupant" groups, instituted earlier in the year, is now well established, and all the conventional facilities are so covered. A cognizant member of the Plant Engineering staff works with each group and serves to coordinate and expedite the program effort. This centralization of responsibility permits more effective communications with and follow-up of ABA work.

Engineering assistance was provided in connection with the use of the present facilities of SLAC. This related primarily to space studies, building and equipment alterations, and temporary or rental housing. This area of service work, present now to a relatively minor degree, will increase as project facilities are completed and put into operation.

B. CONSTRUCTION STATUS

The following is a statement of the status of the major conventional facilities now under construction.

1. Site Improvements

The first increment of this work was begun on July 9, 1962, and is now approximately 80% complete. Excavation and fill for building areas and roads are nearly finished. Slopes have received top soil and are shaped and rolled. Installation of red rock for walkways has been started. Installation of all storm drainage and appurtenances is complete.

2. Test Laboratory

Construction commenced August 2 with the excavation of spread footings and grade beams. The structural steel has been entirely erected in the two-story wing and is 70% complete in the remainder of the building. Most of the underslab conduit is in position, as are the soil stacks and waste piping. Over-all, the building is 20% complete.

3. Administration and Engineering Building

The contractor moved onto the job on September 25. Excavation for spread footings has started.

C. DESIGN STATUS

The following is a statement of the status of the major conventional facilities now being designed or out for bids.

1. Preliminary Design (Title I)

The Klystron Gallery, Heavy Assembly Building, Central Laboratory Building, Main Receiving Substation, and the major portion of the Accelerator Housing are in preliminary design. This work is being actively pursued.

2. Title II Design

The Initial Site Utilities, Construction Office Building, Shops Complex, and the Accelerator Housing "early cut" are in final design, the work being nearly complete in each case.

3. Bids

The 60-kv substation is out for bids, as is the Utility Building "A" and the laboratory-area heat-transfer-system package. These facilities are needed for initial operation of the Test Laboratory starting in the spring of 1963.

D. UTILITY SERVICES

Negotiations for an electrical power contract with the Pacific Gas and Electric Company were carried on by the local board of the Atomic Energy Commission. Stanford provides technical advice to the board regarding project meeds. A draft of the contract is being reviewed in Washington, D. C.

Correlated with the above is a PG&E project which would establish a 220 kv transmission line along the Skyline route in San Mateo County. A tie-in line from this facility to the Sand Hill site would provide SLAC with adequate electrical power for its immediate and long-range needs. Stanford is cooperating with PG&E and with the San Mateo County Planning Commission to obtain the necessary permit for the Skyline installation.

Negotiations for natural gas and sewage services are underway. Water for the project has been contracted for with the City of Menlo Park.

E. COOLING WATER SYSTEM

A reduced-pressure boiling-water temperature control system was installed on each of the two 10-foot sections of the Mark IV accelerator to provide accurate water-temperature control. The installation has performed in a satisfactory manner. During the next quarter the system will be instrumented to control the water-supply temperature from a test point on the accelerator waveguide surface. This will simulate operating conditions on the SLAC machine.

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