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TWO-MILE ACCELERATOR PROJECT

Final Report
AEC Contract AT(04-3)-363

Quarterly Status Report
AEC Contract AT(04-3)-400
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I. INTRODUCTION

This report is the Final Report of work under AEC Contract AT(04-3)-363, and the first Quarterly Status Report of work under AEC Contract AT(04-3)-400, both held by Stanford University. The objectives of each contract are described briefly below.

Contract AT(04-3)-363 began in September 1960 and ended in June 1962. This contract provided for the initial design, engineering and development work for the Stanford two-mile accelerator. Among the specific objectives were master planning of the accelerator site, buildings and laboratories; development of components and systems for the machine; and procurement of test models of particular components that would lead to initiation of construction without delay. The existing Mark IV accelerator at Stanford (80 Mev) was converted to a model section of the two-mile machine, incorporating those components and techniques intended for later use with the larger machine.

Contract AT(04-3)-400 went into effect in April 1962. This contract provides for the construction of the two-mile accelerator project, which is now called the Stanford Linear Accelerator Center (SLAC). Construction of the Center began in June 1962. The present schedule calls for completion of construction in the summer of 1966. The estimated construction cost for 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 three-year program of research-preparation work will begin in Fiscal Year 1964. This work would be funded separately from Contract AT(04-3)-400, and its status would be reported in separate reports.

II. MARK IV PROGRAM

A. GENERAL

The use of the Mark IV accelerator as a test vehicle has developed satisfactorily during this quarter of operation. Two-shift per day operation has been continued when running experiments, and the machine capability and reliability have been improved to the point where the full power-supply voltage available is used routinely. Because of the need for early results from the Mark IV activity, all effort short of a crash program is being made to develop the machine's further capabilities.

Although the machine has been operating as described above, much is planned and under way to increase its peak and average power capability and to improve and expand the instrumentation and control facilities. It is planned that the Mark IV accelerator will be capable, within the limitations imposed by its physical length, of providing adequate experimental means for the investigation of any questions that may arise during the development phase of the two-mile accelerator program.

B. SYSTEM PERFORMANCE

The machine operated throughout the quarter at the same rf output per klystron, approximately 11 Mw, as during the previous quarter. The floating wire calibration of the beam bending magnets, combined with further experiments, indicated a maximum beam energy of about 52 Mev at low beam current and an output of 8 Mw from each klystron.

The frequency for best energy gain of the second accelerator section is 2857.7 Mc/sec at $89^{o}F$. This is, therefore, the experimentally determined frequency (at this temperature) for which the rf wave in the accelerator structure has its phase velocity equal to the velocity of light in free space. Experimental determination of this frequency was carried out as follows. Energy spectra plots were made on an X-Y plotter for various frequencies with both accelerator sections fed with rf power and with only the first section fed. The value of highest energy on each spectrum was plotted versus frequency. Care was taken experimentally to obtain a sharp cutoff on the high-energy end of each spectrum plot. By subtraction of the first section energy from the total energy at each frequency, a third curve of energy gained by the second section was obtained. This curve had an energy maximum at 2857.7 Mc/sec.

Using two sections of constant-attenuation (per-unit-length) accelerator structure, the above experiment was carried out and resulted in 52 Mev maximum total energy and 2857.7 Mc/sec frequency for correct phase velocity. Substitution of a constant-gradient section of accelerator structure for the second section resulted in an approximate maximum total energy of 54 Mev and the same frequency of 2857.7 Mc/sec for correct phase velocity. The entire run of spectrum plots was repeated for the constant-gradient section, and additional data were taken for exploratory purposes.

Figure 1 shows the curves of energy versus frequency using the constant-gradient section. Although the basis for the theoretical curve of Fig. 2 is somewhat uncertain, and although the experimental points were measured with an uncalibrated microwave monitoring system, the curves are presented as an indication of the range of values achieved.

C. SUBSYSTEMS AND COMPONENTS

1. Vacuum

Operating vacuum conditions continued satisfactorily as reported last quarter. Going to full operating conditions from atmospheric pressure of nitrogen takes an approximate total pumping and processing time of four hours. Additional and improved valves have been and will be installed, and as the opportunity arises, improved vacuum flanges and gaskets will be placed in service.

Work continued on the ion gauge interlock wiring, and further needed improvements in ion gauge amplifiers were determined.

2. Klystrons and Windows

The two klystrons in service at the end of the previous quarter have operated satisfactorily throughout this quarter. It has been urgently desired to test the constant-gradient section at considerably higher power than 11 Mw, and efforts to achieve this by lowering the pulse-forming network impedance and pulse length have resulted in a klystron output of approximately 15-1/2 Mw into a dummy load. The next step will be to reconnect the klystron output to the accelerator and to proceed with further testing.

The windows have also continued to operate without any difficulties, although temperature readings seem to be somewhat high. Blowers are on order to relieve this situation.

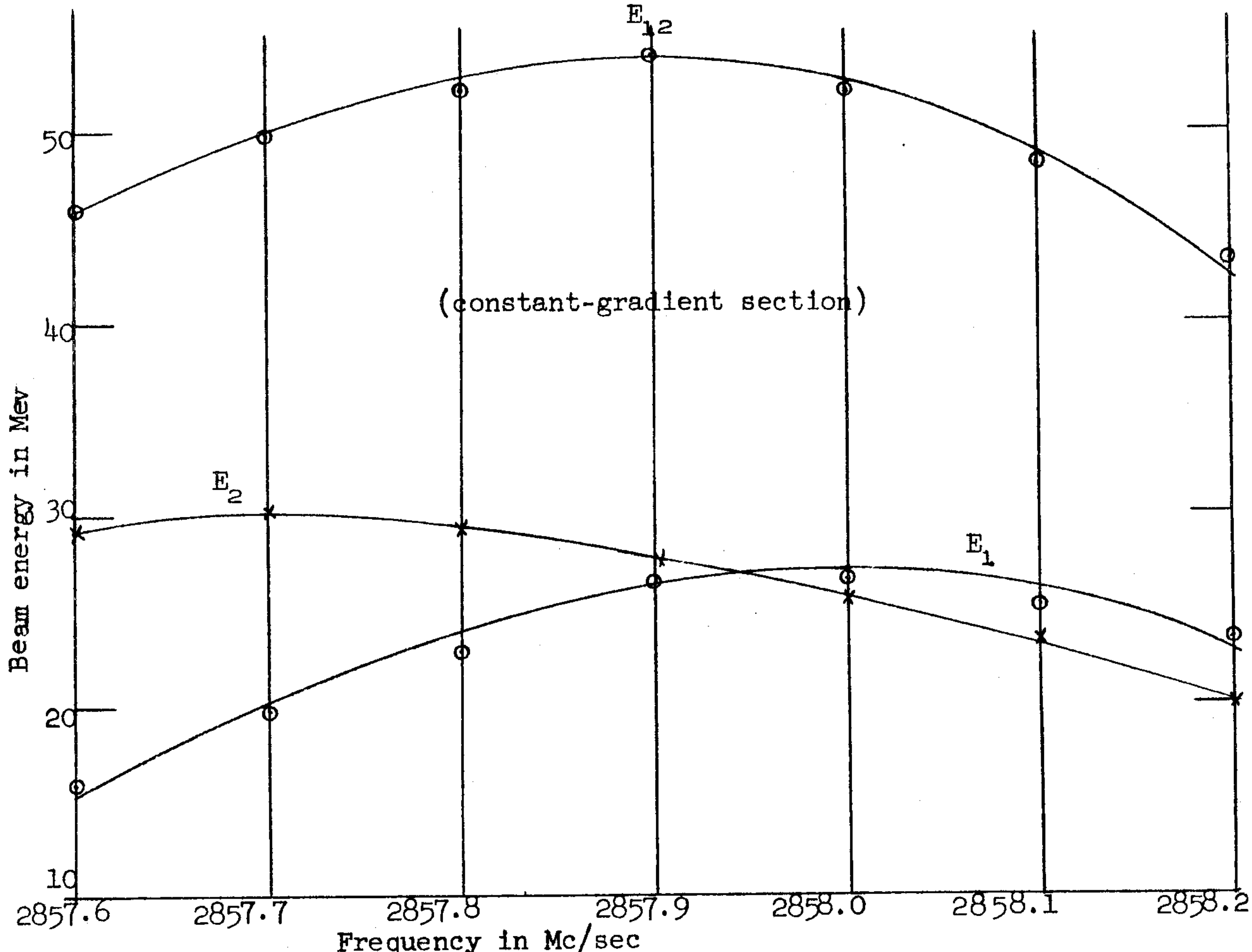

FIG. 1--Total and individual section energy gains vs frequency for Mark IV accelerator.

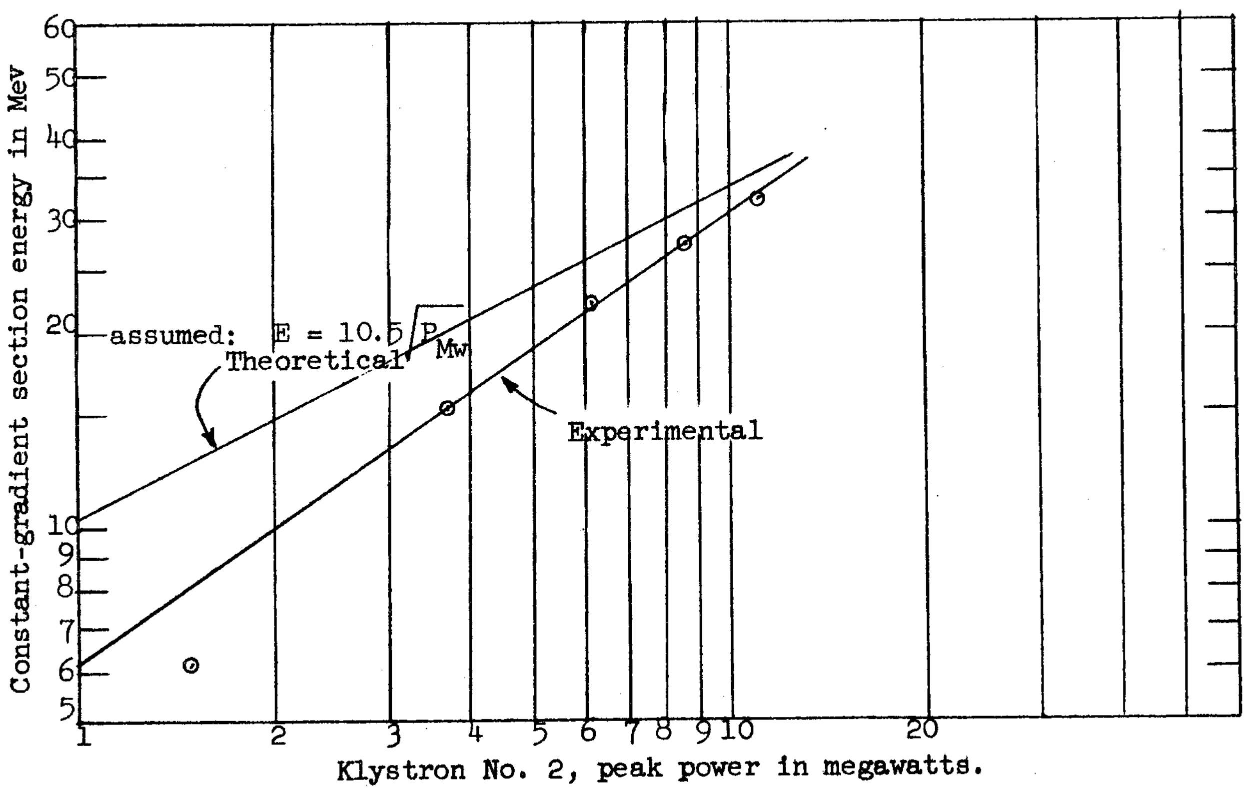

FIG. 2--Calculated and experimental energy gain for constant-gradient section.

3. Modulators and Power Supply

The two developmental-type ignitrons used have each been removed from service, and a type GL-6228 unit has been installed. The results to date have been satisfactory.

Power supply filament transformer trouble developed, and old units were salvaged to keep the machine in operation while a new transformer is being procured.

It is expected that the two 360-pps RCA modulators and their power supply will be installed during the next quarter, obviating the need for extensive improvements in output power capability and instrumentation accuracy that would otherwise be required on the present equipment.

For flexibility in experimental operations a 23 kv, 90 kw dc supply was ordered. It will operate one klystron at 360 pps at the full 24 Mw peak power output level, or both klystrons at full peak power at 180 pps. A high-voltage switching arrangement using vacuum switches is planned for installation with the new equipment to permit all desirable combinations of the modulators and power supplies to be available for experimental purposes. Each power supply and modulator combination will have its own circuit breaker, controls and induction voltage regulator.

4. RF Driver

The rf driver has operated satisfactorily during this quarter except for difficulties with short tube life and detuning in the ceramic triode stages. This has been troublesome, and a decision as to possible remedies is pending. Meanwhile, arrangements to improve the air cooling of these units are being carried out.

5. Beam Hardware

Since it appears that the operating performance of the two-mile machine will depend largely on the quality of the electron beam with respect to energy homogeneity, energy stability, beam size and divergence, and the beam dynamics properties, a comprehensive program of development of improved components and instrumentation for the Mark IV beam hardware system is under way. This includes high-power Faraday cups with calorimetric measurement facilities on the main cup, remote-controlled high-power collimators for observations anywhere in the beam cross section, improved bending-magnet field measurement and sweeping techniques, gating amplifiers for use in taking energy spectra during selected time intervals of the beam current pulse, and circuitry for adjusting injected current pulse and rf driver pulse shapes, timing and duration. Secondary emission monitor, beam current induction and beam location devices are under development by other groups. These will be installed in the Mark IV accelerator as they become available.

6. Injection System

The system has been operating satisfactorily, although some troubles were experienced with high-voltage breakdown of connecting cables. The gun cathode had to be replaced due to difficulties with vacuum valves during a machine shutdown, but an additional valve and ion pump were installed to avoid further failures. A bunching cavity was recently installed, but no operational experience with it has been available because of other work requiring shutdown of the machine with respect to beam operation.

7. Instrumentation and Control

A considerable amount of work has been accomplished during this quarter on the interlock systems for protection of personnel and equipment. An additional four-channel oscilloscope with two separate time bases has been installed. Additional instrumentation switching points are being added to the control console array, and rack installation of patching panels for relay control of signals available to the console array was started.

Components were ordered for improvement of the accuracy and flexibility of microwave measurements made in the waveguide feeds into and out of the accelerator sections.

A recording type ac line voltmeter was ordered.

Recorders for temperature readouts at all points of interest in the water systems were ordered.

General purpose recorders were purchased for such purposes as recording machine shutoffs due to klystron gassing, power supply overcurrents and vacuum system failures.

8. Water Systems

The existing water system was brought up to normal operating capability by replacement of the outdoor heat-exchanger-tube bundle, and replacement of the surge tank. The old bundle was corroded and had heavy mineral deposits both inside and out, so that the water system temperature could not be reduced below about 89°F, and would not have handled the heat load to be developed when the high-power modulators are put into operation. The old surge tank was made of wood and was open to the air. The new tank is a plastic-lined steel tank with provision for a blanket of nitrogen over the water, thus preventing continual introduction of oxygen into the system.

Two new water systems have just been installed, one for each of the two accelerator sections. These are improved versions of the water temperature control system described in the previous Status Report.[1] These water systems will use part of the capacity of the improved existing water system as their cooling means and will greatly increase the experimental accuracy and flexibility of temperature control on the accelerator sections. The two sections can be operated at the same or at widely differing water temperatures under close temperature control with light or heavy beam loading.

A third smaller water system of the above type is being fabricated solely for use with the main Faraday cup of the Mark IV accelerator. This will isolate any possible radioactive solids or water decomposition products from all other water systems and will have the additional advantage of providing means for making accurate beam power calorimetric measurements as a check on bending magnet determination of beam energy. Knowing the Faraday cup average beam current and the average beam power, the beam energy can be calculated from $V = W/I$.

9. Shielding, and Radiation Monitoring

A small amount of shielding was added to extend the length of outside wall protection along the ground inside the fenced-in area north of the trench.

Radiation surveys on x-ray and neutron intensities have been made and are continuing, as machine time is available, for the purposes of establishing more well-defined mapping of the Mark IV space and for evaluation of radiation monitoring equipment loaned to us by vendors. It is intended that a remote area monitoring survey system will be installed at the Mark IV accelerator. This system will enable continuous monitoring to be performed on x-rays during machine operation at points where personnel are allowed and in the trench. Induced radioactivity of

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[1]Status Report, M Report No. 298, Stanford Linear Accelerator Center, Stanford University, Stanford, California, April 1962, p. 12.

objects in the trench will be monitored by this system immediately upon machine shutdown, so that personnel may enter the trench only when the radiation level is below the tolerance value and will not be required to enter to make radiation surveys.

III. ACCELERATOR STRUCTURE AND HIGH-POWER WAVEGUIDE COMPONENTS

A. RF STUDIES OF THE ACCELERATOR STRUCTURE

1. Studies of the Accelerator Structure

a. Symmetric field couplers

The investigation of techniques for obtaining symmetrical fields within the coupler of the accelerator structure continued.[2] Figure 3b shows field variations about the beam aperture for .040-in., .080-in., and .100-in. offsets. Figure 3a shows the total field variation within the coupler cavity. For the .100-in. offset the field is still not quite symmetric about the axis; however, there is very little change in field strength over the middle half of the beam aperture. The criterion[3] that $\left(\lambda/E_0\right) \left(\partial e_3/\partial x\right) < .02$ is satisfied over the central portion of the aperture for both the .080-in. and .100-in. offsets.

b. Tuning mechanisms

A tuning mechanism design is again being actively pursued. An interim device consisting of a simple motor-driven remotely-controlled plunger positioner will be completed shortly.

c. Phase measurements

A double probe (quarter-wave spacing) carriage for a slotted line null detector has been constructed and is in use. It adds significantly to the accuracy and ease with which phase can be measured using a detuning plunger, by being very sensitive to wave position even with a low VSWR and by being insensitive to amplitude fluctuations of the signal generator. A transistor difference amplifier, designed and made by the Instrumentation and Control Group, worked very well in conjunction with the probes.

A constant temperature water system to further improve section temperature control during tuning is being assembled. This will also be used to check the phase variation with temperature.

d. Thin disk design

Parts fabrication for coupler design of constant-gradient and uniform thin-disk structures is under way.

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[2] Status Report, M Report No. 294, Stanford Linear Accelerator Center, Stanford University, Stanford, California, January 1962, p. 5.

[3] R. H. Helm and W.K.H. Panofsky, "Beam Dynamics of the Project M Accelerator," M Report No. 201, Stanford Linear Accelerator Center, Stanford University, Stanford, California, November 1960, pp. 29-30.

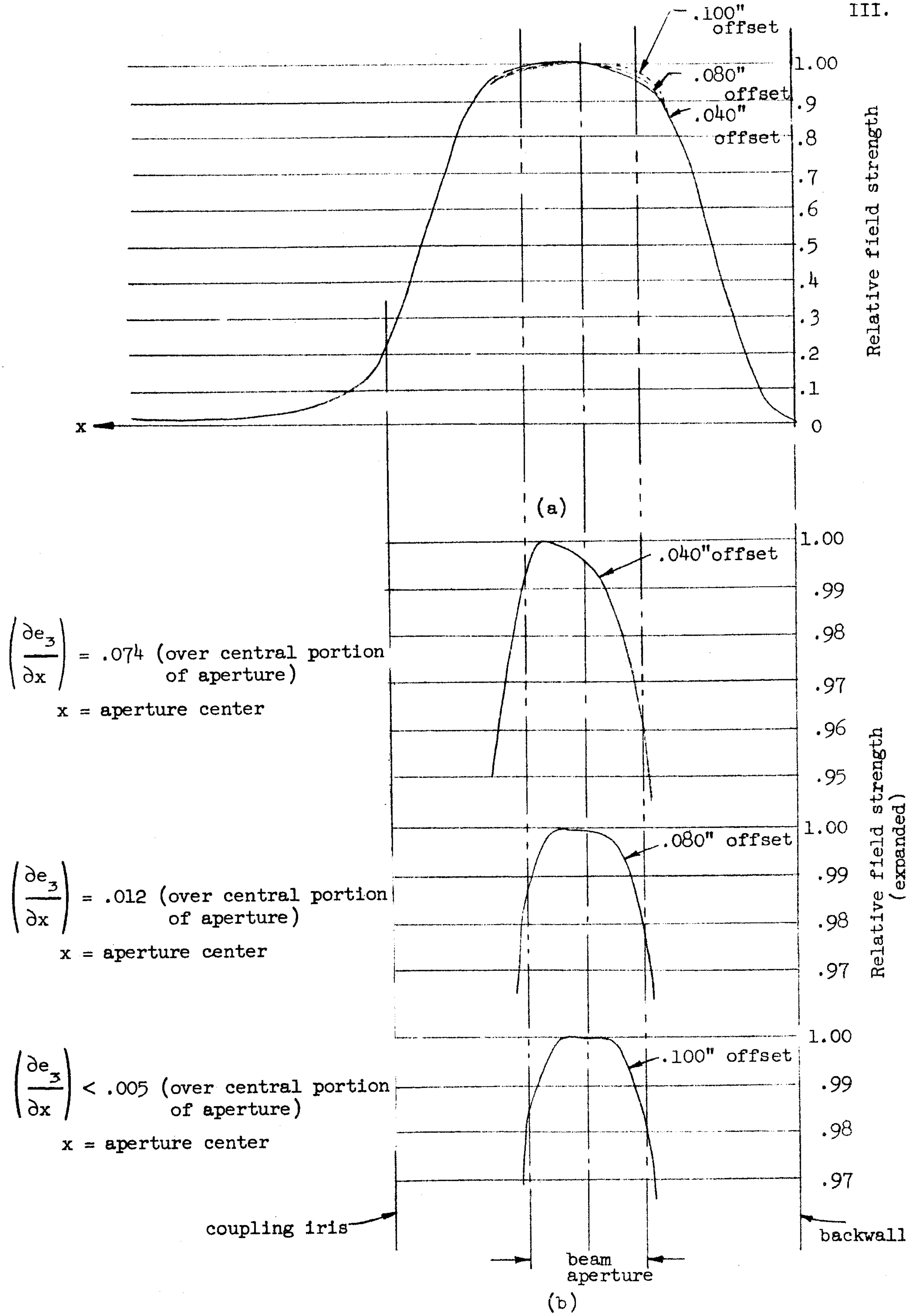

FIG. 3--Coupler field variations for different offsets.

e. Constant-gradient structure

A 10-ft electroformed thick-disk constant-gradient section was prepared for Mark IV and installed. This section was reported to work very well on the Mark IV machine. Little outgassing and breakdown were observed, and the section was brought to the available power level of 11 megawatts in a short time. The beam spectrum and energy were satisfactory.

f. Comparison of phase behavior of electroformed and brazed uniform structures

Two electroformed and two brazed uniform 10-ft thick-disk sections were compared prior to tuning as part of the evaluation of electroforming and brazing techniques. Three factors were considered: the lowest frequency to which each section could be tuned (using wall indentation exclusively), the amount of tuning required at this frequency, and the amplitude and frequency of the phase deviations. The results are summarized in Fig. 4. The two electroformed sections (Nos. 9UE and 10UE) were capable of being tuned to the lowest frequency, required the least amount of tuning and exhibited a narrower spectrum of phase variations than the brazed sections (Nos. 11UB and 12UB). Unfortunately, even the best electroformed section, No. 9UE, required some tuning of each cavity for a total of 71° removed from the section at the lowest frequency to which it could be tuned.

2. Resonant Structure and Resonant Ring Tests

a. Thick-disk structure (.230-in.)

The repeated outgassing on application of rf noted in the previous Status Report[4] on analysis was found to include water vapor and nitrogen, indicating a slow leak to air. This was traced, using helium, to an auxiliary valve in the system. Removal of the valve reduced the tendency of the cavity to break down under the initial application of rf, although the pressure in the system ($\approx 6 \times 10^{-7}$) was not improved. ($\approx 6 \times 10^{-7}$ is the base pressure of the pumping station.)

b. Thin-disk structure (.120-in.)

Two thin-disk three-period resonant cavities have been prepared, and one is currently being tested. The objective is to determine whether significant differences in behavior exist in comparison with thick-disk

[4]Status Report, M Report No. 298, Stanford Linear Accelerator Center, Stanford University, Stanford, California, April 1962, p. 8.

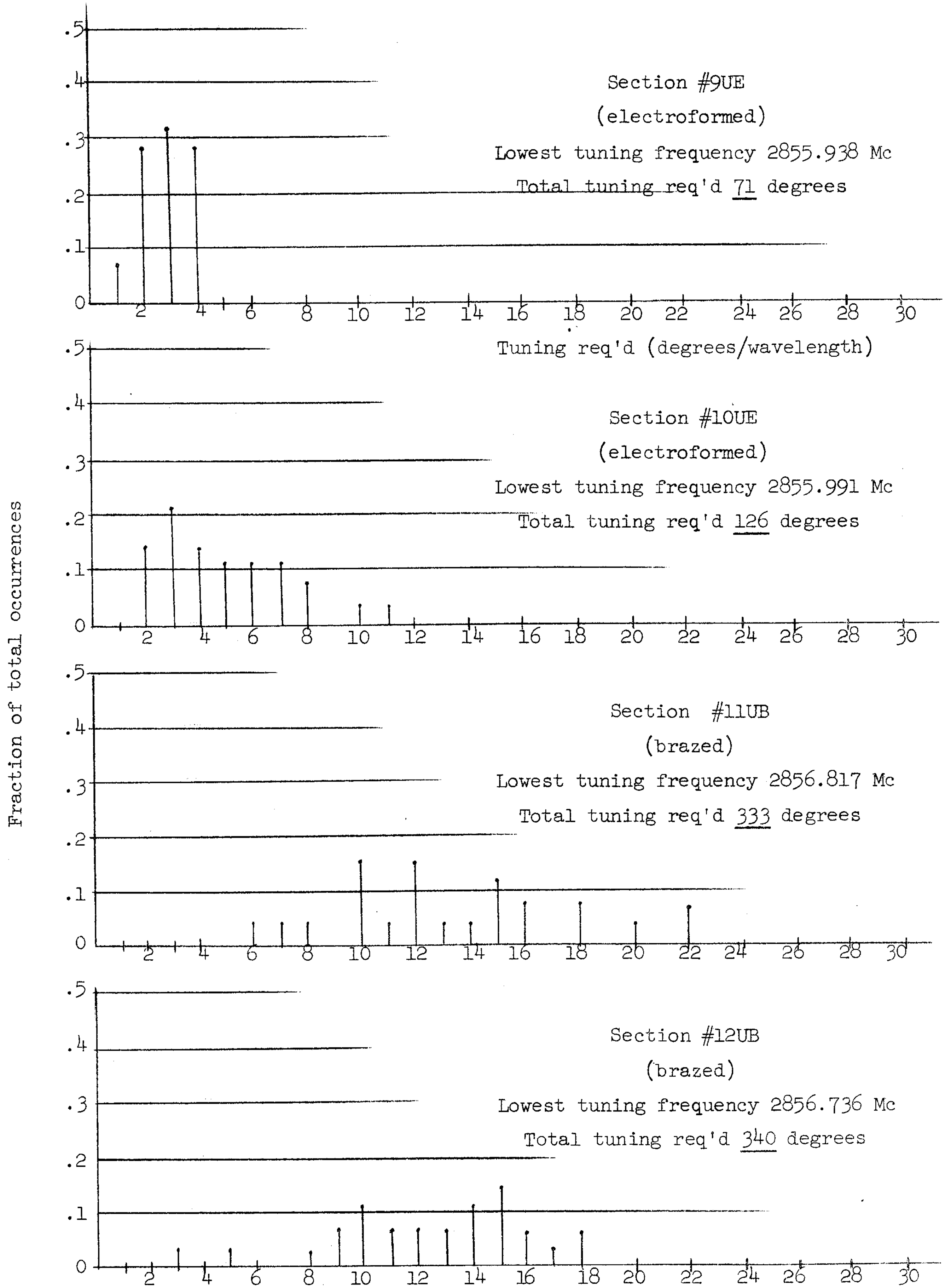

FIG. 4--Comparison of electroformed and brazed sections; distribution of phase variations.

structures.

c. Resonant ring tests

With the aid of the Window Test Group, we are considering the use of a traveling-wave resonant ring for further tests of short sections of accelerator structures.

3. High-Power RF Test Area

Considerable progress has been made toward setting up a high-power test stand. A constant temperature water unit is ready for installation. Concrete shielding for a 10-ft section has been cast. A 24-section pulse-forming network has been installed and adjusted, and a klystron has been delivered.

Specifications for an SAS 61 klystron modulator have been completed and will shortly be placed for bid.

B. ELECTROFORMING AND BRAZING

Five 10-ft sections were made during the period (two electroformed and three brazed). These initially have been used in the evaluation of electroforming and brazing techniques.

After careful consideration we have come to the conclusion that we should fabricate the disk-loaded waveguide by the brazing method. While we have every reason to believe that no difficulties will arise, the importance of this component to the project warrants care in planning. Therefore, we intend to retain the electroforming capability on a standby basis.

Our reasons for selecting the brazing method may be summarized as follows.

1. Cost Comparison

Our analysis of the cost of electroforming and brazing indicates that the cost of electroforming would be approximately 9 percent higher than the cost for brazing. The electroforming would require approximately 1300 sq ft more floor space than the brazing method.

2. Performance

A review of the technical data indicates that within the accuracy of cold test measurements the electroformed and brazed sections should give equivalent performance.

3. Flexibility

The electroforming method of fabrication has less flexibility, from a scheduling point of view, than the brazing method. It appears unrealistic to plan on producing more electroformed pipes than the capacity of the initial installation, which would yield two to three 10-ft sections per day. Using the brazing method, we have the possibility of producing up to six sections per day on a three-shift basis. Accordingly, the brazing method provides greater flexibility and, hence, more assurance in scheduling.

C. WATER JACKET

1. Longitudinal Cooling-Tube Tests

Several tests of the longitudinal cooling-tube arrangement were made using an electrical heater in a mock-up of an accelerator pipe. Individual temperature measurements were not always consistent, but averages of many readings showed that, at full power conditions along the accelerator mock-up, temperatures were held to 0.2°F. The problem of obtaining accurate temperature measurements has been studied in some detail. A technique for making thermocouples having the required degree of accuracy has been developed. New thermocouples accurate to within 0.1°F are currently being installed on the accelerator mock-up. In addition, resistance type temperature sensors are on order and will be installed on the mock-up with the thermocouples.

2. Water-Temperature Control System

A water-temperature control system similar to the one used in the water jacket test work has been fabricated and installed in the high-power test-stand area for use in high-power rf work.

The water-temperature control system design has been improved, and two units of the improved design have been fabricated for the Mark IV test accelerator sections. A third smaller unit is currently being fabricated. The latter unit will be used to maintain the temperature of an accelerator section constant during rf tuning.

3. Cooling-Tube Installation

Cooling tubes and their associated manifolds and thermocouples have been installed on several accelerator sections. Of these, a constant-gradient section has been installed in the Mark IV accelerator, and a uniform-structure section is to be used for high-power tests.

D. HIGH-POWER WAVEGUIDE COMPONENTS

1. Waveguide Wall Thickness Problem

Experimental evaluation of 5/32-in. and 7/32-in. wall OFHC waveguide (2.840 × 1.340 nom i.d.) for electrical phase shift due to uniform wall pressure variations, temperature variations and coolant channel pressure variations has been essentially completed in the last quarter.

The measured phase shifts agree very well with those calculated from the measured mechanical deflections for atmospheric pressure loading. Agreement between measured temperature effects and the theoretical value is also very close. As an illustration, the data for the 5/32-in. wall OFHC waveguide annealed at SLAC appears as $\Delta\theta$ per foot of waveguide (which is $\approx 0.0067^{\circ}$/in. of Hg) plus $10.63 \times 10^{-3\circ}$ per psi coolant plus $0.01^{\circ}/^{\circ}$F.

2. Waveguide Vacuum Valve

The waveguide vacuum valve described in the last Status Report[5] has been fabricated in OFHC copper for a resonant high field breakdown test. The cavity is slightly overcoupled (VSWR = 1.65) but the unloaded Q of the structure is about 9500. These values are sufficient to enable field strengths considerably larger than those corresponding to 25 megawatts to be obtained in the structure. This test should be completed within the next month.

Three complete valve assemblies with actuating mechanisms are being fabricated. These are designed for high-power test on the recirculator in the window test area. Testing has started on seating materials and configuration for the valve seat.

Figure 5 shows plots of field strength within the waveguide valve obtained as described in the last Status Report.[6] As shown, the bead was moved along three different paths. The highest field strength is seen to occur at the rim of the coupling aperture, where the field increases both because of the rim and the location of the necessary tuning stub formed by the guide and shorting plate.

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[5]M Report No. 298, *op. cit.*

[6]*Ibid.*, p. 16.

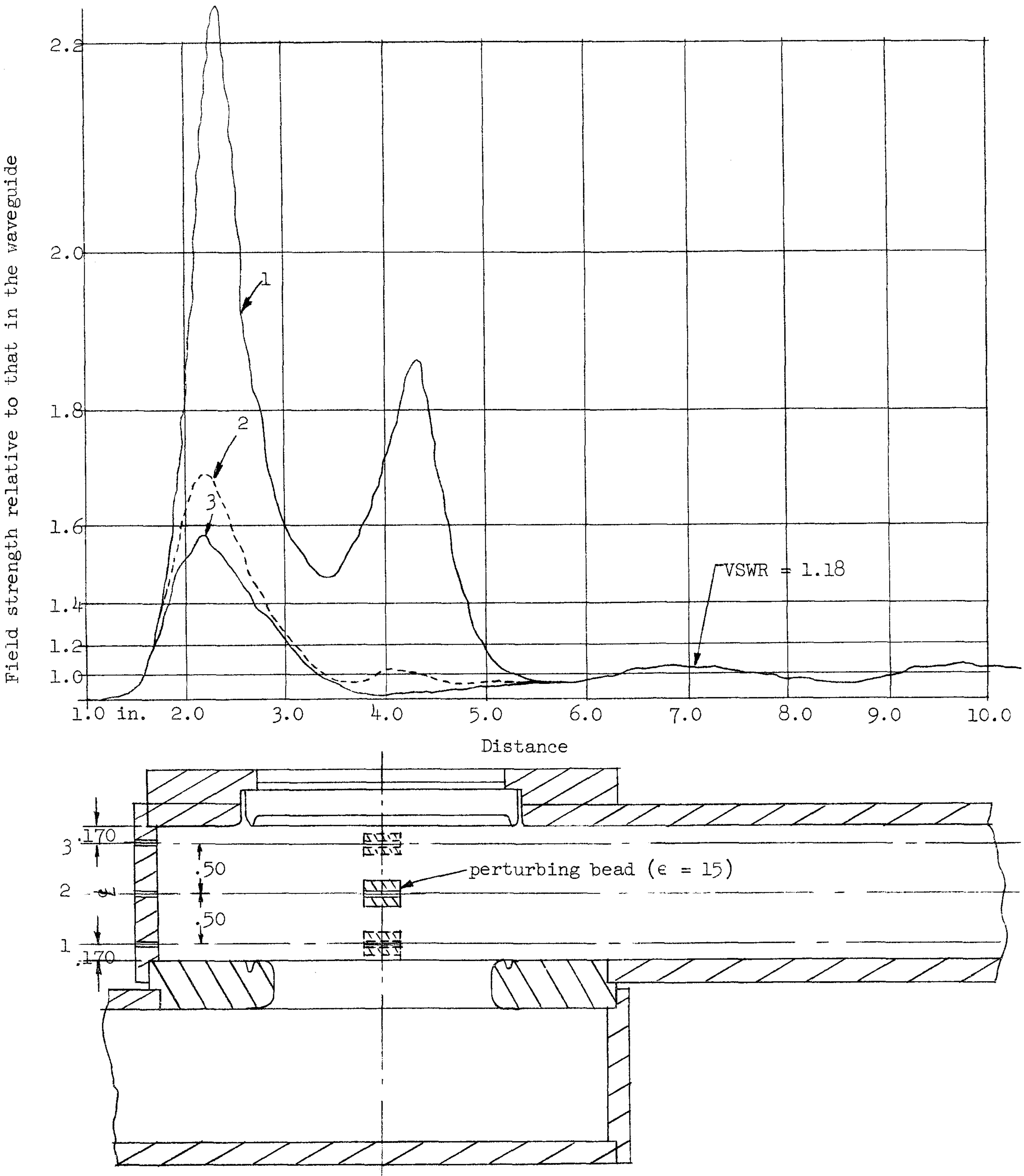

FIG. 5--Electric field strength within waveguide valve.

3. RF Loads

Several types of high-power load are being considered. A design for one of these has been completed, using a technique developed in similar applications[7] where stringent vacuum and power dissipation requirements were met. The dissipative elements consist of carbon-loaded alumina whose resistivity may be chosen and controlled.

[7]R. A. Craid, K. Zublin, and R. Borghi, "A Novel Attenuator for High Power Traveling Wave Tubes," delivered at Conference on Electronic Tube Research, Berkeley, California, 1957.

IV. INJECTION SYSTEM

A. MARK IV PROGRAM

The Mark IV gun failed once during the quarter as a result of a vacuum failure at the gun. The gun was removed and the cathode cleaned and recoated by the Microwave Laboratory tube shop. The gun was then reinstalled and activated. In June this same gun was removed and stored on an auxiliary vacuum station for several days when the failure of a vacuum valve made it impossible to maintain a vacuum at the gun while installing equipment for the phasing experiment being carried out by the Microwave Engineering Group.

While the gun was gone from the accelerator, a thin valve and a 5-liters/sec ion pump were mounted on the gun flange. The thin valve was built from a modification of the design used on the thin valves presently installed on Mark IV. The modification strengthened the operating mechanism and added a pump port to pump the gun side of the valve when the valve is closed. This arrangement provides the gun with a self-contained portable vacuum station. For example, when the gun was reinstalled on Mark IV a vacuum of about 1×10^{-7} mm Hg was maintained while the gun was being moved from the tube shop to the accelerator trench and installed on the accelerator.

The advantages of making the gun assembly a self-contained vacuum system are obvious. It will greatly facilitate buncher research on Mark IV. It will permit activation of the cathode, emission checking and even measurement of beam optics prior to the installation of a gun on Mark IV or on the M accelerator.

B. GUN PROCUREMENT

Two high-current guns have been ordered from Quantatron, Inc., Santa Monica, Calif., for use on Mark IV. These guns are to be delivered by August 9, and one will be installed on Mark IV at that time.

In addition to acting as a spare gun for Mark IV, the second gun will be tested on the gun tester to determine its optics accurately. Following the tests it will be used to test a low-energy inflection system and to study focusing in the buncher region.

The following are the most important characteristics of the Quantatron gun:

1. Cathode voltage: 50 to 100 kv
2. Cathode material: oxide
3. Maximum gun current: 5 amps
4. Beam diameter at minimum: 4 mm
5. Gun is grid controlled with a coaxial input to the grid.
6. Grid-to-cathode voltage for maximum current: ≈ + 800 volts
7. Grid-to-cathode voltage for cut-off: ≈ - 300 volts

C. GUN TEST APPARATUS

The gun test apparatus was put into operation during this quarter. A number of modifications and improvements have been made or designed for the apparatus. The transverse resolution was improved by a factor of 6 to about .010-in. by reducing the diameter of the beam sampling iris and improving the sensitivity of the current-measuring equipment. The gun modulator was modified to permit application of a cut-off bias to the grid of triode guns.[8]

Although the vacuum system maintains a moderately good vacuum when the gun is not being pulsed ($\sim 3 \times 10^{-7}$mm Hg), even when the cathode is hot and the probe is in motion, nearly disastrous pressure rises occur whenever large currents (on the order of 2 amperes peak) are drawn from the gun being tested. It is believed that some of the electrons strike the sliding plate that carries the probe. Since this plate must be greased to maintain a vacuum seal, electrons striking it cause evolution of considerable gas. Accordingly, a shield that will screen the greased surfaces from the electron beam has been designed and is now being machined.

Also being fabricated is a new probe tip and collector cup. The new cup will be made of carbon and much deeper than the present one and will reduce secondary emission errors (believed to be 20 to 30 percent). In addition, the new cup will be split so that the current striking each half can be measured. This will permit the determination of the radial velocities in the beam.

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[8]Although the gun presently used on the Mark III and Mark IV accelerators is cut off with zero grid bias, the commercially available triode guns suitable for our application require a negative grid bias for cut-off.

D. INJECTOR TEST STAND

Design of the injector test stand to be located in the Test Laboratory Building was begun during the quarter. In addition to the standard test-stand equipment, the injector test-stand will consist of a gun with modulator, a buncher with associated microwave circuitry, the first two feet of a ten-foot accelerator section, a momentum spectrometer, and bunching and optics measurement equipment. The bunch-monitoring equipment will consist of a resonant cavity that will produce a sinusoidally varying transverse impulse with peak value of about 1 Mev/c. With a drift space of 1.5 meters the bunch monitor will yield a resolution of 2° of phase. This resolution is 15 percent poorer than that achieved with the optimum drift space of 3 meters. If the sweeping cavity is designed to have maximum Q, about 1 megawatt of S-band power will be required to drive it. However, in this case about 3 microseconds will be required for the field to rise sufficiently close to steady state. Since this is longer than the M-type klystron rf pulse, it will require a separate high-power amplifying tube to drive the cavity. An alternative is to cut the Q of the sweeper by a factor of about 3, and drive it with 3 megawatts derived from the M klystron output. The second alternative appears to be cheaper and more desirable.

E. SUBHARMONIC BUNCHING

The Research Division indicated during the quarter that it would be desirable for some experiments to have a 30 centimeter spacing between bunches (i.e., a bunch on every third wave crest in the accelerator, with two bunches missing in between). A preliminary study was carried out to investigate the feasibility of achieving bunching with this subharmonic structure. The approach used in this study was suggested by the fact that a sawtooth voltage can produce very good bunching and can be generated by adding harmonics in the proper phase and amplitude.

The bunching system visualized consists of either a triply-resonant velocity-modulation cavity resonant at 952, 1904 and 2856 megacycles (i.e., the first, second, and third harmonics of the third subharmonic of the accelerator frequency) or three cavities, each resonant at one of these frequencies, placed close together. A calculation neglecting space charge indicated that 79 percent of the electrons entering during one cycle of 952 megacycles will be bunched into one bunch in the accelerator, while 2.2 percent of the electrons will go into each of the other two bunches. Thus, while fairly good capture efficiency can be expected, some electrons will still ride on each wave crest. Study is continuing on the desirability and feasibility of this bunching scheme.

V. MICROWAVE ENGINEERING

A. GENERAL RF STUDIES

1. Constant-Gradient Accelerator Structure Design

During the past quarter a new constant-gradient structure using thin disks (.120-in thickness) was designed. The linear variation of group velocity was the same as for the previous design (.230-in. disk thickness).

$$\text{Input end:} \quad v_g/c = 0.0206$$
$$\text{Output end:} \quad v_g/c = 0.00658$$

Figure 6 shows the variations as a function of length of the cavity diameter 2b, the disk diameter 2a and the steel ball height h measured as shown in Fig. 7. The latter dimension is calculated from a geometrical formula as a function of 2a and is used to control the machining tolerances in applying the correct disk edge radius ρ. Table I gives the individual dimensions for each of the 87 cavities. It should be pointed out that some mathematical refinements have been used in this design above and beyond the previous thick-disk design. These refinements should insure an even smoother phase velocity variation than that obtained for the earlier design, thereby requiring less eventual tuning on 10-ft sections. In view of these improvements and the results outlined in the next paragraph, the .230-in. design is being revised.

2. Constant-Gradient Structure Tuning

During the month of April the Accelerator Structures Group completed the fabrication of several 10-ft sections, some of them brazed and others electroformed. One of the brazed sections (No. 7) was tuned by the Microwave Engineering Group; another one (No. 6) was checked after it had been tuned by the Accelerator Structures Group and before it was delivered for installation on the Mark IV accelerator. Figure 8 shows the nodal shift diagrams for these two cases. The results of the attenuation measurement as a function of cavity shorting plunger position are shown in Fig. 9 for both accelerator sections No. 7 and No. 6. It is seen that the attenuation results are in good agreement with the design objectives. Curves of beam energy versus frequency and rf power are given in Section II

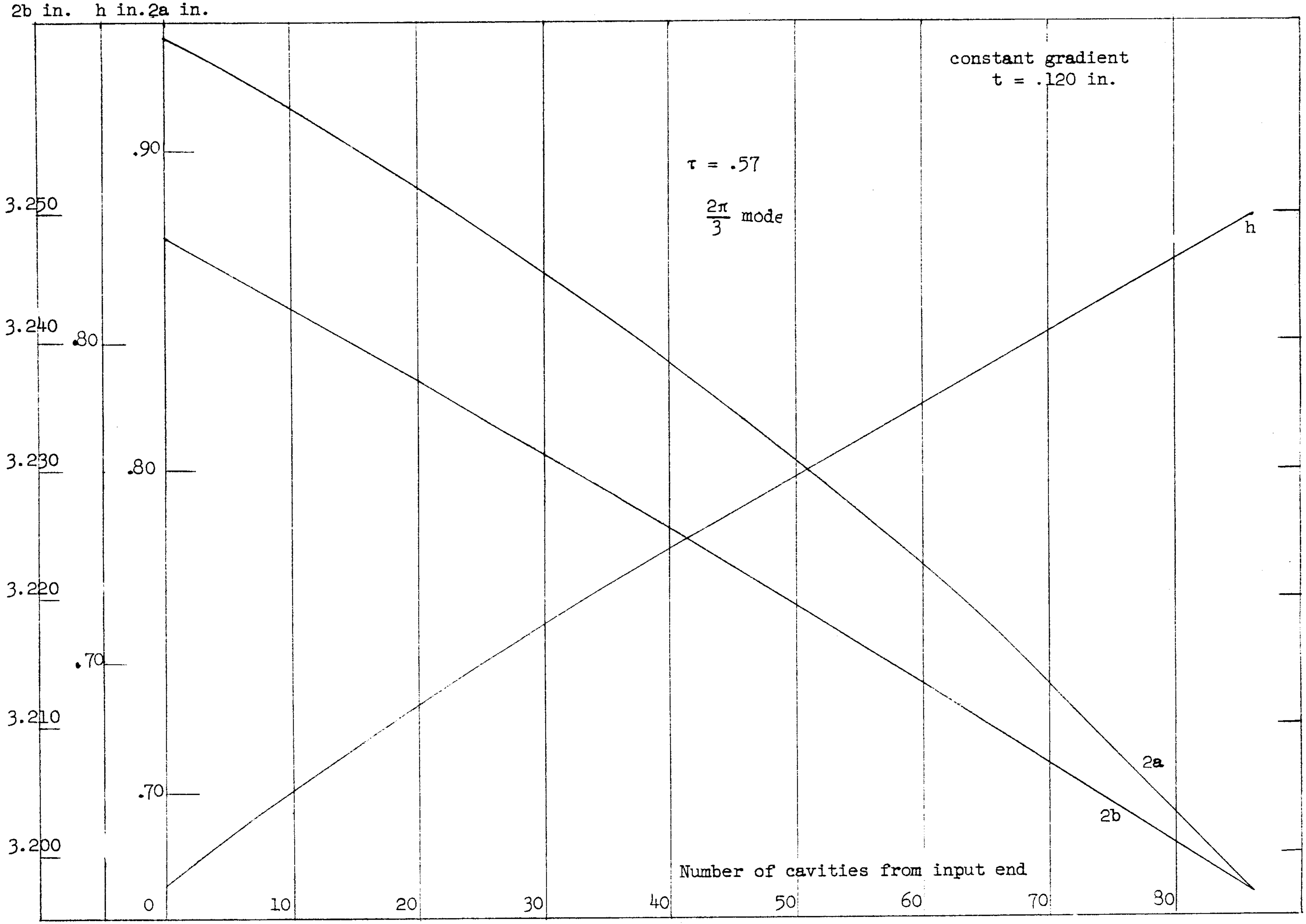
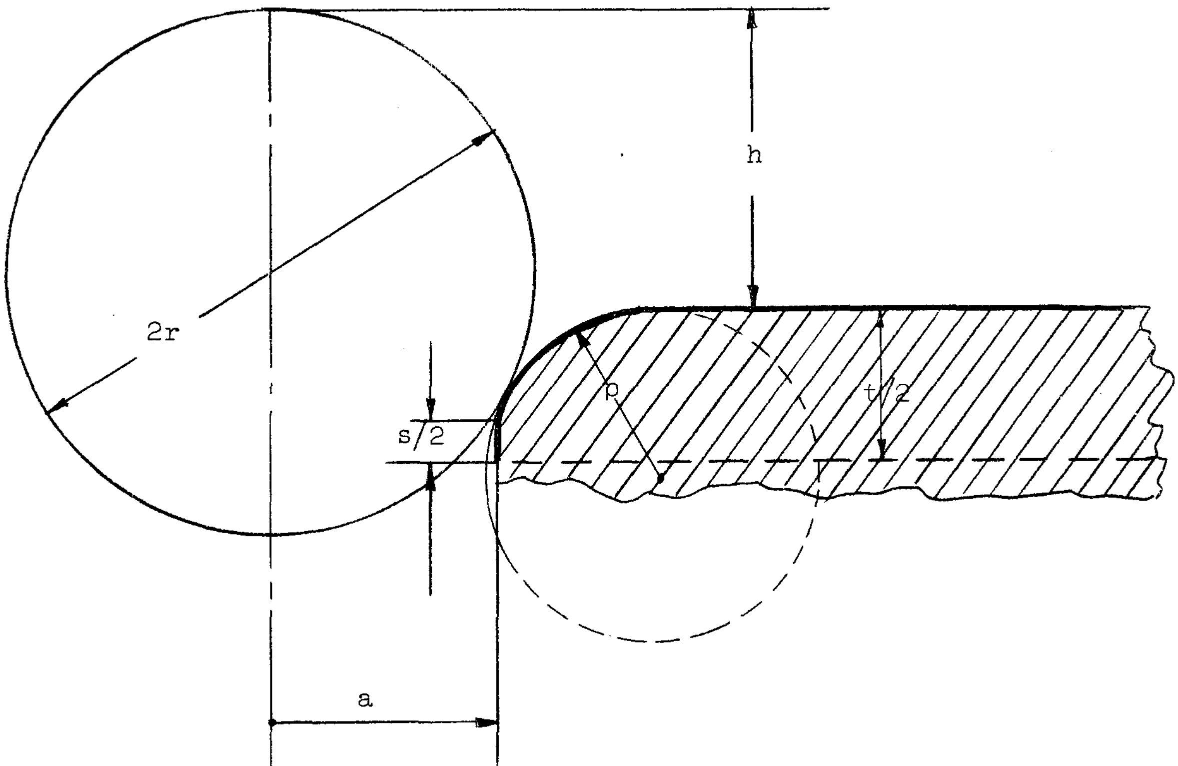


FIG. 6--Design of constant-gradient accelerator structure using thin disks (.120-in. disk thickness) showing variations of 2a, 2b and h as a function of cavity number.



2r = steel ball diameter	2r = 1.0000 in.
s = flat land in disk hole	s = .031 in.
ρ = edge radius	ρ = .0625 in. ± .0005 in.
t = disk thickness	t = .120 in.
2a = disk-hole diameter	
h = steel ball reading	$h = r - \rho + \sqrt{(r + \rho)^2 - (a + m)^2}$

$$m^2 = \rho^2 - \left(\frac{s}{2} + \rho - \frac{t}{2}\right)^2$$

FIG. 7--Illustration of symbols and conventions used in specifying disk dimensions for a constant-gradient accelerator structure using thin disks (.120-in. disk thickness).

C# CPL	2a (Input)	2b	h*	v_g/c	C#	2a	2b	h*	v_g/c
	.9360	3.2482 -0.050**	.6318	.02043	43	.8224	3.2234	.7449	.01342
1	.9336	3.2476	.6350	.02027	44	.8195	3.2228	.7471	.01326
2	.9313	3.2471	.6381	.02011	45	.8165	3.2222	.7494	.01310
3	.9289	3.2465	.6412	.01994	46	.8135	3.2217	.7516	.01293
4	.9265	3.2460	.6442	.01978	47	.8106	3.2211	.7538	.01277
5	.9241	3.2454	.6473	.01962	48	.8075	3.2205	.7560	.01261
6	.9217	3.2448	.6502	.01945	49	.8045	3.2199	.7582	.01244
7	.9192	3.2443	.6532	.01929	50	.8014	3.2193	.7604	.01228
8	.9168	3.2437	.6561	.01913	51	.7983	3.2187	.7626	.01212
9	.9143	3.2431	.6591	.01896	52	.7951	3.2181	.7648	.01195
10	.9118	3.2426	.6620	.01880	53	.7920	3.2175	.7670	.01179
11	.9093	3.2420	.6648	.01864	54	.7887	3.2169	.7693	.01163
12	.9067	3.2414	.6677	.01848	55	.7855	3.2163	.7715	.01147
13	.9042	3.2409	.6705	.01831	56	.7822	3.2157	.7737	.01130
14	.9016	3.2403	.6733	.01815	57	.7788	3.2150	.7759	.01114
15	.8990	3.2397	.6761	.01799	58	.7754	3.2144	.7782	.01098
16	.8965	3.2391	.6788	.01782	59	.7720	3.2138	.7804	.01081
17	.8938	3.2385	.6815	.01766	60	.7685	3.2132	.7827	.01065
18	.8912	3.2380	.6842	.01750	61	.7649	3.2125	.7850	.01049
19	.8886	3.2374	.6869	.01733	62	.7613	3.2119	.7873	.01032
20	.8859	3.2368	.6896	.01717	63	.7577	3.2113	.7895	.01016
21	.8833	3.2362	.6922	.01701	64	.7540	3.2106	.7918	.01000
22	.8806	3.2356	.6948	.01685	65	.7502	3.2100	.7941	.00984
23	.8779	3.2350	.6974	.01668	66	.7464	3.2093	.7965	.00967
24	.8752	3.2345	.7000	.01652	67	.7425	3.2087	.7988	.00951
25	.8725	3.2339	.7025	.01636	68	.7386	3.2080	.8011	.00935
26	.8698	3.2333	.7050	.01619	69	.7347	3.2073	.8034	.00918
27	.8671	3.2327	.7075	.01603	70	.7306	3.2067	.8057	.00902
28	.8644	3.2321	.7100	.01587	71	.7266	3.2060	.8081	.00886
29	.8617	3.2315	.7125	.01570	72	.7225	3.2053	.8104	.00869
30	.8589	3.2310	.7149	.01554	73	.7183	3.2047	.8127	.00853
31	.8562	3.2304	.7173	.01538	74	.7142	3.2040	.8150	.00837
32	.8534	3.2298	.7197	.01522	75	.7100	3.2033	.8174	.00821
33	.8507	3.2292	.7221	.01505	76	.7057	3.2027	.8197	.00804
34	.8479	3.2286	.7244	.01489	77	.7014	3.2020	.8220	.00788
35	.8451	3.2280	.7267	.01473	78	.6972	3.2014	.8242	.00772
36	.8423	3.2275	.7291	.01456	79	.6929	3.2007	.8265	.00755
37	.8395	3.2269	.7314	.01440	80	.6886	3.2000	.8287	.00739
38	.8367	3.2263	.7337	.01424	81	.6843	3.1994	.8309	.00723
39	.8339	3.2257	.7359	.01407	82	.6800	3.1988	.8331	.00706
40	.8310	3.2251	.7382	.01391	83	.6758	3.1981	.8352	.00690
41	.8281	3.2246	.7404	.01375	84	.6715	3.1975	.8373	.00674
42	.8253	3.2240	.7427	.01359	CPL	.750	3.1969 -0.040**	(Output)	.00658

*With s = .031 in. (1 in. steel ball)
t = .120 in. ρ = .0625 in.
r = .500 in.

**Coupler cavities: dimensions are approximate.

TABLE 1--Design data for ten-foot constant-gradient structure using thin disks (.120-in. disk thickness).

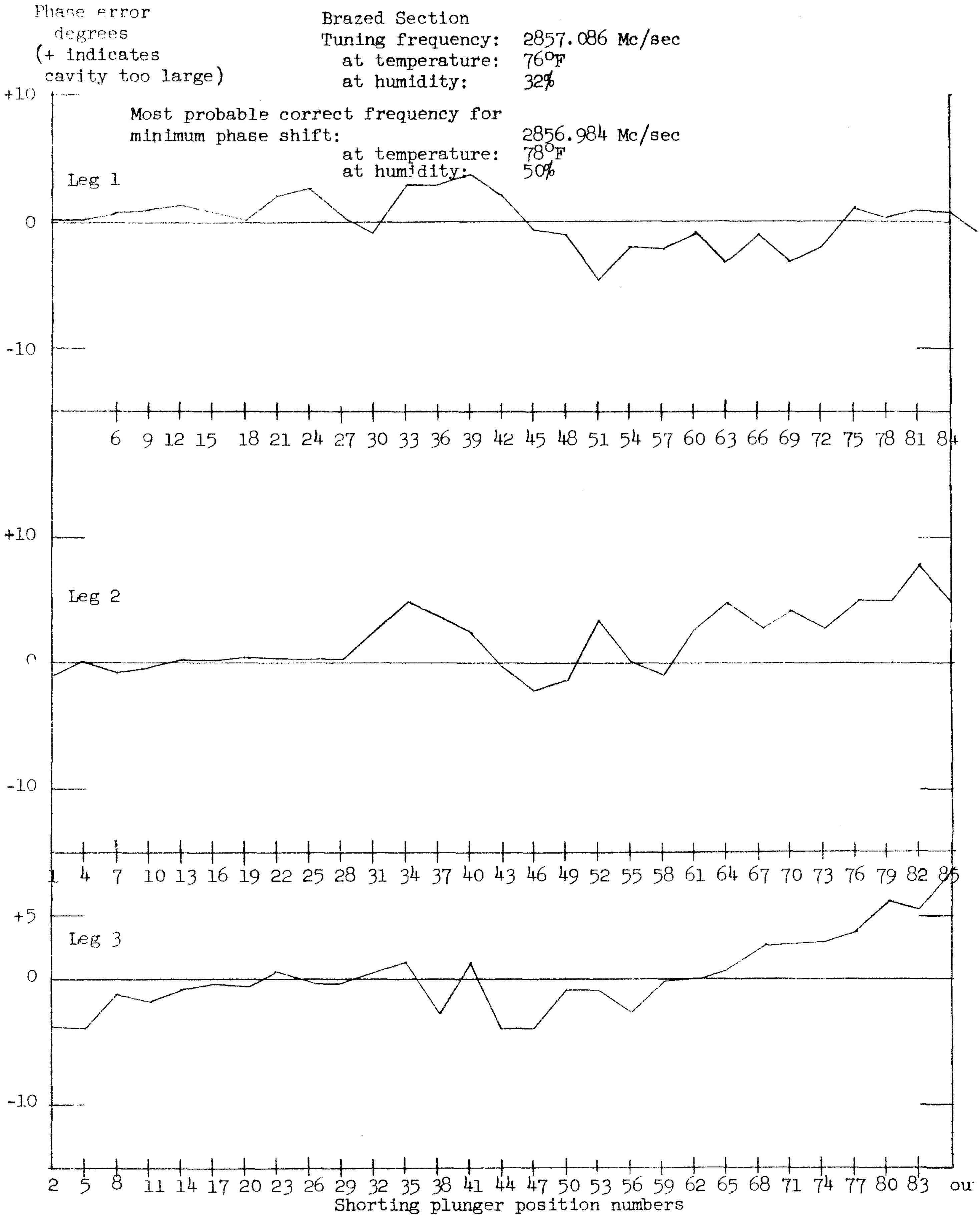


FIG. 8--Phase shift excursions observed on constant-gradient structure (section No. 6) before installation on Mark IV accelerator.

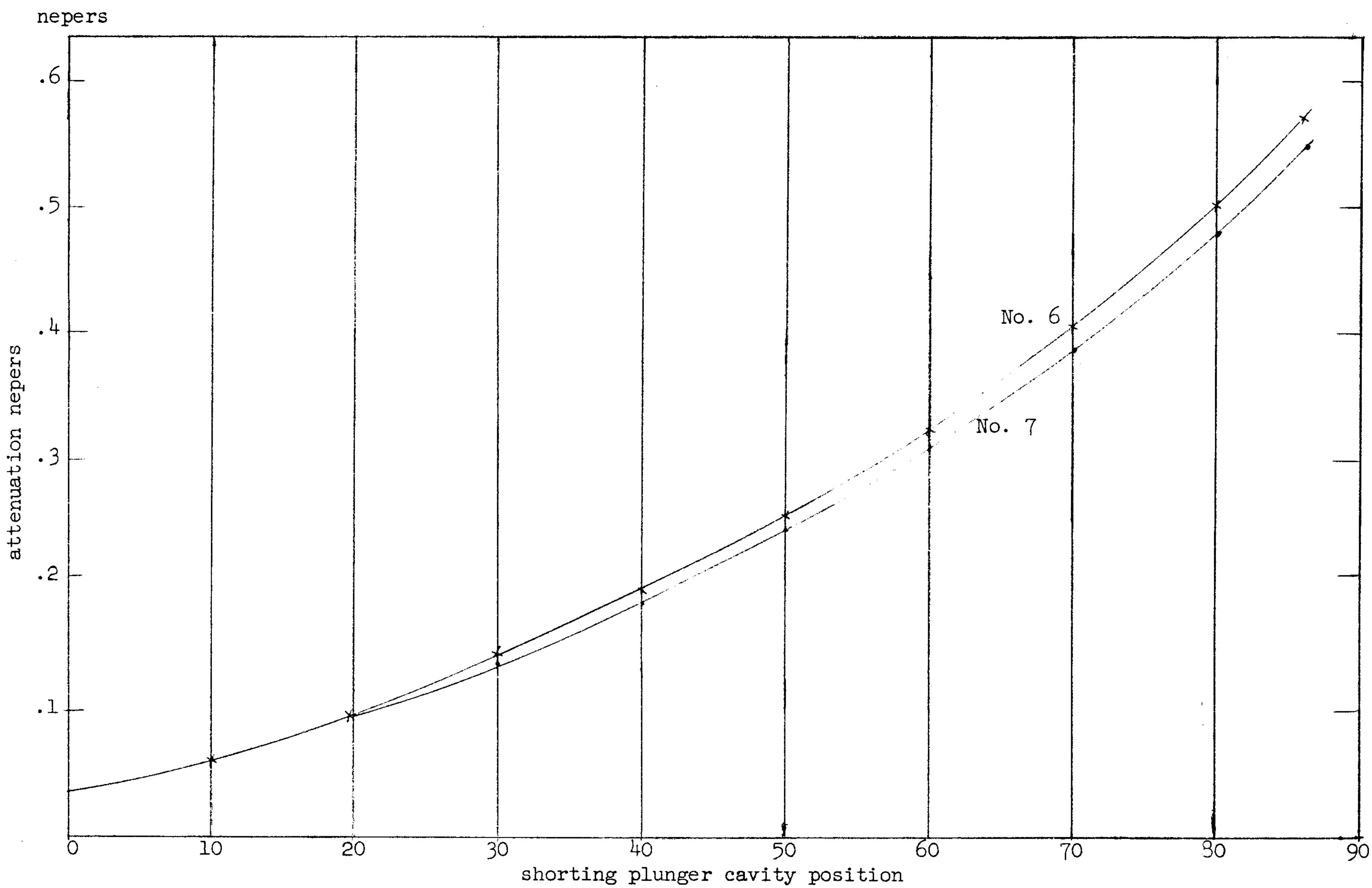


FIG. 9--Attenuation (nepers) as a function of shorting plunger cavity position for constant-gradient sections No. 7 and No. 6, the latter before installation on the Mark IV accelerator.

of this Status Report (Figs. 1 and 2).

3. Tuning and Matching Theory

For some time there has been some discussion concerning the tuning and matching theory of linear accelerators operating in the $2\pi/3$ mode. During the past quarter an attempt has been made to understand the substance of some informal remarks suggested by R. L. Kyhl from MIT. A scheme using a demountable coupler and ten stacked cavities with micrometer-mounted tuners has been assembled to test these ideas, and the results will be given next quarter.

4. Pump-out

During the past quarter the rf tests of the waveguide pump-out were completed. The resulting design is shown in Fig. 10. A unit was built for high-power testing and will be installed on the Mark IV accelerator. In this application the pump-out will serve as a roughing vacuum line and, subsequently, as a means for injecting Freon gas into the waveguide run. The power used in this test will be about 2 Mw peak. If the pump-out is satisfactory for this power level, a higher power test will be arranged. In conjunction with this pump-out another method is being examined and a model is being constructed. Results of the tests should be available for the next Status Report.

5. Waveguide Vacuum Valve

Tests have progressed on a new approach using two rectangular waveguides connected by a circular waveguide section. Tests indicate that good matching and transmission through the valve section can be obtained. The preliminary model has been constructed without the sealing section. When the preliminary tests are complete, a model incorporating the sealing sections will be tested.

6. High-Power Waveguide Couplers

The Klystron Group's design of a Bethe-hole coupler has been used to obtain the first couplers needed for various Mark IV tests.

7. High-Power RF Loads

During the quarter data was gathered indicating that silicon carbide in its present form will outgas indefinitely. However, a silicon carbide load has been offered to the project by an outside firm for testing under high rf power and high vacuum to determine under what conditions the load material can be processed.

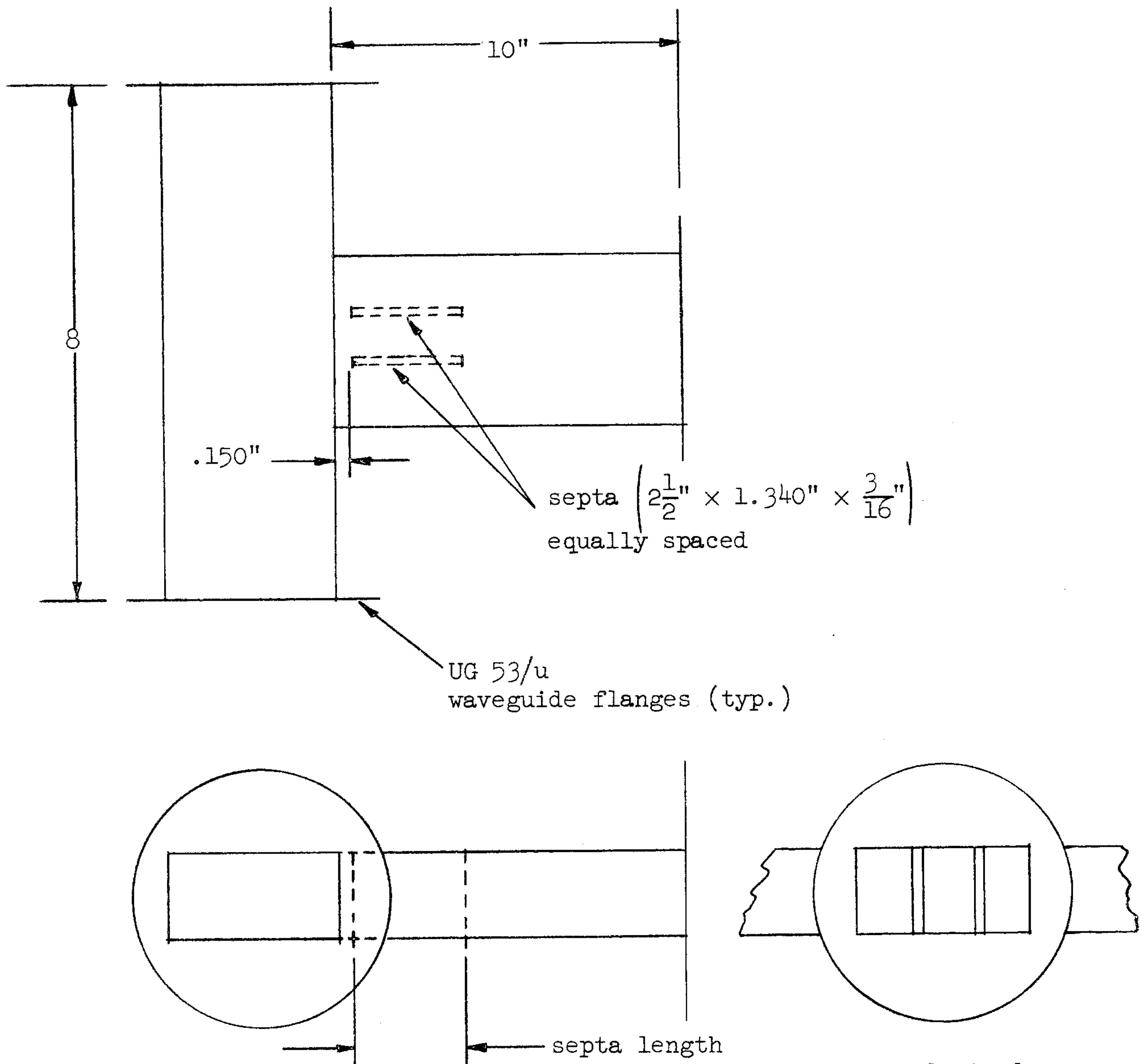


FIG. 10--Design of an S-band waveguide pump-out.

8. Beam Breakup Studies

C-band waveguide runs have been installed on the Mark IV accelerator, and a C-band 2-kw peak generator is being procured to attempt to induce the beam breakup phenomenon with a 4300 Mc/sec signal injected directly into the first accelerator section.

B. DRIVE SYSTEM

1. Over-all Design of the Drive System

Again during this quarter studies continued on the over-all design of the drive system. A visit was paid to the Bell Telephone Laboratories in Holmdel, New Jersey, to consult their staff on the feasibility of a 25-in. diameter low-loss helix-waveguide. A similar 2-in. waveguide propagating the TE_{01} mode has been developed by the Bell Telephone Laboratories for millimeter-wave communication. Although feasible it appears that such a guide, with a phase velocity ratio $v_p/c = 1.02$ and a loss of less than one db for 2 miles, would be very expensive and impractical both to support and to couple power from. Therefore, this idea is being abandoned.

Another solution based on transmitting a cw signal at 2856 Mc/sec is being abandoned because the low power and low gain of commercially available cw tubes would require a large number of amplifiers and would yield poor reliability. Thus, only two basic alternatives remain for the coherent drive signal transmission. Their basic properties are outlined below.

RIGID COAX-LINE TRANSMISSION

Pulsed Signal at 2856 Mc/sec	CW Signal at 119 Mc/sec
Only 3 pulsed boosters required.	No boosters required.
Possible pulse-to-pulse phase variations.	30 varactor multipliers, including isolating amplifiers, at each sector coupling point.
Fair reliability.	Reliability not yet known.
No cw signal available along or at end of machine.	CW signal available anywhere along machine, including end, for multiplication up to 2856 Mc or any subharmonic. This signal would be useful for intermediary injectors and rf separators.

Work will continue during the next quarter on these two alternatives.

Regardless of the final choice it has been decided that both the main and subdrive lines will be thermally stabilized by running them parallel to the ignitron water supply line and wrapping them together with insulating tape.

2. Boosters

The Sperry SAS-60A cw amplifier tube was examined for phase stability. The phase shift as a function of beam voltage was measuredto be about 10° per 1% beam voltage change, which is in good agreement with theory. However, the tube is mechanically unstable and extremely sensitive to temperature changes, having a phase shift with temperature of about 1° per $^{\circ}F$.

3. Test-Stand Drive Systems

Two drivers purchased for the early test-stands from the Gombos Microwave Corporation, New Jersey, have been delivered. There are pulsed triode oscillators delivering 2 to 3 kw with a frequency stability of about $\pm$ 10 kc and a pulse length of 2.5 μsec.

For the tunable test-stand drivers a decision has been made to use cw triode-cavity oscillators, which will be bought from an outside vendor and packaged by the Instrumentation and Control Group.

For the test-stands requiring high stability drivers one microwave source has been ordered from the Syntax Corporation, Berkeley, California. This unit will deliver 250 mw at 2856 Mc/sec with a frequency stability of 1 kc/hour. The oscillator and varactor multiplier portions of this equipment have already been partially evaluated, and performance seems good. If the entire package proves satisfactory, at least three more such units will be ordered.

This program will provide additional information about varactor diode multipliers.

Concerning the layout of the Test Laboratory Building, preliminary parts lists and drawings have been prepared. Orders for microwave equipment will be placed when the over-all layout is finished.

4. Stable Oscillator

A highly stable 15 Mc/sec tunable oscillator was developed during this quarter. This oscillator showed a stability of $\pm$ 3 parts in 10^7 in a two-hour period and has much greater tuning range than can be achieved with crystal oscillators. With improvement this oscillator should be able to hold ± 1 part in 10^7 for many hours or several days.

5. Mark IV Drive System Modifications

Several modifications were made in the Mark IV Granger driver to improve the life of the ML-6442 tubes used in cavity multiplier and amplifier sections. Filament and plate voltages were reduced, and provision was made for more accurate metering of tube voltages and currents. Tuning changes still occur due to thermal expansion, but the problem has been reduced with the lowering of the power input to these stages.

Also, in view of the low-level saturation of the ferrite components ordered originally for phase shifters and attenuators, mechanical units are presently being installed with motor-driven controls.

6. Modification of Crystal Chains

The cavities ordered for the final output stages of the crystal chains to be modified were finally delivered. These cavities do not work with the usual 2C39 tube series as planned. However, early tests show that operation of one cavity with a 6442 triode yields about 250 mw at 2856 Mc/sec. This result is satisfactory.

7. Sub-Boosters

The bids mentioned in the last Status Report[9] were received and duly processed. The present date expected for signing the subcontract is July 2, 1962.

The sub-booster modulator has progressed into the prototype assembly stage. Within a few weeks, after the expected completion of the two prototypes, testing will begin. Some sub-assembly testing has already been completed. The completion of the modulators is planned to coincide with the delivery of the sub-booster tubes.

8. Miscellaneous Tube Tests

During the past six months several medium power klystrons were obtained on a loan basis for test purposes. The recent purchase of a Radiation at Stanford 40 kv, 30 ampere modulator has now made possible the testing of these tubes. Experiments have been conducted with a new 1 kw cw Eimac amplifier, which appears capable of a pulsed output of 7.5 kw

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

with a gain of 50 db. Tests have also been made on a 150-kw pulsed klystron from the E.M.I. Company of England. Also, tests are beginning on two CFTH 20 kw, 2101 klystrons. Results of all these tests will be kept on file for possible use of these klystrons in the Test Laboratory Building. One or more of these tubes could serve as substitutes for the sub-boosters in the event their delivery should be delayed.

C. PHASING SYSTEM

1. Current-Variation Detection Technique of Phasing

An experiment to simulate the phasing of one klystron in 240 using this technique is planned for the Mark IV accelerator. This experiment was briefly described in the last Status Report.[10] All of the necessary rf components and controls have now been constructed. The rf cavity has been installed, and the connecting waveguide runs are nearly completed. The experiment is scheduled to take place early in the next quarter.

2. Hybrid Method of Phasing Linear Electron Accelerators

This method of phasing is essentially a combination of two previously proposed methods: the direct rf phase comparison and the beam induction method. It allows continuous phase monitoring without the presence of a high beam current.

The principle of the hybrid method can be best understood by reference to Fig. 11, which shows three accelerator sections with their attendant klystrons and phase shifters and the equipment necessary for the hybrid method. This equipment consists of a directional coupler at the output of the section prior to the high-power load, and a coaxial cable feeding a magic-T through a simple T junction and isolator. To the other ports of the magic-T are connected an identical circuit from the adjacent section, a movable short and a crystal detector with a suitable indicator. The phasing operation consists of the following steps.

While the beam is passing through two consecutive sections, the two klystrons are turned off and the movable short circuit in the magic-T is adjusted to give a null in the detector arm. This determines the minimum produced by the beam induced signals arriving from the two couplers and provides a reference for comparing the phase of adjacent klystrons.

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[10] M Report No. 298, op. cit., p. 27.

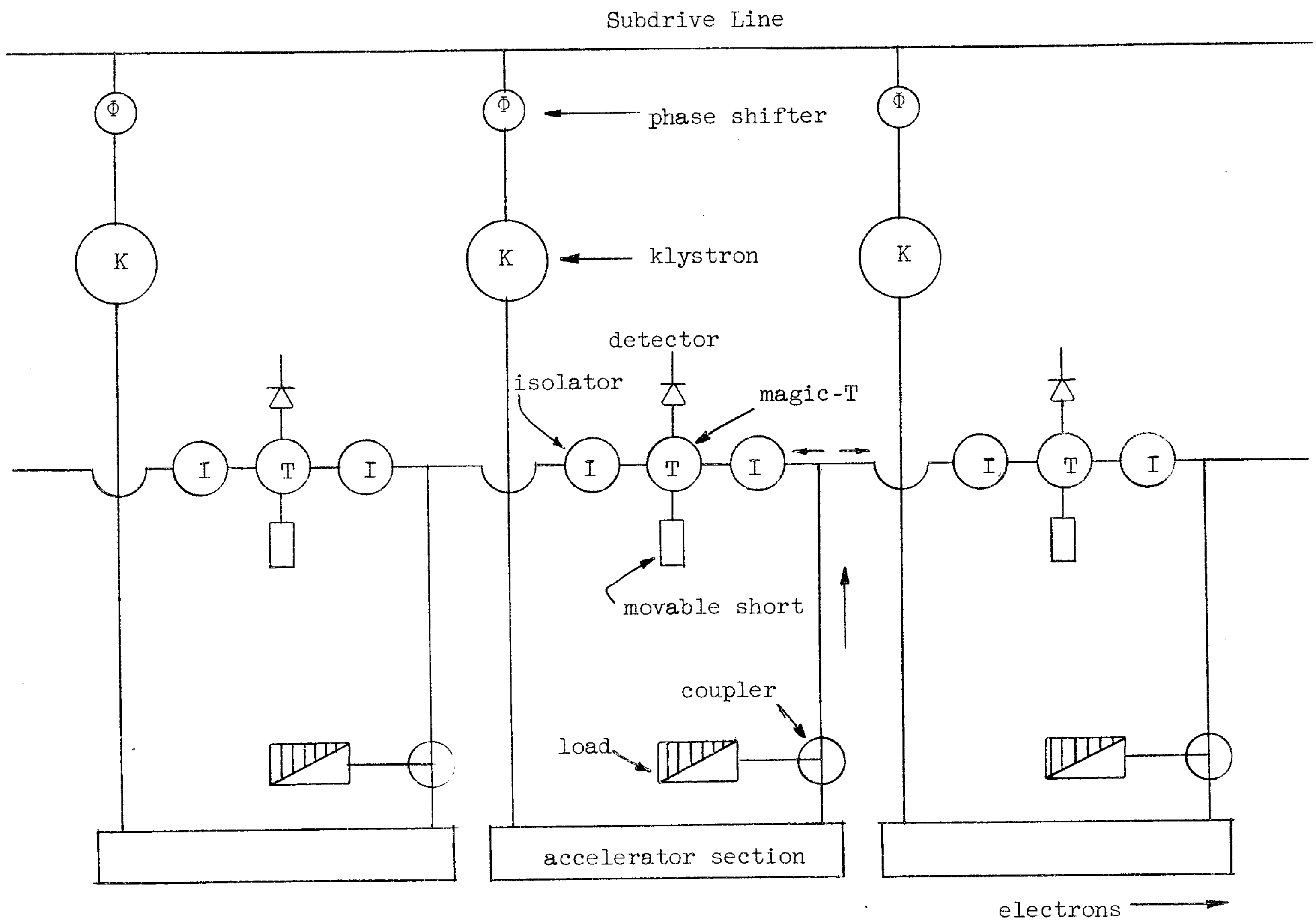

FIG. 11--Hybrid method of phasing linear electron accelerators.

With the two klystrons on, the phase of one of the klystrons is adjusted to again provide a minimum in the detector arm of the magic-T. This sequence of operations can be repeated for all adjacent klystrons within a sector, thus insuring that they are all "beam phase coherent" with the first klystron of the sector. The correct phase of the entire sector can be determined by the same method or by some other technique such as energy maximization.

This technique assumes that a peak beam current of at least 5 ma is available to establish the minimum with the beam induced rf signals (however, this current would only be needed during the phasing operation), and that it is practical to place a directional coupler at the output of the accelerator section.

Advantages of the hybrid method are that it provides a continuous monitor of the phase of the klystrons and does not require gating. This technique does have the disadvantage that errors accumulate in a random walk manner. In Stage I this would involve a loss of energy of approximately $\frac{1}{4}\%$ assuming a phase error per section of $\pm 3^{\circ}$.

The hybrid method has been tried out on four sections (Nos. 3, 4, 5 and 6) of the Mark III accelerator. No quantitative results were obtained, but it was observed that the maximum beam energy and minimum spectrum width obtained by the operator using the secondary emission monitor as an indicator could be easily reproduced using the hybrid technique. Application of this technique to the remaining sections is under consideration.

Measurement of the phase stability of the rf system required for the hybrid method, under accelerator operating conditions, is being undertaken. This is accomplished by observing on a slotted line the position of the minimum produced by the induced beam signals from sections No. 5 and No. 6. The variation in the position of this minimum under different operating conditions is a measure of the phase stability of the system.

3. Some Measurements on the Present Mark IV Klystrons

The measurements of gain and phase shift as a function of drive power and beam voltage for one of the Mark IV klystrons (M10A) have been completed.

4. Specifications for Isolators, Phase Shifters and Attenuators

Proposals were received during this quarter (RFP No. 23201) for the development of the isolators, phase shifters and attenuators called for in SLAC specifications S-801-000-R0, S-810-000-R0 and S-801-001-R0. The proposals received indicate that the best interests of the project will be served by rejecting all proposals received and inviting bids on a fixed-price procurement basis. Accordingly, an invitation to bid (No. 26061) on 20 of each of these units has been requested. These units will be used on the high-power klystron life stations, for the test-stands and for evaluation of the final drive system.

5. Phase Detector Unit

The introduction of the field-effect transistor with its high input impedance has resulted in a simplification of the unit described in the last Status Report.[11] Commutation and decommutation with the attendant switching circuitry is no longer necessary, thus eliminating a large number of transistors. A block diagram of the dual-channel unit proposed is shown in Fig. 12. One channel has been constructed and tested for drift and resolution. Short-term drift corresponded to less than 0.1°, and full scale sensitivity is approximately 1.5°. Both these characteristics can be improved if necessary.

The amplifier required to drive the pulse stretcher still requires major work. The amplifier requirements of high-input impedance and low-output impedance with good high-frequency response are difficult to meet. A complementary symmetry amplifier is being designed, which may solve this problem.

[11] M Report No. 298, op. cit., p. 28.

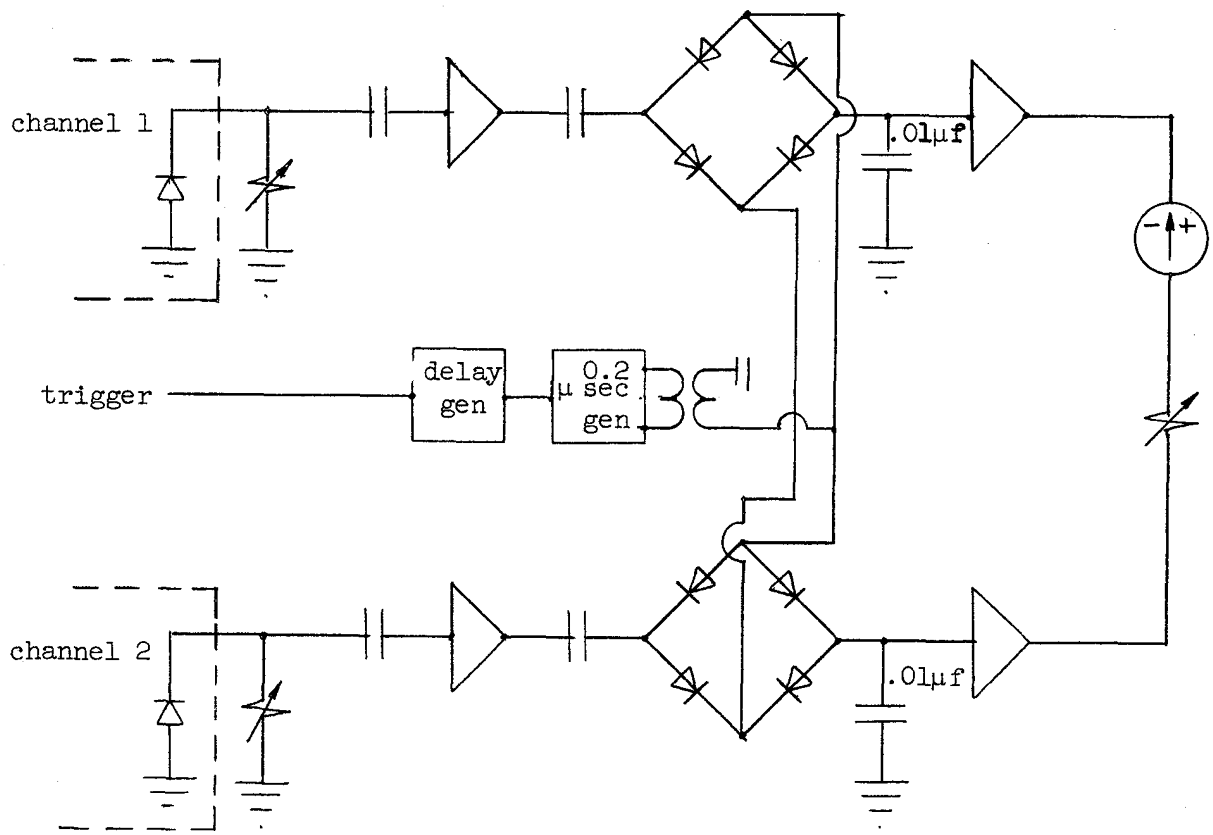

FIG. 12--Two-channel phase detector unit.

VI. KLYSTRON STUDIES

A. SUMMARY

During the past quarter, in addition to the continuing work on permanent magnet-focused klystrons, major decisions have been reached concerning the klystron tube design and procurement for the Stanford two-mile linear accelerator.

Specifically, as a result of new information on output window performance, the design decision was reached early in May that the tube for the two-mile accelerator will have only one output waveguide compared to the two outputs that had been considered up to now.

During this period a large portion of the time of the Klystron Group has been devoted to the investigation of the best procurement scheme to enable us to meet the schedule of accelerator construction at a minimum cost to the program and with a maximum chance of success. In addition, the Klystron Group has started preparations to undertake the responsibility of life-test studies of windows, both of Stanford fabrication and of those purchased from outside manufacturers.

Finally, the initial subcontracts with RCA and Sperry for the development and procurement of sample quantities of klystrons for the two-mile accelerator have been terminated, and an extension was granted to RCA for the fabrication of two additional klystrons to be delivered to Stanford before the end of June.

B. DECISION ON OUTPUT SYSTEM

As mentioned above, the decision has been made to standardize on a klystron design with a single output window and single output waveguide as opposed to the double output window and waveguide that had been originally planned. The advantages of the single output are quite obvious and should result in a lower cost per tube. From an operator's standpoint the main difficulty envisaged with a double output klystron was related to the necessity for making two vacuum seals between the two output waveguides of the klystron and the two waveguides that are a part of the fixed installation in the Klystron Gallery. The necessary tolerances that had to be maintained to permit achievement of the vacuum joint and to provide good rf contact, without at the same time placing undue strain on either the waveguide system or the klystron, were extremely critical. Although they could have been met, the result would have required unduly expensive jigging at that point. In addition, studies of performance of klystrons under conditions of mismatched loads in the two arms indicated that there was a good possibility of phase differences of the power produced by the two arms. To alleviate this difficulty it would have been necessary to recombine the power produced at the klystron output before dividing it in a magic-T. All of these added complications and costs would probably have been necessary if an unforeseen development had not permitted us to reverse the decision reached several years ago and to decide now that a single window would in fact be satisfactory for operation of the two-mile accelerator klystrons.

The evidence on which the decision was reached has been accrued on the Mark III accelerator at Stanford. For the one-year period ending July 1961 there was on Mark III an average of seven window failures per month. Since July 1961, however, there has been a total of only five window failures on Mark III. The monthly number of operating hours has not been appreciably altered, the power level of operation of the machine and the klystrons is the same now as it was a year ago, and the windows used on the klystrons are the same as those which were in use before July 1961.

The main difference to which this rather startling change in window-life performance can be attributed is that of an operating procedure change which was introduced early in July 1961. Prior to that change, whenever a vacuum failure or other reason necessitated shutdown of the rf power to the Mark III accelerator for any length of time, the beam power of the klystrons was re-applied suddenly to its nominal full value. The rf power output was also re-applied within one or two pulses to its nominal value. Since July 1961 a voltage change and an attenuator have been introduced so that when the klystrons are turned back on after any machine operation interruption, the rf power output is approximately 20 percent of the nominal operating value. The power is then brought up gradually in approximately five seconds.

It is suggested from this experience on Mark III that it is possible to operate klystrons having long-life windows under the rather poor vacuum conditions that are obtained on the Mark III accelerator provided some precautions are taken when the power is first applied. The approximate mean time to failure of windows prior to July 1961 was 1500 hours. The lack of sufficient statistical evidence does not permit an accurate evaluation of the present mean time to failure, but the mean life of the windows (including the five failures) presently on the machine exceeds 6000 hours.

C. PROCUREMENT PLAN

After discussions with the representatives of the vacuum tube industry about the best over-all plan for procurement of the klystrons for the two-mile accelerator, we arrived at the decision that an incentive plan based on a type of graduated rental would not be practical at the present time, since the total number of operating hours of klystrons during the next three fiscal years is going to be reasonably small by comparison with their eventual use after the machine is in full operation. Specifically, during the next few years we will have a few dozen sockets undergoing tests, which might result in a total number of klystron hours of approximately 50,000 to 100,000 per year. On the other hand, it is expected that after full operation has been achieved the number of klystron hours per year will approach two million. At this later time an incentive plan for insuring the longest possible tube life at the lowest possible cost to Stanford will be again considered.

At present we are planning to procure tubes under a fixed-price procurement contract. We wish, however, to maintain a certain incentive to the tube manufacturers, in addition to the incentive of the two million hours that might result if their tubes are in operation in, say, 1968. We are proposing to apply this incentive in the form of an option feature in our initial procurement. We should then procure between the initial procurement and the option enough tubes to fill all the test-stand sockets, all the sockets on the two-mile accelerator and the injectors, and have enough spares on hand so that full operation of the machine can begin on July 1, 1966.

In addition, we shall also request that the interested companies submit proposals for the repair of the tubes that have failed during operation at Stanford. We expect to reach a decision on the selection of two manufacturers to supply these klystrons to Stanford by the end of August 1962.

D. TUBE COMPLEMENT AND PERFORMANCE

At the present time the total number of spare tubes, which can be used either on Mark IV or by the Window Test Group, is minimal. One of the reasons for decreasing the emphasis on the repair of these klystrons is the decision to build single output klystrons, which are physically not interchangeable in the existing waveguide systems at either location. However, the single output klystrons should present a very minor problem of adaptation to the areas where the existing double output klystrons are in operation. A klystron is being installed also for the Accelerator Structures Group and will be processed in place before being used to test accelerator sections.

E. SUBCONTRACTS

At this time, the research and development subcontracts with Sperry Gyroscope, Long Island, New York, and RCA Electron Tube Division, Lancaster, Pa., are complete, and we have received the technical reports, drawings and other information from both companies. In general, one can say that neither company has been fully successful in achieving the objectives of the specifications set forth in these subcontracts. Until a month ago Sperry had been able to obtain only 12 to 15 megawatts with permanent-magnet focusing. Since that time it has continued working with the tube bodies that originally had been built for Stanford but not yet shipped. We understand that, as of June 18th, Sperry had achieved 20 megawatts with a permanent-magnet-focused klystron. Unfortunately, all its klystrons exhibit oscillations at pulse lengths in excess of one or one and a half microseconds. In spite of considerable work on Sperry's part, it has not been able to eliminate all the oscillations originally present in the Sperry design.

The results at RCA are essentially the same as were reported in the last Status Report.[12] That is, RCA has achieved 16.7 megawatts with permanent-magnet focusing. The limitation is caused by pulse breakup

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

at higher beam voltages and can conceivably be remedied by a stronger focusing magnet. We have received five operable tubes and one mechanical sample from RCA. RCA also has available for us a test diode and, as mentioned in the summary, it is building a number of additional tubes. We should receive two of these before the end of June 1962. The permanent magnet for the RCA tubes was returned to Crucible Steel Company for remagnetization before shipment to Stanford.

F. NEW FACILITIES

Three modulators are now available for testing klystrons either on life tests or performance tests. It has been difficult to operate these modulators consistently at voltages in excess of 200 kv on the tube. Accordingly, data-taking at the higher power levels is time-consuming and unreliable. Many modifications have been introduced to the modulators, specifically in the ignitron cooling-water system and the trigger amplifier systems, in an attempt to improve this situation. So far, the results are not as satisfactory as we would like.

The second bake-station is now in full operation and is operating very satisfactorily. The combination of a diffusion pump with liquid nitrogen trap and an ionic pump for the final clean-up of the tube permits a bake and activation cycle that is much faster than we had obtained with ionic pumps alone. The main difference comes during the activation, where the ionic pump alone would stall if one attempts to activate the cathode too rapidly. The first tube that was baked on this station has performed very satisfactorily from a standpoint of cathode operation and voltage stand-off.

Work is also proceeding on the components for the additional window test facilities. The design of the vacuum facility for window testing is complete, and all the components are ordered. Approximately 50% of them have arrived, and assembly has been started on some of the items. The instrumentation necessary for this window facility is being carefully investigated, and a great deal of equipment has been ordered but not yet received for this operation. We hope to be able to instrument the window test facility in such a way that it will be possible to monitor pulse by pulse and, in this way, to discover the actual mechanism of the window failure during life tests. It turns out, however, that available recording equipment is not quite adequate for the job of pulse-by-pulse recording.

Another difficulty has been encountered in obtaining an adequate measurement of either the window temperature or the arcing that might take place on the face of the window. However, the window test facility should be operating early during the next quarter even if the full instrumentation is not yet available.

G. LIFE TESTS

The life tests have been continued on the Ling modulator during the first month and a half of this quarter. We have been able to achieve over 1200 hours of operation for the last klystron that was tested to destruction. Since that time this facility has been needed for performance tests, because we are testing our own tubes and the RCA and Sperry tubes already received at Stanford.

H. EXPERIMENTAL TUBES AND NEW DESIGN

The first type C klystron designed at Stanford has been built and tested. The main differences between the original klystron design and the type C consist of a new output circuit and a reduced drift tube diameter and interaction gap length in the cavities. The purpose of the reduced drift tube diameter and interaction gap length was to improve the gain of the tube. The main purpose of the new output circuit was to make the tube conform to the outline drawings of the double output tube that was planned for operation on the two-mile accelerator.

The results of the first tube tested are not completely satisfactory. First, there appears to be more beam interception in the reduced diameter drift tube than was anticipated from the measurements of beam diameter we carried out several months ago. Second, a mistake was apparently made in the design of the output system. The efficiency of the tube was found to be quite low, but an impedance transformer in the output waveguides raised this efficiency to approximately 30% at all voltages between 175 and 250 kv. It is not known whether the transformation achieved by this transformer is optimum; that is, whether the effective output coupling has now been optimized. On the other hand, the gain of the tube has come up to full expectations now, and saturation has been achieved with a drive of less than 30 watts peak.

The main reasons for believing that the interception is higher than had been anticipated are (1) the rather high magnetic field requirements of this particular tube, and (2) the fact that oscillation can be observed if the magnetic field is not properly adjusted. It is believed that these oscillations are caused by secondaries focused back along the drift tube by the field. The oscillations can always be eliminated by proper focusing; hence we are convinced that this is a body interception problem.

In any case, we have started a redesign of this particular tube, not only to achieve a single output (this corresponds only to a redesign of the output coupling system) but also to increase the drift tube diameter to eliminate some of the above mentioned problems having to do with high focusing currents and oscillations in the body.

At this time we have received only one of the six new permanent magnets that were ordered to test our tubes. Unfortunately, this magnet also does not come up to our full specifications, and the tube performance with this magnet has not been adequate. There is more than 20% body interception at 200 kv, and the efficiency stays below 30% at that voltage.

VII. HIGH-POWER KLYSTRON WINDOWS

A. SUMMARY

The window-life test system has continued in operation with only minor difficulties during this quarter. Two damaged windows were removed. The resonant ring now has a new drive tube, and runs have been made at 90 Mw peak power at 60 pps and at 65 kw average 60 Mw peak at high pulse rates. The resonant cavity has proved to be a very useful tool, and a large number of tests have been run. The all-metal ring and cavity should both be operable next quarter. They will allow tests of the effects of contaminants in the vacuum and will probably have higher gain and, therefore, higher fields.

Perhaps the major result during the quarter was obtained on the cavity tests, where the breakdown was observed to follow the fairly definite sequence described below. The destruction was similar to that found on windows that have failed on the Mark III accelerator, with two exceptions: the number of surface punctures is fewer in the cavity windows, and the damage in the interior of the window is greater in the test disks. This may be due to the manner in which the tests were conducted. There is a suspicion, not yet fully confirmed, that windows fail at lower fields in the cavity tests than they do on the resonant ring. In either case, the fields are greater than the fields in normal matched accelerator operation but may not be greater than the case when a breakdown occurs in the accelerator.

B. WINDOW-LIFE TEST STAND

The Stanford Mark V klystron has continued to perform satisfactorily on the window-life test stand at powers up to 12 Mw (limited by the pressurized section of guide) and repetition rates up to 240 pps. The failure of the tube to give full power at the design frequency has been traced to a 2:1 mismatch in the windows and not to the combiner or tube as reported last quarter. The system has now had a total of 2200 hours of operation on a three shift, 5-day week basis. The system will be transferred to the Klystron Group next quarter in order to consolidate all life testing in one group.

Two leaking windows were discovered this quarter. One is rather severely punctured and cracked. The other has only a few small punctures. Their lives were 1800 and 2100 hours respectively.

C. RECIRCULATOR WINDOW TESTS

1. Modifications

After some time had been lost in attempting to use the L3302 klystron installed last quarter, this gassy tube was replaced by a Litton L3617, 5 Mw klystron, which fitted the existing socket and was in stock. With this tube we have an input of 3.2 Mw into the ring at 60 pps, limited by the modulator. The peak power is somewhat lower at higher repetition rates, but we are still a factor of two over our former levels. The L3460 magnetron oscillator driving this system is not as stable as we would like, but it is usable.

A new input coupler, an improved vacuum pump-out section and another viewing port have been installed on the ring. The coupler gives lower loss and a better match to the ring. The pump-out section increases the pumping speed of the ring. The viewing port will enable us to view both sides of a window under test. The increased power has required installation of more water cooling on the ring. The radiation has also increased not only from the windows but from other parts of the ring. Shielding has been added as needed resulting in a rather cumbersome and bulky arrangement. We hope to install better tailored and more compact shielding next quarter. Our new camera has greatly improved our window photography both on the ring and the cavity.

2. Recirculator Tests

a. Sperry beryllia windows

A Sperry beryllia window was tested to 26 Mw last quarter without failing. We will retest it soon at the higher power now available. Results on the other five beryllia windows are as follows. One had a vacuum leak and was not tested; one ran very hot and had breakdowns which limited it to 10 Mw peak; one ran to 25 Mw, where it failed due to an arc at the metal-to-ceramic seal; one ran successfully at 60 Mw, 40 kw, failing later due to a seal arc at 80 Mw peak; and one was tested both at the maximum available power of 90 Mw peak and at 58 Mw, 65 kw, without failing. Some surface arcing occurred during these tests, which marked the window but otherwise left it undamaged. Figure 13 shows the surface of one of these windows operating stably at 40 Mw sometime after a breakdown had taken place.

b. Boron nitride

One of the 3-in. pyrolitic boron nitride samples received last quarter[13] was tested in a geometry similar to the Type A windows used on Mark III. Although the surface of the sample was rather rough (the disk had not been machined flat), it was possible to run it to 35 Mw peak power before severe breakdown occurred. Figure 14 shows the type of arcing observed on the window at approximately 30 Mw peak power. Arcing occurred within the material and apparently forced the surface layers loose. Figure 15 shows the damaged face of the disk after the loosened surface layers had been removed. The material has been darkened, and several apparent punctures were found in this region. The other face of the disk was not damaged.

A symmetrical matching structure has been designed for two 2-1/2 in. diameter disks recently given us by High Temperature Materials, Inc., Boston, Massachusetts. This structure is nearly complete, and the disks will be tested early next quarter. These disks are of better material than the one discussed above and are machined smooth on both faces. These new tests should give a much better evaluation of this material.

c. Type A, alumina window

A standard Type A window, as used on the Mark III accelerator, was tested to 85 Mw peak at 60 pps and to 58 Mw peak and 65 kw average power at a higher pulse rate to evaluate the performance of the ring. This window had previously been tested to 25 Mw on the ring. Although surface arcing was observed in isolated instances, no sustained breakdown occurred and no damage was done to the window.

d. Half-wave disk

Half-wave disk No. 7 was retested to higher power than was available on its first test and failed at 75 Mw peak power in a manner similar to the other half-wave disks.[14]

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[13]Status Report, M Report No. 298, Stanford Linear Accelerator Center, Stanford University, Stanford, California, April 1962, p. 36.

[14]*Ibid.*, p. 35.

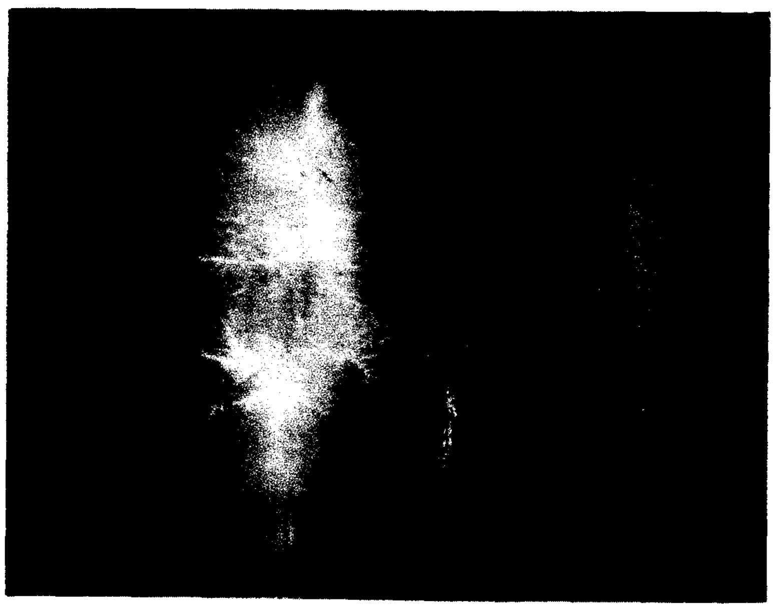

FIG. 13--Aftermath of activity on surface of BeO window running stably at ≈ 40 Mw while picture was taken.

VIII. MODULATOR STUDIES

During the first part of this quarter the field engineer from RCA was at the project assisting in the setting up of the RCA modulators. A number of circuit changes were made in these units on the recommendation of RCA to overcome the difficulties experienced during its test program.

Following this, the Modulator Group began its own test program. Past experience indicated additional improvements could be made in the circuits employed. It also became apparent that several trouble areas needed further study if satisfactory operation was to be achieved. The problem of spurious signal trip-outs experienced at RCA was in evidence. This was found to be related to various feed-back loops in certain low-level trigger and pulse circuits. Most of this trouble has been eliminated, but there still remain some transient problems in the driver circuits. Continuous conduction is sometimes experienced with certain of the silicon-controlled rectifier units employed. The manufacturer of these units has produced new types having faster turn-on and turn-off characteristics, which should correct this difficulty.

During this period a trip to the Seventh Symposium on Hydrogen Thyratrons and Modulators at Fort Monmouth, New Jersey, was made. Several papers delivered during the symposium were related to the problems of silicon-controlled rectifiers in pulse switching service, and these proved very informative. Two side trips were also made. The testing of the British Deuterium Thyratron VX 3336 at the RCA plant, Lancaster, Pennsylvania, was witnessed. This new thyratron is rated at 40 kv with a pulse current rating of 10,000 amperes. No life information was available on this thyratron.

At the General Electric plant, Syracuse, New York, useful information related to modulator procurement, scheduling and production techniques was gained from discussion of the production of high-power radar equipment.

Continued testing at higher power has brought out the reported transient problem in the de-Q'ing circuit experience at RCA. The damping circuit developed by them does not provide sufficient damping when operating near full power. Several approaches have been taken in solving this problem. Measurements of the transactor parameters related to transients have been made along with the parameter of the damping circuits. Similar measurements have been made on a transactor of a different design. These two units are being compared in the modulator circuit at the present time. The study of this problem has also resulted in the development of a new de-Q'ing circuit having power scavenging ability without employing a transactor. This circuit is also under test at this time.

A study of the electric circuits related to instrumentation and control is in process. Circuit drawings incorporating the fault detection, metering and control elements are being prepared for the final modulator design.

The sub-booster modulator is under construction, and the driver section is currently under test.

IX. MECHANICAL ENGINEERING

A. RESEARCH AND DEVELOPMENT WORK

Reports and studies of the Klystron Gallery requirements, electrical power system and cooling tower water system preliminary criteria were completed. Final studies on machine low-conductivity cooling-water system were substantially completed. Other studies in the areas of accelerator vacuum system arrangement, machine special grounding requirements, special equipment-handling requirements, and accelerator support and alignment are underway. Work on vacuum pump oils, seals and pump-out arrangements continued. Work on low-conductivity water treatment was started, as was a review of requirements of accelerator tube initial alignment and subsequent realignment.

1. Low-Conductivity Cooling-Water Criteria

Low-conductivity cooling-water criteria developed call for three subsystems.

a. Accelerator tubes, dummy loads and the waveguides, arranged in series and in that order. A minimum of 13 gpm per 10-ft accelerator section will be provided. The accelerator tube metal temperature will be held at 113°F (45°C) by varying the temperature of the water supplied. The return leg outflow will hold the waveguide metal temperature at 112°F ± 1°.

b. Modulator components (other than ignitrons), pulse transformer and klystrons, arranged in series and in that order. This loop will provide a minimum of 10 gpm per klystron at 95°F (35°C) maximum, but the temperature will be allowed to fall below this level when the cooling-tower water-supply temperature is below maximum.

c. RF drive lines and ignitrons arranged in series and in that order. A minimum of one gpm, at about 97°F (36°C) will be provided per ignitron. The supply header will trace rf drive lines in order to maintain the rf drive lines within 1°F of 97°F and then will be supplied to ignitron cooling circuits.

2. Vacuum System

Vacuum system design studies indicate that the cost will be the same for either a centralized system having large manifolds and relatively few large pump stations or for a system having a small pump set at each waveguide service penetration and small manifolds for high vacuum reliability and for roughing. Accordingly, emphasis is now placed on checking out aspects of the unitized pump set and penetration vacuum finger arrangement, since it should better provide for equal vacuum at each window, reduce effects of manifold outgassing and increase over-all machine evacuation reliability.

3. Accelerator Tube Support

Added review of accelerator tube support requirements eliminated consideration of need for interchangeable 10-ft long box sections, and further study will be based on 40-ft, 6-in. long girders under the accelerator tubes (and 9-ft, 4-in. long supports for the drift section tubes). Criteria established indicate that the tops of the girders must be close to the accelerator tubes and their power input couplers and dummy loads and that the girders must be nonmagnetic. Already established are requirements that girders be inexpensive and rigid against torsional thrusts and deflection because of the dead weight of the girders and the equipment carried. Possible use of concrete girders was re-examined. Concrete girders pose problems because of uncertainties concerning long-term creep in concrete, the effect of reinforced steel on the magnetic field near the tubes, and potential increases in handling costs during fabrication and installation. (Combination steel girders with top-mounted aluminum strut arrangements pose similar problems.) Emphasis has been shifted to refinements of arrangements of open aluminum box trusses using standard angle and rod joist fabrication arrangements.

B. TEST-STANDS

Design and procurement work continues, and the test-stands project is on schedule. A purchase order was issued for 14 evacuation pump sets. The test-stand layout and arrangement drawings and low-conductivity cooling-water manifold details were issued. Specifications are being prepared for requisitioning material and equipment for vacuum, cooling water and electrical connections. Final budget and manpower forecasts were prepared and submitted for approval. Engineering design is about 50% complete and procurement about 40% complete for mechanical engineering portions of the work.

C. TWO-MILE ACCELERATOR

Design work was authorized and is just getting underway. Budget and manpower forecasts were prepared, reviewed and revised for FY 1963 through FY 1966. Transfer of personnel from research and development work to accelerator work started. Definitive scheduling of design and installation work items continues both for purposes of over-all critical path analysis and for planning of specific systems design work. Detailed breakdowns of final approved budgets were issued for approval. Division of machine cooling water and electrical systems into machine budget accounts and building services accounts was completed.

D. TECHNICAL SERVICES

First project standards were issued in two volumes: (1) SLAC Standards and Procedures and (2) SLAC Supply Catalog. Review and approval of project standards was started. Work on catalog groupings and assignment of part numbers were started. A central file for document control was established. Assistance to mechanical engineering and other project groups is available in preparation of specifications, quality control procedures and engineering estimates.

X. CONTROL SYSTEM STUDIES

A. DATA HANDLING

An evaluation program is being prepared by the data-handling section. This program will consist of setting up experimental tests of preliminary design concepts using "off-the-shelf hardware" to evaluate equipment in an operational environment simulating that of the accelerator. An investigation of rf interference has been initiated in cooperation with the Window Test Group. A new grounding setup is being installed so that controlled experiments can be conducted to determine the most efficient coaxial cable arrangement on a lowest-cost vs result basis. These experiments will help the shielding and grounding requirements and the cable and connector standards for the instrumentation and control system.

Engineering is progressing on the instrumentation and control cable tray and conduit distribution installation specifications for the Klystron Gallery and Accelerator Housing.

B. BEAM GUIDANCE

The largest amount of time was spent in further work involving the beam position problem. Some rather crude coils were built up and tested in the laboratory in order to obtain sensitivity figures. These lie in the range from 2 to 30 mv output voltage per centimeter deflection with a current of 100 ma. The larger voltages are, in general, obtained with coils with poor low-frequency response. That is, there is pronounced droop on the top edge of the output pulse, resulting from a rectangular input current pulse. Investigations are continuing on the best coil design to use with the range of pulse-current peak amplitudes and pulse widths that will be encountered in the accelerator itself. In addition, the best way to match the coil to the cable that will connect it to the instruments in the Klystron Gallery is being investigated.

Considerable thought has been given to the question of how best to utilize, in the over-all accelerator system, the information obtained from the position and intensity pick-up coils. For example, the output from a position coil could be used to control the current through a dipole correction coil situated nearer the gun end of the tube by incorporating it directly into a servomechanism, rather than by displaying the beam displacement on a meter and then using a human operator to vary the correction coil current and position the beam correctly.

Such beam positioning would be done on a per sector basis and would require 30 such servomechanisms. Depending upon the way in which servomechanisms are used they may or may not tend to interact, with consequent possibilities of unstable operation. While the ultimate test of such an over-all system is the manner in which it performs in the completed accelerator, thought is being given to the use of analog representations of the beam steering system, which may be tested experimentally in order to give some indication of the final performance to be expected from the accelerator.

C. TRIGGER SYSTEM

The proposed trigger system will work as follows. The master trigger generator derives a 360-cps sine wave from the 60-cycle line voltage rectification and narrow band filtering. The output is squared and differentiated to produce impulses that are precisely 6 times the line frequency. The synchronized pulse generator feeds this output into time delays and divider circuits to produce synchronized pulses at all the required rates, i.e., 60, 120, 180, 300, 360 cps and a special rate of 60/n for the bubble chamber. The synchronized pulses are spaced to follow close behind the main pulses to minimize the possibility of false triggering of the modulators. Only those synchronized pulses asked for by master control are generated and sent out to the sectors. The pulses are delayed, sorted and sent to the proper blocking oscillator (either positive or negative) for amplification, mixing and coupling to the main trigger line.

The electronics at each sector utilize the synchronized pulses to gate the corresponding main pulses, thus providing the sub-booster and modulator with pulses of the required repetition rate.

Frequency dividing will be done once at the master trigger generator instead of repetitiously at each sector. This will simplify and increase the reliability of each sector but will make the trigger generator more complex. The net effect will be a simpler over-all system. The sector electronics will be solid state for reliability and minimum maintenance, provided output voltage requirement to the modulators can be met. Output amplifiers may be necessary, depending on modulator requirements.

Work accomplished to date, in addition to over-all trigger system design, includes a solid-state breadboard of the frequency multiplier (60-cps sine wave to 360-pps impulses) and a breadboard of the blocking oscillator driver stage. Future development work will be on key system components, such as the output blocking oscillator, "and" gates and frequency divider circuits.

D. TEST STAND INSTRUMENTATION

The test stand instrumentation has been completed and detailed equipment specifications are in process. Prototype design and fabrication of special chassis have been started by the electronics shop of the Instrumentation and Control Group. Block diagrams of the rf drive have been developed using a common trigger and, for some test stands, a common sub-booster modulator and sub-booster driver tube.

Electronic equipment rack specifications were prepared, and bid requests have been solicited from a number of rack manufacturers.

Intra-rack power distribution circuitry design has been completed, and requisitions for the fabrication of the breaker and terminal block panels have been issued.

Sub-assembly shop area requirements have been detailed, and requisitions have been issued for necessary shop equipment and tools.

E. ELECTRONICS SHOP

This department was organized in March 1962 and currently entails the following sections and responsibilities.

1. The prototype section will work with the electronics engineering staff in the construction of breadboard circuits to facilitate the design of control circuits applicable to the linear accelerator. The primary effort in this section has been on three major control problems generated by the engineering staff: the master trigger generator, the sector trigger generator and the beam guidance. The section is also doing some breadboard design work for other SLAC groups.

2. The fabrication section will work with the prototype section in the transfer of an accepted breadboard design to a standardized, functional assembly to be installed on the linear accelerator. The principal effort

during the last quarter has been the assembly of 20 gate generators for the Research Division. The first 10 units were delivered June 1; the completion of this work is expected about July 1. An rf phase and attenuator control panel was wired for the Microwave Engineering Group. The Klystron Group has requested assembly work on a vacion pump power supply.

This section has a projected work load based on the progress of the prototype section in transferring a voltage comparison patch panel, a transistorized gate circuit and a focus coil power supply from the design state to the complete package requirement.

3. The instrument repair and calibration section will work with all SLAC groups in repair, maintenance, calibration and issue of all SLAC test equipment. In addition, it will provide assistance to all SLAC groups in the selection of proper test equipment and any measurement problems.

4. A standards laboratory to preserve and use all standards traceable to the National Bureau of Standards that are required by the various SLAC groups will be established when on-site facilities permit. Primary calibration requirements are currently being handled at outside standards laboratories.

XI. RESEARCH AREA DESIGN

A. MAGNET AND BEAM STUDIES

1. Hall Probe Irradiation

An experiment has been conducted on Mark IV to find the radiation effects in Hall probes. The probes were constructed from InAs. In this experiment the total undeflected beam hit the probe. The Hall voltage was deflected continuously from the probes, which were placed in a solenoid. After 3 hours of electron bombardment the Hall voltage decreased by a factor of three. The total number of electrons on the probe was estimated to be about 10^{16}. To obtain more quantitative data about the damage caused by the radiation another experiment is in preparation. The radiation damage with photon beams will be investigated also.

2. Frequency Response of Hall Probes

To find out the frequency response of the Hall generators a simple experiment in a pulse magnet was conducted. The Hall voltage was measured after amplification. It was found that the frequency response can be as good as 1 Mc, using adequate amplification. The ultimate frequency response is set by the time which is needed for the charge carriers to reach the Hall leads during the periodic time (T) of the oscillation. Then the traveling time $t = \ell/v$ has to be smaller than T. Using $v = \mu E = \mu j/\sigma$, the ultimate frequency response is

$$T = \frac{\ell\sigma}{\mu j}$$

where ℓ is the linear size of the probe, j is the control current density, σ is the conductivity of the material, and μ is the charge carrier mobility.

3. Pulsed Magnet Instrumentation

The remanent field in a small pulsed magnet core is about 12 gauss. To insure that the magnet will reach the same top field in each pulse the low field should be degaussed or regulated. To do this a flux-gate meter may be used. A flux-gate meter which is not radiation sensitive is under construction.

4. Pulsed Magnet

The coil design for the pulsed switching magnet is finished. The magnetic field measuring devices (Hall probes) are under construction. The different kinds of exciting systems and field regulators will be presented in a separate report.

5. Harmonic Analyzer for Quadrupole Measurements

A rotating search coil is being developed which can measure a large number of the harmonic coefficients in a quadrupole. This measuring device enablesdetermination of the contribution of each term to the whole magnetic field. In a perfect quadrupole only the second harmonic should be present. If the poles are not equipotential surfaces (for example, because they are saturated) the higher harmonics will contribute, too. By measuring the amplitude of the existing harmonics it is possible to draw conclusions about the "quality" of the quadrupole.

6. Magnetic Momentum Slit

The preliminary calculations on the slit, briefly described in the last Status Report,[17] have been completed. They show that it is possible, by means of current strips placed appropriately in the gap of a steel magnet, to get fields which are almost zero in the center of the gap and finite elsewhere.

The currents required, while large, are within the capabilities of available modulators and pulse transformers.

As a result of this analysis a model has been designed that will scale at roughly 1/20 of the actual device. This will employ dc currents of several hundred amperes in the correcting sheets and will be used for field mapping and to obtain actual current values for the full-scale magnet. This model will also have adjustable gaps. A technical report on these calculations is in preparation.

7. Beam Angular Divergence

A measurement of the angular divergence of the Mark III beam is planned. The technique contemplated is to place a collimator covered with a large number of small holes (1/64th in.) at the end of the accelerator. The beam will pass through these, and the magnification of the collimator pattern and the size of the electron distribution from the

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

individual holes will be measured by the darkening on a glass plate located approximately 100 ft from the collimator.

The minor equipment required is being constructed, and it is hoped that experimental time will be available on Mark III during the next quarter.

It is felt that results from this can be extrapolated to allow a better estimate of the expected beam angular divergence of the SLAC machine.

8. Extension of Beam Switchyard, Beam Transport Design

Work is continuing on the design of a high-momentum-resolution magnet analyzing system for the beam switchyard. Calculations to date have not uncovered any serious objection to the system studied by Penner.[18] Magnet apertures, gradients, fields and lengths all appear reasonable in terms of present state-of-the-art limits. However, a number of aspects of the system are still to be investigated. Computer programs are being prepared to study the effect on the second half of the system of secondary electrons produced at the slit and to study second-order effects. Tolerances on the various design parameters of the system are being evaluated. An attempt is being made to optimize the angle of bend of the deflections system with respect to over-all tunnel costs.

A number of other deflection systems are being investigated to determine if appreciable improvements in cost, resolution, length or performance can be obtained. Each system studied to date possesses various desirable features, but none devised possesses the over-all performance of the Penner system.

B. RADIATION PROBLEMS

1. Transverse Shielding Thickness

During this quarter it was decided to reduce the thickness of the earth shielding along the accelerator from 35 ft to 25 ft. This decision was based on a calculation similar to the previous calculations, but with some refinements which reduce the uncertainties considerably. The complete calculation is too complicated to give here (a detailed

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

report is being written), but we will enumerate a few of the considerations.

a. There have been no changes in the radiation policies.[19] Design tolerance levels are about three times less than the levels currently recommended by the AEC.

b. The 25-ft thickness gives a radiation level at the surface of the shield (in the Klystron Gallery, for example) that is at least 10 times less than the design tolerance level under "average operating conditions." In an ideal machine there would be no radiation along the machine at all because all of the electrons would be accelerated. An estimate was made of the beam loss by extrapolating from measurements made at Mark III. It was found that it is reasonable to take the two-mile accelerator structure as a uniform line source of penetrating radiation. This means that the shield thickness is the same everywhere. This approximation gives too thick a shield for the first few hundred feet of the machine. It is inapplicable if there is a strong localized source of radiation (for example, a positron radiator , or a collimator); in such a case some dense shielding should be added near the hot source so that the physical thickness remains 25 ft, but the equivalent thickness of earth is appreciably greater than 25 ft.

c. The new calculation uses more refined estimates for the number of neutrons per beam electron and for the biological effect per neutron. Numerically these changes compensate for each other, but confidence in the final answer is improved.

d. The biggest difference between the new calculation and the old calculations, and the difference which accounts for almost all of the change from 35 ft to 25 ft of earth thickness, is in the method of calculating the radiation level far from the machine. Previously a one-dimensional nucleon cascade in the shield itself was used to estimate the radiation level at the surface of the shield, while a three-dimensional calculation describing scattering and attenuation of the fast neutrons in the air was used to estimate the level far from the machine. There was an appreciable uncertainity associated with the second part of the calculation. Now the one-dimensional calculation is used throughout, and the air beyond the earth shielding treated as part of the shield but

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[19] W.K.H. Panofsky, "Proposed Radiation Policies for Project M," M Report No. 234, Stanford Linear Accelerator Center, Stanford University, Stanford, California, December 1960.

with a different density. A result of this method is that, for a given thickness of earth shielding, the radiation level at the surface of the shield relative to radiation worker tolerance is approximately equal to the radiation level 500 ft from the machine relative to general population tolerance.

Previously the requirements of the general population dominated the shield thickness; now the requirements for the general population and for the radiation workers are about the same, and the uncertainties are reduced.

e. The effect of penetrations through the shield is presently being considered, but no firm conclusions have yet been reached.

2. <u>Radial-Shower Development</u>

Instrumentation has been completed, and some very preliminary data taken indicates the methods planned[20] will be adequate.

C. THEORETICAL PHYSICS

A theoretical study is being made of inelastic photoproduction cross-sections into final states involving the newly discovered resonance particles ρ, ω, K^*, and ζ. Since these particles have been found in processes involving pions and nucleons and apparently have strong interactions, it is expected that they will also be produced by photons.

Since these particles decay rapidly into pions, kaons and photons they are not directly observed, but rather their presence is ascertained by definite correlations in the final decay products.

Rough estimates for the photo cross-sections can be made using the idea of peripheral collisions. Coupling the fact that some of the resonance particles are charged with the information already known from existing experiments means that the calculations will involve a minimum of parameters.

In particular it is proposed to study the processes

$$
\gamma + p\ (n) \longrightarrow
\begin{cases}
\rho + p\ (n), & \rho \to 2\pi \\
\zeta + p\ (n), & \zeta \to 2\pi \\
K^* + \Lambda\ (\Sigma), & K^* \to K\pi \\
\omega + p\ (n) + n\pi, & \omega \to 3\pi
\end{cases}
$$

[20] Status Report, M Report No. 298, Stanford Linear Accelerator Center, Stanford University, Stanford, California, April 1962, p. 53.

in the photon energy range from 1.5 to 5 Bev.

After the cross-section is computed the known quantum numbers of the resonance particles are used to predict the energy and angular distribution of the final decay products. Finally, the resultant expressions are integrated over the photon spectrum and over the Fermi motion for a complex nucleus as a target.

Since there exist no experiments on photo production above 1.5 Bev, some theoretical investigations appear to be useful for estimating the magnitude of the cross-section and the expected angular distribution of the resultant pions and kaons.

XII. PLANT ENGINEERING

All necessary contracts have been signed to allow the start of construction of the conventional facilities, but the actual ground breaking has been prevented due to a strike of the Northern California construction workers. This strike is expected to be settled by July 1st, and construction is expected to proceed as rapidly as possible.

A "follow on" contract with Aetron-Blume-Atkinson for the architect-engineer-management services required to complete the entire construction job has been negotiated and is now waiting final signatures. The present design effort under this contract is 100 men/day and will be increased rapidly to meet the peak design effort that arises in late fall 1962.

A. STATUS OF MAJOR CONVENTIONAL FACILITIES NOW UNDER DESIGN

1. Site Improvements

The first increment of this work is being delayed due to a labor strike.

2. Site Utilities

The first increment of site utilities is in Title II design. These drawings cover natural gas, sewer, water, telephone and electric power service to the project. Negotiations for obtaining the above services are proceeding on schedule to make these services available to the first building on the site.

3. Test Laboratory Building

Contracts for the construction of this building have been awarded, and construction will start as soon as site improvement work will allow.

4. Administration and Engineering Building

This building is now ready for construction bidding.

5. Fabrication Shops, Electronics and Stores Buildings

Title II design work is proceeding on these facilities.

6. Central Laboratory

Title I work has started on this building.

7. Accelerator Housing and Klystron Gallery

Design criteria have been presented to the architect-engineer for design of these facilities. Title I work has started on the Accelerator Housing. In connection with the geological investigation of the site, the first 3,000 feet of the accelerator cut (at the west end) will be made at the earliest possible date. This early cut will reveal earth rebound and other foundation design information.

B. ELECTRICAL POWER SYSTEM

A re-evaluation of the 220 kv and the 12.5 kv distribution systems has been made. The results of this study will be used as the design criteria for the electrical power system for the project. The negotiation for electrical service from Pacific Gas & Electric Company will begin in July.

C. COOLING WATER SYSTEM

The design criteria were fixed for the primary (cooling tower) side of the accelerator cooling water system. These criteria were forwarded to the architect-engineer for detail design. Studies are proceeding on the secondary loop of this cooling system.