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UC-28, Particle Accelerators
and High-Voltage Machines
UC-34, Physics
TID-4500

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 October to 30 December 1962

March 1963

Technical Report
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1. E. L. Chu and J. Ballam, "The principle of design of magnetic momentum slits," SLAC Report No. 6 (October 1962).
2. R. B. Neal, G. Loew and A. Eldredge, "Design and fabrication of the accelerating structure for the Stanford two-mile accelerator," SLAC Report No. 7 (November 1962).
3. H. DeStaebler, "Transverse radiation shielding for the Stanford two-mile accelerator," SLAC Report No. 9 (November 1962).

B. JOURNAL ARTICLES

1. R. F. Mozley and J. DeWire, "Monochromatic bremsstrahlung from thin crystals," PUB-4 (December 1962).

I. INTRODUCTION

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

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

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

II. MARK IV PROGRAM

A. INSTALLATION AND OPERATION

During the first month of the quarter, the installation work that was started in the previous quarter continued. The office trailers arrived on October 25. These trailers were moved into position on October 29, with occupancy during the week starting November 12.

The first combined operation of the new equipment was done on November 1. This was operating Modulator and Klystron No. 1, with Klystron No. 1 operating into an rf dummy load. The testing and processing of Klystron No. 1 was continued for several days. The second modulator and klystron were turned on November 15, using Power Supply No. 2 (the Magnatran). During the time up to November 23, the machine was never run as an accelerator because the RCA klystrons were connected only into rf dummy loads. During all of this time, calibrations were being run for calorimetric measurement of rf power and on electrical parameters such as klystron voltage, klystron perveance, and high-voltage dc power-supply voltage. By November 23, it had been decided to remove the RCA klystrons and replace them with the new design of klystrons built by the Klystron Group. It was decided that the new klystrons would be connected directly to the accelerator itself. The SLAC klystrons were installed and put into operation by December 5. Initial evidence of beam current through the accelerator was obtained by checking for residual radioactivity after the machine was shut down. The first measured beam current was observed on December 12. The machine was operated through December 21 and was then shut down for installation of water-temperature control system wiring and completion of installation of getter-ion vacuum pumps. This work continued until the end of the quarter. Just at the end of the quarter the equipment ordered in the previous quarter, consisting of a remote area monitoring system (RAMS) for radiation and a neutron survey meter, was received. The RAMS includes recording units as well as amplifiers with meters.

Figures 1 through 6 illustrate some of the major Mark IV components and areas as they appear after the recent installation work.

B. PLANS FOR NEXT QUARTER

We were unable to accomplish any experimental work with the machine other than getting it into operation and checking out some of its own components during this quarter; however, work is planned for the next quarter along the following several lines.

1. A comparison test for temperature control between the reduced-pressure boiling water system already installed at Mark IV and a blended water system to be installed by the Mechanical Engineering Department at Mark IV.

2. A check of operation of the major components of the machine at high power, consisting of the high-power modulators, the new klystrons, and the acceleration sections. These tests are to be made at both high peak power and high average power.

3. Tests of components furnished by the Physics Research Group, which will be placed in the beam of the machine.

4. It is planned to install a modulator protection scheme, using system concepts and components to be used on the two-mile machine.

5. It is planned to check again the energy gains of the constant-gradient acceleration section.

6. Another test planned is to remove an ignitron and replace it with a hydrogen-thyratron gas switch.

7. Comparison tests of machine and vacuum-system performance, using the oil diffusion vacuum pumps, and using getter-ion vacuum pumps.

Beam hardware components, that is, collimators and Faraday cups, should be completed during the early part of the next quarter and installed in the machine during that time.

The remote area monitoring system for radiation monitoring will be installed and put into operation during the next quarter.

A much more complete system of high-voltage and radiation-interlock protection will be designed and installed during the next quarter. We will use locks with captive keys to protect personnel against both high voltage and against radiation, by placing locks on access panels to high-voltage equipment and on doors to radiation areas, where such locks do not already exist.

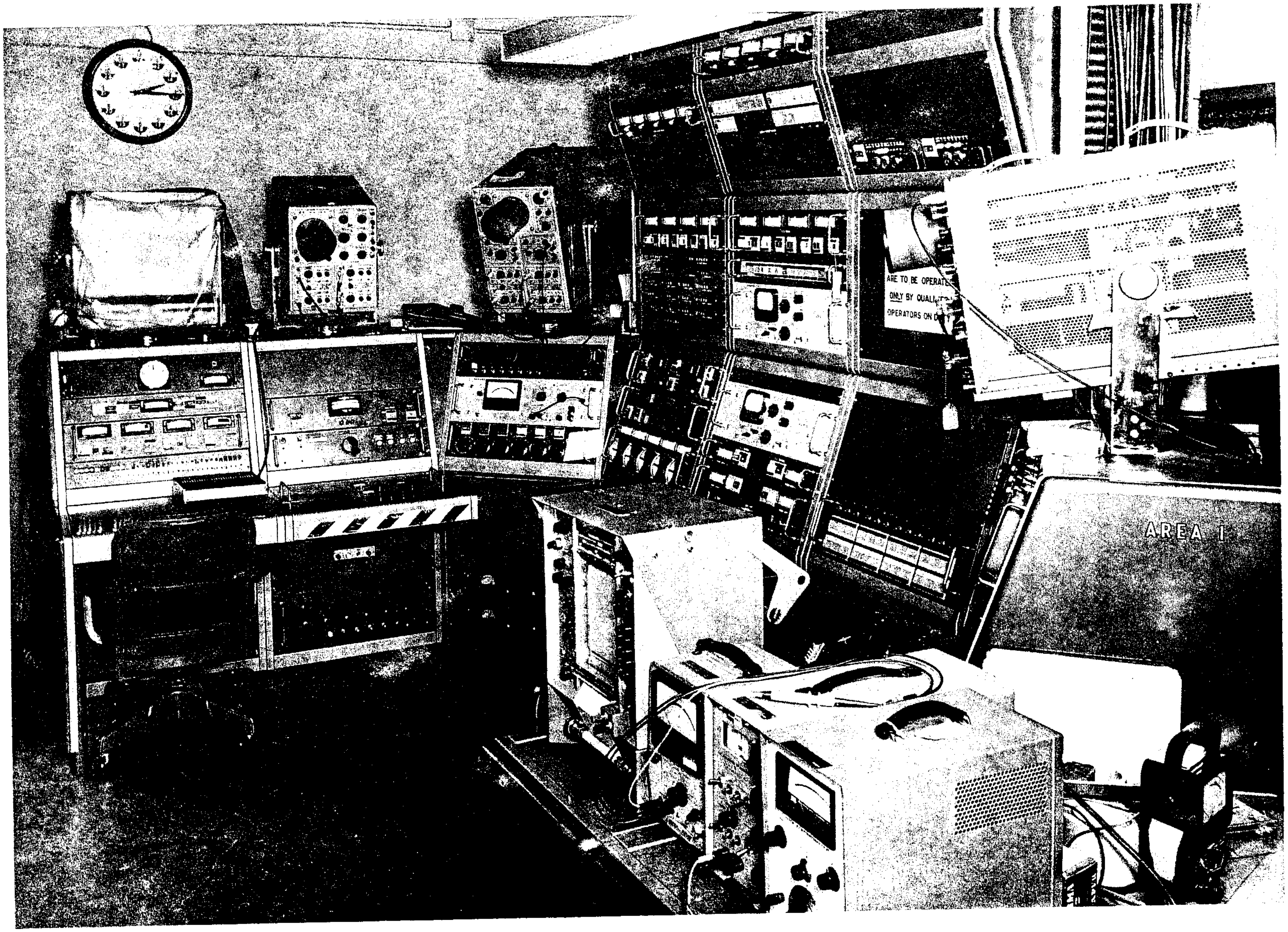

FIG. 1--Mark IV operating console.

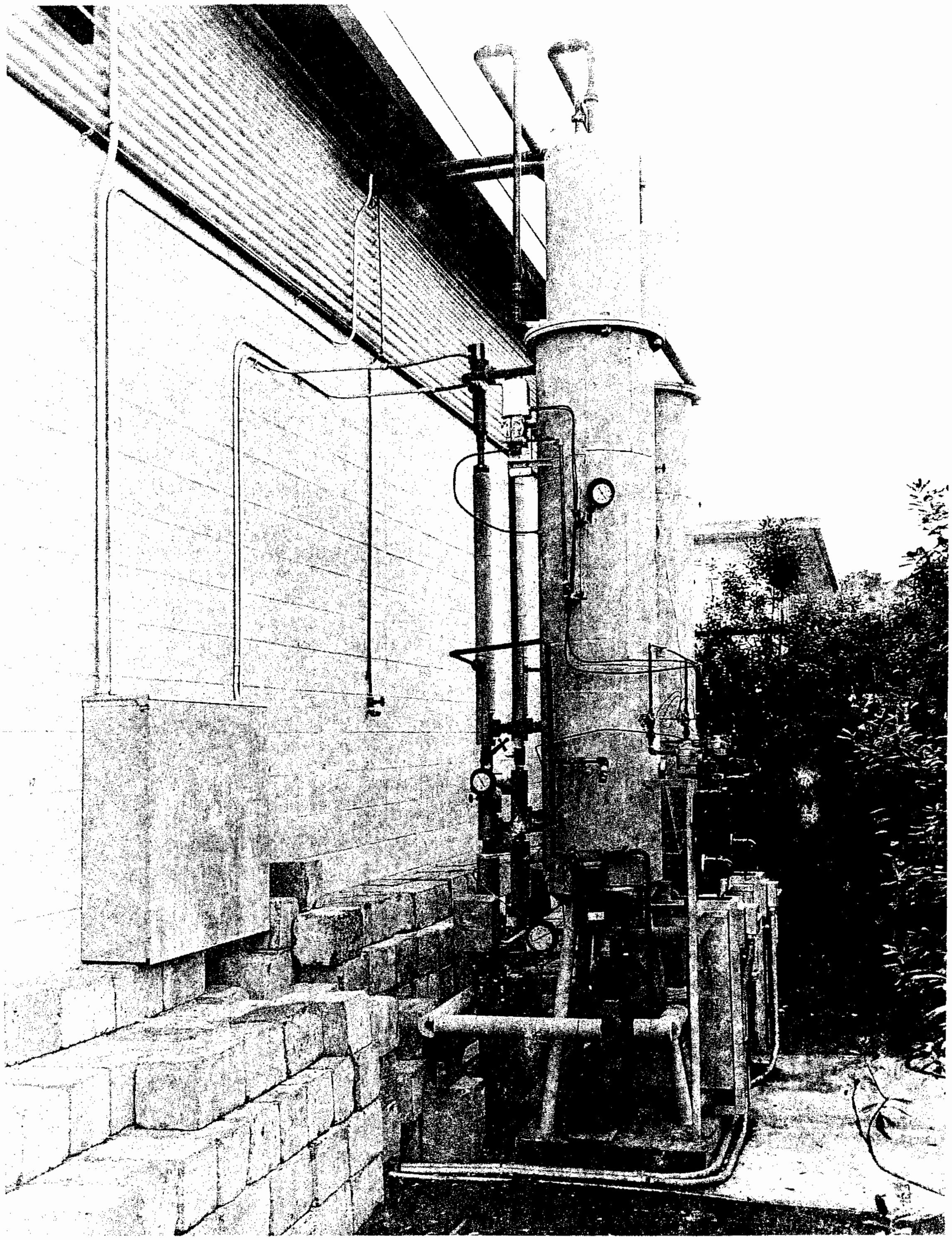

FIG. 2--Reduced pressure boiling water system installation at Mark IV accelerator.

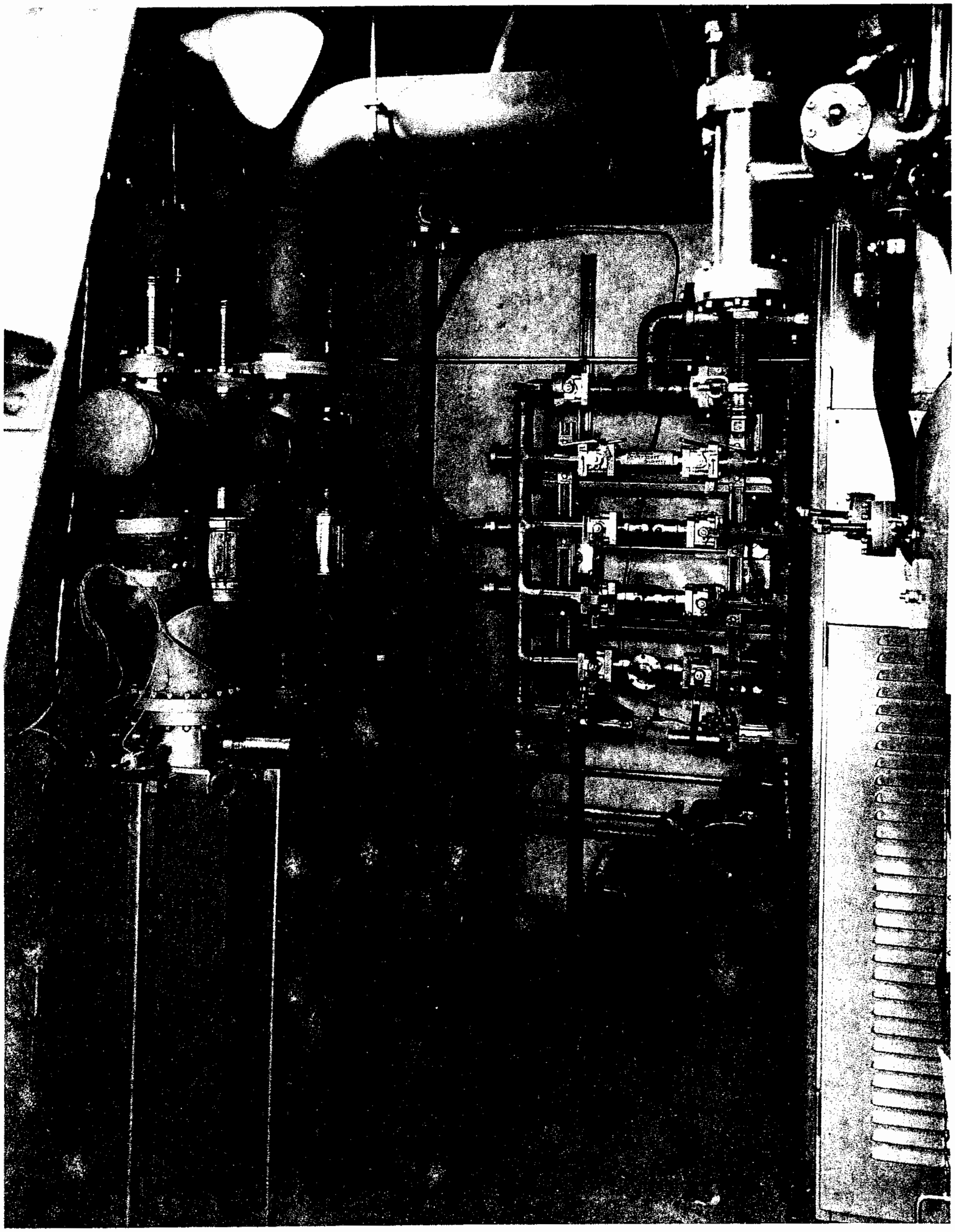

FIG. 3--One of two Getter-Ion pumps installed in Mark IV accelerator.

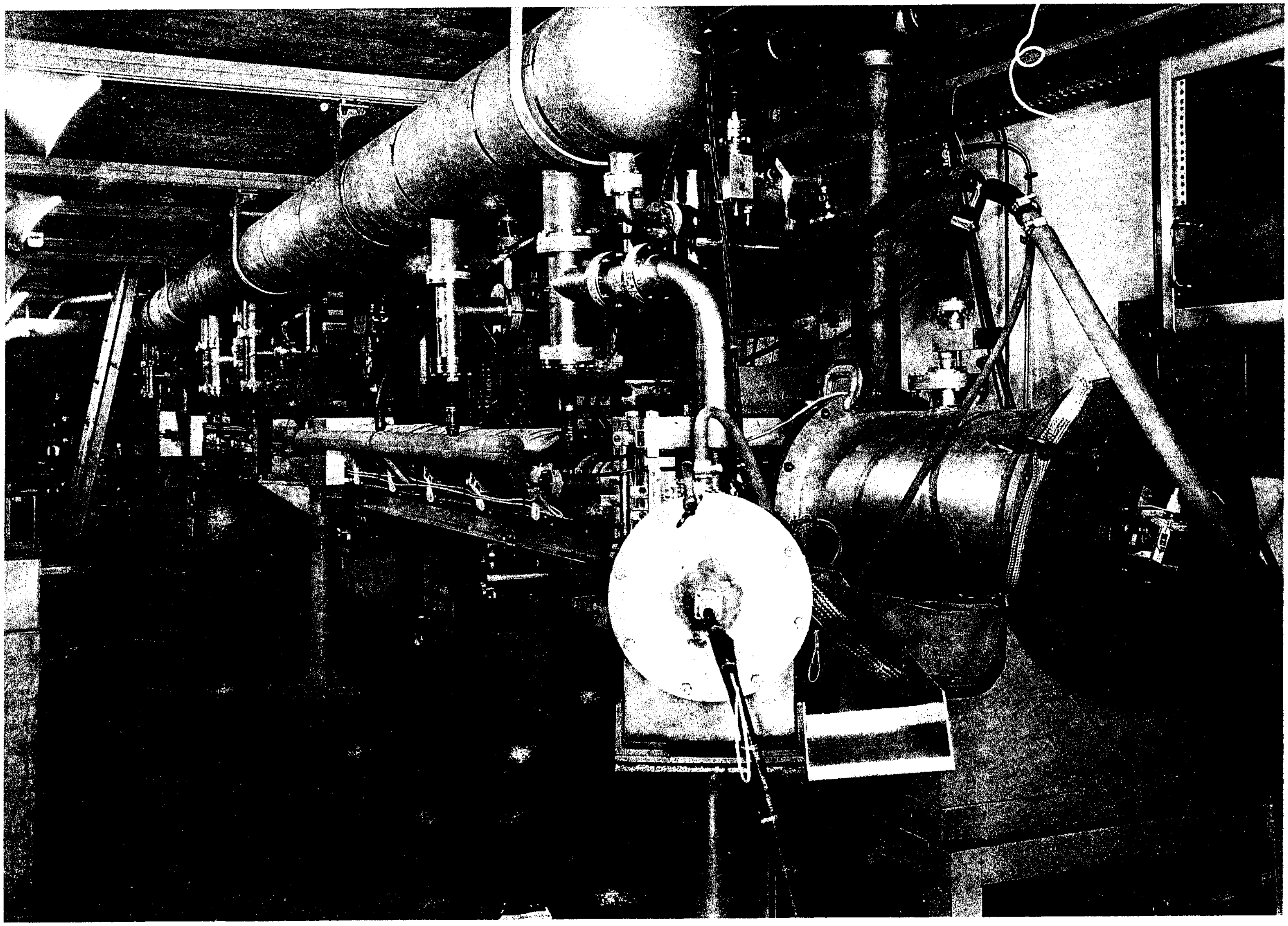

FIG. 4--Mark IV trench accelerator installation.

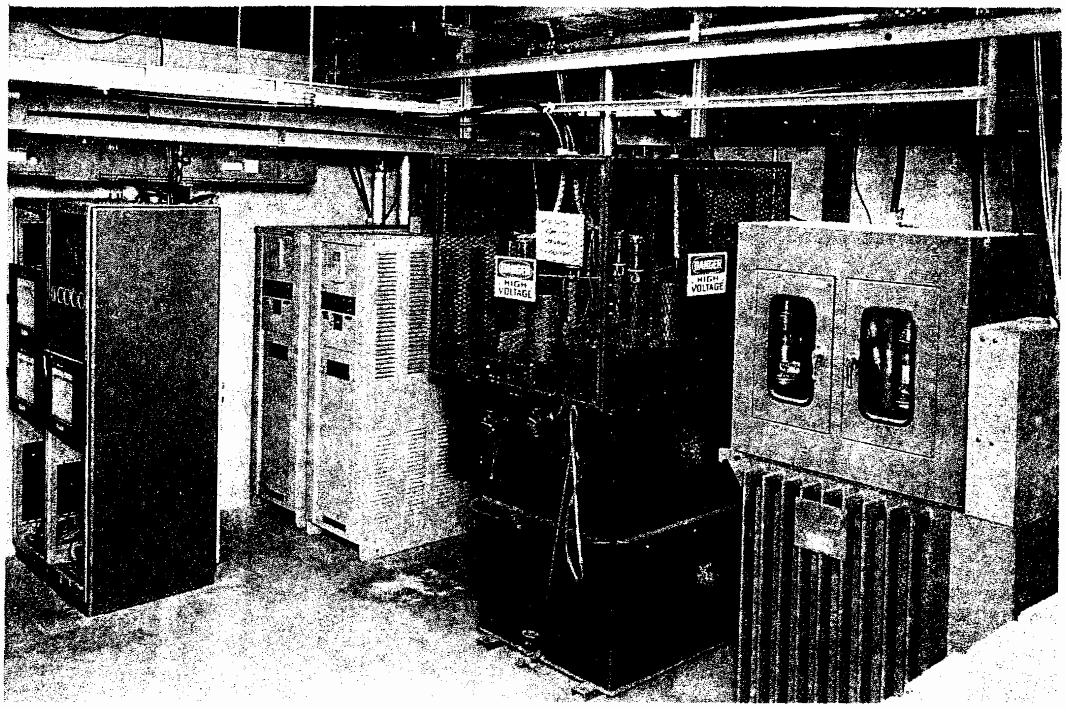

FIG. 5--Mark IV induction voltage regulators and high voltage dc power supplies (water temperature recorder units at extreme left).

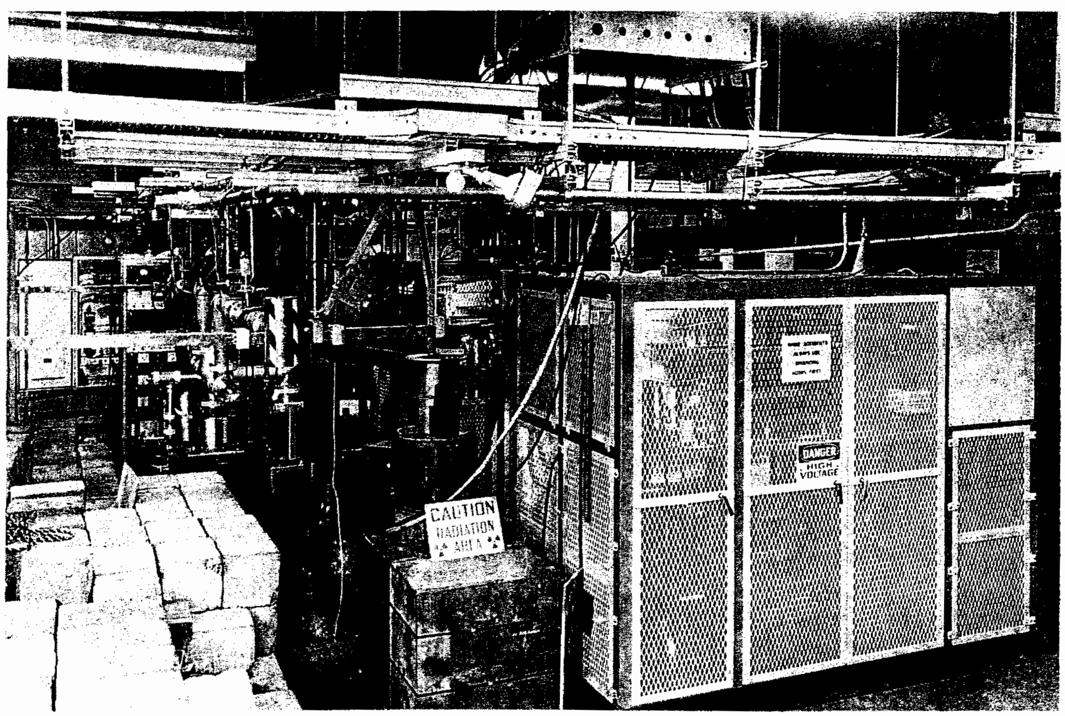

FIG. 6--Mark IV klystron room installation (left to right: waveguide vacuum pumps, klystrons, high power modulators).

III. ACCELERATOR STRUCTURES

A. DISK-LOADED WAVEGUIDE

The design of the disk-loaded waveguide has been frozen. The waveguide will be of the constant gradient type as indicated in the previous status report.* A series of seven accelerator sections is being made for the purpose of checking disk and cylinder dimensions. Three of these have been brazed and preliminary data has been obtained from using them.

1. <u>Accelerator Structure Tuning</u>

Fabrication and assembly of the production tuning mechanism is under way and is expected to be completed during the next quarter.

2. <u>High Power Testing of Accelerator Sections</u>

a. Test Stand No. 1 (Purple Coffin)

During this period the major test stand activities were the installation of a deuterium thyratron switch and the use of the test stand and disk-loaded waveguide as a test vehicle for evaluating two water systems which are under consideration for final use on the machine.

b. Mark II

The constant gradient thick-disk section installed for the Mark II accelerator has been operated at 16 megawatts peak power. Careful measurements of rf power and beam energy show good correspondence between expected and measured beam energies.

3. <u>Water Jacket</u>

a. Heat Transfer Tests with Accelerator Mock-Up

Heat transfer tests aimed at optimizing the water jacket configuration continued during the quarter using a resistance-heated accelerator mock-up. Assembly of the second test section was completed and the section was installed and instrumented. The flows through the eight cooling channels were adjusted until they were all within $\pm 2\frac{1}{2}\%$.

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*Quarterly Status Report, SLAC Report No. 8, "Two-mile accelerator project," Stanford Linear Accelerator Center, Stanford University, Stanford, California, November 1962.

A check of the thermocouples showed that their readings were repeatable and that they agreed with each other within $\pm$ 0.1°F. The tests were performed over a range of power levels. At Stage I power, the accelerator temperature varied by $\pm$0.3°F except at the ends where the temperature dropped by 1.5°F. At Stage II power, the accelerator temperature variation was $\pm$0.8°F with a 2.5°F drop-off at the ends. These test results are better than those obtained from the first test section and it is felt that they can still be improved. Better temperature uniformity can be obtained if the cooling tubes are furnace-brazed to the accelerator section so that more uniform contact is maintained. Methods of obtaining a more uniform braze joint are being investigated and plans are being made to construct a large brazing furnace for brazing on cooling tubes. Accelerator sections with brazed cooling tubes should be available starting next quarter.

b. Heat Transfer Tests with RF

Accelerator sections fabricated for test in the high power test stand are thoroughly instrumented for temperature measurement. Data was obtained from a constant gradient section cooled by 16 tubes, 0.430" ID, soft soldered to the section. At 6-kw average power, the difference between temperature extremes was 1.8°F. At 16 kw, the difference was 2.9°F. During the calibration check, all thermocouples had agreed within 0.2°F. Here again, fabrication technique was responsible for the temperature variation.

c. Cooling Tube Flow Balancing

In the last status report it was reported that unequal flows in the accelerator cooling tubes were responsible, at least in part, for the circumferential temperature variations observed. The cause of the flow maldistribution was investigated further and it was found that even the most carefully made manifold yielded differences in flow from tube to tube of $\pm$ 4%. Thus, after the water jackets are installed, it will be necessary to adjust the water flows in each cooling tube. Special Pitot-static probes and a manometer board were fabricated and set up for measuring the flow in each tube. The probes were checked for interchangeability and were found to agree to $\pm$ 1%. These instruments were used to balance the flows in the accelerator mock-up mentioned earlier. Other flow balancing methods which may be simpler, faster, and more reliable are being sought.

d. Heat Transfer Analysis

The results of the water jacket test program have not been as satisfactory as they should be because of the difficulty encountered in attaching cooling tubes to the accelerator sections uniformly and reliably. Since satisfactory cooling-tube-to-accelerator joints cannot be made without a brazing furnace capable of handling the 10-foot-long accelerator sections vertically, and since such a furnace has not been available, it was deemed necessary to put additional effort on the water jacket analysis. Earlier heat transfer analyses of the water jacket were confirmed and further work is currently being done to determine the temperature distributions in the accelerator sections by using a flux-plotting technique. The flux-plotting setup with a typical model cut from conducting paper is shown in Fig. 7. Figure 8 shows a schematic arrangement of the setup. It will be noted that because of symmetry, a 45° sector of the accelerator section-cooling tube arrangement is being used.

The flux-plotting equipment was set up so that any longitudinal position along the accelerator section could be examined simply by adjusting the water temperatures in adjacent tubes. Average accelerator-wall temperatures are being determined at several longitudinal stations by averaging the readings obtained from a uniform grid. This work is continuing and the effects of water flow rate, tube wall thickness, number of tubes, and tube-to-accelerator contact area will be investigated in this optimization. Several small design modifications to the basic water jacket are also being considered. At least one of the modified water jacket designs appears promising as a backup and can be adopted if full power tests in the test stand and Mark IV show the present design to be unable to maintain the desired temperature uniformity.

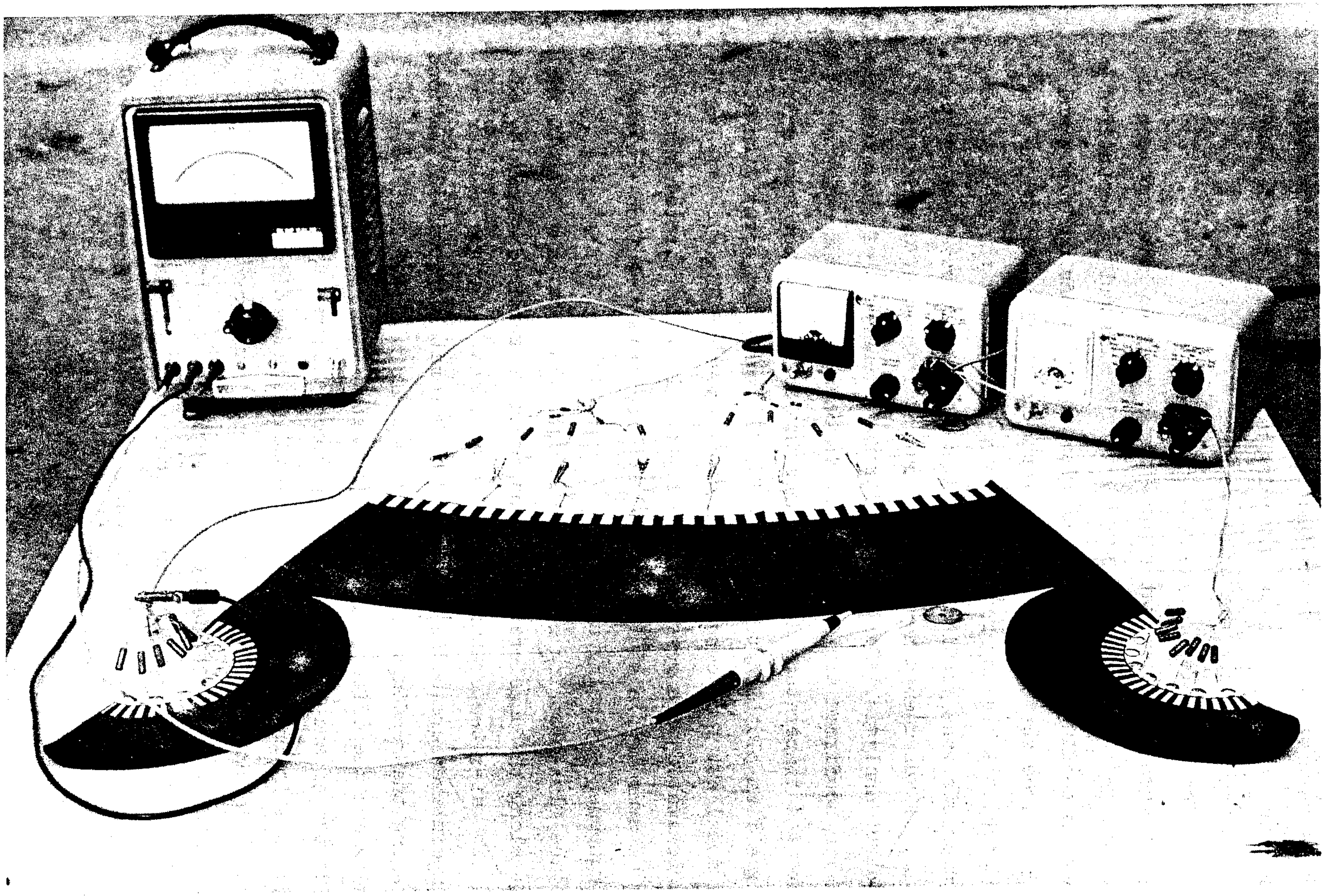

FIG. 7--Flux-plotting setup.

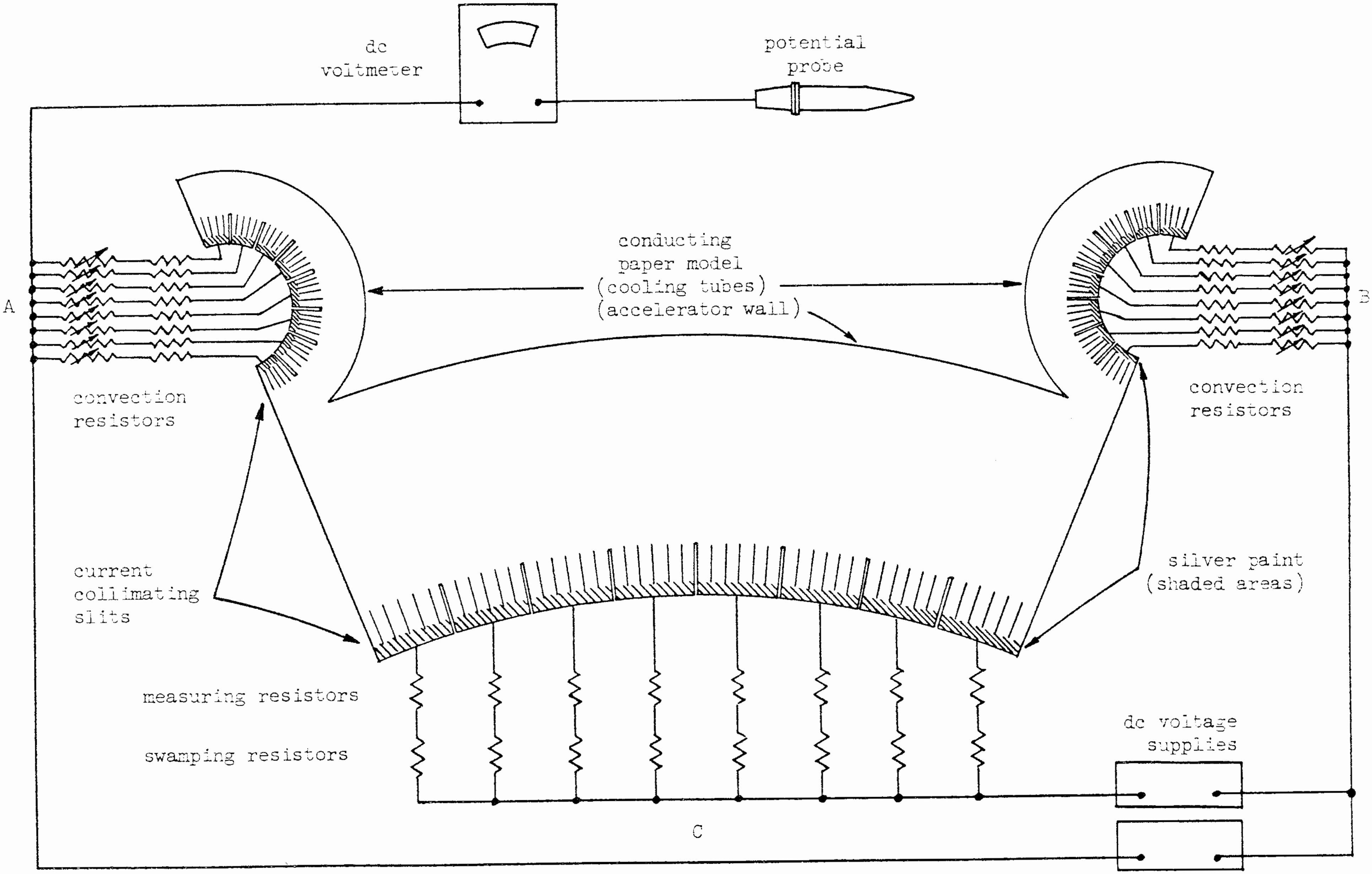

FIG. 8--Schematic of flux-plotting setup for determining accelerator wall temperature.

B. HIGH POWER WAVEGUIDE COMPONENTS

1. Waveguide Vacuum Valve

Progress in the past quarter on waveguide vacuum valve Model A has been primarily in machine and parts procurement, fabrication techniques and high power rf testing. By the end of the quarter, parts were on hand for eight complete valve assemblies. The use of a prebraze, hydrogen firing cycle for the stainless parts eliminated the previous assembly braze leaks. One complete valve was assembled and three others were in the process of assembly.

The use of indium trichloride as a flux to wet indium to stainless steel appears quite promising. The fluxing occurs above 450°C in dry hydrogen and qualitatively it appears that the use of $InCl_3$ gives better wetting than straight dry H_2 up to 1000°C. The excess flux has been removed by firing to 700-800°C.

The high power rf tests have been hindered by difficulties with rf arcing through a demountable vacuum joint required in the prototype valve for development reasons. The best test results to date were made using a complete valve assembly which handled 38 megawatts peak, 70 kw average, on a resonant ring test. Sporadic arcing (1/2-30sec) at the demountable seal marred this test but the joint between the retracted valve head and the waveguide wall showed only an initial burn in. Cycling of the valve head joint did not result in any new arcing after each valve cycle.

Development of the alternate valve, designated Model B, has progressed during this period through parts fabrication and it is now ready for assembly. The Model B valve, shown pictorially in Fig. 9, is an in-line type structure. The valve is shown in the closed position with the knife edge of the lid "A" pressed into indium seat "B". To open the valve, an actuator (not shown) moves flanges "C" and "D" approximately 3/16 inch apart allowing a short section of waveguide "E" to be moved into position by an external handle. Movement of the handle is made possible by means of a bellows section.

All parts for two test models of this valve have been made and assembly has begun.

Low-power tests, vacuum tests and high-power tests are planned for the next period for this Model valve.

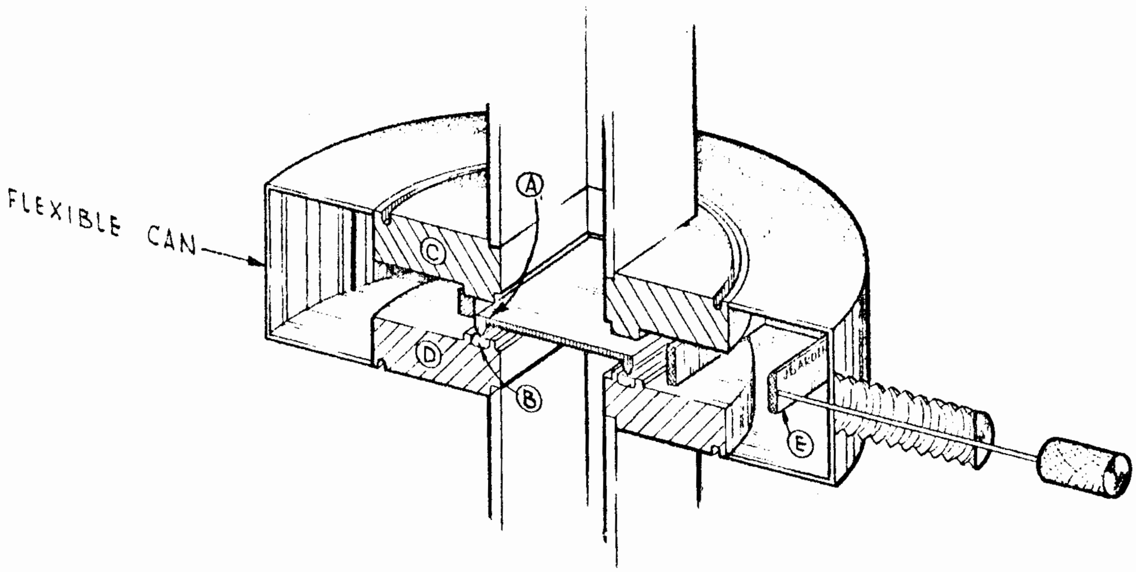

FIG. 9--Pictorial sketch of Model B waveguide vacuum valve.

2. Phase Measurements

The system design for making waveguide phase measurements was completed during this period and the necessary equipment is on order. Two distinct phase measuring systems are under construction to accomplish the two types of measurements discussed in the last progress report.

3. Waveguide Flanges

Evaluation tests were started during this period on three variations of the conflat-type waveguide flange and five variations of the stepped-type waveguide flange. The evaluation tests involve a measurement of vacuum leak for various bolt pressures, rf standing wave ratio, rf loss and high power transmission capability. The differences between each of the flange variations are gasket thicknesses and the geometry of the shear edges.

The design criteria for the flange that will be adopted is that is must give a satisfactory vacuum of 10^{-7} torr at room temperature for 20 consecutive closings (each closing with a new gasket) and that it will transmit the full klystron output power of 24 Mw peak and 21 kw average. Preliminary test results indicate that the vacuum design criteria have been satisfied.

4. Dummy Loads

Tapered slabs of silicon carbide provide low reflection terminations when mounted properly in a waveguide. An experiment was performed to determine if this material might operate in a vacuum. A slab of niafrax four inches by 0.85 inch by 0.25 inch was first outgassed in a hydrogen furnace for two hours at 1000°C. Then when placed in a vacuum chamber it was observed that a vacuum of 10^{-8} torr or better was achieved using an Ultek ion gettering pump with the sample cold. With external heating of the sample at 200°C (to simulate rf heating) outgassing increased the pressure; however, the vacuum gage remained in the 10^{-8} torr scale. This encouraging result suggests that we repeat this experiment during the next period with a variety of manufacturers' samples of silicon carbide using different grit sizes. During the next period several methods will be investigated for attaching both powdered and sintered silicon carbide to copper walls. These will include brazing and embedding by mechanical force.

5. Tree House Test Facility

Structural work on a "Treehouse" facility, shown photographically in Figs. 10 and 11, was nearly completed during this period. When the facility is finished it will house a test stand modulator, a klystron, waveguides, vacuum system, constant temperature water cooling system and a forty-foot section of accelerator pipe. The accelerator pipe will be mounted in a shielded concrete tunnel in approximately the same fashion as will be used in the "M" system; however, an electron beam will not be used.

Figure 12 is a cutaway sketch of the facility illustrating where the various components will be located. The design of the structure will permit a full-scale evaluation of the waveguide runs, vacuum, surface temperatures, etc., in a system that closely approximates the structural conditions to be found in the M machine. The upper house is mounted on motor-driven jacks that can vary its position with respect to the ground level $\pm$ 3 inches. This will permit a test of the phase characteristics of the waveguide when deformed under a simulated ground movement.

Installation of the test apparatus and waveguides will be completed during the next period to permit testing to begin.

6. Accelerator 10-Foot Support

Each section of disk-loaded waveguide will be supported by an individual beam to protect the soft copper pipe and its couplings from distortion due to handling.

The 10-foot support beam will be assembled to the disk-loaded waveguide as soon as the cooling tubes are in place.

Ten support units of a preliminary design are on order and will be used in the Treehouse experimental setup. The final 10-foot support design is scheduled for completion within two months.

FIG. 10--"Treehouse" facility, view A.

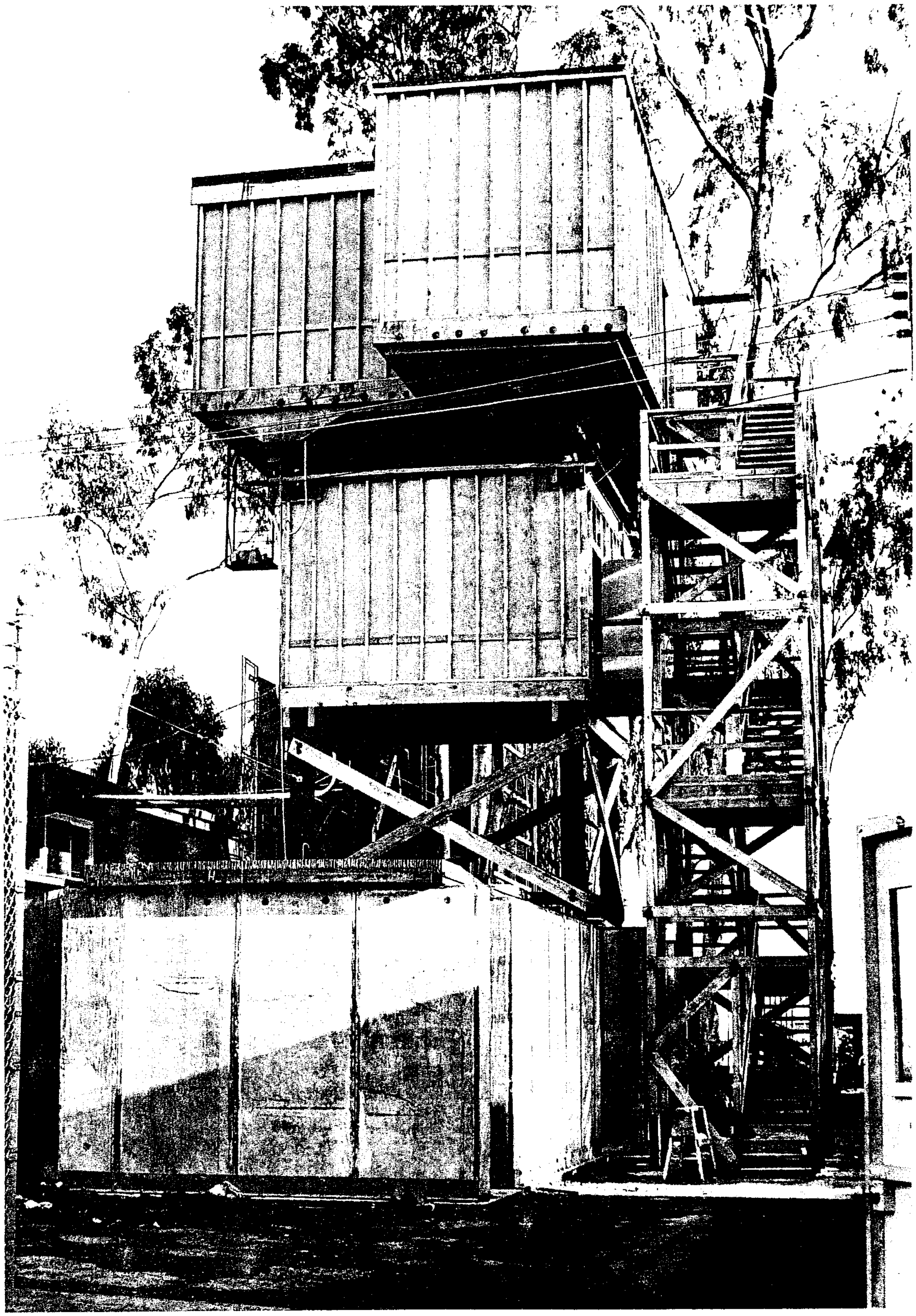

FIG. 11--"Treehouse" facility, view B.

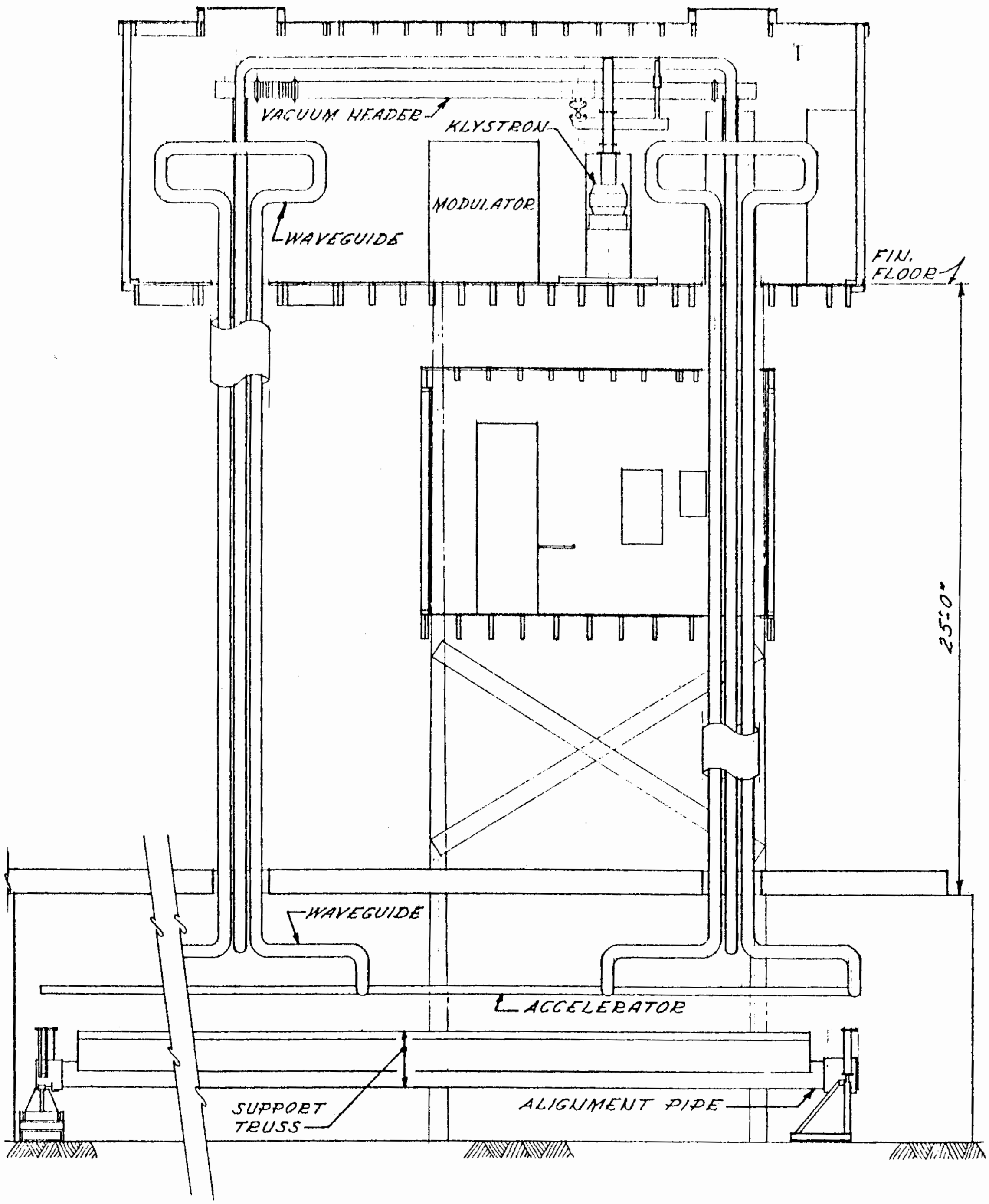

FIG. 12--Cutaway sketch of "Treehouse" facility.

IV. BEAM DYNAMICS

A report* has been prepared on a study of misalignments and quadrupole errors in focusing systems for the two-mile accelerator. Numerical examples are given for a particular system consisting of quadrupoles of essentially equal strength, alternating sign, and equally spaced at 40-foot intervals.

The chief conclusions of the report may be summarized briefly:†

(1) Random, independent misalignments of the quadrupole optical axes relative to the mean reference axis†† should be not greater than about .009 in., rms, in order to operate with not more than 2 (magnetic dipole) steering periods per sector.

(2) The alignment of the quadrupole optical axes should be stable, to within about .001 in., rms, relative to the mean reference axis, against vibrations and other short-term fluctuations.

(3) For random angular bends of short or intermediate correlation range (i.e., strong positive correlations between the angular bends of adjacent quadrupoles, but negligible correlation at distances on the order of orbit wavelengths) the summation over all bends, $(\Phi_1^2 + \Phi_2^2 + \ldots)^{1/2}$, should not be greater than about 10^{-5} radian. Some implications of observed site movements are discussed, and it is estimated that some sort of realignment might be necessary at less than one-month intervals.

(4) For isolated "large" bends the sum $\varphi_1 + \varphi_2 + \ldots$ should not exceed $\approx 10^{-5}$ radian.

(5) If the misalignment has a component of constant curvature, the maximum misalignment (relative to a chord through the ends of the machine) should not exceed ≈ 1 cm.

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*R. H. Helm, SLAC-11 (now in preparation).

†It should be emphasized that these results apply only to the particular focusing system (40-foot spacing of equal-strength quadrupoles) on which the numerical examples of the report are based.

††Defined as a curve which is smooth and nearly straight over the range of a few sectors, and which approximates the "mean" position of the accelerator axis.

(6) In terms of a harmonic analysis of the transverse misalignments, the most important error components are in the wavelength bands of > 400 ft (coherent with orbit oscillations), and in the vicinity of 80 ft; and the latter probably couple more strongly with the beam deflection.

(7) Random axial rotations of the quadrupoles should not exceed about 0.2°, rms.

(8) Random errors in quadrupole strength of about 0.3% may be tolerated.

(9) Random errors in longitudinal position of the quadrupoles of ≈ 1.9 in. may be tolerated.

(10) A sector "superperiod" associated with an extra length of ≈ 10 feet every 320 feet would introduce a stopband of about 6% relative width, at a beam energy of (typically) about 1.6 Bev.

Because of the extremely difficult tolerances (in particular on the short-range alignment) imposed by the quadrupole system at 40-foot spacing, it appears desirable to investigate other types of focusing systems. A design consisting of closely grouped multiplets (doublets or triplets) at $\approx$ 320-foot intervals appears promising; although the power requirement would be much greater, the short-range alignment problem should be much easier. Studies of such systems will be reported in the near future.

It would also be extremely desirable to undertake a computer study of the machine focusing problems. The computer program should be devised in such a way that it could handle non-random perturbations (e.g., observed misalignments from site surveys) and also be capable of playing games of steering and realignment.

V. MICROWAVE ENGINEERING

A. GENERAL RF STUDIES

1. Constant-Gradient Accelerator Structure Design

During the past quarter all constant-gradient structure designs using the simple disk-loaded waveguide were completed. The data for two structures with an attenuation parameter of $\tau = 0.57$ was published in the last Status Report.* The corresponding data for $\tau = 0.40$ are shown in Tables 1 and 2 and Figs. 13 and 14 for disk thicknesses of 0.230 and 0.120 in. respectively. In spite of several improvements obtained with a lower value of τ, these two designs will not be used for the two-mile accelerator because they exhibit a reduction in energy of about 7%.

2. Ventilated-Disk Accelerator Structure

An alternate method of designing a constant-gradient structure, by drilling so-called ventilating holes in the disks, was described in the last Status Report.** Experiments to obtain a design using this method have led to the following preliminary conclusions:

(a) The value of $(r/Q)_T$ decreases slightly with increased radial distance of the ventilating holes from the center of the iris.

(b) The ventilating hole diameter must not exceed 3/4 of an inch. Beyond this size, the ω-β diagram has a tendency to break up.

(c) The change in group velocity with radial distance of the ventilating hole increases with the number of ventilating holes and their diameter.

(d) However, the design objective of a group velocity (v_g/c) variation from 0.0240 to 0.0065 $(\tau = 0.57)$ does not seem obtainable with a single aperture in the center of the disk. Two disk apertures (for example $2a = 1.161$ in. and 1.060 in.) would be needed. In each case, eight equally spaced ventilating holes of 5/8 in. diameter would

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*Quarterly Status Report, SLAC Report No. 8, "Two-mile accelerator project," Stanford Linear Accelerator Center, Stanford University, Stanford, California, November 1962.

**Ibid.

be used, and their radial distance from the disk center would have to be varied from 1.00 in. to 1.25 in. In the first case, v_g/c would vary from 0.0204 to 0.0134. In the second case, v_g/c would vary from 0.0134 to 0.0065. Experiments to verify this preliminary design are in progress.

3. Q Measurements

With the acquisition of new highly stable signal generators, it has been possible to improve the Q measurements. It appears now that the most severe limitation on accuracy stems from the reproducibility of contact-surface conditions. For this reason, the demountable systems used previously were brazed whenever possible. As could be expected, the values of Q for two particular situations were increased by about 10%. In order to get consistent data, it is concluded that further work should be concentrated on comparing several sets, all electro-polished and brazed in the same manner.

4. Shunt-Impedance Measurements for 2.5 and 3.5 Disks Per Wavelength

To complete some of the existing curves of experimental values of shunt impedance as a function of number of disks per wavelength, data have been obtained for 2.5 and 3.5 disks per wavelength. Complete curves will be published in the next Status Report.

5. RF Transient Effects in Accelerator Structures

The study performed for SLAC by the National Bureau of Standards* has been completed. The general conclusions obtained from this study are as follows:

(a) Because of the dispersiveness of the accelerator structure, rf pulses transmitted through a section exhibit transient amplitude and phase fluctuations. For the $\pi/2$ mode, only amplitude fluctuations are expected. Calculations were made with 10 to 90% rise times for input rf pulses of 0, 0.1, 0.2 and 0.3 microseconds. These calculations indicate that the size of the amplitude fluctuation decreases rapidly as the rise time of the input rf pulse is increased.

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

TABLE I

DIMENSIONS OF CONSTANT GRADIENT ACCELERATOR SECTION

(t = 0.230")

$2\pi/3$ mode, 86 cavities, $\tau = 0.40$, $\rho = 0.1215$

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	1.0977	3.3052	.72693	.0250383	43	.99844	3.2750	.83110	.0180883
1	1.0955	3.3045	.72979	.0248767	44	.99590	3.2743	.83328	.0179267
2	1.0933	3.3038	.73261	.0247151	45	.99336	3.2736	.83545	.0177651
3	1.0911	3.3030	.73540	.0245534	46	.99079	3.2729	.83761	.0176034
4	1.0889	3.3023	.73816	.0243918	47	.98821	3.2722	.83977	.0174418
5	1.0867	3.3015	.74089	.0242302	48	.98562	3.2715	.84193	.0172802
6	1.0845	3.3008	.74359	.0240686	49	.98300	3.2708	.84409	.0171186
7	1.0823	3.3001	.74627	.0239069	50	.98038	3.2701	.84624	.0169569
8	1.0801	3.2994	.74891	.0237453	51	.97773	3.2694	.84839	.0167953
9	1.0779	3.2987	.75154	.0235837	52	.97507	3.2686	.85053	.0166337
10	1.0757	3.2979	.75413	.0234220	53	.97238	3.2679	.85268	.0164720
11	1.0735	3.2972	.75671	.0232604	54	.96968	3.2672	.85482	.0163104
12	1.0712	3.2965	.75926	.0230988	55	.96696	3.2665	.85696	.0161488
13	1.0690	3.2958	.76179	.0229372	56	.96423	3.2658	.85909	.0159872
14	1.0668	3.2951	.76430	.0227755	57	.96147	3.2651	.86123	.0158255
15	1.0645	3.2944	.76679	.0226139	58	.95869	3.2643	.86336	.0156639
16	1.0623	3.2937	.76926	.0224523	59	.95590	3.2636	.86549	.0155023
17	1.0600	3.2930	.77171	.0222906	60	.95308	3.2629	.86763	.0153406
18	1.0578	3.2923	.77415	.0221290	61	.95024	3.2622	.86976	.0151790
19	1.0555	3.2916	.77657	.0219674	62	.94738	3.2614	.87189	.0150174
20	1.0533	3.2909	.77897	.0218058	63	.94450	3.2607	.87402	.0148558
21	1.0510	3.2902	.78136	.0216441	64	.94160	3.2599	.87615	.0146941
22	1.0487	3.2895	.78373	.0214825	65	.93867	3.2592	.87828	.0145325
23	1.0464	3.2888	.78609	.0213209	66	.93572	3.2585	.88041	.0143709
24	1.0441	3.2881	.78844	.0211593	67	.93275	3.2577	.88254	.0142093
25	1.0418	3.2874	.79077	.0209976	68	.92976	3.2570	.59008	.0140476
26	1.0395	3.2867	.79309	.0208360	69	.92674	3.2562	.59421	.0138860
27	1.0371	3.2860	.79540	.0206744	70	.92370	3.2554	.59827	.0137244
28	1.0348	3.2853	.79770	.0205127	71	.92063	3.2547	.60229	.0135627
29	1.0325	3.2847	.79998	.0203511	72	.91754	3.2539	.60625	.0134011
30	1.0301	3.2840	.80226	.0201895	73	.91442	3.2532	.61017	.0132395
31	1.0277	3.2833	.80452	.0200279	74	.91128	3.2524	.61404	.0130779
32	1.0254	3.2826	.80676	.0198662	75	.90811	3.2516	.61788	.0129162
33	1.0230	3.2819	.80903	.0197046	76	.90492	3.2508	.62167	.0127546
34	1.0206	3.2812	.81127	.0195430	77	.90169	3.2501	.62542	.0125930
35	1.0182	3.2805	.81350	.0193813	78	.89844	3.2493	.62914	.0124313
36	1.0157	3.2798	.81572	.0192197	79	.89517	3.2485	.63283	.0122697
37	1.0133	3.2791	.81794	.0190581	80	.89186	3.2477	.63648	.0121081
38	1.0108	3.2784	.82015	.0188965	81	.88853	3.2469	.64010	.0119465
39	1.0084	3.2778	.82235	.0187348	82	.88517	3.2461	.64370	.0117848
40	1.0059	3.2771	.82455	.0185732	83	.88178	3.2453	.64726	.0116232
41	1.0034	3.2764	.82674	.0184116	84	.87835	3.2445	.65080	.0114616
42	1.0009	3.2757	.82892	.0182500	85	.87490	3.2437	.65431	.0113000

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

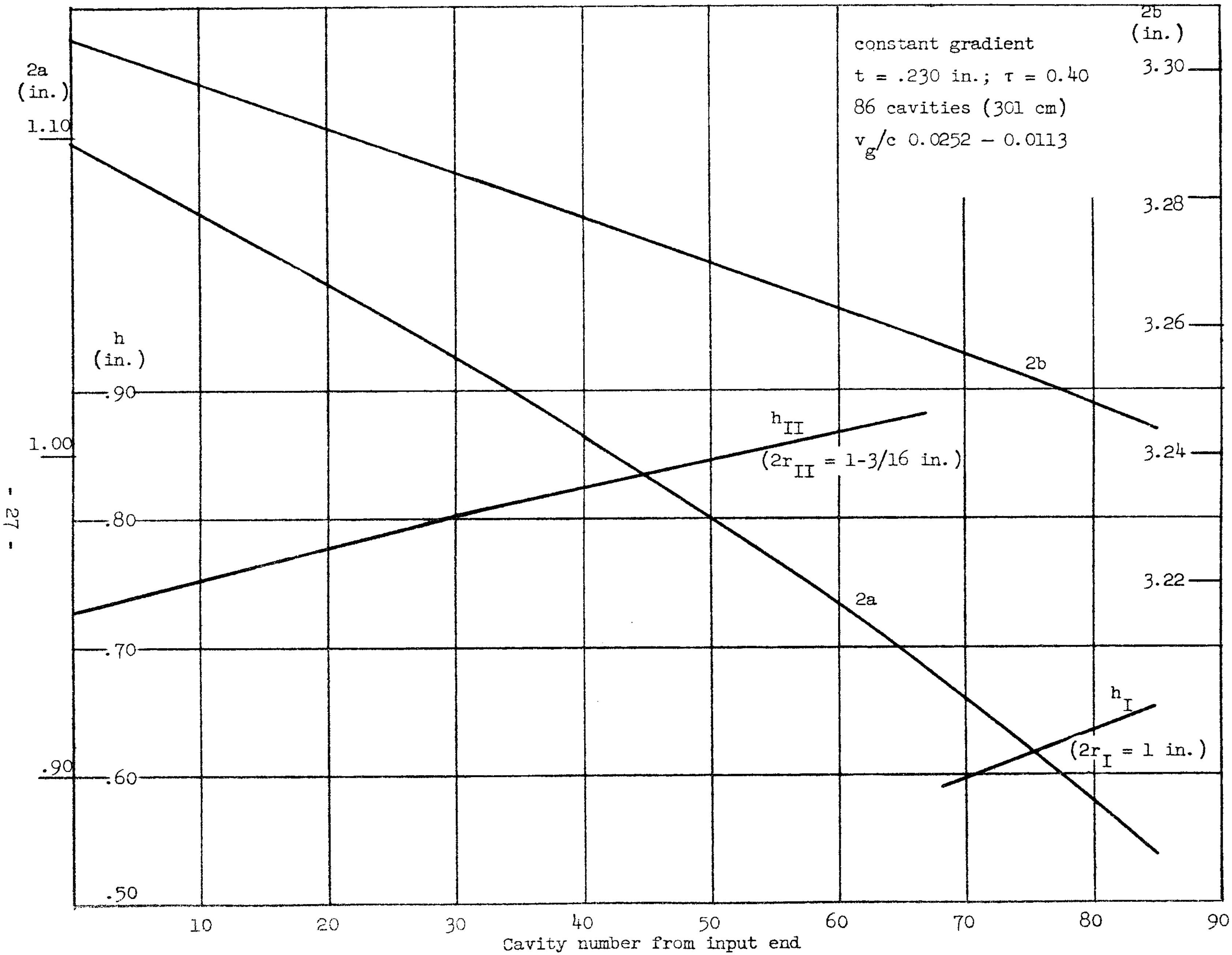

FIG.13--Variations of 2b, 2a, and h as a function of accelerator cavity number.

TABLE II

DIMENSIONS OF CONSTANT GRADIENT ACCELERATOR SECTION

(t = 0.120")

$2\pi/3$ mode, 86 cavities, $\tau = 0.40$, $\rho = 0.0625$ in.

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	1.0006	3.2645	.87306	.0250383	43	.89981	3.2399	.67530	.0180883
1	.99878	3.2640	.87463	.0248767	44	.89729	3.2394	.67799	.0179267
2	.99682	3.2635	.87622	.0247151	45	.89476	3.2388	.68064	.0177651
3	.99482	3.2630	.87783	.0245534	46	.89222	3.2383	.68327	.0176034
4	.99279	3.2625	.87945	.0243918	47	.88969	3.2377	.68586	.0174418
5	.99073	3.2620	.88110	.0242302	48	.88714	3.2371	.68843	.0172802
6	.98863	3.2614	.88275	.0240686	49	.88459	3.2366	.69097	.0171186
7	.98651	3.2609	.88442	.0239069	50	.88204	3.2360	.69349	.0169569
8	.98435	3.2603	.88611	.0237453	51	.87947	3.2354	.69598	.0167953
9	.98217	3.2598	.88780	.0235837	52	.87690	3.2349	.69845	.0166337
10	.97996	3.2592	.88950	.0234220	53	.87432	3.2343	.70090	.0164720
11	.97773	3.2587	.89121	.0232604	54	.87173	3.2337	.70333	.0163104
12	.97547	3.2581	.89292	.0230988	55	.86913	3.2332	.70574	.0161488
13	.97319	3.2575	.89464	.0229372	56	.86651	3.2326	.70814	.0159872
14	.97089	3.2570	.89636	.0227755	57	.86389	3.2321	.71052	.0158255
15	.96858	3.2564	.89809	.0226139	58	.86125	3.2315	.71288	.0156639
16	.96624	3.2558	.89981	.0224523	59	.85860	3.2310	.71522	.0155023
17	.96389	3.2552	.90154	.0222906	60	.85594	3.2304	.71756	.0153406
18	.96153	3.2546	.90326	.0221290	61	.85325	3.2298	.71988	.0151790
19	.95914	3.2540	.90499	.0219674	62	.85056	3.2293	.72219	.0150174
20	.95675	3.2534	.90671	.0218058	63	.84784	3.2287	.72449	.0148558
21	.95435	3.2528	.90843	.0216441	64	.84511	3.2281	.72679	.0146941
22	.95193	3.2522	.91014	.0214825	65	.84235	3.2276	.72907	.0145325
23	.94951	3.2516	.91185	.0213209	66	.83958	3.2270	.73135	.0143709
24	.94707	3.2511	.91355	.0211593	67	.83678	3.2264	.73362	.0142093
25	.94463	3.2505	.91525	.0209976	68	.83396	3.2259	.73588	.0140476
26	.94218	3.2499	.91694	.0208360	69	.83112	3.2253	.73814	.0138860
27	.93972	3.2493	.91863	.0206744	70	.82825	3.2247	.74040	.0137244
28	.93726	3.2487	.92031	.0205127	71	.82536	3.2241	.74265	.0135627
29	.93479	3.2481	.92198	.0203511	72	.82244	3.2235	.74490	.0134011
hπ 30	.93231	3.2475	.92364	.0201695	73	.81949	3.2229	.74715	.0132395
hI 31	.92983	3.2469	.64003	.0200279	74	.81651	3.2224	.74939	.0130779
32	.92735	3.2463	.64322	.0198662	75	.81350	3.2218	.75164	.0129162
33	.92486	3.2457	.64636	.0197046	76	.81046	3.2212	.75386	.0127546
34	.92237	3.2451	.64944	.0195430	77	.80739	3.2206	.75613	.0125930
35	.91988	3.2446	.65248	.0193813	78	.80429	3.2200	.75838	.0124313
36	.91738	3.2440	.65548	.0192197	79	.80115	3.2194	.76062	.0122697
37	.91488	3.2434	.65843	.0190581	80	.79798	3.2188	.76287	.0121081
38	.91238	3.2428	.66134	.0188965	81	.79477	3.2181	.76512	.0119465
39	.90987	3.2422	.66421	.0187348	82	.79153	3.2175	.76737	.0117848
40	.90736	3.2417	.66703	.0185732	83	.78825	3.2169	.76962	.0116232
41	.90485	3.2411	.66983	.0184116	84	.78494	3.2163	.77188	.0114616
42	.90233	3.2405	.67258	.0182500	85	.78158	3.2157	.77413	.0113000

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

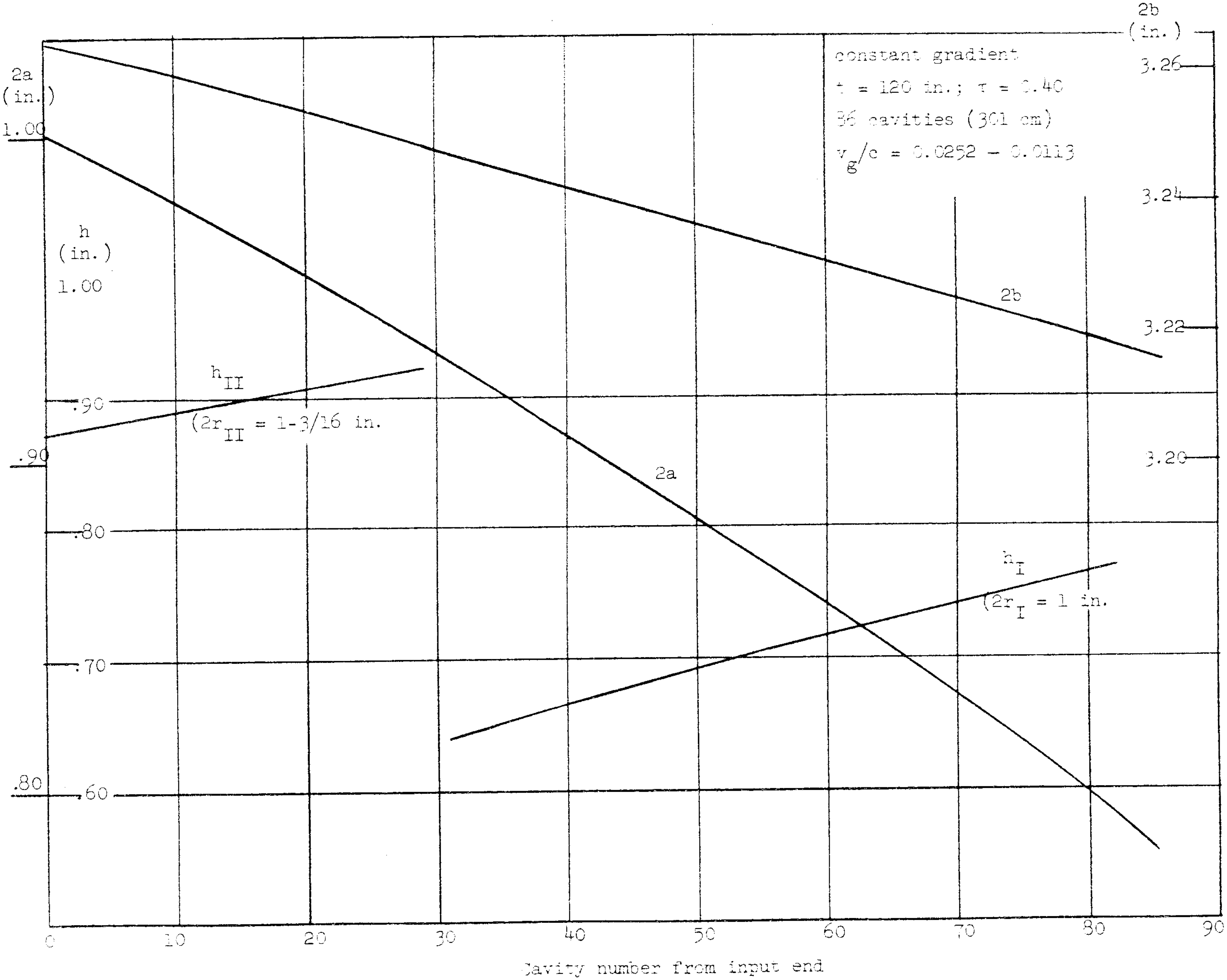

FIG.14--Variation of 2b, 2a and h as a function of accelerator cavity number.

(b) For a typical rise time of 0.2 microseconds, and neglecting beam loading, calculations show that the energy picked up by the electron beam averages out these rapid fluctuations, and that the energy spread is essentially negligible (less than 1/2 %).

(c) When beam loading is included, the chief effect of the amplitude and phase fluctuations is to increase the beam-energy loss slightly: 2% if injection is done on each rf cycle, 8% if injection is done every third cycle, and 14% if injection is done every fifth cycle. For very short electron beam pulses, the energy spread due to beam loading is considerably greater than would be expected by calculations which ignore dispersive effects.

(d) While the effect of space harmonic modes can generally be disregarded for long beam pulses, for very short beam pulses it appears that excitation by the beam will constitute an additional source of energy loss and energy spread.

(e) In order to understand possible effects in accelerator performance with subharmonic injection, the excitation of the second waveguide passband (TM_{11} mode) has been examined. For typical Stanford waveguides, the frequency at which $v_p = c$ for the second passband is very close to three-halves the frequency of operation in the lower passband. It appears for this reason that injection at even space harmonics would entail a greater tendency for the phenomenon of beam blowup to occur. However, this would not be the case for injection at odd subharmonics. Hence, injection every third rf cycle should be satisfactory.

6. RF Particle Separators

During the past quarter, progress has been made towards better understanding the rf characteristics of two types of disk-loaded waveguides to be examined as rf separators. The first structure consists of a disk-loaded waveguide with an off-center aperture. It has the advantage that it exhibits a very strong variation of the electric field E_z across the aperture. However, because of the asymmetry, it is probable that this structure will not be free of aberrations. The second structure is a conventional disk-loaded waveguide designed to operate with a phase shift of $2\pi/3$ per cavity in the TM_{11} mode at 2856 Mc/sec. This structure is similar to the ones proposed by CERN and Brookhaven. Experiments to obtain complete design information are in progress.

7. Waveguide Vacuum Valve

The sealing section mentioned in the last Status Report* was incorporated in the rectangular-circular-rectangular vacuum valve. Tests now show that both end-cap positions need to be adjustable in order to obtain the best rf match. Initially only one end was made adjustable with an rf choke joint. A final model should be available within the next quarter.

8. C-Band to S-Band Couplers

The C-band to S-band coupler for the beam-breakup experiment was designed, built and tested. It appears that the coupling is only 13 db instead of 3 db. A technique to tighten the coupling is presently being sought.

B. DRIVE SYSTEM

1. Over-all Design of the Drive System

A decision has been made to adopt a 3-1/8 in. coaxial line for the main drive line and to use a frequency of 476 Mc/sec for the basic drive signal. Sextuplers will be incorporated to multiply this frequency up to 2856 Mc/sec at each sector coupling point. Preliminary investigations indicate that varactor diode harmonic generators can be designed to have adequate phase stability. In order to confirm this result, further tests have been started. A drive line simulator using six harmonic generators purchased from the Syntax Corporation is being assembled.

The signal transmitted in the main drive line will be cw, and the input power at the injection end of the machine will be high enough (17.5 kilowatts) to eliminate the need for any further boosters along the line. Purchase specifications for the main booster to be placed at the injection end have been completed, and a contract should be awarded during the next quarter.

Design and specification of the two drive lines (main and sub-drive lines) are near completion. Beyond the studies performed during the past quarter, the effects of reflections, coupler characteristics and other

*SLAC Report No. 8, op. cit.

physical discontinuities in the drive lines have been examined. It can be concluded that the total phase shift due to the above effects is small and can be considered to be linear with frequency. The effect of the supporting stubs and wafers is equivalent to adding approximately one foot of ideal line per sector. Thus, to correct for the long-line effect, a maximum of 30 feet of ideal line (or its equivalent electrical length) have to be added to the parallel path linking the first main drive line output to the first klystron. Alternately, the total length of the main drive line can be shortened by 30 feet.

2. Stable Test Stand RF Sources

The OS-2 stable oscillator manufactured by the Syntax Corporation has continued to perform very well. It has operated continuously since delivery in September and has failed in operation only once; the failure resulted from a human error in short-circuiting power-supply components. Six similar stable oscillators are to be delivered in January 1963 for the test-stand program.

3. Tunable Test Stand RF Sources

Four tunable test stand drivers were delivered to the Microwave Engineering Group by the Instrumentation and Control Group. The units are now essentially complete.

4. Test Stand Drive System

Directional couplers for the test-stand rf distribution system have been ordered. Bids were received and the contract was let. The drive lines and miscellaneous components have been ordered and received. Two special drive units, each using a chain of SAS-60 and SAS-61 Sperry klystrons, are essentially complete except for the modulators.

5. Mark IV Granger Driver

The Mark IV Granger driver has undergone one major modification. The 6442 triode multiplier chain was removed and replaced by two solid-state harmonic generators. In this manner, both the short triode life problem and thermal detuning described in the previous Status Report* should be eliminated.

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*SLAC Report No. 8, op. cit.

6. Sub-Booster Klystrons

The contract with the Eimac Company of San Carlos, California, for the sub-booster klystrons appears to be on schedule. The first four tubes are due for delivery on March 15, 1963. Studies of the diode, focusing, and beam transmission have been completed with good results.

7. Isolator, Phase Shifter and Attenuator Units

The delivery of twenty units, each consisting of an isolator, phase shifter and attenuator, which are being built by the Sperry Microwave Corporation, Clearwater, Florida, for use on the Mark IV and test stands, has been delayed. However, two prototypes were made available during this quarter and some preliminary acceptance tests were carried out. A complete program for acceptance tests was prepared, and two difficulties were incurred in this program: (1) the measurements of standing-wave ratio at high power levels; and (2) the measurement of phase variation through the units as a function of temperature. The former difficulty arises since at high power levels a slotted line is difficult to use on account of crystal breakdown. The second difficulty arises because external connections must be made to the units which are undergoing temperature changes, thus causing variations of phase shifts which are not directly attributable to the units under test. A modified reflectometer has been used to make measurements of the VSWR at high power levels, and preliminary measurements indicate that this technique is now satisfactory. Considerable attention to details, including the use of rigid coaxial lines whose parameters are well known, has resulted in a solution to the second difficulty. All 20 units will be delivered and tested early in the next quarter.

C. PHASING SYSTEM

1. Current-Variation Detection Technique of Phasing

An analysis of the results obtained with experiments performed on the Mark IV accelerator has been completed. A new series of experiments is planned as soon as the Mark IV accelerator is available for this activity. It appears that this technique of phasing cannot be used to phase single klystrons on the two-mile accelerator because of lack of sensitivity and inherent machine instabilities which are greater than the current variations induced by the technique. However, it is possible that the principle of this method will be used to phase 333-foot sectors of the machine.

2. Hybrid Phasing Method and Sector Simulator

The hybrid technique of phasing linear accelerators was described in the previous Status Report.* Cost estimates on manual and automatic phasing systems using this technique show that the cost differential between these two is marginal. For this reason, an automatic system for phasing all systems within a sector has been designed. A sector simulator is presently under construction, and upon completion it will enable the automatic system to be checked out without the actual use of a sector on the machine. The simulator will generate all the rf signals normally present at the output of each accelerator section and will simulate the operating status of the klystrons. Hence, the entire phasing sequence for a sector can be carried out. The purpose of this simulator is threefold: (1) to show the feasibility of automating the hybrid technique under environmental conditions close to those which would be expected to exist on the final machine; (2) to check the accuracy of such a system; and (3) to operate this system continuously for a period of several months to obtain information on reliability.

The construction of this simulator is well advanced, and the beginning of operation is scheduled for the first part of the next quarter. A discussion of this automatic system will be given in a separate report.

*SLAC Report No. 8, *op. cit.*

3. Beam-Induction Technique of Phasing

The phase-detector unit described in the previous Status Report* has been completed and will be installed on the Mark IV accelerator. In view of the decision to use the hybrid method, priority on this program has decreased somewhat. However, an additional advantage of the hybrid method is that all rf circuits are such that it would be very simple to substitute the beam-induction technique for the hybrid technique by simply modifying a few rf components and some of the circuits of the programmer. Hence, work on the beam-induction-technique equipment will be continued.

4. Attenuation Measuring Equipment

A canvas of the commercially available attenuation-measuring equipment is now being carried out and will be completed early in the next quarter. This equipment must be of high enough quality, accuracy and range to be suitable for use in a standards laboratory for the whole project.

5. Phase Measurements

The phase-measuring equipment described in the previous Status Report** has undergone preliminary testing, and experiments indicate that phase measurements can be carried out with an accuracy of $\pm 0.1^\circ$. Development of a double-sideband modulator and oscillator, a microwave discriminator, and readout electronics has been completed. At the present time, the unit is being packaged.

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*SLAC Report No. 8, op. cit.

**Ibid.

VI. INJECTION SYSTEM

A. 45 DEGREE INFLECTION

A tentative choice of a 45 degree off-axis inflection system has been made. The system chosen consists of two bending magnets and one quadrupole for the off-axis beam and three additional dc compensating magnets on the main axis. While not identically isochronous, the proposed system is within the reasonable limits for debunching and defocusing. Calculations, including second order effects, will be made during the next report period to further evaluate the proposed system.

B. INJECTION TEST STAND

Work progressed on the design of the pumping for the vacuum system of the "Tree House" test stand. Pumping speeds were calculated and preliminary vacuum manifold and waveguide sizes and locations were determined. The high-power phase shifter and attenuator designs were integrated into the waveguide layouts. The coaxial phase shifter and attenuator for remote operation were designed and construction was almost completed. These will be completed early in the next quarter. Preliminary design of rack layouts was completed. Final design of the injector test stand equipment, locations, wire routing, circuit diagrams and chassis design will be emphasized during the next quarter.

C. MARK II ACCELERATOR

The prebuncher, which is a fixed-tuned stainless steel cavity with a Q of approximately 500, was tested during this quarter. It increased capture efficiency to 60% and doubled the output current of the accelerator. The energy spectrum was decreased by the buncher from 5% to 1-3/4%. Work was continued on the phase-shifter attenuator which will be completely finished and installed in the next quarter.

D. EXPERIMENTAL BUNCH MONITOR

An experimental bunch monitor has been designed for testing on the Mark IV accelerator consisting of a $TM_{0,1,30}$ cavity resonant at 60 Gc. This will be fabricated during the coming quarter.

E. BEAM ANALYZER

The original Beam Analyzer, Model 1-1, and its vacuum station were calibrated and used for materials analysis. An attempt was made to analyze the effects of various carbons, plastic materials, and lubricating greases on the attainable vacuum and gun cathode. The major decisions on the mechanical design of an all-metal Beam Analyzer, Model 2-1, have been completed. Purchasing has been initiated on 50% of the components. Design and initial procurement have been started on electronics equipment needed for control, read-out, and recording.

F. MARK IV ACCELERATOR

All preliminary work was done to prepare the Mark IV gun modulator for the installment of the new 2-amp gun. The load leveler regulation was developed on the lab modulator and will be incorporated in the Mark IV modulator upon installation of the 2-amp gun. The magnetic lens for the 2-amp gun, Model 3-1, is fabricated, wound, and ready to be installed with the 2-amp gun. An rf phase shifter and attenuator were installed in Mark IV to operate the buncher.

G. GUNS

Acceptance testing on the Electron Guns, Models 2-1 and 2-2, was completed. The results were compiled during this quarter and will be published early in the next quarter. The Hughes gun was delivered, sealed off with a hard vacuum. The vacuum was periodically checked for leakage but remained tight. Inter-element capacitance measurements were completed but further testing was impossible due to prior commitments and unavailability of thin valves. The gun will be high potted to 100 kv dc to help determine gun modulator specifications during the next quarter.

H. GUN MODULATOR SPECIFICATIONS

Gun modulator specifications for an electron gun modulator to be built in-house were sent to the Modulator Group.

VII. KLYSTRON STUDIES

A. SUMMARY

During the past quarter, most of the work of the Klystron Group has been concentrated on building a stockpile of single-output klystrons to be used by various groups in the laboratory who will require such klystrons before the production contracts which are being negotiated with RCA and Sperry have delivered a sufficient number of tubes to satisfy those needs. The efforts of the group have been slowed by two unforeseen developments: punctures of the cathode-anode seal, and oscillations at a frequency very nearly equal to the drive frequency.

B. KLYSTRON PROCUREMENT

Contract negotiations with Sperry and RCA for the procurement of klystrons were concluded during the quarter. Basically the contract provides for a fixed-price procurement of an initial quantity of klystrons (72 from each company) with an option on the part of Stanford University to increase the purchase from either company by as many as 180 klystrons after tube performance has been evaluated. The total anticipated procurement is 324 klystrons, and it is expected that the contract will be signed in January 1963 with delivery of klystrons beginning between August and December 1963 The klystrons are to be permanent-magnet focused, and will be mechanically interchangeable in the system although not necessarily within the permanent magnets. In addition, these klystrons will be repairable by the companies at charges which will be determined by further negotiation.

C. STANFORD FACILITIES

In addition to the general planning which has begun for the move on site, some new facilities are being provided within the present building. A double-vacuum bake station for klystrons has been completed and tested out. The system appears satisfactory and should be in full operation very shortly.

The window-test-area equipment has been completed and tested out, but the new window-test facility is not yet connected electrically to the rf source because it is necessary to have additional instrumentation, specifically to measure the vacuum at each window or as near each window as possible. It is expected that this instrumentation will be installed in January, and that the window-test station will begin to operate with additional windows by February 1.

D. TUBE PERFORMANCE

As noted above, the main emphasis during this quarter has been to accumulate sufficient spare tubes to satisfy the needs of our own and other groups between now and the arrival of the first production klystrons. Since there will be a total of 20 klystron sockets by about July 1963, it is desirable that we have by that time a minimum of 30 operable klystrons on hand.

Although our production rate and testing rate have been adequate (better than one per week), unfortunately we have had a number of anode bushing failures. This is a high-voltage puncture of the ceramic insulator which appears to take place at almost exactly the same position in the bushing, and has resulted in a large percentage of tubes being unusable after the testing was completed. The following 3 steps have been or will be taken to remedy this situation: (1) The upper corona shield has been lengthened by approximately 1 inch. This results in a better potential distribution along the seal, and should prevent arcing across the seal if for some reason the inside surface becomes conducting over a length which is not effectively shielded by the corona ring. (2) Investigations are being carried out to produce a slight conductivity on the inside surface of the seal (approximately 1 megohm from face to face, compared to the 1000-ohm beam impedance). (3) Steps are being taken to replace our present 6-inch diameter bushing by one 7 inches in diameter.

A second problem has been that of oscillation in the first section of the tube. The oscillation appears as an amplitude modulation on the top of the rf output pulse. The frequency of this amplitude modulation is in general between 5 and 10 Mc/sec, and the amplitude can be from 10 to 20% of the pulse amplitude. It was eventually determined that this amplitude modulation is most probably caused by a beat between the drive frequency

(2856 Mc/sec) and an oscillation caused by fast electrons returning down the drift tube and producing oscillation in the first 2 or 3 cavities of the klystron. On one tube that was opened up it was discovered that the frequency of the 3 cavities was slightly in excess of 2860 Mc/sec and that all 3 were within 1 Mc/sec of each other. The steps now being taken to remedy this situation are: (1) ensuring that the first 3 cavities of the tube have at least a 10 Mc/sec difference in their resonant frequencies, and (2) changing the drift-tube length between cavities.

E. TUBE LIFE

No systematic tube-life testing is now being carried out, since it is more important at present to build a stockpile of tubes than to life-test the ones we already have on hand. However, the following information has recently been obtained:

(1) The klystron used on the window-life-test station has been in operation for approximately 4000 hours, and its performance has not appreciably changed during that period. Most of the operation of this tube has been at fairly low voltage and repetition rate (not over 200 kv nor 300 pps), but this operation was limited by the pressure built up between the windows rather than by the tube.

(2) The tube used in the Accelerator Structures modulator failed after 560 hours of operation, most of which was at near full peak and average power. The failure of this particular tube was probably caused by accidental disconnection of the vac-ion pump and improper starting procedure.

(3) One tube failed on Mark IV after approximately 50 hours of operation at levels of approximately 6 megawatts peak. This failure may have been caused by the lack of an interlock system on the vacuum on the outside of the output window. The window of this tube was cracked, and the failure is quite similar to those which have been observed in windows where the interlocking system is not adequate.

VIII. HIGH-POWER KLYSTRON WINDOWS

A. SUMMARY

Tests have been continued on the all-metal cavity, providing similar results to those reported last quarter. The resonant ring has tested a series of polished disks and a series of coated disks. A series of tests was also carried out on models of waveguide valves and of all-metal gaskets for the accelerator structures group. The all-metal ring has been vacuum tested and is complete except for the phase shifter.

B. RESONANT-RING WINDOW TESTS

1. Polished Alumina Windows (AL 300)

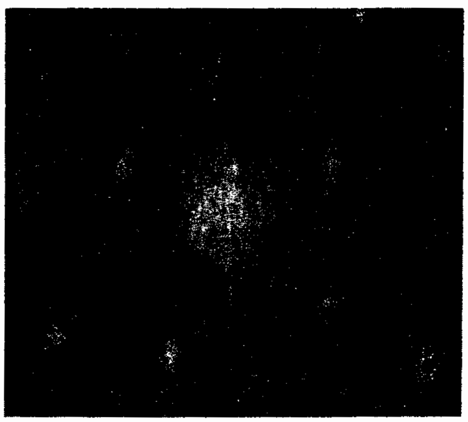
Six alumina disks were polished (courtesy of the Crake Packing Co., South San Francisco, California.) and tested in the resonant ring. A summary of the results is given in Table I.

TABLE I

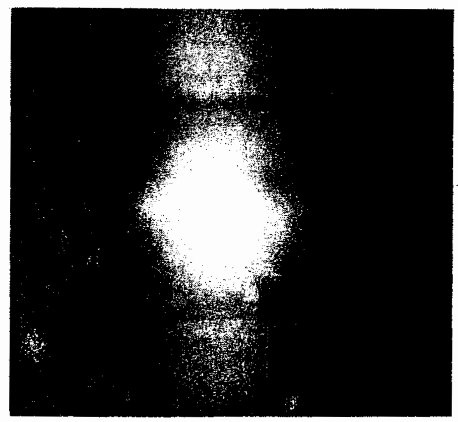
RESULTS OF TESTS ON POLISHED ALUMINA DISKS

No.	Grit Used	Finish	Peak Power	Failure
1	Al_2O_3	80 μin.	87 Mw	none
2	Al_2O_3	80 μin.	77 Mw	none
3	Al_2O_3	80 μin.	30 Mw	breakdown internally
4	Diamond	20 μin.	77 Mw	chipped
5	Diamond	20 μin.	20 Mw	arcing
6	Side 1: boron carbide Side 2: Al_2O_3	25 μin. 25 μin.	63 Mw	chipped

The major operating difference occurred between the Al_2O_3-polished disks and those which were diamond or boron-carbide polished and much smoother. None of the latter had the characteristic punctures; all three showed (1) a concentrated central glow (Fig. 15) on the generator side, (2) high x-ray intensities, (3) relatively high temperatures, and (4) sporadic surface arcing. The behavior of the disks polished with Al_2O_3 grit was very similar to the normal test disk which is ground to size and has about the same rms surface roughness.



No. 1



No. 2

FIG. 15--Glow on two diamond-polished disks.

2. Heil Windows

A series of seven alumina (Al 300 disks) and one quartz disk, designed and constructed by Dr. Oskar Heil of Eitel-McCullough Inc. of San Bruno, California, were tested. Six of the alumina disks and the quartz disk had grooves cut in the surfaces as shown in Fig. 16. They were mounted in a Type-A structure so that the field was perpendicular to the grooves at the center of the window. Three (Nos. 1, 2, 3 in Table II) alumina disks were first run and showed a normal glow pattern except that the glow occurred only at the tips of the grooves. (A picture of the punctures in one of these is shown in Fig. 17.) The next two (Nos. 4, 5) alumina disks were TiO-coated

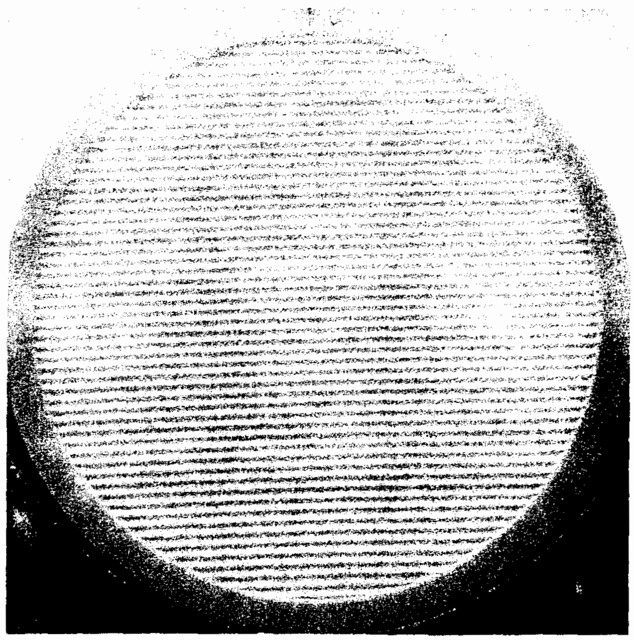


FIG. 16--Grooved window disk designed by Oskar Heil of Eitel-McCullough.

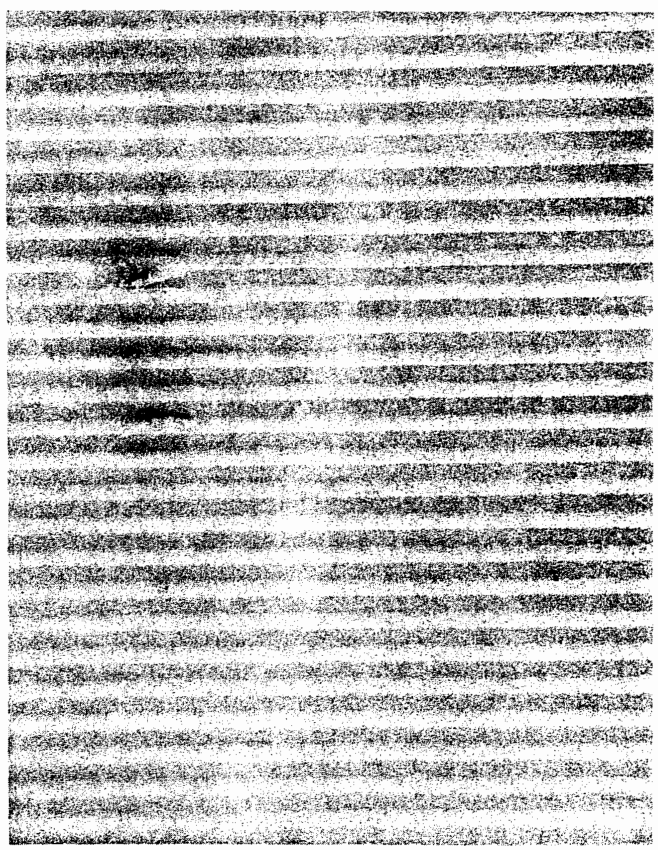


FIG. 17--Punctures in uncoated grooved disk.

(on the tips). Operation of these two was notable for (a) low evolution of gas, (b) relatively low window temperature, (c) low x-ray intensity, (d) almost complete absence of glow on the window. The sixth (No. 6), was only partially coated. It behaved identically to the other coated disks (4,5) except that some glow was visible on the uncoated half but only during initial operation. It was suspected that the coating may have migrated during operation. To test this, an ungrooved window (No. 7) was partially coated in a dot pattern. It showed no signs of migration. A grooved and coated quartz disk (No. 8) was also tested. It behaved like the coated alumina disks. This is distinctly different from the smooth quartz disks previously tested.* These tests are summarized in Table II.

The grooves provide a gradient at the window which it was hoped would prevent electrons from bombarding the surface. This was unsuccessful but shows that the electron trajectories are very nearly parallel to the surface since only the tips glow. The coating used is a titanium suboxide applied by sputtering from a TiO block. It is not known yet whether such coatings can withstand tube processing and are stable over long periods of operation.

C. ALL METAL RESONANT RING

The all-metal ring is now complete except for the phase shifter. The ring was assembled and given a preliminary bake at $\approx 200^{\circ}$C, after which the vacuum in the ring was 2×10^{-8} torr. The Viton O-ring on the valve was then baked and the pressure dropped to 5×10^{-9} torr where it has remained for two weeks. This is more than two orders of magnitude better vacuum than the vacuum achievable in the original ring which is sealed by O-rings. The phase shifter should be completed in early January, at which time tests can begin on this system.

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*Quarterly Status Report, SLAC Report No. 8, "Two-mile accelerator project," Stanford Linear Accelerator Center, Stanford University, Stanford, California, November 1962, p. 51.

TABLE II

RESULTS OF TESTS ON HEIL WINDOWS

Window Number	Material	Surface	Coating	Max. Power	Failure
1	Al_2O_3	grooved	none	34 Mw	puncture
2	Al_2O_3	"	"	35 Mw	puncture
3	Al_2O_3	grooved	none	78 Mw	cracks and puncture
4	Al_2O_3	"	TiO	77 Mw	none
5	Al_2O_3	grooved	TiO	63 Mw	puncture*
6	Al_2O_3	"	TiO(partial)	85 Mw	none
7	Al_2O_3	smooth	TiO(partial)	85 Mw	puncture
8	Quartz	grooved	TiO	87 Mw	none

* Believed due to mounting defect.

D. ALL-METAL CAVITY TESTS

A large amount of the effort spent on this system during the last quarter was concerned with obtaining good vacuum conditions. We have been limited to baking temperatures of 150°C by the use of indium gaskets and by the shrinking technique used to mount the test disk in the cavity. Although this moderate bake is helpful, long operation at high-average, low-peak powers is needed to clean up the system. Unfortunately this has reduced the number of tests we can run at very good vacuum levels.

E. LOADING EFFECT OF VACUUM

We have continued the tests on the loading effect of vacuum. Three disks have been tested. The first of these did not exhibit much loading, but the pressure could not be made better than 2×10^{-7} torr. The next showed a slight loading between 5×10^{-8} and 10^{-6} torr. Between 10^{-5} and 10^{-6} torr, the loading would suddenly become very heavy, usually with distortion of the pulse shape as shown in Fig. 18. The position of the "pip" can be moved by shifting the driving frequency, the pip occurring later as the frequency is increased. The last disk tested gave (on one run) the data in Fig. 19. Note that it also exhibits a sudden drop of power at about 10^{-5} torr. All these pressure data are quite scattered. We believe this is, in part, because we read pressure at the ion pump, while the pressure at the window may be different. The gas comes from the window or is deliberately introduced to the system. Since the conductance to the pump is not the same for these sources, some ambiguity can result. All three disks were tested to destruction after the vacuum tests were run. The first failed at 125 Mw, 20 cps due to severe internal breakdown. The second went to 100 Mw, 20 cps without failing; it failed at 100 Mw, 100 cps due to internal breakdown. The third failed by cracking at 43 Mw, 180 cps due to excessive heating. It had been previously operated to 75 Mw at 20 cps.

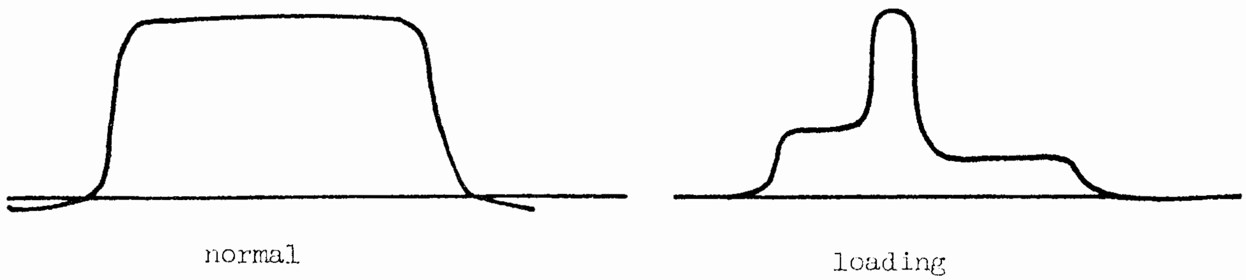

FIG. 18--Effect of loading on cavity pulse in cavity.

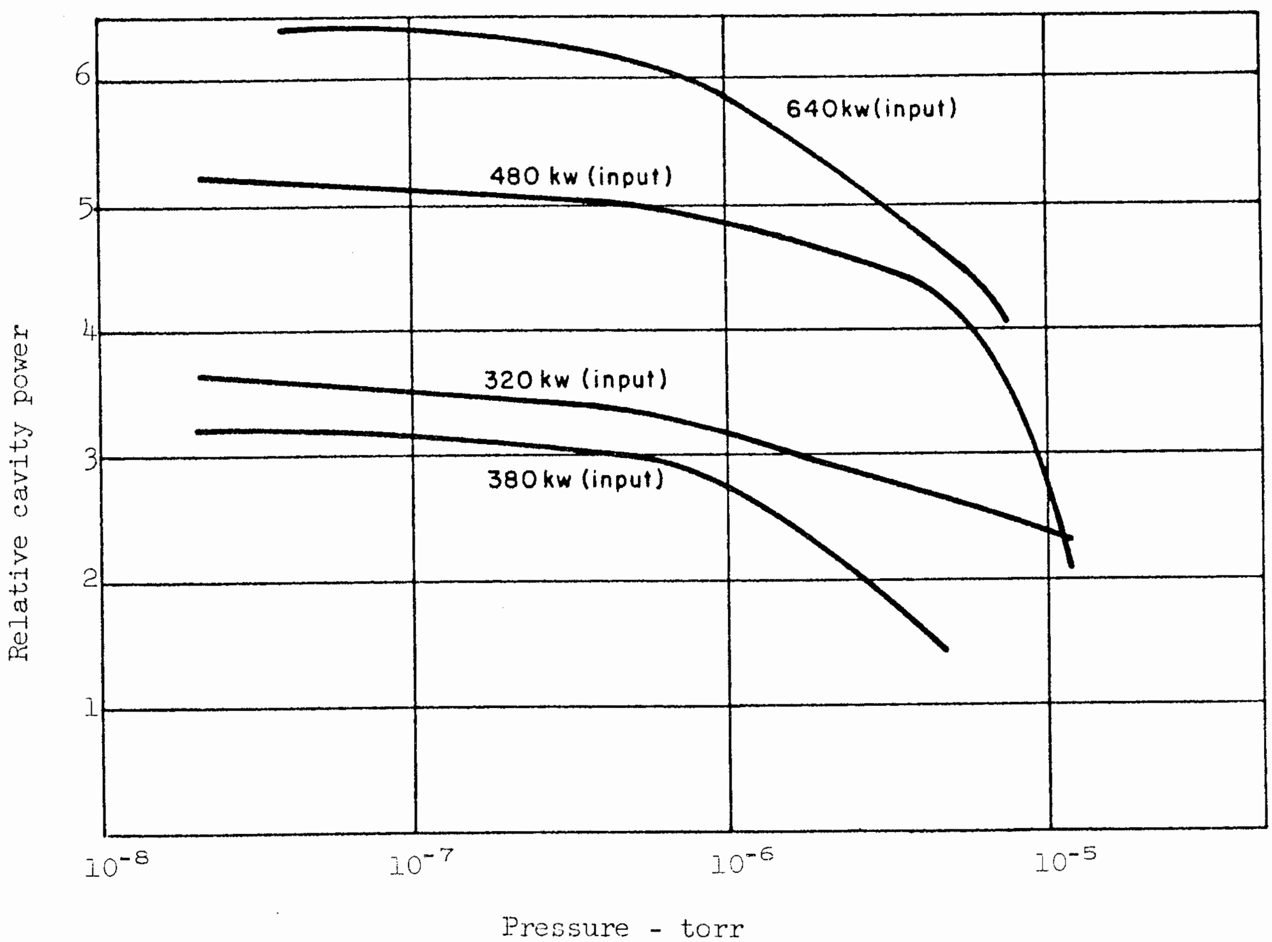

FIG. 19--Cavity loading due to pressure (constant power input).

IX. MODULATOR STUDIES

A. HIGH POWER MODULATOR SWITCH TUBE

The investigation of the thyratron as a switching device for the main modulators has been continued. As was pointed out in the last quarterly report,[1] the deuterium thyratron Type E 2986, manufactured by the M. O. Valve Company, London, England, was one possible choice for a switching device. This thyratron was first placed in the RCA modulator and subjected to a series of tests.

Deuterium Thyratron Tests in RCA Modulator

The power supply voltage was run up to a value of 20 kv at the start of these tests with no indication of voltage failure due to the thyratron. It was operated at this level for about 1 hour. The network was then readjusted to a lower impedance value. No effort was made to optimize the pulse shape at this time. With the load resistance adjusted to 1000 ohms and the power supply voltage set at 20 kv, an output voltage of 243 kv was obtained with a load current of 243 amperes. The switch tube current was found to be 3000 amperes. Under these conditions the time jitter was found to be less than 2 nanoseconds.

A heat test was then performed under the following conditions:

E_{DC} = 21 kv (power supply voltage)
E load = 265 kv
I load = 263 amps
PRF = 360 pps

During this run the maximum operating time before a tube failure occurred was 17 hours and 50 minutes. Because of trigger problems, which developed during this test run, it is conceivable that some of the tripouts may have been caused by the drive circuit malfunctioning rather than the switch tube.

Deuterium Thyratron Tests in Stanford Modulator

The deuterium thyratron was then placed in a Stanford modulator working into a klystron load and operating at 360 pps. This circuit was equipped with an inverse clipper diode. The power supply voltage was gradually increased to 19 kv. At this point the output voltage was 235 kv with a load current of 196 amperes. The switch tube current was 2450 amperes.

[1] Quarterly Status Report, SLAC Report No. 8, "Two-mile accelerator project," Stanford Linear Accelerator Center, Stanford University, Stanford, California, November 1962.

After about 1 hour of operation an arc occurred in the pulse transformer tank, followed by additional arcing at the same power level.

On replacing the oil in the tank it was possible to raise the power level to 21 kv dc which gave an output voltage of 251 kv at 219 amperes. The average dc current input was 3.95 amperes when running at a PRF of 360 pps. A total operating time of 53 hours was logged without tripouts from switch tube failure.

Observations Concerning the Deuterium Thyratron

There was a considerable amount of radiated interference generated when this tube was used. Shielding and filtering were necessary to minimize this condition. This interference apparently was due to the extremely rapid rise of current in the tube (approximately 8200 amps per microsecond). By lowering the gas pressure in the tube the noise interference disappeared. The tube is rated and warranted at 40 kv, but was tested in the factory at 44 kv.

The performance of the deuterium thyratron, over all, has been good to date. It has some objectionable features such as requiring 1.8 kw of heater power, a bias supply, a separate 20-watt getter supply, and air cooling to the base of the tube as well as liquid cooling.

Tests of Ceramic Thyratron

The Kuthe-275 ceramic thyratron was placed in the RCA modulator for tests. This sample tube is one of the first tubes of this type built and, therefore, the test results below should be weighed with this in mind. A brief description of the tests on the Kuthe tube follows:

Considerable seasoning and aging of the tube was required initially since it had never been operated at SLAC power levels. The tube developed a grid-cathode short when the filament was operated above 5.0 volts. The short disappeared when the tube temperature decreased. The maximum continuous operating time, without a tripout at full power levels, was 1.7 hours.

With a filament voltage setting of 4.5 v and a reservoir voltage setting of 4.0 v, the best operation was obtained. This consisted of three operating runs, 1.7 hours, 1.0 hour and 1.2 hours respectively, with no tripouts in these intervals. All other combinations of reservoir and filament voltage resulted in excessive tripouts.

There was evidence of improved operation with the end-of-line clipper circuit disconnected, which resulted in considerably more inverse spike voltage on the thyratron. Reducing the load impedance, to get more inverse voltage with the end-of-line clipper in the circuit, did not improve the operation; however, further work is required in this area before any conclusions can be drawn.

Tube faults observed indicated premature firing in the charging cycle, indicative of voltage breakdown rather than of deionization type of failures.

The following data were obtained during this work:

$$E_B = 18.5 \text{ kv}, \quad E_L = 226 \text{ kv}, \quad I_L = 234 \text{ amps}, \text{ PRF} = 360 \text{ pps}$$

$$T_{rise} = 0.6 \ \mu s \ (0 \text{ to } 100\% \text{ ampl. pts})$$

$$T_{fall} = 1.0 \ \mu s \ (100\% \text{ to } 0\% \text{ ampl. pts})$$

Pulse width = 2.65 μs (measured at flat top of pulse)

With an ignitron in operation the previous week, at an imput water temperature of $35.5^{\circ}C$, the following data were obtained:

$$E_B = 21 \text{ kv}, \quad E_L = 243 \text{ kv}, \quad I_L = 235 \text{ amps}, \text{ PRF} = 360 \text{ pps}$$

$$T_{rise} = 1.0 \ \mu s \ (0 \text{ to } 100\% \text{ ampl. pts.})$$

$$T_{fall} = 1.2 \ \mu s \ (100 \text{ to } 0\% \text{ ampl. pts.})$$

Pulse width = 2.5 μs (measured 1% down from peak of ripple)

B. HARD TUBE MODULATOR

The design of the hard tube modulator (for the sub-booster klystrons) is progressing satisfactorily. A 30-kv solid state power supply, utilizing only one high vacuum regulator tube, has been built and the initial testing of the regulating system indicates that the 0.01% regulation aimed for, to meet the overall specification, is achievable. Prototypes of solid state regulated screen and bias power supplies are being built.

The rise and fall time requirements for the beam pulse can be met with the existing blocking oscillator driver. However, the flatness that can be realized with this type of circuit is limited to the order of ± 0.5% which will not meet the specified value of 0.04%. Another circuit will have to be developed to meet this specification.

Directly related to this problem is the technique of measuring the actual flatness of the pulse with an accuracy comparing favorably with the specified percentage. The Textronix Type Z plug-in unit, which was planned to be used for this purpose, has severe limitations which were first observed during measurements in the Narda hard-tube pulser. Another technique will have to be developed to make measurements of this order of accuracy possible.

X. MECHANICAL ENGINEERING

A. TECHNICAL DIVISION SUPPORT ENGINEERING

Work performed for various groups of the Technical Division this quarter included the following:

1. Plant Engineering

Study of SLAC power requirements to January 1966; modifications to SLAC campus model; review of documents for Title II Electronics Stores and Fabrication Building, Early Cut Accelerator Housing Excavation, Title I 220 KV Master Substation, and Title I Accelerator Housing Earthwork; inspection of Hansen Laboratory trailer units; design drawings, estimates and inspection supervision for the contract construction of the Test Tower foundation, superstructure and electrical services plus concrete and steel shielding.

2. Microwave Engineering

Design for Packaging-Card Case, Resolver Angular Positioner, Pulse Amplifier, Variable Short Circuit and RF Detector Chassis and Panel.

3. Injector Systems

Revised layouts for in-line and off-axis injector equipment, furnishing of two 4-inch vacuum valves and design work on bunch monitor for testing in Mark IV accelerator.

4. Accelerator Structures

Scale model of Heavy Machine Shop including floor plan, superstructure and equipment layout, development of criteria for Salt Bath Building and $\frac{1}{2}$ scale (or full) model of accelerator tube water manifold.

5. Klystron Group

Study model of machine shop to be located in the Test Laboratory.

6. Window Group

Table and vacuum system for the rf ring test stand were completed this quarter. The system is assembled and working satisfactorily from the vacuum standpoint.

7. Modulator Group

Review of modulator bid package and economic studies, including specifications for distribution of manufacturers, of individual versus central dc power supplies. The parameters, including costs, are under intensive review preparatory to making a final decision on type of supplies in January 1963.

8. Instrumentation and Control

Layout of in-line and off-axis injector area cable trays and drafting for I & C Test Stands project work and their Electronics Department.

9. Mark IV Operations

Design of Faraday cups, beam-sampling collimator, new adjustable supports for equipment alignment screens and lamp holder positioner and as-built drawings drafting.

B. RESEARCH DIVISION SUPPORT ENGINEERING

1. Review of Requirements

Expansion of the electrical and mechanical staff is underway to provide required capability in the systems-design area for research projects.

2. Work for Research Division

Work included design and drafting of magnet-field analyzers, quadrupole magnet center probe, calculations of heat transfer for the positron source radiator, instrument and quadrupole center probe cases. Drafting services were provided for a coil flipper, instrument dials and technical reports.

C. TEST STAND PROJECTS

1. Temporary Test Stands Locations

It was decided to locate one of the two test stands scheduled for temporary location in the M-1 Building in the Test Tower structure. Installation is keyed to January 15, 1963, delivery date of the first two Ling modulators. Both test stands will ultimately be relocated to the Fabrication Building.

2. Work on Test Stand Design and Procurement

Purchase orders were issued for pump and heat exchange equipment and instrumentation. M-1 Building test stand floor plan is being revised and Test Tower test stand floor plan layouts were revised and issued. Drawings for vacuum system, water system, junction boxes and Test Tower piping were issued. Installation labor contract specifications are being prepared.

Three vacuum pump sets and pump and heat exchanger for the Test Tower were received. The vacuum pump sets were tested and rejected for failure to meet performance tests and are being reworked by the vendor.

D. TWO-MILE ACCELERATOR PROJECT

1. Planning

a. Design Coordination

Study models at a scale of 3/8" = 1'-0" of the combined Klystron Gallery and Accelerator Housing are being periodically studied by all component groups and general modifications in spatial relationships of component items have been instituted. Recent decisions relative to M-machine equipment and its structures are as follows:

Cooling-water headers serving the accelerator tubes were relocated from the Klystron Gallery to the Accelerator Housing. An additional penetration per sector (total now is 18 per sector) is to be located near the temperature control areas and will accommodate the cooling water supply and return lines, sight tube vacuum service lines, accelerator tube temperature control instrumentation, and power conduit. FIAT racks were located south of the penetrations with modulators centered on the penetrations at 8-feet spacing.

b. Installation Management

Cost guidelines for the two-mile accelerator project will be developed on the basis of time, material andequipment cost estimating procedures common to the construction industry to reflect large project installation techniques. Installation management responsibilities were discussed with component groups of the Technical Division and the Business Services Division. Discussions related to design services for component groups, preparation of drawings and specifications indicating spatial relationships of major equipment, correlation of equipment installation and time phasing of the work and field installation supervision and inspection services.

Review and revision of project responsibility chart and critical path networks is continuing as a result of the above meetings. A report on the installation management program of the two-mile accelerator is in progress.

2. Vacuum

The R & D program has been expanded to test the two alternative vacuum pumping schemes (oil diffusion pumps and vacuum ion pumps) and other roughing systems under consideration such as cryo-sorption, turbomolecular pumps and titanium getter pumps.

Tests were concluded on the 3-inch Marman "Conoseal" flange. Tests were run with two separate gaskets. Under thermal cycling there was a leak at 395° C in the second test run but the flange was leak-tight at all other conditions.

Vacuum ion pumps were installed in the Mark IV accelerator to obtain additional data on the operation of ion pumps.

Equipment is being assembled for the following tests: 10-inch diffusion pumps with molecular sieve traps; Purple Coffin Test (Accelerator Section High Power Tests) wherein the diffusion and ion pump schemes will be tested in a full power accelerator tube system; Test Tower, which will be a full scale mock-up of four accelerator tube sections with corresponding vacuum system; and cold cathode ion gage vs hot filament ion gages.

3. Supports

A sub-sector support truss design was approved by the project and four prototypes were procured.

Preprototype supports were designed and released to the shop. These supports will be available to mount the truss in the test tower facility.

An Interim Design Report which describes the proposed accelerator-tube support system was issued in December for project review.

4. Alignment

A decision was made to test a proposed optical-interference alignment system with a 1,000-foot-long experiment to be located in a vacant railroad tunnel in Brisbane. This scale is large enough to yield results that can be extrapolated to the SLAC machine dimensions. The design of the experimental gear is essentially complete, and testing is scheduled to begin early next quarter.

5. Electro-Mechanical Group

In anticipation of an increasing requirement for design services for the Research Division and component groups of the Technical Division a new group has been formed. This group will also be responsible for special material handling systems. Studies are proceeding on the feasibility of using pneumatic tired vehicles to install and maintain equipment in the accelerator housing.

6. Cooling Water

Work included analytic study of system transients, development of final piping and instrument diagrams for "M" machine, preparation of preliminary piping layout drawings for "M" machine, and study of availability of accelerator tube temperature sensing elements. The cooling water supply and return headers for M-accelerator tube were relocated to the Klystron Gallery.

Testing of temperature control systems, demonstrated that it is possible to maintain accelerator tube metal temperature within $\pm$ 0.15°F under varying heat loads, with best transient response time occuring with a pneumatically controlled three-way bypass valve on the machine cooling water side of the heat-rejection exchanger.

Various heat-rejection systems were coupled in parallel at the Purple Coffin area with an instrument control package which is interchangeable with all systems installed. Comparative tests will be made of the candidate cooling systems. When tests are completed the systems will be moved to the Mark IV accelerator for further testing and evaluation.

The fabrication of five test loops for the Water Treatment Methods Study has been deferred pending a receipt of a report from our consultant on corrosion. Preliminary discussions resulted in a decision to proceed with a comprehensive test program, to develop more information for final design of the M-accelerator cooling water system treatment.

Equipment is being assembled for the Test Tower Cooling Water System.

7. Electrical

A design report was issued on the SLAC accelerator ac electrical services. This report covered detailed ac electrical requirements in all areas except injection. Requirements for the injection areas will be issued when data for these areas is developed. Ac electrical service will be 208Y / 120 volts to accelerator components and 480 volts to motors. Modulator services will be segregated for RFI control. The report was approved and final design is underway.

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 Workmanship Standards; Personnel Safety; Building Materials and Hardware; Welding of Metals and Welder Certification; Degreasing of Metals; Surface Cleaning of Metals; Specification Control; Identification and Marking; Electronic Calibration Laboratory Procedures; Cable Color Designation; Drafting Standards; Chemical Treatment of Aluminum; Soldering; and Motor Control Centers, Controls and Starters.

2. Parts Catalog

Data sheets on tube and pipe fittings, electrical plugs and receptacles are being prepared for distribution.

3. Specification Service

A survey of requirements for sub-contract labor and installation was made. Procurement specifications for permanent and portable electrical machine tools, S-band directional couplers, precision waveguide phase measuring equipment and internal dimension measurement and recording instruments, hard tube modulator and klystron amplifier were prepared for review and distribution by appropriate groups.

4. Document Control

Additional file facilities and IBM card document control system were initiated. Studies for streamlining document handling are continuing.

XI. CONTROL SYSTEM STUDIES

A. STATUS OF THE BEAM SWITCHYARD INSTRUMENTATION

The accelerated electron beam is expected to be shared by three principal experimental areas. A pulsed magnet deflects some (or all) of the 360 pulses per second to the left toward the electron-photon area and some to the right toward the area for secondary-particle production. The straight ahead beam will go to the neutrino area.

A great variety of instruments is required in order to obtain beam pulses with the desired geometrical properties, the desired energy spread, and the desired intensity through the beam channels into the experimental areas. The high power contained in the electron beam and the high radiation levels constitute serious hazards requiring much instrumentation to protect equipment and personnel. To this end, all control and monitoring will be done remotely.

We plan to set up, control, and monitor the switchyard beams from the central control room. Since the mean cable length between the central control room and the switchyard is about 1700 feet, a separate control room close to the switchyard was considered in an attempt to reduce costs. It was tentatively rejected because it is not possible to set up the three beams in the switchyard without also having access to other accelerator controls. At present, the following solution is considered most satisfactory from an operational and economic point of view. This solution provides for all essential monitoring and controls in the central control room, and locates the detailed fault and status signals in racks near the magnet power supplies at the klystron gallery level above the switchyard. Access to the switchyard itself will probably not be possible for several hours after shutdown, and it may therefore be desirable to have more equipment status signals available than is normally required.

A systematic study of the best procedure for setting up simultaneous beams, each with a particular repetition rate and a particular energy, will be started as soon as the details of the switchyard equipment and the beam requirements are better understood. A difficult task will be to design an interlock system that will not shut down the beam because of initial small mis-steering during the beam setup period. A practical criterion has to be established for the actuation points of the interlocks.

A layout of the beam switchyard area is indicated schematically in Fig. 20 . It shows all of the equipment that is firmly established in present planning. It is expected that other pieces of equipment will have to be added, since the switchyard system is still in a preliminary state of design. The second pulsed magnet system is being seriously considered, but the details are not well known at this time.

For these reasons, the control racks in the central control room, the cable system, and the data transmission system will be designed with sufficient flexibility to permit future change and expansion. The design of some of the equipment for the beam switchyard is either in a preliminary state or else has not yet been started, so the control requirements may only be guessed at this time. One of the more complicated controls may turn out to be the triggering for the pulsed deflection magnets, the magnetic slits, and the gated intensity monitors. The trigger rate for each beam must be adjustable from 360 pps down to 1 pps or lower. When a bubble chamber is used, it may be desirable to suppress the pulses in all other beams during the sensitive time of the chamber (about 0.01 sec). (This complication will probably show up in the master trigger controls at the central control room, rather than in the switchyard itself.)

A study is being made of the possibility of adapting the beam-position and -intensity monitors developed for the SLAC accelerator and the beam-spectrum monitor developed for Mark III machine to the requirements for the switchyard. The other instrumentation must wait until the equipment to be monitored is better defined.

B. PROGRESS DURING THE PAST QUARTER

1. Trigger System

Tests are being made using 500 ft of RG-58/U cable to simulate the main two-mile trigger line. A reflection test has shown that simple high-impedance taps for sector takeoffs introduce insignificant

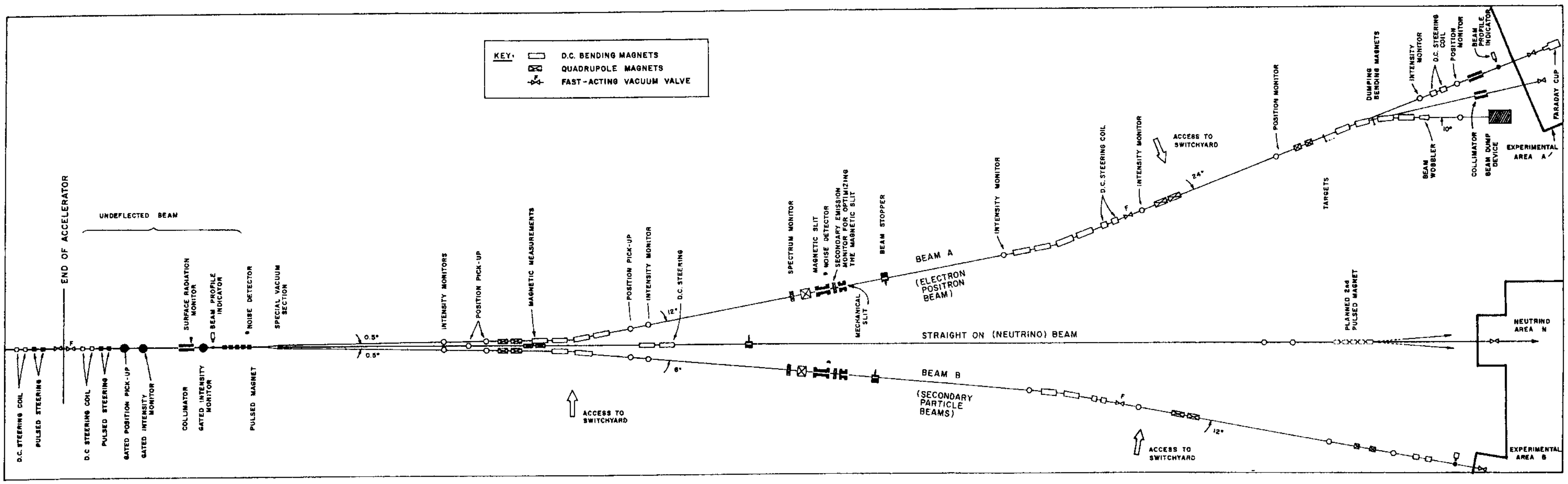

FIG. 20--Beam switchyard area layout.

reflections. The cable will also be used to study the effect of frequency-dependent loss on the rise-time of variously shaped input pulses.

The relative merits of soft tubes versus hard tubes for the trigger generator are being evaluated, especially with regard to expected lifetime and reliability. Life test of six 3C45 thyratrons under typical SLAC conditions has begun, and similar tests of hard-tube generators will start early next quarter.

A trigger generator with output-pulse patterns similar to those planned for the big machine has been delivered to the Mark IV accelerator and is in use. A mock-up of the interface logic between trigger, drive and modulator, using SLAC-type components where possible, is being prepared for test on Mark IV during the coming quarter.

2. <u>Beam Guidance and Monitoring</u>

The main effort during the last quarter has been directed towards improvements in the beam-position monitor, with particular attention to the problem of the mode of operation of the pick-up coils. The resonant method, in which the leading edge of the beam pulse causes the coils to ring, is being investigated thoroughly. An optimized design for the given geometry results in a sensitivity of 5.8 volts/amp-cm operating at a resonant frequency of about 3.0 Mc to enable accurate measurements of pulse durations down to 100 ns. To keep the resonant frequency high, it is necessary to keep the stray capacity across the coils to a small value. The coils must therefore drive the cable between the accelerator housing and the klystron gallery by way of cathode-follower units close to the coils themselves. Such circuits, using nuvistors rather than transistors or standard vacuum tubes, are being developed and will be tested in a high-radiation environment to determine, in particular, a measure of the radiation-induced noise. This noise may set the limit of resolution which will ultimately be obtained from the position monitors.

3. <u>Data Handling</u>

Preliminary engineering designs of the data acquisition and remote control system and of the battery, cable, and personnel communication subsystems have been prepared. A program for evaluation of concepts and equipment in the above areas has been prepared, and an equipment and system evaluation facility is being built.

A shielded 25-pair 22-gauge cable was installed between a mock-up sector control point in building M-1 and a mock-up central control point in building M-2. Test racks have been provided at each end of the cable for evaluation tests of terminal equipment. The tests will include operating one or more test stands using only those signals expected for use on the accelerator. A 24-volt battery plant is being installed in the "sector" area and will be thoroughly tested.

4. Measuring and Actuation Devices

(a) Vacuum. A survey of commercially available vacuum gauges and controllers was conducted with a view toward finding the most reliable equipment for SLAC operation. A Hughes cold-cathode gauge (type PG-7) and a 0.2 liter/sec Vacion appendage pump were selected as suitable measuring elements. Tests are being conducted by the vacuum group in order to learn more about the PG-7 gauge, which has been on the market for only a short time. Specifications for the electronic circuits associated with these gauges were established, including the control functions required for normal and emergency operations.

(b) Accelerator alignment. A circuit is under development to measure the maxima of light intensity of interference fringes obtained in the process of optical alignment of a long tube. A rotating or reciprocating mirror scans through small portions of the waveform, the maximum of which has to be located accurately in position. The phase of the first harmonic of this effective modulation determines whether viewing is to the left or the right of the peak position, while the peak itself is detected by the second harmonic of the modulation frequency.

5. Electronics Shop

The Electronics Shop facility has been enlarged. During this quarter several technicians have been loaned out to other groups. The Engineering Support Section and the Prototype and Fabrication Section have developed, modified, and fabricated equipment in support of the above I & C projects, the Test Stands, and various jobs for the Mechanical Engineering Department, the Research Group, the Klystron Group, and the RF Group.

The Instrument Repair and Maintenance Section has improved its facilities for high-accuracy calibrations. Emphasis during this quarter has been directed toward enlarging the instrument pool. Assistance has been given to other departments with the selection of equipment.

6. Test Stands

The I & C equipment racks for 14 test stands have been assembled. AC power distribution within the rack has been completed, and system wiring is on schedule. Layout and design of the rf drive system for the "tree house" and the M-1 Building installation was completed.

XII. RESEARCH DIVISION

A. GENERAL

The overall design of the switchyard proper is being actively pursued. Computer studies have demonstrated the practicality of two magnetic-beam-transport systems under consideration (see below). Criteria for the tunnels associated with these portions of the switchyard are in preparation for presentation to Plant Engineering. The final sections of the switchyard, linking these transport systems to the end stations, are not yet definite. Outstanding problems which remain in this area are:

1. Levels of induced radioactivity.
2. Heating problems in the slits, collimators and beam dumps.
3. Alignment of the elements in the deflecting system.

B. MAGNET AND BEAM STUDIES

1. Magnet Systems for the Beam Switchyard

The final design of the 25-Bev beam transport system leading to End Station A was completed this quarter in sufficient detail to allow the surrounding tunnel to be designed. The system has two 12-degree deflections; it is achromatic and essentially isochronous. The momentum band pass of the system is $\pm$ 1%. A momentum resolution of $\pm$ 0.05% can be achieved through a $\pm$ 0.5-cm slit. The ultimate resolution of the system is approximately $\pm\, 0.03x_0$, where x_0 is the object radius in centimeters. The minimum image size which can be achieved by the target is somewhat less than 1 millimeter square.

Second-order (chromatic) aberrations in the quadrupoles do not significantly increase the image size at the target. Parabolic fall-off of the field toward the edge of the bending magnets will affect resolution and spot size if the field falls off faster than 1 part in 10^4 at 1 cm from the center line of the magnet.

Alignment tolerances on the magnets are rather severe. The bending magnets and the symmetry quadrupole must be located to within 20 mils and leveled to within 0.5 milliradians to maintain the high quality of the system beam optics. The quadrupole doublets must be aligned to within 10 mils and 0.1 milliradians. The relative position of the magnetic axis of the two quadrupoles in the doublet must be 4 mils or less.

The beam transport system to the "secondary" target area, End Station B, is also finished. The design momentum is 40 Bev/c. The system has two 6-degree deflections, is achromatic and essentially isochronous. The alignment tolerances and the second-order aberrations are currently under study but should be of the same order as those of the two-12-degree-delection system.

The design of bending magnets and quadrupoles for the beam switchyard is being continued. Sufficient details have been determined to permit inquiries to be sent out. The gap of the magnets will be 6 cm with 30-cm pole width. For 3-degree deflection per magnet at 25 Bev (1.45 Wb/m^2) a power of 60 kw/magnet will be required. Calculations on the rim shape for minimum aberrations and saturation effects continue. Similar calculations on the quadrupoles are being undertaken to keep the resulting increase in image size at the energy slit less than 0.2 cm for 10^{-4} radian angular spread.

2. Pulsed Magnets

A prototype pulsed magnet has been constructed, and its associated modulator is now working. Magnetic measurements on the peak fields obtained and on the residual fields are under way.

3. Quadrupole Center Locator

The instrument designed to position a vial of suspended ferrite particles in the field of a quadrupole is almost completed. Measurements with this device will begin as soon as a power supply is available for the small quadrupole which is already in the laboratory.

4. Magnet Coil Irradiation

We have obtained some samples of magnet coil windings from National Coil and plan to irradiate these in the beam of the Mark IV linear accelerator to evaluate the epoxy-impregnated windings and to determine the extent of radiation damage under intense bombardment.

5. Magnet Power Supply

Specifications have been drawn up for a power supply capable of supplying any of the units presently envisaged for the beam switchyard. This will go out for bid shortly.

6. Secondary Electron Emission Studies

A series of experiments will be conducted on the Mark IV linear accelerator to measure the secondary electron emission yield from different metals. The experimental values will be compared with the existing theory of secondary electron emission. Reliable yield data exist only for aluminum which was used in a high-energy beam monitor.* Using different metals or metalized dielectric and metal plates one might find a very-high-efficiency beam current monitor for the SLAC accelerator.

7. Beam Dump

Studies have been made on some of the problems arising when the beam is completely stopped. These studies are the subject of a technical report being prepared. No completely satisfactory system has as yet evolved.

C. RADIATION PROBLEMS

1. Transverse Shielding

A report describing the new calculation for the transverse shielding along the machine, which supports the choice of a 25-foot-thick earth shield, has been issued.**

2. Effects of Penetrations and Passageways Through the Transverse Shielding

Preliminary calculations have been finished concerning the radiations leaking through the passages and penetrations in the transverse shielding along the machine. The leakage of low-energy neutrons can

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*G. W. Tautfest and H. R. Fechter, Rev. Sci. Inst., February, 1955.

**H. DeStaebler, "Transverse Radiation Shielding for the Stanford Two-Mile Accelerator," SLAC Report No. 9, Stanford Linear Accelerator Center, Stanford University, Stanford, California, November 1962.

be calculated fairly accurately from reactor work. However, the leakage of the high-energy particles is complicated, and there is little experimental or theoretical work on this subject. With some reasonable, but not especially conservative, assumptions, the amount of leakage radiations for "average operating condition" of the machine has been calculated. There are three different kinds of penetrations along the machine: (a) the waveguide penetrations, which are straight and about 28 inches in diameter; (b) the personnel accessways, which are offset and are principally manholes three feet in diameter; and (c) large accessways for personnel and material, which are also offset but which have a cross section of about 6 ft $\times$ 15 ft. Our calculations indicate that too much radiation would leak through all of these ducts, and that additional shielding will be required. It seems that most of the leakage radiation will have fairly low energy ($\approx$ 1 Mev) when it reaches the surface of the shield, and that a few feet of ordinary concrete capping off the duct at the surface of the shield should suffice to reduce the levels to acceptable values.

3. Preliminary Calculation of Radiation Levels Inside the Accelerator Housing After the Machine Is Turned Off

Calculations have been made of the radiation levels inside the accelerator housing arising from the absorption of 3% of 2.4 Mw of beam power uniformly over 10,000 feet. These calculated levels take into account only the residual activity in the concrete walls and in the copper of the accelerator; they do not include the activity in the air.

The concrete activity arises from reactions with the sodium content which is typically about 1%. The principal reaction is Na^{23} (n capt) Na^{24} initiated by the giant resonance neutrons from the machine which are thermalized and captured in the wall of the tunnel.

In the copper the giant resonance (γ, n) reactions dominate until the machine has been off for about 10 to 20 hours. After this time the long-lived Co^{58} and Co^{60} activities dominate. The formation of these nuclides means that 3 to 7 nucleons must be ejected, and these cross sections are poorly known.

After the machine is turned off the radiation levels start to decrease, but the detailed time behavior is complex because so many nuclides are involved. When the machine is first turned off, the radiation level in the tunnel is about 1 rem/hr. (Tolerance is 0.75 mrem/hr.) Ten hours later the level is about 300 mrem/hr with somewhat less than half of the radiation coming from the concrete. Fifty hours later the level is about 50 mrem/hr. Beyond this time the concrete activity is negligible, and the copper activity decreases only slowly.

Certain qualifications to this calculation should be kept in mind. First, the levels are directly proportional to the beam-power loss in the immediate neighborhood, and it is easy to suppose that there will be some hot spots where the radiation level is 10 to 100 times larger than discussed above. Second, so far we have neglected any shielding of this residual activity, either self-shielding in the radioactive material itself or external shielding placed over the hot areas or around the object to be shielded. Third, the relevant cross sections are uncertain by various amounts, but probably only the cobalt activities have substantial uncertainties.

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

At Oak Ridge a three-dimensional Monte Carlo calculation was carried out for the amount of electromagnetic ($e^{\pm}$, γ) energy scattered out of the machine when a beam electron strikes it. The complex geometry of the disk-loaded waveguide was greatly simplified. The calculation yielded the distribution in energy and angle of the scattered-out energy carried by the various kinds of particles. The results are similar to those which were given earlier*, but now they are on a firmer basis.

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*H. DeStaebler, "Radiation Levels Inside the Project M Accelerator Tunnel," M-263, Stanford Linear Accelerator Center, Stanford, California, May, 1961.

5. CERN Shielding Experiment

We are cooperating in the analysis of a shielding experiment organized by a number of European laboratories and to be carried out at CERN. An emulsion exposure with 9 Bev/c protons on steel has been made. A 20 Bev/c exposure is forthcoming. We expect to scan some of the emulsions from the 20 Bev/c exposure.

D. THEORETICAL PHYSICS

1. CEA Experiment

The code for calculating pair-production of spin-$\frac{1}{2}$ particles at high energy, including the finite-size effects of the target nucleons, has been completed. Results obtained for the energies and angles of interest for the experiment at the Cambridge Electron Accelerator show little change from the results reported in the last status report. Currently the code is inefficient for extensive use and improvements are being studied.

2. Photoproduction of Spin-1 Particles; Intermediate Vector Bosons

Work has been completed on the calculation of the photoproduction of vector mesons; numerical results will be presented at the Cambridge Gamma-Ray Conference, January 26-29. The calculation of the pair production of spin-1 particles which have no strong interactions (i.e., the intermediate vector boson of the weak interactions) is continuing, and it is expected that the complete analytic expression for the differential cross section will be obtained during the forthcoming quarter. Due to the complexity and length of this expression, its content will be studied by numerical calculation on the IBM 7090. A paper entitled "A Model of Weak Interactions with Six Intermediate Vector Bosons" (in collaboration with S. Glashow of the University of California) has been submitted for publication.

3. Resonances

Calculations made in connection with the experiments of Goldhaber et al. on the reactions

$$
\begin{aligned}
K + p \rightarrow\ & K^{*} + N^{*} \\
& K + N^{*} \\
& K^{*} + p
\end{aligned}
$$

give good agreement with the observed angular distributions and polarizations. However, the calculated total cross sections seem to be a factor of four larger than experiment. A written report of these results is in preparation. A comprehensive survey of what is currently known about meson and baryon resonances has been presented as a series of lectures, and a written report is in preparation.

E. EXPERIMENTAL PHYSICS

1. Shower Development

New measurements done on the Mark III accelerator with 187-Mev electrons are not in disagreement with the Zerby calculations (ORNL-3329). However, it has become apparent that the method used can easily be subject to large errors due to small variations in beam shape and centering. It is hoped that these uncertainties can be eliminated in future runs by a new measurement technique.

2. Collimator Studies - C. D. Zerby and H. S. Moran, Oak Ridge.*

A study has been made to determine whether a collimator placed at the 2500-foot point of the accelerator will be effective in reducing the amount of radiation produced in the remaining 7500 feet of the accelerator. It is clear from this study that there will be a net reduction but that for a few hundred feet after the collimator a greater degree of contamination might result under certain beam conditions.

3. RF Particle Separators

Measurements on a section of disk-loaded (off-center disk aperture) waveguide have been completed and are now being analyzed. The measurements consisted of determination of the ω-β diagram for the lowest order mode, dielectric rod measurements of the variation of shunt impedance as a function of radial position within the aperture, and dielectric bead measurements to study the harmonic composition of the mode.

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*C. D. Zerby and H. S. Moran, "A Collimator Study For A 5-Gev Electron Beam," ORNL-TM-423, December 7, 1962.

A section of disk-loaded (symmetrical) guide has been assembled, and measurements of dispersion diagrams of the lower order modes are now in progress. These measurements will be made as the disk aperture is varied. The shunt impedance will be determined at various radial positions. Theoretical analysis of the deflecting mode (TM_{11}) is being developed to compare with measurements.

4. Magnetic Momentum Slit

The calculations for this slit have been published.* Measurements on the model are proceeding using various configurations of current strips. The arrangement is shown in Fig. 21. Figure 22 shows the vertical field as a function of x. It is not too different from a quadrupole field. Figs. 23, 24 and 25 show the cancellation achieved with the arrangement of strips as shown. The slope of the field fall-off as well as the flatness at the center are both close to satisfactory. However, the reverse wings that occur near the top and bottom of the gap are too large. Further arrangements are being tried to minimize this.

5. CEA-SLAC Experiment

Several trial runs have been made to test the counters at CEA. The latest run was with the accelerator at 4 Bev. The threshold Cerenkov counter has been tested and works. The optics for the $\Delta\beta$ counter (Argonne) that was designed at SLAC have been completed and shipped to Argonne for final assembly test.

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* E. L. Chu and J. Ballam, "The Principle of Design of Magnetic Momentum Slits," SLAC Report No. 6, Stanford Linear Accelerator Center, Stanford University, Stanford, California, October 1962.

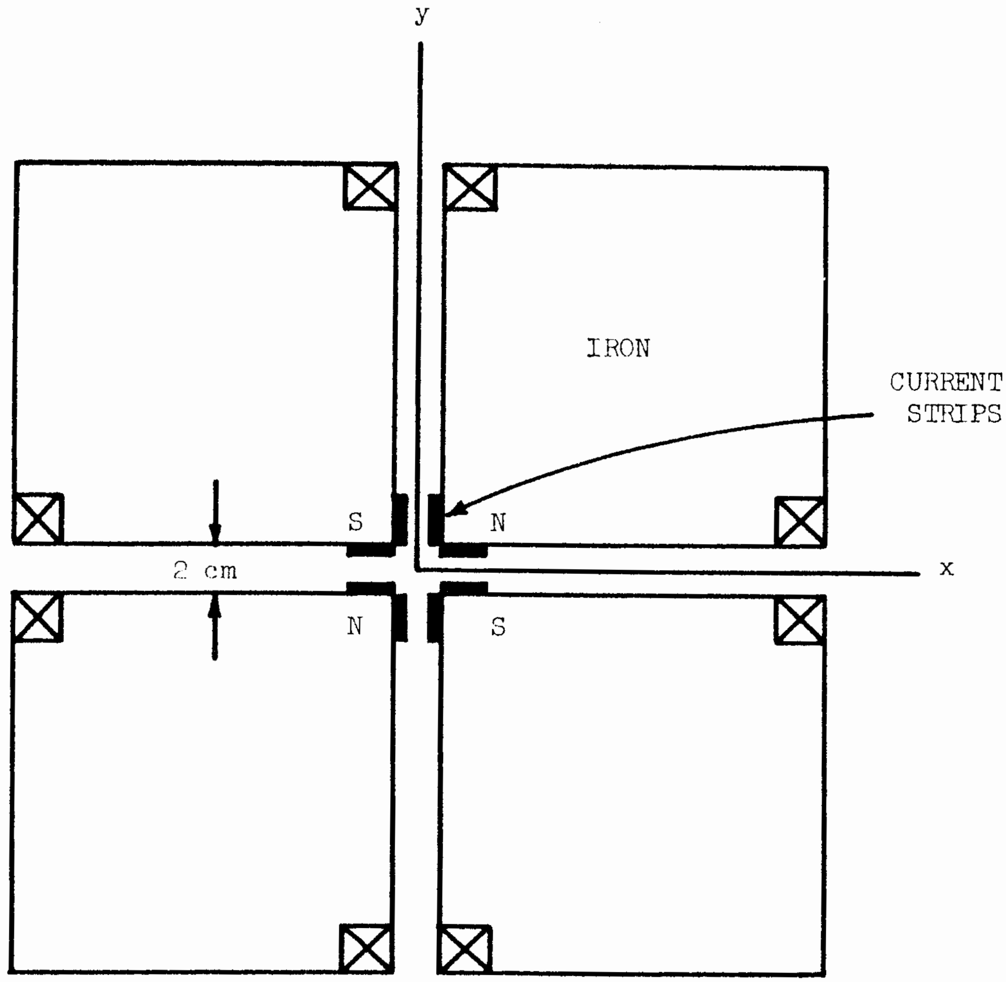

FIG. 21--Schematic diagram of magnetic slit. The arrangement of the current strips is shown in the upper right hand corner of Figs. 22 through 25.

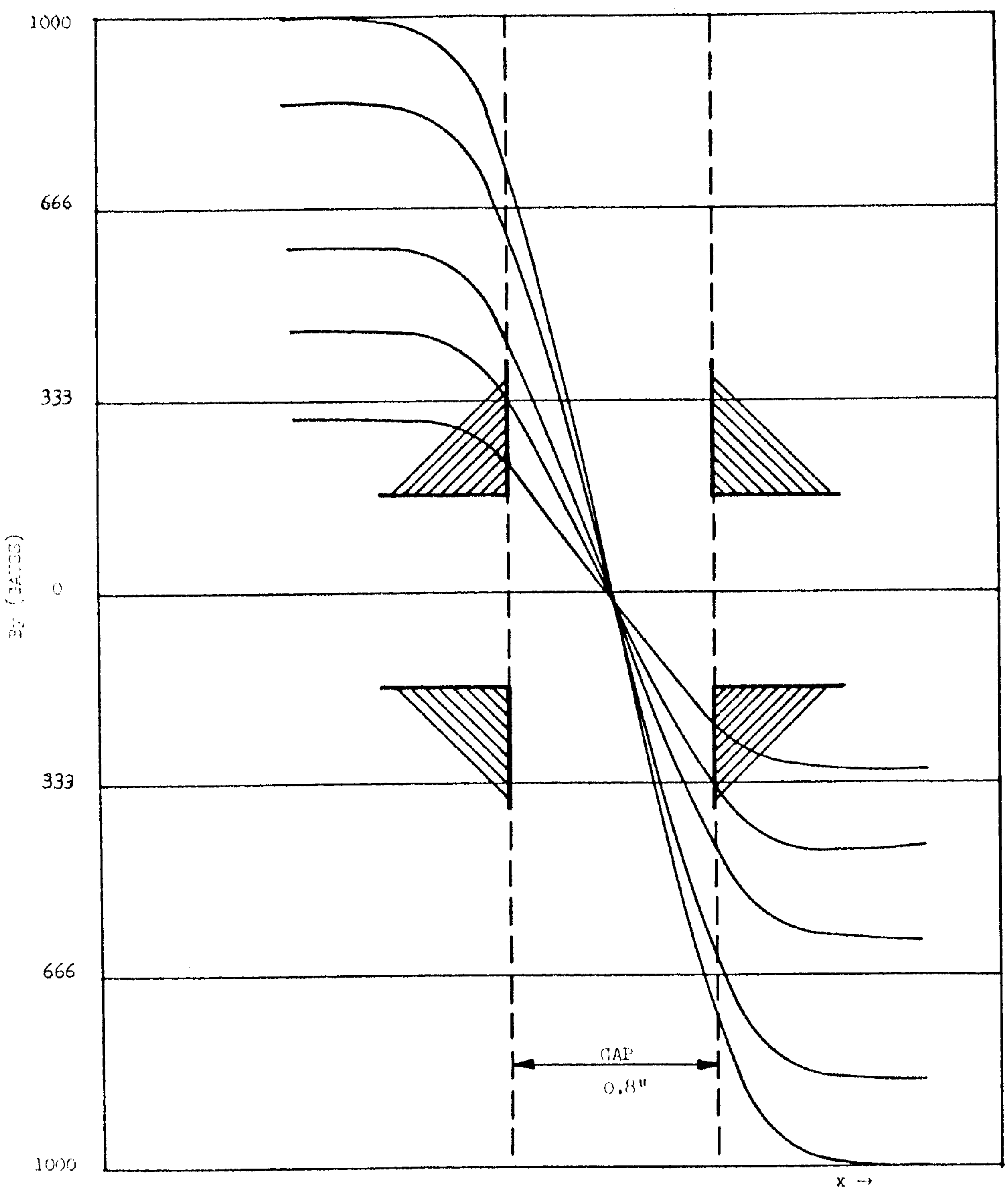

FIG. 22--Vertical field of magnetic momentum slit.

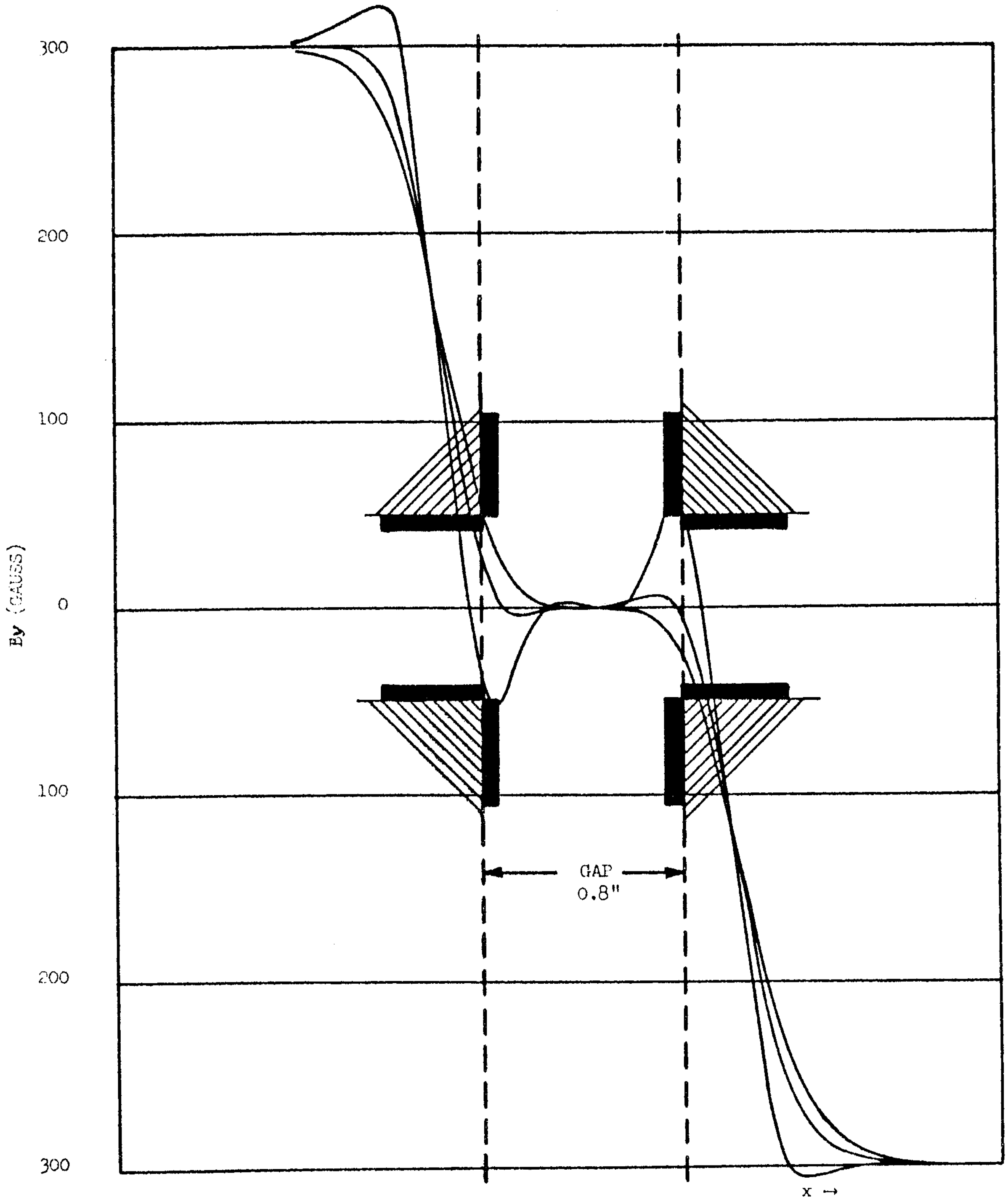

FIG. 23--Effect on vertical field with current strips.

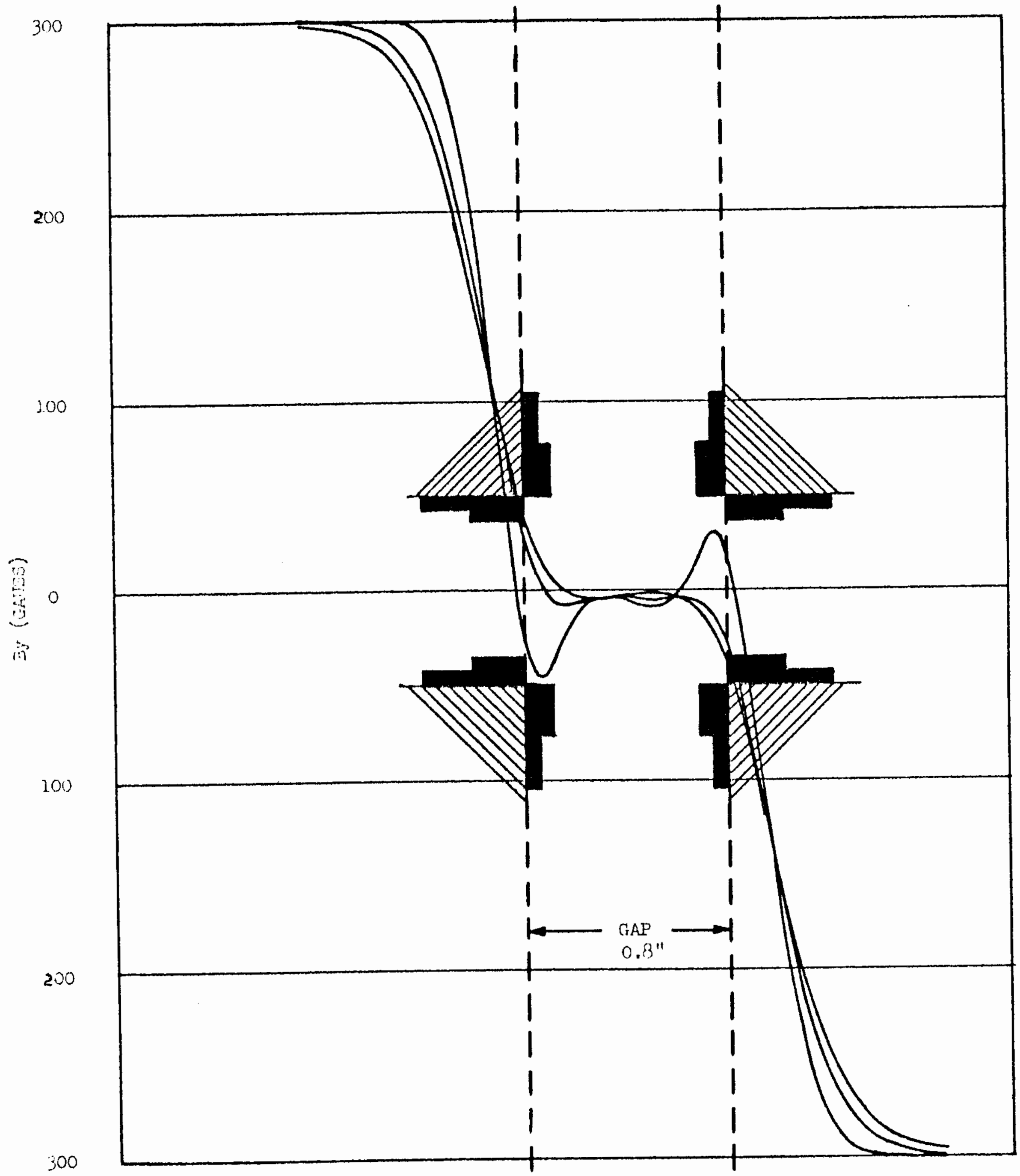

FIG. 24--Effect on vertical field with current strip modification 1.

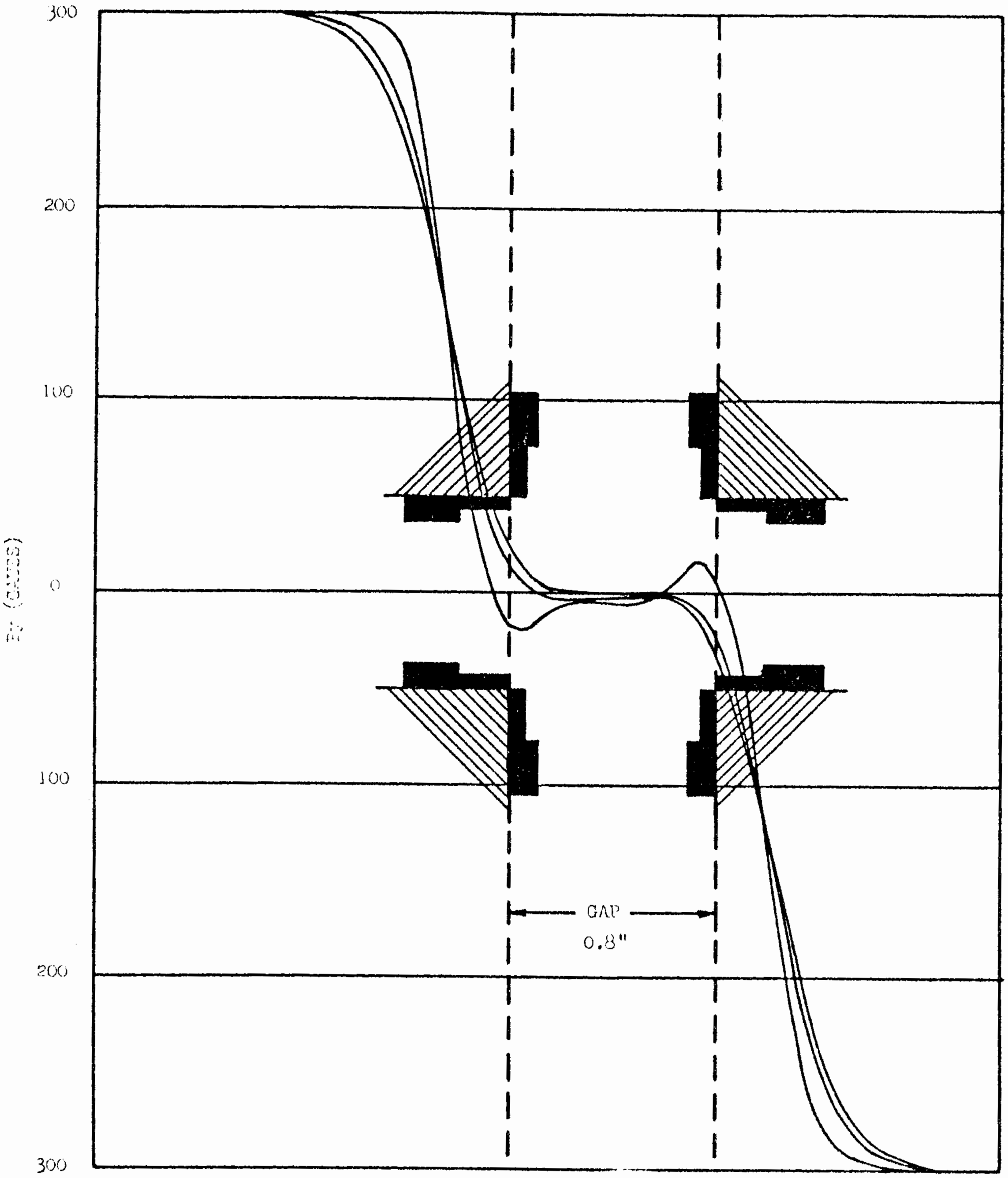

FIG. 25--Effect on vertical field with current strip modification 2.

XIII. PLANT ENGINEERING

A. GENERAL

The design phase of the conventional facilities program continued throughout the quarter and several new construction starts were made. Construction-contractor personnel at the Sand Hill Site totaled 80 at the end of the period, contrasted with 55 previously. The total ABA work force numbered 123 people in all categories, this level having remained substantially unchanged.

A new schedule was developed in December for the Accelerator Housing and Klystron Gallery. The availability of these housings for beneficial occupancy will be in terms of individual sectors rather than an initial 1,000 feet as originally planned. The first sector is to be available March 2, 1964, followed by the next three at approximately one-month intervals.

Regular biweekly meetings are now being conducted by Plant Engineering cognizant staff members on facilities being designed. Attended by both ABA personnel and SLAC customer groups, these meetings are intended to improve communications and minimize the chance of significant delay when criteria or design changes are made.

A procedure for improved handling of construction-contract modifications was developed jointly with ABA and the SLAC Business Services Division, and approved by the A.E.C. Both change orders and supplemental agreements are provided for, together with a mechanism for quick approvals when conditions warrant . The new procedure was put into effect in December and should be of considerable value in the field construction program.

Engineering assistance was provided in connection with building and equipment alterations, temporary housing, and space studies. The latter is particularly applicable to occupancy of the first buildings scheduled for completion at the Sand Hill site during the spring and summer of 1963. This general area of service work will increase as project facilities are completed and put into operation.

B. DESIGN

Preliminary design is nearly complete on the Klystron Gallery, Heavy Assembly Building, and the Main Receiving Substation. Site landscaping has just entered this phase. Criteria for the Control Building have been established, and preliminary design will start in the near future.

The Accelerator Housing and Central Laboratory are in final design, this work having started in November, 1962. The Shops Complex is out for bids, the bid opening date having been scheduled for January 4, 1963. Bid opening for the Geodetic Survey Towers is January 8, 1963.

Final design of all unit substations for the project is well advanced. It is planned to purchase these under a single contract, as needed on site.

Engineering services were provided to the Accelerator Structures group in setting up the Test Tower facility near Building M-1 and in obtaining the necessary concrete shielding blocks for the forthcoming experimental program.

C. CONSTRUCTION

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

1. <u>Test Laboratory</u>

Approximately 46% complete. Contract beneficial occupancy date is March 15, 1963.

2. <u>Administration and Engineering Building</u>

Approximately 17% complete.

3. <u>Utility Building "A"</u>

Approximately 5% complete.

4. <u>Initial Site Utilities</u>

Contractor was given notice to proceed on December 4, 1962.

5. <u>Initial Excavation (Accelerator Housing)</u>

Contractor was given notice to proceed on December 13, 1962.

6. <u>Construction Office Building</u>

A contract for this facility was approved December 27, 1962, and work will commence shortly.

7. The initial increment of site improvement work was completed by the contractor and accepted by SLAC in November.

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 provided technical advice regarding project needs. The contract has been approved by the A.E.C. and returned to PG&E for signing.

A correlated project is the proposed establishment of a 220 kv transmission line along the Skyline route with a tie-in line to the Sand Hill site, and a 60 kv tie-in line to an existing service near Alpine Road. Stanford is cooperating with PG&E and the appropriate public agencies to obtain the necessary permits.

Negotiations for natural gas services are underway. Sewage services were contracted for with the Menlo Park Sanitary District.

E. COOLING WATER SYSTEM

Installation of instrumentation was completed on the Mark IV Accelerator and on a 10-foot accelerator section mounted in the middle-bay test stand of Building M-1. This permits control of the water-supply temperature from a test point on the accelerator waveguide surface.

A test run using power levels up to 85% of the Stage II maximum was conducted on the reduced-pressure boiling system in the Building M-1 test stand. Temperature control results were excellent. Tests will be run at the Mark IV Accelerator during the next quarter.

LEGAL NOTICE