SLAC-18
UC-28, Particle Accelerators
and High-Voltage Machines
UC-34, Physics
TID-4500

# TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

1 April to 30 June 1963

August 1963



Technical Report
Prepared Under
Contract AT(04-3)-400
for the USAEC
San Francisco Operations Office

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A. TECHNICAL REPORTS

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

B. JOURNAL ARTICLES

1. S. M. Berman and S. D. Drell, "Coherent production as a means of determining the spin and parity of bosons," PUB-10 (May 1963).
2. D. B. Lichtenberg, "Methods of determining the quantum numbers of excited meson and baryon states," PUB-14 (April 1963).

## I. INTRODUCTION

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

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

The terms of Contract AT(04-3)-400 provide for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision is made for an initial complement of general-use research equipment with which it will be possible to perform certain exploratory studies, such as measurement of the intensity and energy distribution of various secondary-particle beams. However, AT(04-3)-400 does not provide for the more specialized items of research equipment that will eventually be necessary for a full program of experimental physics with the machine. A program of research preparation is now underway at SLAC under the support of another AEC contract.

# II. PLANT ENGINEERING

## A. GENERAL

Design and construction of the conventional facilities continued throughout the quarter, with considerable progress made in both phases of the program.

The Test Laboratory, as the first major building under construction, was also the first to be occupied. The test stand maintenance organization moved into the high bay area on May 15. Shortly thereafter, the Plant Engineering group and a major portion of the Instrumentation and Control group transferred to temporary quarters in the new building. Additional SLAC groups are scheduled to move in during July as beneficial use of the facility is expanded.

A time and materials contract was executed in June with the Rosendahl Corporation of Richmond, California. This provides an interim craft service in support of activities in the Test Laboratory Building.

## B. DESIGN STATUS

Criteria studies for the Cafeteria and Auditorium have been completed and a report is being written; preliminary architectural sketches have received Trustees' Committee approval. A draft of the criteria report for the beam switchyard structure has been submitted by ABA for review.

Preliminary design is essentially complete on the Control Building, the initial site landscaping phase, and the Chemical Cleaning and Plating Area. The latter will be an addition to the Fabrication Building facility. Title I reports on all these have been prepared and are being reviewed.

Final design (Title II) is in progress on a number of facilities. These facilities, together with their percentage of completion as of the end of June, are as follows: Central Laboratory (95); Accelerator Housing and Earthwork (97); Heavy Assembly Building (90); Klystron Gallery (80); Klystron Gallery Utilities (41); 220 kv Substation (8).

Bid opening for the major Accelerator Housing contract is scheduled for July 23, 1963. An advance notice was sent to potential bidders in June.

## C. CONSTRUCTION STATUS

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

| Facility | Percentage of Completion |
|---|---|
| Construction Office Building | 100 |
| Test Laboratory | 99 |
| Utility Building "A" | 92 |
| 60 kv Substation | 100 |
| Initial Site Utilities | 92 |
| Administration and Engineering Building | 80 |
| Electronics and Stores Building | 45 |
| Fabrication Building | 33 |
| Initial Accelerator Housing | 8 |

The first concrete was poured for the Accelerator Housing on June 27 and is a significant milestone in the project. This work is proceeding quite satisfactorily and the contractor handling this phase is ahead of schedule. Work at the surcharge fill area and on the bypass road is nearly complete. The present status of construction at the Sand Hill site is illustrated in Figs. 1 through 4.

The ABA organization moved from its two Palo Alto locations to the Construction Office Building on May 27 and will occupy this space for the duration of the project. The next facility scheduled for occupancy is the Administration and Engineering Building; several SLAC groups will move in during the latter part of August.

## D. UTILITY SERVICES

The Pacific Gas and Electric Company is constructing a 220 kv transmission line along the Skyline route. A correlated project is the proposed tie-in line to furnish electric power to the Sand Hill site. Stanford is cooperating with PG&E and the appropriate public agencies to obtain the necessary permits.

Negotations for natural gas services were completed and the contract signed. Domestic water supply and sewage services for the project had already been contracted for prior to the period of this report.

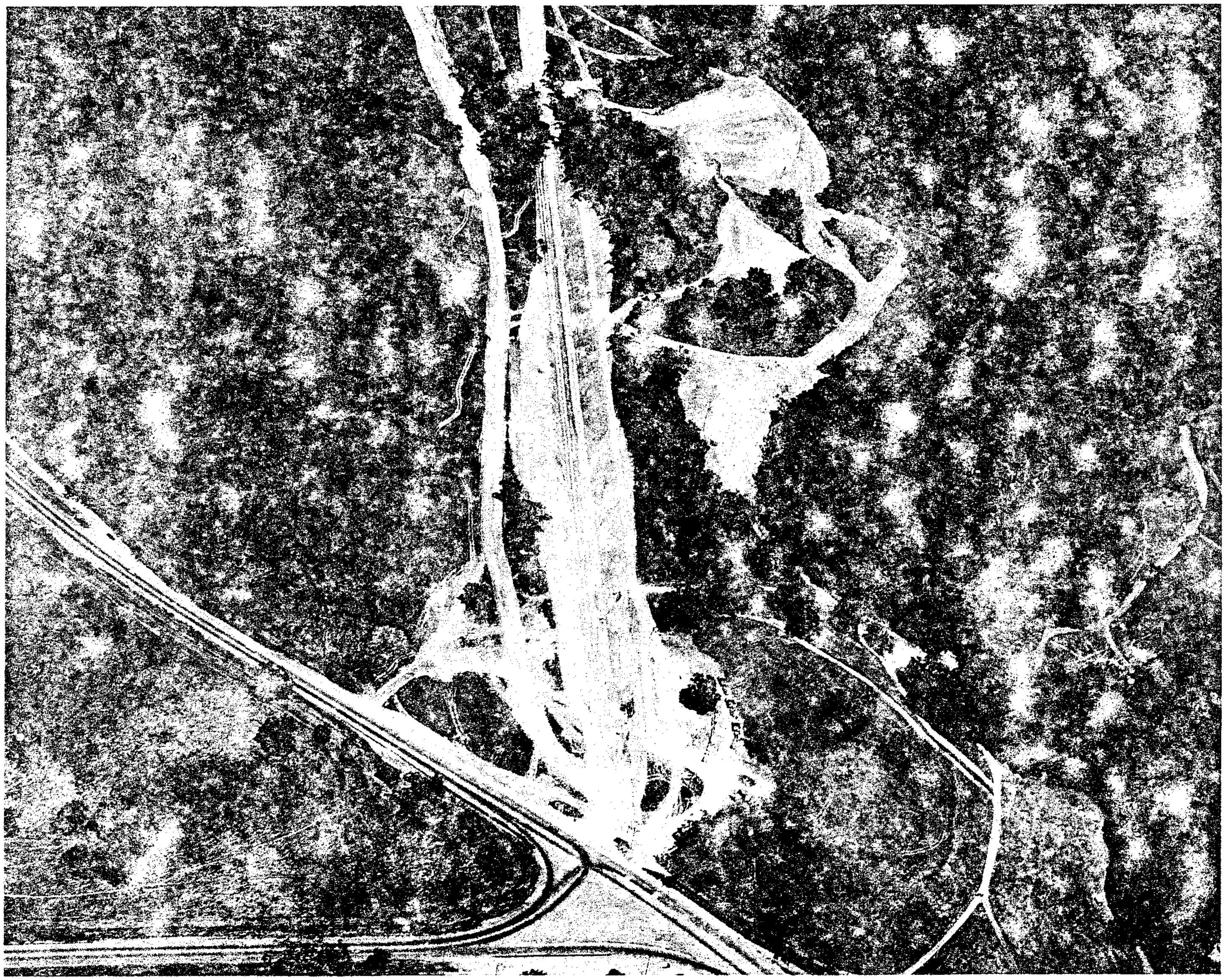

FIG. 1--The initial accelerator excavation viewed from the west end.

FIG. 2--Aerial photo of the "campus" area at the Sand Hill site.

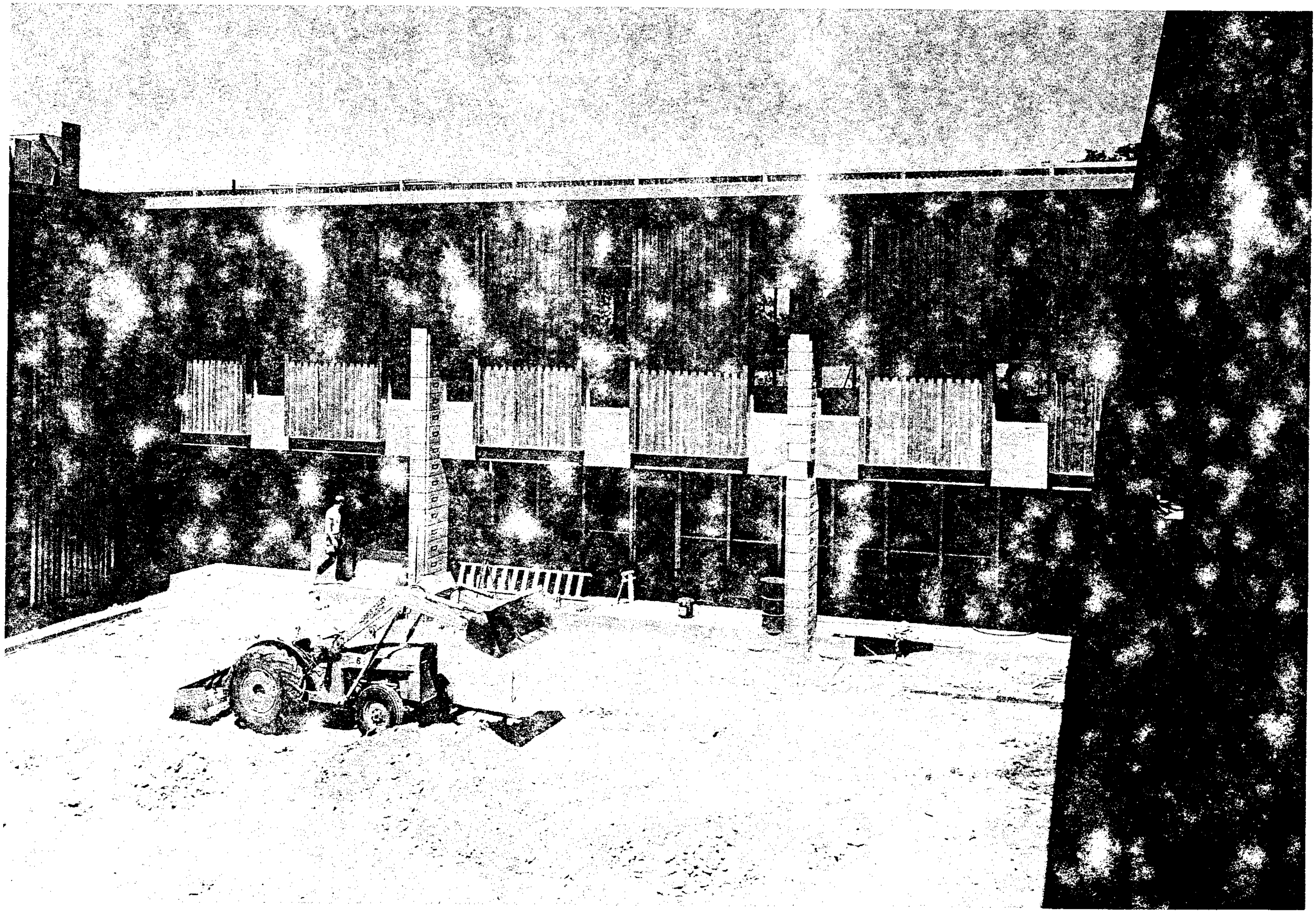

FIG. 3--Interior court, Administration and Engineering Building.

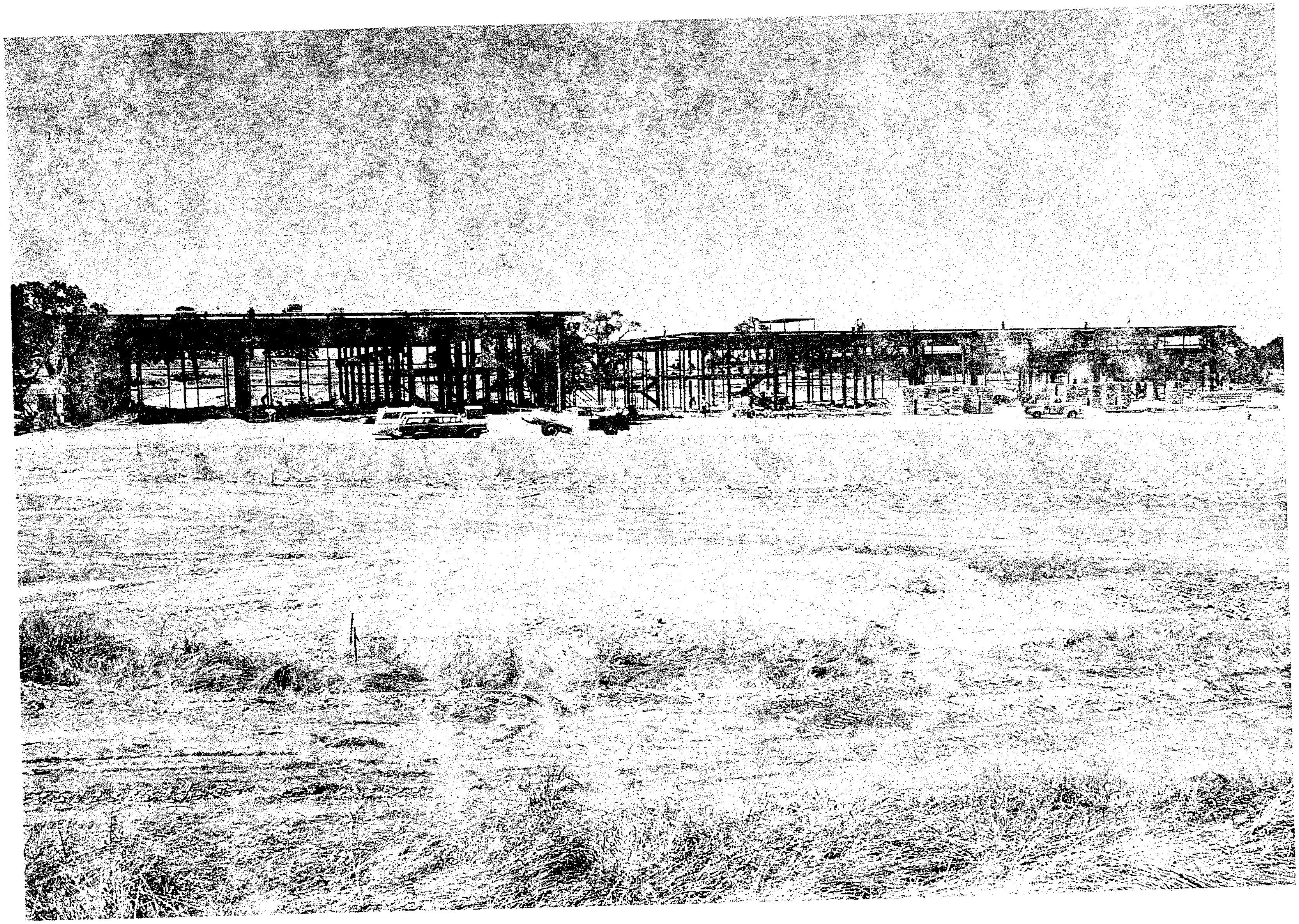

FIG. 4--Electronics and Stores Building and the Fabrication Building, as viewed from the south.

# III. ACCELERATOR STRUCTURES

## A. ACCELERATOR STRUCTURE

Four accelerator sections were completed and installed in the Tree House. Work continued on the design and procurement of equipment for low and high power testing and tuning of accelerator sections.

### 1. Accelerator Section Tuning and Phase Checking

The basic system design for structure phase measurements during production tuning remains unchanged. The current status of various aspects of the system are as follows.

(a) Electronic phase measuring equipment: The commercial phase meter mentioned in the previous quarterly report* has been ordered with an expected delivery date of August 1.

(b) Dielectric control: A vacuum system with the objectives of evaluating possible contamination difficulties and evacuating structures for tuning is virtually complete. The system has been run and preliminary tests for contamination made. A dual channel system (one channel for evacuating the structure and a second channel for use during tuning) has been designed and ordered. It is planned to use this dual channel system simultaneously at the structure tuning station and at a Quality Control Inspection Station.

(c) Precision phase standard: The construction of two high precision phase standards of the shorting plunger type continues. The precision waveguide casings and dumb-bell shorts have been completed. A control mechanism by which the short can be positioned accurately and automatically has been designed. The mechanism parts are being fabricated.

(d) Attenuation measurement: Consideration and evaluation of attenuation measurement systems continue. A semi-automated system which will measure and record the attenuation cavity by cavity is being evaluated for installation at the Quality Control Station.

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*"Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1963," SLAC Report No. 10, Stanford Linear Accelerator Center, Stanford University, Stanford, California (May 1963).

(e) Coupler tuning: Development of an automated coupler tuning technique continues. By the use of a thicker iris it appears likely that a machinable dimension can be used. Phase adjustments in the coupler cavity would then be made by dimpling the cavity wall rather than by iris adjustment. The feasibility of this approach will be checked on future coupler sub-assemblies.

2. Accelerator Structure Tuning Machine and Associated Control Systems

The mechanism mentioned in previous reports for semi-automatically tuning the cavities of ten-foot sections of accelerator pipe has been evaluated. Modification of the hydraulic indenting mechanism to improve the return of the rams is in progress; other than that the machine appears satisfactory. A semi-automated electrical control unit for the mechanism has also been tested. The control unit is undergoing minor modification before installation in the tuning station system.

3. Quality Control Station

The decision was made during the period to establish a Quality Control Station with the function of certifying that the accelerator structures meet the required phase and attenuation specifications. For that purpose, a mechanism similar to that used in tuning the pipes is being constructed. Procurement of a commercial phase meter for this station will follow testing of the unit on order.

4. High Power Tests of Accelerator Sections

Three sections for the Tree House were processed satisfactorily. A brief run to power levels of 3 megawatts per section was made on the Tree House, and the vigorous outgassing region occurring below 3 megawatts, noted in the last progress report, was clearly in evidence. As in previous tests, it was possible to raise the system pressure by lowering the power level to this range. Further experiments are being planned to define this behavior more closely.

5. Instrumentation for High Power Accelerator Station Tests

The coffin for the second test stand was completed and available instrumentation for this stand installed. The stand is now ready for use in vacuum system testing. Test Stand No. 1 has been supplied with an

8-channel recorder for pressure and power recording. A temperature control system for the accelerator section has been received, tested, and found to be quite satisfactory for this application. A signal, derived from this system, which indicates the temperature at one point on the surface of the accelerator section, is now being recorded on the 8-channel strip recorder. A 24-point temperature recorder has been received and is being tested.

Three waveguide valves of the in-line Model B type were installed to protect the klystron while switching the rf from between coffins. These have been used repeatedly, proving invaluable in sealing klystrons with leaky windows.

It has been decided to use an ion pumping system for processing of accelerator sections. Procurement of components has begun.

a. RF Attenuation

The technique to be used in measuring the rf attenuation of the accelerator sections was decided upon. Figure 5 shows a block diagram of this system. Microwave signals sampled from the input and output of the accelerator section as it is under high power test are fed into identical precision variable waveguide attenuators. To facilitate the discussion below, the attenuator connected to the input of the accelerator section is called the "input attenuator" and the attenuator connected to the output of the accelerator section is called the "output attenuator."

At the output ports of these attenuators, the microwave signals are detected by barretters, and the outputs of the barretters are amplified and detected to dc signals. These dc signal voltages are then proportional to the microwave power levels incident upon the barretters. The variable waveguide attenuators are ganged together so that their attenuation values are very nearly equal (within 0.1 db) over the full range of attenuation used in this system. The attenuators are driven by a servo control system in such a way as to keep the output signal from the input attenuator nearly constant (within 0.1 db). This is done by using, as the input to the servo amplifier, an error signal that equals the difference between the dc signal at the output of the amplifier connected to the input attenuator, and a dc reference signal.

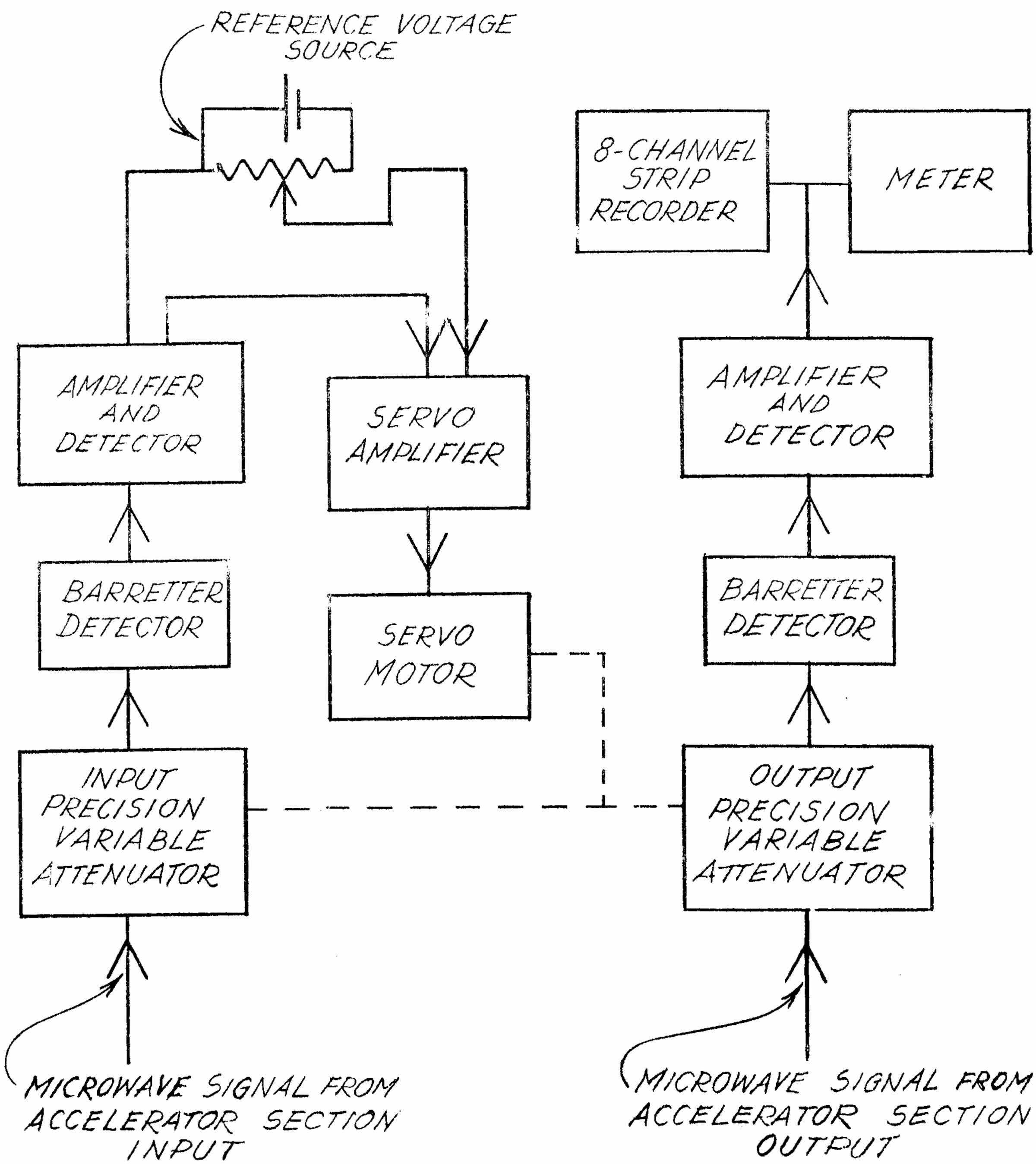


FIG. 5--Attenuation measurement system for high power accelerator section tests.

If there were no change in the attenuation of the accelerator section as the microwave power level is changed, the microwave signal at the output of the output attenuator would be constant and independent of the power level. In fact, any change in the microwave power at the output of the output attenuator indicates a corresponding change in the attenuation of the accelerator section. In this system, then, any change in the dc amplifier signal that is derived from the output of the output attenuator is taken to indicate a change in attenuation of the accelerator section. This signal will be metered directly and recorded on the 8-channel strip recorder.

b. Input RF Power

Standard microwave power meters will be used to measure samples of the microwave power incident on the accelerator section reflected from its input and transmitted through it. However, the readings from power meters have suffered from instability for the lower levels of microwave power measured, because of changes in the ambient temperatures in the vicinity of their thermistor detectors. As a result, these thermistors will be located in temperature-controlled chambers. One such chamber has been procured and will be tested in the next quarter.

c. Phase Variation

Equipment for measuring the variation in the phase shift through the accelerator section has been ordered from an outside vendor. Delivery is expected in September, 1963. Figure 6 shows a block diagram of this equipment. Microwave signals sampled from the input and output of the accelerator section are fed into opposite ends of a waveguide slotted section. At the microwave frequency, well-matched impedances are seen looking outward from the two ends of the waveguide slotted section. On the slotted section is mounted a carriage that is capable of axial movement along it. The carriage in turn holds two probes, axially displaced by a quarter guide wavelength, which couple to the fields inside the slotted section; crystal detectors are connected to the probes. The pulsed outputs of the two crystal detectors are fed into a gated differential amplifier. The gating, or sampling period, in this amplifier has a width of 1/4 microsecond, and this is adjusted to occur within

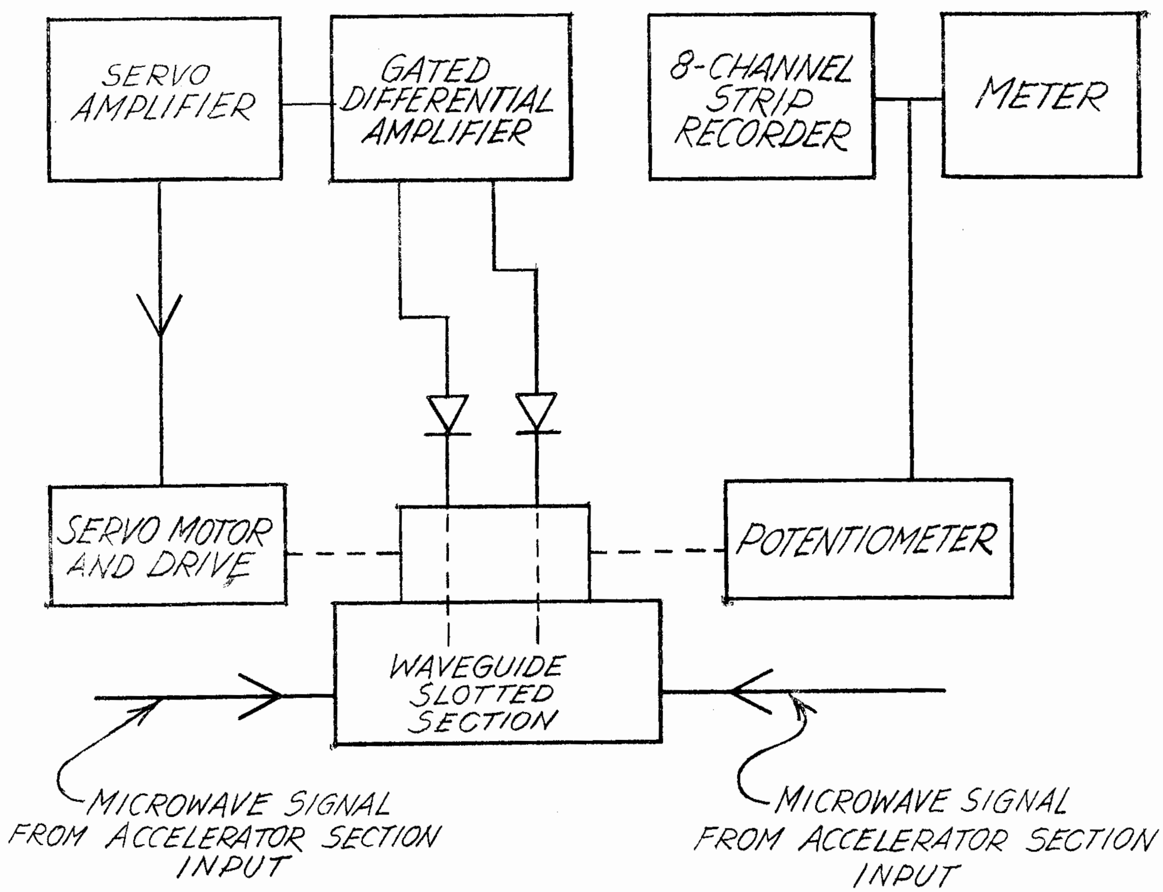


FIG. 6--Phase measurement system for high power accelerator section tests.

the central portion of the 3 microsecond microwave pulses that appear at the input and output ends of the accelerator section. When the output of this amplifier is zero, the pulsed outputs of the crystal detectors are equal within the gating period. The dc output of the gated differential amplifier is used as an error signal to drive a servo system that moves the carriage along the slotted section. As a result, a movement of the carriage is linearly proportional to a change in the phase relationship between the microwave signals that appear at the ends of the slotted section. A linear potentiometer, coupled to the carriage drive, is used to provide a voltage proportional to the carriage movement. This voltage is metered directly, and is also supplied as an input to the 8-channel strip recorder.

## 6. Accelerator Water Jacket

A 12-foot-high retort furnace was put into operation during the previous quarter. The furnace was constructed to prove the feasibility of attaching the cooling tubes to the accelerator pipe by brazing and for use until the pit furnace at the site is in operation. A cooling jacket assembly was brazed successfully to accelerator section No. 22 in the furnace. It was found that the entire assembly, including manifolds, feed tubes, fittings, and cooling tubes, could be brazed in a single operation.

The water jacket on accelerator section No. 22 was modified slightly from the previous models. The inlet and outlet manifolds were located at the midpoint of the section so that the water flow from the supply manifold would flow through four feed tubes, split into eight "hairpin" cooling tubes, and flow back through four return tubes into the return manifold. Such an arrangement is shown in Fig. 7. It was desirable to move the manifolds away from the accelerator section ends where accelerator support members, waveguide transition supports, end flanges, and rf input and output waveguides are located. The modification also cuts in half the number of manifolds and feed and return tubes required.

Tests on accelerator section No. 22 in Test Stand I with up to 15 kw of average input rf power have shown that the performance of the modified water jacket arrangement is essentially equal to that of the best of the

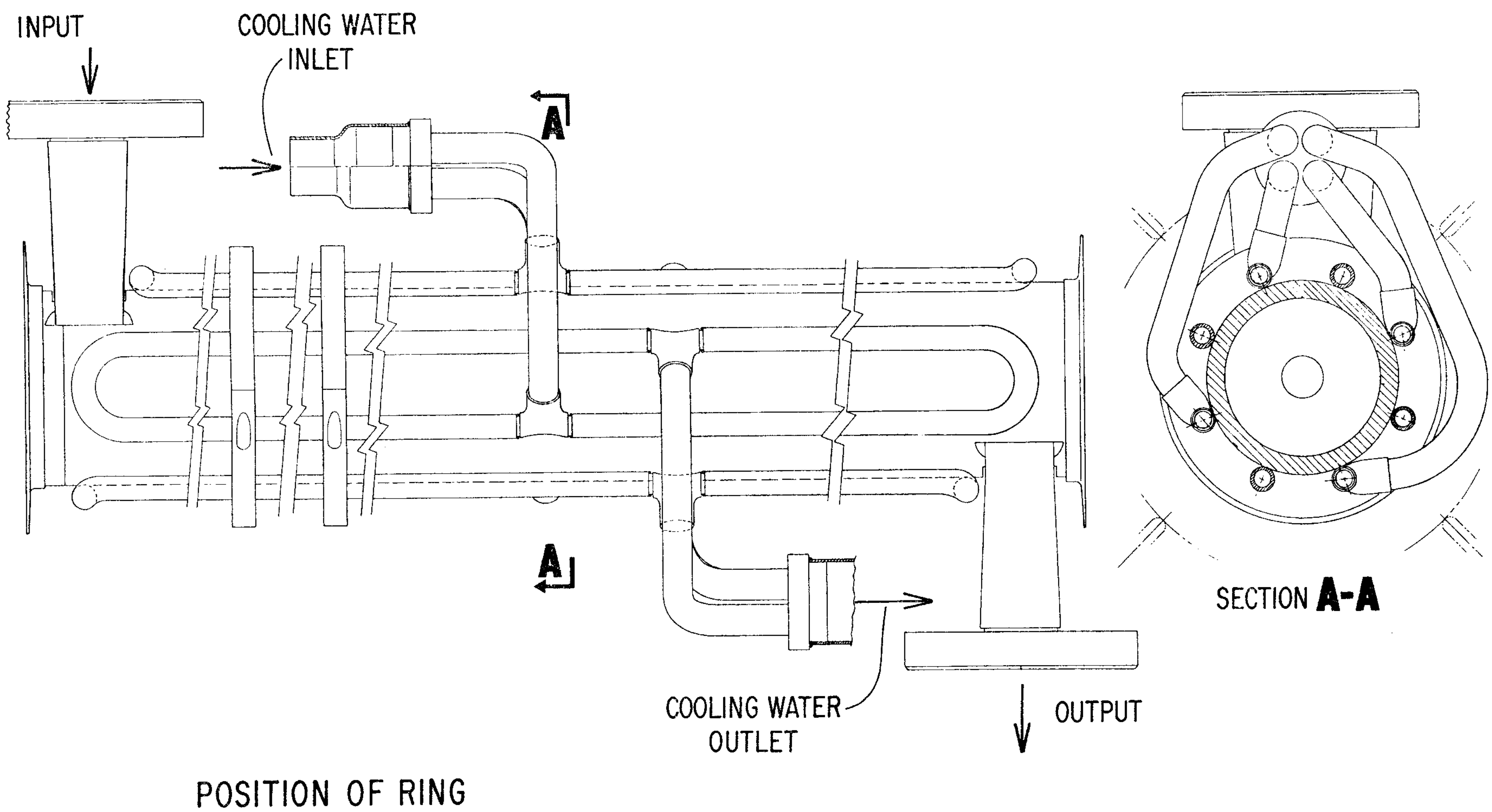


FIG. 7--Accelerator cooling tubes assembly.

earlier water jackets. Temperatures on the accelerator fell within a 1.0°F band at the highest power level. The temperature was found to be high in the first two cavities at the input end. This effect is attributed to the heat that is dissipated in the uncooled input waveguide and then transferred into the cooler accelerator section. It is expected that cooling the input waveguide will allow us to attain a temperature uniformity on the accelerator section of ± 0.4°F at full Stage II operating conditions.

7. Dummy Load Water Jacket

A water jacket to cool the disk-loaded load was designed. The cooling water flows around the load in a spiral path. Accelerator cooling water in a series flow arrangement will be used to cool the loads on the accelerator sections. The water jacket will allow the load to absorb up to 7 kw of rf power continuously without affecting its VSWR or the temperature of the accelerator section to which it is attached.

8. Accelerator Ten-Foot Support (Strongback)

After the water jacket with its manifolds is brazed onto the disk-loaded waveguide, the assembly is mounted onto the strongback. During the mounting, adjustments are made to bring the two ends and the two-thirds points of the disk-loaded waveguide straight within 0.002 inches. The strongback is designed to protect the disk-loaded waveguide and the waveguide transitions throughout the tuning and rf processing, which take place after assembly. In particular, the strongback is designed to support the disk-loaded waveguide so that it will not take on a permanent set if exposed to an acceleration of one "g" in any direction.

In addition to the above functions, the strongback provides strength adequate to carry the forces imposed on the waveguide transitions by the adjoining waveguide and vacuum systems after final installation of the strongback on the 40-foot support beam. Accurately located alignment holes in the end assembly of each strongback are used for optical alignment of four strongbacks while they are being mounted onto the support beam. The largest axial differential thermal expansion allowed between any of the four copper disk-loaded waveguides and the 40-foot aluminum structure is 0.320 inch. Therefore, the other functions of the strongback must not be influenced by an axial displacement of ± 0.160 inch of the disk-loaded waveguide relative to its strongback.

The final design of the strongback has been completed, and specifications for this design have gone out for bids. The ten-foot beam member is an extrusion. The end assemblies will be fabricated out of castings, extrusions, and bar stock before final machining takes place. Six sets of castings for end assembly prototypes are now on order. Current plans are to use the final strongback design for the 31 sections required to rebuild the Mark III accelerator.

B. HIGH POWER WAVEGUIDE COMPONENTS

1. Waveguide Valve

Valve $A_6$ of the offset model A design was tested satisfactorily at 52 megawatts of peak power and 9 kw average with no evidence of any rf arcing problems. The prototype design valves have been modified to eliminate O-rings and are now completely an all-metal construction. The production design offset model A valve (complete all-metal design) is now complete and three samples have been fabricated.

The initial prototype of the in-line model B valve and two improved models with actuators have been in operation on the Purple Coffin test stand facility. Operating experience to date has been very good and these valves have permitted much better klystron usage since window vacuum leaks do not necessitate klystron replacement with each new test load. An improved actuator design is being incorporated into the production design of the in-line waveguide valve.

The major problem which is common to both valve types is that of obtaining a reliable method of wetting the indium vacuum sealing material to the stainless steel base. Effort now directed to this problem is expected to yield a satisfactory solution to improve the present 30% yield of the valves that are satisfactorily wetted in the initial assembly. It now appears that a properly wetted seat will allow in excess of 100 closures which are vacuum tight against helium before a re-melt of the indium seat is required.

A test program is in progress to fabricate twelve each of the model A and model B valves to evaluate their performance for application as final production designs.

2. Waveguide Flanges*

The waveguide flange selected for the SLAC machine is a round flange with a round stepped-type vacuum seal incorporating a 0.030 OFHC copper gasket.** These flanges have satisfied all design criteria, with one exception: the female flange which is on the klystron has to go through a relatively high temperature bakeout cycle. During this bakeout cycle the copper gasket tends to weld to the flanges. To minimize this welding bakeout tests will be performed on flanges using plated copper gaskets. The first metals which will be tried as plating are nickel and rhodium. Final specifications for procurement of 6500 pairs of waveguide flanges and their associated gaskets were prepared and sent to prospective bidders. The successful bidder will fabricate 250 pairs of flanges as a pre-production run using tooling identical to that he would use during manufacture. The pre-production run will be evaluated carefully for conformance to mechanical and metallurgical specifications. In addition, vacuum and high power microwave transmission tests will be made to establish further the performance characteristics of the flange design. Upon satisfactory completion of these tests the vendor will be authorized to proceed with manufacture of the flanges at a rate of approximately 500 pairs per month. It is expected that evaluation of the pre-production run will be made during the next quarter. Approximately 20,000 bolts (5/16 - 24 NF) are required for assembling these flanges. At present it is planned to have the bolts and nuts chemically cleaned along with the gaskets and flanges to minimize contamination of the waveguide system during final assembly. To minimize friction between the cleaned bolts and nuts a flask of indium or copper plating on the bolts will be used. The final specifications for the nuts and bolts are completed and have been sent out to prospective bidders.

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*"Two-mile accelerator project, Quarterly Status Report, 1 January to 31 March 1963," SLAC Report No. 16, Stanford Linear Accelerator Center, Stanford University, Stanford, California; p. 19 (May 1963).

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

3. Waveguide Layout

A decision was made during the quarter to revise the layout of the waveguide system for Stage I to that shown in Fig. 8. The effect of this revision is to lower costs by reducing the number of waveguide valves, flanges, bends, and feet of waveguide. By placing two of the three power dividers per forty-foot segment in the accelerator housing, only one waveguide per penetration is needed, rather than the two required in the earlier design. A disadvantage of this new approach is that conversion to Stage II requires shut down of the machine on a sector basis.

4. Power Dividers

With the change in the waveguide layout described above, a change was made in the type of power divider to be used. Dr. Leo Young of Stanford Research Institute has reported in private communication that side wall 3 db hybrid junctions can transmit 70 percent of the power transmission capacity of the waveguides terminating the junction, while matched magic tee junctions transmit less than 25 percent. Short-slot side wall hybrids are now in use at SLAC in vacuum resonant ring structures, in which ring power levels have been achieved in excess of 100 megawatts peak and 100 kw average. Incorporating this type of power divider into the waveguide layout will eliminate the need for matching irises and may permit conversion to Stage II without the need to remove waveguides from the accelerator housing.

5. RF Loads

Further development of the lossy wall disk-loaded waveguide section was accomplished during the quarter, and four loads of this type were fabricated and tested. These loads are now in use terminating the accelerator sections in the Test Tower. Tests on one of the loads made in High Power Test Stand No. 1 (purple coffin) showed the load behaves in the same manner as an accelerator section during the processing procedures. After three hours processing (i.e., slowly increasing rf power while the interior wall surfaces are cleaned up by outgassing) the load operated in a stable condition with 11.5 megawatts peak power and 13.3 kw average power. No attempt was made to increase the power beyond this

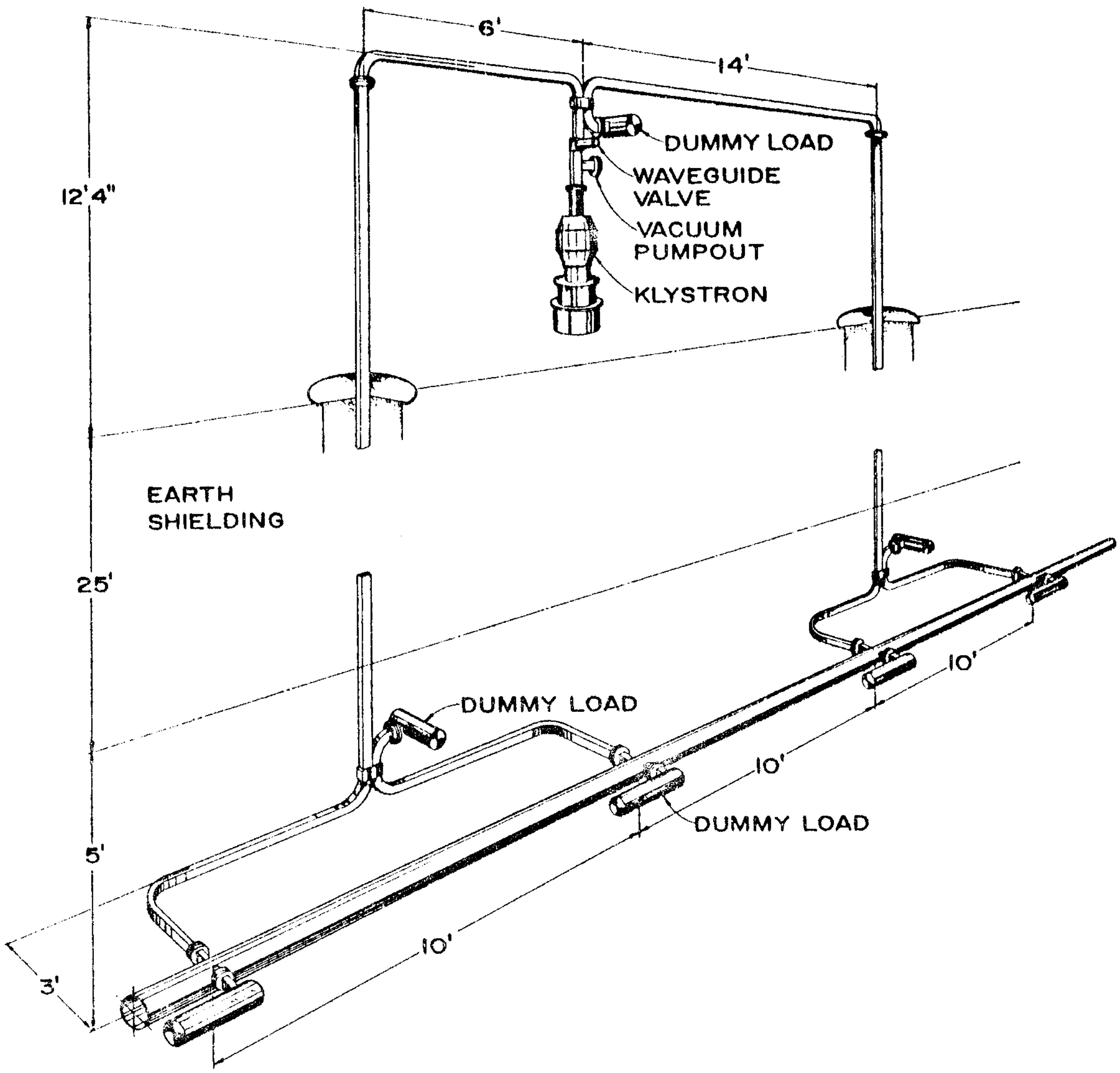



FIG. 8--Modular arrangement of klystron, accelerator sections and connecting waveguide.

value because the load used an interim design for its cooling jacket. With this successful operation of the load, the design for an improved cooling jacket was made and an order for eight more loads was submitted to the fabrication shops. In parallel with the above circular cavity loads, a design was made for a rectangular cavity load using a lossy wall direct-coupled resonator filter as the basic structure. This design uses a tapered attenuation characteristic such that equal amounts of power are absorbed in each cavity, thus minimizing the heat transfer problem. A transverse electric field is used in the rectangular cavity load; hence it is expected that radiation resulting from acceleration of free electrons will be much smaller than in the circular cavity loads.

6. Directional Couplers

Directional couplers are required in the rectangular waveguide of the accelerator system to perform the following tasks:

1. Monitor forward power out of the klystron.
2. Monitor reflected power from the waveguide.
3. Monitor forward and reverse wave shapes.
4. Provide a relative phase signal at output of accelerator sections.
5. Provide a measure of VSWR for interlock protection.

The basic directional coupler developed for use in the test stand program is illustrated in Fig. 9. This coupler is of the loop type with an aluminum oxide window to preserve the waveguide vacuum. The coupler body was purchased from Microwave Devices, Inc., a subsidiary of the Bendix corporation. A stripline directional coupler package is used to terminate, with low VSWR, the basic directional coupler and to divide the coupled power into the various monitoring circuits. The circuit of the stripline is illustrated in Fig. 10. When the basic coupler and its stripline package are combined together, coupling and performance characteristics are obtained as shown in Fig. 11.

7. Test Tower

Measurements of the power division using a full scale waveguide system were made using the Test Tower (tree house) test facility. The waveguide run is shown schematically in Fig. 12, in which the power dividers consist of magic tees.

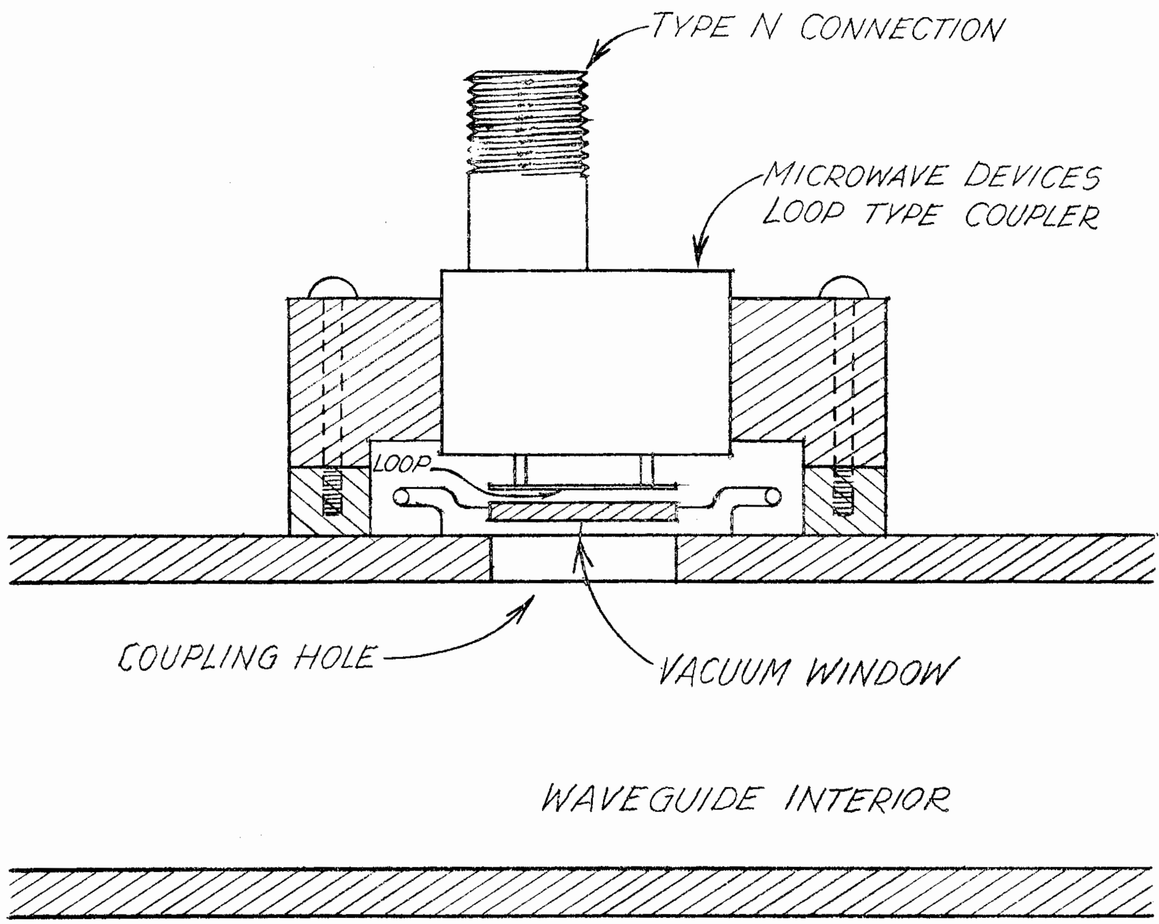



FIG. 9--Directional coupler used in test stand program.

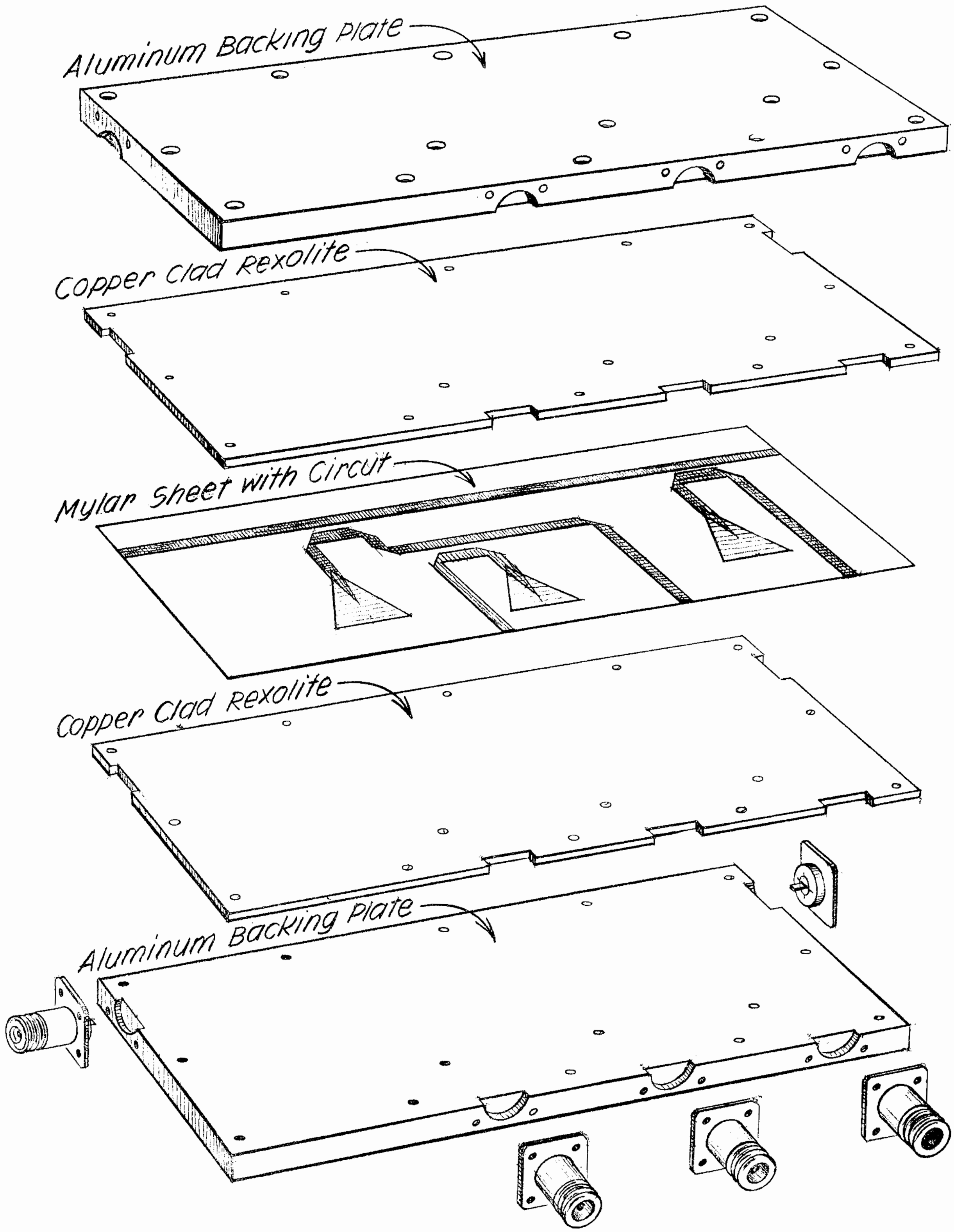
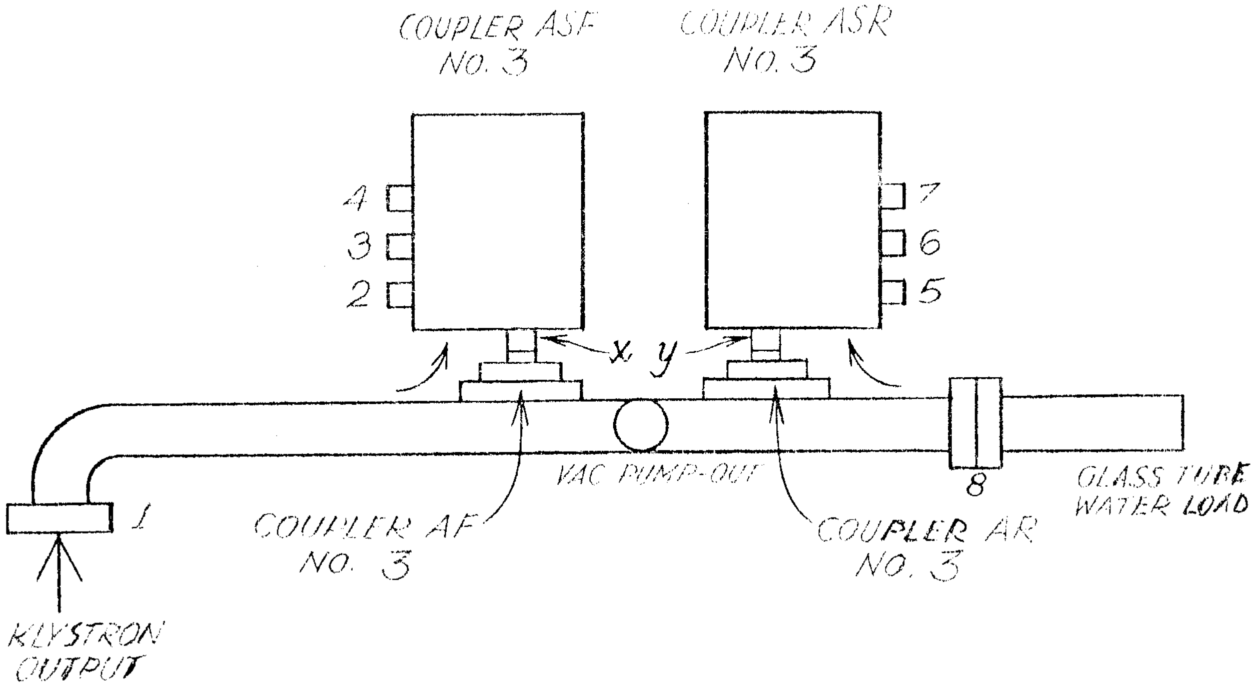



FIG. 10--Stripline circuit type directional coupler.




CALIBRATION FREQUENCY — 2856 mc

| Coupling in db | |
|---|---|
| 1 - 2 | 69.7 |
| 1 - 3 | 70.2 |
| 1 - 4 | 101.0 |
| 1 - x | 50.0 |
| 8 - x | 80.2 |
| 8 - 5 | 69.6 |
| 8 - 6 | 70.3 |
| 8 - 7 | 90.3 |
| 8 - y | 50.2 |
| 1 - y | 78.7 |
| x - 2 | 19.7 |
| x - 3 | 20.2 |
| x - 4 | 50.0 |
| y - 5 | 19.4 |
| y - 6 | 20.1 |
| y - 7 | 51.0 |

| VSWR into port | |
|---|---|
| *1 | 1.06 |
| 2 | 1.09 |
| 3 | 1.10 |
| 4 | 1.03 |
| 5 | 1.03 |
| 6 | 1.14 |
| 7 | 1.04 |
| x | 1.02 |
| y | 1.12 |

*With matched load terminating Port 8

Directivity in db

Forward coupler = 30.2
(Model AF)

Reverse coupler = 28.5
(Model AR)

FIG. 11--Calibration data, coupler system.

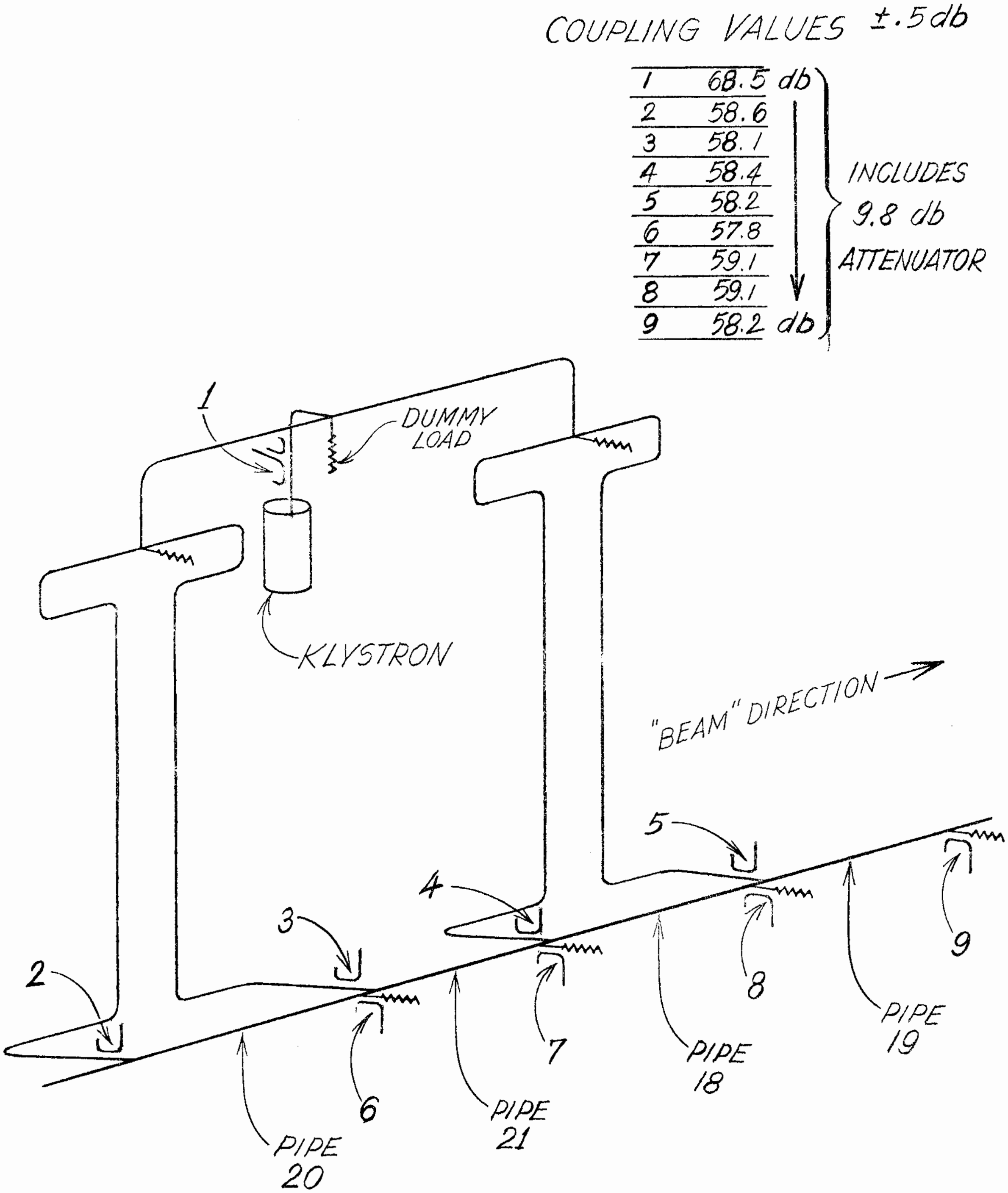



FIG. 12--Location of directional couplers in Test Tower waveguide system.

The average rf power was measured at the klystron output and at the input and output of each accelerator section. All measurements were made at an operating frequency of 2857.1 Mc/sec with accelerator pipe temperatures at 113°F. A duty cycle of 0.00108 was used (3 microsecond pulse width, 360 pulse repetition frequency). Test results and computations are presented in Table I.

The finite line losses and mismatches encountered in the waveguide system reduce the power available to each accelerator section. A tabulation of representative values is given below, these being order of magnitude figures not established by separate measurement of each item:

"Theoretical" Composition of $\alpha$ Waveguide

| | |
|---|---|
| Waveguide losses ($6.3 \times 10^{-3}$ db/ft $\times$ 70 ft) | 0.441 db |
| Input VSWR to first tee (1.35:1) | 0.100 db |
| Non-perfect power split in tee | 0.100 db |
| Input VSWR to second tee (1.15:1) | 0.020 db |
| Non-perfect power split in tee | 0.100 db |
| VSWR of harp assembly (1.15:1) | 0.020 db |
| Loss due to butt joints (0.001 db/joint $\times$ 17) | 0.017 db |
| Loss due to stainless steel flange joints (0.01 db/joint $\times$ 9) | 0.090 db |
| Input VSWR of 'S' assembly into pipe (1.10:1) | 0.010 db |
| Loss due to waveguide pumpout (0.01 db/pumpout) | 0.030 db |
| Estimated Total Loss Per Run | 0.928 db |

The power measurements reported herein were made with a Hewlett-Packard model 431-B power meter and model 478-A thermistor mount. The directional couplers used in these tests were designed and fabricated by SLAC and calibrated to an absolute accuracy of ± 0.5 db. The relative coupling level from one coupler to the next is within ± 0.1 db. The same power meter was used at each measurement point to minimize meter error.

Table I provides the measured power levels at the inputs and outputs of each of the four accelerator sections in the Test Tower. From this table, decibel attenuation levels for the accelerator sections were calculated as shown. These values are nearly 0.5 db higher than those measured under cold test conditions.

Low power tests indicated that the output arms of the power dividers used in the Test Tower measured within 0.1 db of power division by a

TABLE I

| | | | | |
|---|---|---|---|---|
| Measured klystron power output (directional coupler) | 10.6 kW | | | |
| Power division by four | Pipe #20 | Pipe #21 | Pipe #18 | Pipe #19 |
| * Calculated power input to pipes based upon .9 db loss to pipes 20 and 21 and .96 db loss to pipes 18 and 19 | 2.16 kW | 2.16 kW | 2.13 kW | 2.13 kW |
| Measured power input to pipes (directional coupler) | 2.31 kW | 2.30 kW | 2.15 kW | 2.27 kW |
| Measured power input to pipes (calorimetry) | 2.4 kW | 1.8 kW | 1.9 kW | 1.9 kW |
| Measured power output from pipes (directional coupler) | 632 W | 698 W | 617 W | 662 W |
| Measured power output from pipes (calorimetry) | 570 W | 490 W | 520 W | 520 W |
| Indicated pipe loss (directional coupler) | 5.63 db | 5.17 db | 5.41 db | 5.34 db |
| Measured pipe loss (at low levels) | 4.86 db | 4.86 db | 4.95 db | 4.99 db |

*NOTE: The path length to pipes 18 and 19 is 10 feet longer than to pipes 20 and 21.

factor of two. Reference to Table I will show this to be confirmed for the power divider which feeds pipes 20 and 21. The power divider feeding pipes 18 and 19 appears to be unbalanced by 0.3 db.

The indicated power input to the accelerator sections is higher than is predicted with a path loss of 0.9 db for pipes 20 and 21 and 0.96 db for pipes 18 and 19. As determined by directional coupler measurements, the path loss to pipes 20 and 21 is 0.7 db.

Several sets of temperature measurements were made on the waveguide accelerator sections and loads in the Test Tower concurrent with the above microwave power measurements. Before the waveguide runs were insulated, average temperatures differed by as much as 1.0°F in those runs where power division by four had taken place. The waveguide is now approximately 75 percent insulated and the average differs by approximately 0.4°F on the 1/4 power runs. The measurements were made at a klystron output power of 13.3 kw. More complete and more uniform coverage of the waveguide with water cooling tubing and additional insulation would reduce the leg-to-leg temperature difference.

Calorimetric measurements on the accelerator sections and loads showed the power picked up by the water to be about 20 percent lower than the power inputs determined from attenuation measurements. Agreement was very good on one accelerator section which was insulated. The differences can be attributed to the heat loss from the 113°F components to the 70°F ambient temperature and to uncertainties in the temperature, water flow, and attenuation measurements. The heat losses were approximately 20 percent. In addition, the calorimetric measurements are accurate to approximately ± 15 percent and the attenuation measurements to ± 10 percent. In future tests, the components will be well insulated and the calorimetric measurement technique improved.

Stage II of the Test Tower operation was begun during the quarter. This stage connects the full output of the klystron directly to a single accelerator section, thus providing a test of the change to Stage II in the SLAC machine.

Fabrication of waveguide for Stage III of the Test Tower operation was begun concurrent with Stage II. Stage III will utilize the present vacuum system and accelerator sections, but will use the new waveguide arrangement shown in Fig. 8. It is planned that refined power division measurements will be made and that a careful phase tuning of the waveguide system will be achieved to test the measurement procedures before manufacture of the SLAC system.

# IV. KLYSTRON STUDIES

## A. SUMMARY

During this quarter the work of the subcontractors for klystron procurement has been carefully monitored, but neither company appears ready to deliver acceptable tubes on the early delivery dates. The fabrication and test of the Stanford tube has continued and the latest improvements introduced in these tubes appear to have resulted in higher power output performance and elimination of troublesome oscillations. An effort has been made to produce diodes which can be used for final tests of the Stanford prototype modulator. Test procedures and acceptance of purchased tubes have been studied in collaboration with the vendors. Installation of klystrons and handling of klystrons in the klystron gallery has been under active study. The window study activity has been greatly aided by the availability of the all-metal resonant ring; the effect of coating on windows is being studied systematically both on the "new" ring and on the old ring.

## B. SUBCONTRACTS

Liaison with Sperry and RCA to monitor activities under their procurement subcontracts has uncovered some discrepancies among the beam voltage measuring techniques used at Sperry, at RCA, and at Stanford. Until these differences either are fully resolved or the subcontractors' tubes are tested in Stanford sockets with Stanford equipment, it is difficult to quote meaningful performance data from the subcontractors. However, as of the end of the quarter, Sperry had reported measuring more than 24 Mw at 250 kv with electromagnet focusing and RCA had reported approximately 22 Mw under the same conditions. Detailed phase measurements have not yet been taken; the gain of the Sperry tube appears marginal, and the performance in the permanent magnet is not yet up to that in the electromagnet. Hopefully, both Sperry and RCA will be able to ship us some tubes for test and evaluation purposes during the coming quarter.

## C. STANFORD FABRICATION AND TESTS

During the past quarter Stanford has repaired, built, baked, activated and tested 26 klystrons. The majority of these were rebuilt tubes, although from approximately the first of June four tubes of a new type (Stanford's "G" series) have been tested. Of all tubes tested, three were lost by rf window failure before completion of tests and several were declared non-usable for various reasons.

One of the processing stations was inactive during the quarter because of modifications introduced to change the switch tube from ignitron to thyratron, to improve the pulse shape, and to permit operation at a higher repetition rate. On the other two stations a total of approximately 900 hours was spent in tube processing, 160 hours in tube and load installation, and 260 hours in station maintenance and trouble shooting. Accordingly, the two operating stations were available more than 85 percent of the time for testing and tube installation.

Five cases of broken windows, one case of low emission, and one shorted filament necessitated changes of klystrons in the various stations using them. The number of hours before window failure varies from 50 to 300, although at present one tube has 500 hours of operation without failure on the Mark IV accelerator. Collector failure (probably from insufficient cooling water) terminated the use of one diode after 48 hours of operation on the modulator tests. In addition, three tubes in storage were found to have broken windows when an attempt was made to operate them in the socket. As a result, we have at present ten operable tubes in storage, four of which are of the G version.

## D. KLYSTRON DEVELOPMENT

At the present time the Stanford klystron development is divided among three main areas: (1) modifications of the rf structure to eliminate oscillations, (2) modifications in the gun to eliminate occasional gun oscillations and to improve beam optics, which should result in lower magnetic field and better tube performance, (3) permanent magnet tests.

1. A brief review of the various types of tubes built by Stanford is given in Table I.

TABLE 1

TUBE NOMENCLATURE

| | Drift Tube Diameter | Output | Gap-To-Gap Length | Cavities |
|---|---|---|---|---|
| A | 1-1/8 in. | Dual, waveguide cavity | 17 in. | All different, various configurations |
| B | 1-1/8 in. | Dual, waveguide cavity | 14 in. | |
| C | 1 in. | Dual, waveguide cavity | 14 in. | Cylindrical, various heights |
| D | 1 in. | Single, waveguide cavity | 14 in. | Symmetrical gaps ≈ 0.5 in. |
| E | 1-1/8 in. | Single, cylindrical cavity | 14 in. | Output $Q_e \approx 30$ to 45 |
| F | 1-1/8 in. | Single, cylindrical cavity | 13 in. | Input $Q_e \approx 160$ |
| G | 1-1/8 in. | Single, cylindrical cavity | 13 in. | Same as above, offset gaps<br>Output $Q_e \approx 19$<br>Input $Q_e \approx 160$ |

A few C and D version tubes were built, but the body interception was excessive with the reduced drift tube diameter. The E and F version tubes showed various body oscillations and a rather low efficiency in general. The modification that now appears to be the solution to most of these problems has been introduced in the G version; it consists primarily of offsetting the gaps in all cavities, as well as reducing the Q external of the output cavity to a value somewhat less than 20. Some of the G tubes have shown remarkably good performance with efficiencies exceeding 35 percent and gains higher than 50 db. However, if a frequency response curve is taken on these tubes, it is always found that the power output does not maximize at 2856 Mc/sec but rather at between 2860 and 2870 Mc/sec. In some cases the difference in power between 2856 Mc/sec and the maximum appears to be as high as 10 percent. The reason for this power output change over a very narrow frequency band (as compared to the theoretical band width of the output system) is not understood at the present time and will be studied. Meanwhile, we are in the process of building tubes where all cavities (except the penultimate) will be tuned intentionally to approximately 2850 Mc/sec.

2. Occasional gun oscillations are still observed between 175 and 225 kv unless the heater power is reduced to a point where the cathode is almost temperature limited. Some minor changes are being introduced

in the present gun structure, but since these oscillations are not present on all guns it is difficult to say that the changes introduced are contributing to the improvement. An entirely new gun has been designed, all the parts have been machined, and we hope to test this gun during the coming month. Theoretically, it should produce approximately the same beam diameter but, because of entirely different entrance conditions, it should be possible to operate the tube at a somewhat reduced peak magnetic field.

3. Toward the end of the quarter we were able to undertake again some tests of tubes on permanent magnets. Unfortunately, the magnets available at present are known to have weak fields compared to that needed to operate our tubes at full voltage (see Fig. 13). Tube "G-3" had given satisfactory performance in electromagnets with fields which duplicate those of curves A or B of Fig. 13, and reasonable performance up to 200 kv in fields duplicating curve C of Fig. 13. Accordingly, tube "G-3" was tested in a permanent magnet and the results are shown in Fig. 14. It can be seen that up to 200 kv, where the magnetic field of the permanent magnet approximates that of the electromagnet, the decrease in power output is less than 10 percent, and that the gain increases by almost 3 db at the higher voltages. During electromagnet saturation tests approximately the same gain and power output can be obtained with minimal changes in magnetic focusing. It is not fully understood why such a small change in magnetic field can cause the effects observed. In the hope of eliminating these effects a new gun is being built, which should be less sensitive to small variations in magnetic field.

E. ACCEPTANCE AND LIFE TESTS

All equipment necessary to test the tubes procured from RCA and Sperry has been ordered during the quarter and should be installed and checked out in an acceptance test stand by the time the first tubes are received from these companies. It is expected that during the coming quarter the total number of test stands needed for life testing of klystrons will be made available, and at this time the window life test facility will be reactivated for direct life comparison of coated and uncoated windows of the same design.

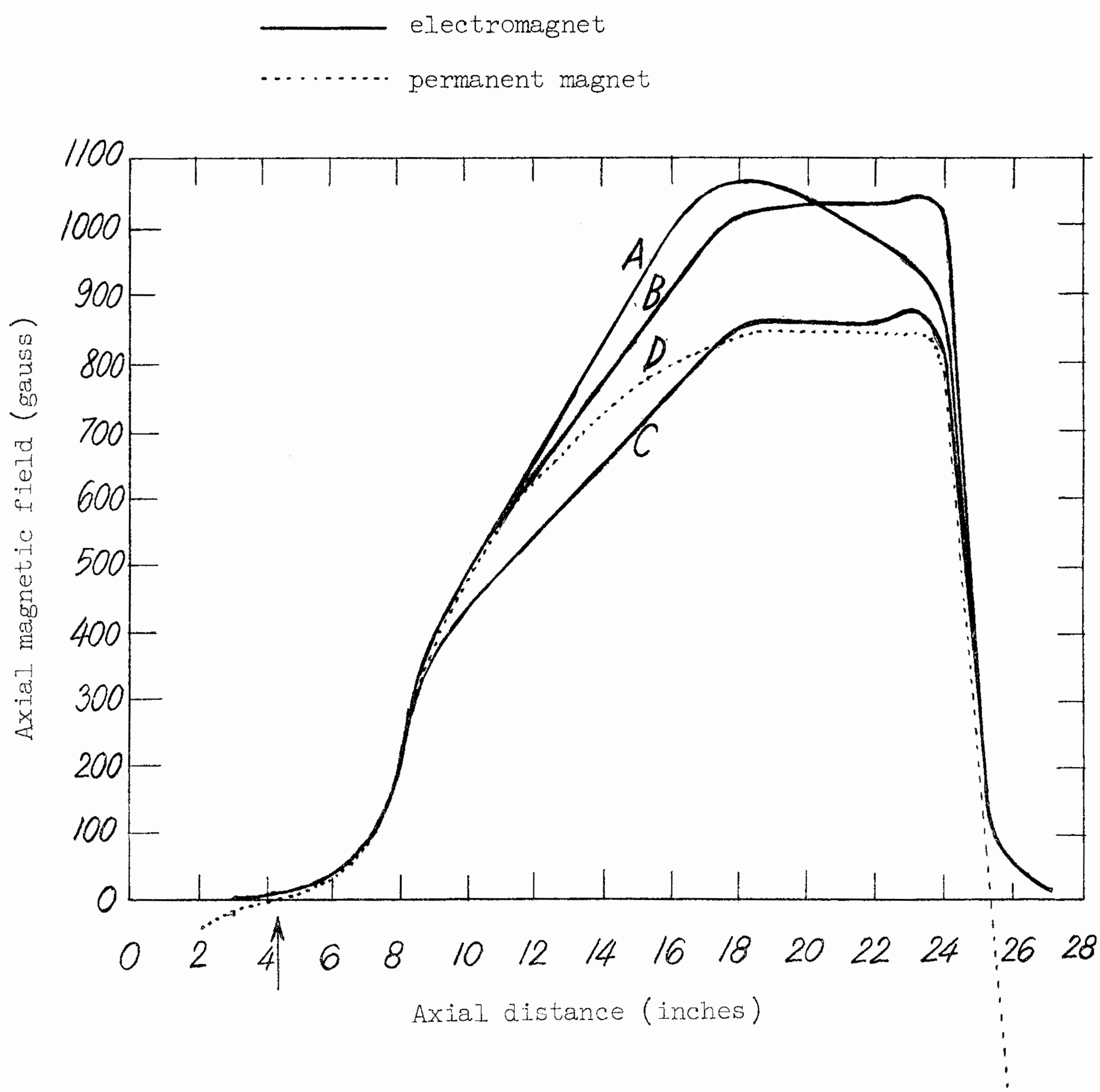



FIG. 13--Magnetic field curves.

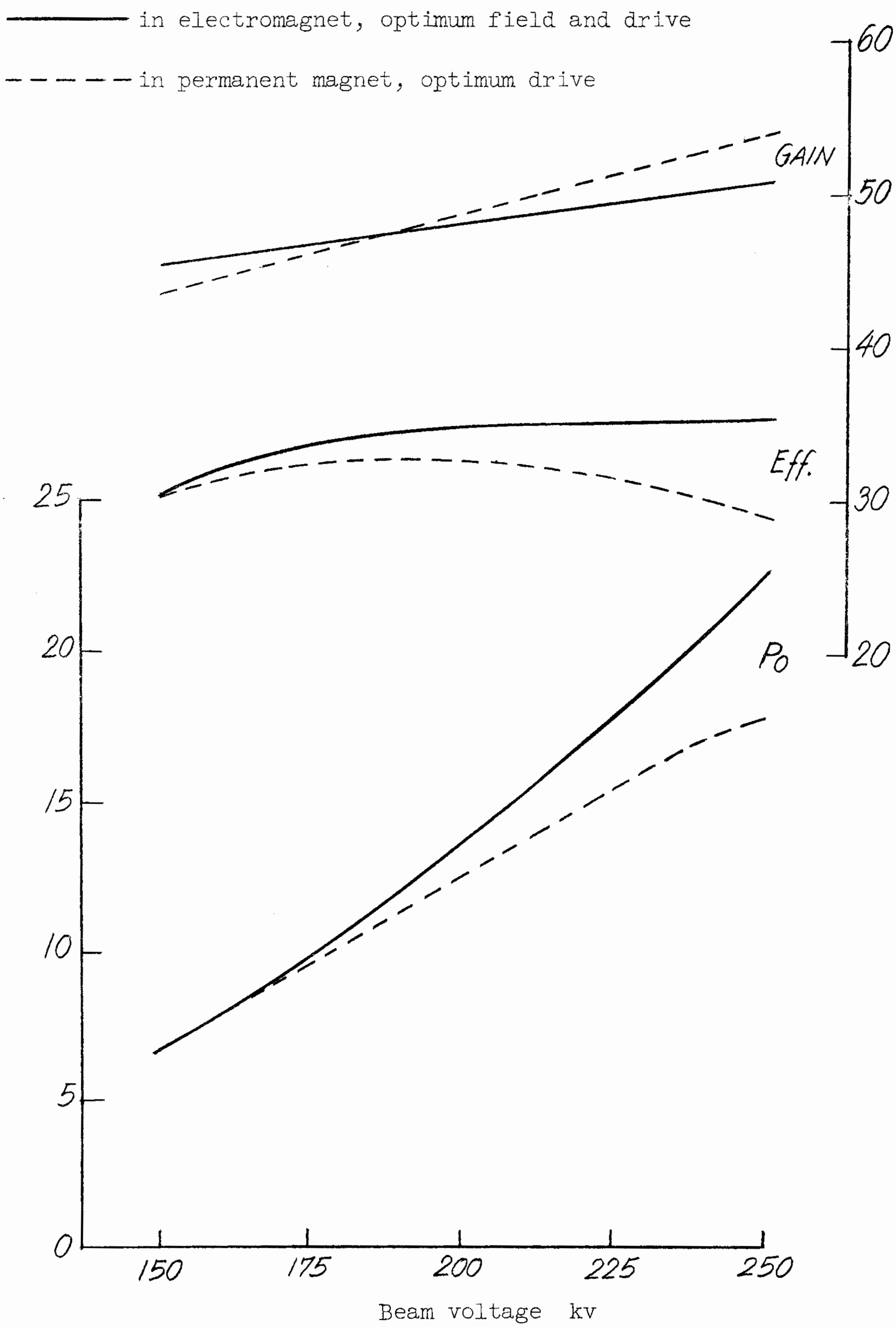



FIG. 14--Performance of klystron tube G-3-A.

F. SUB-BOOSTERS

During the past quarter Stanford has received thirteen sub-booster tubes from Eimac. In addition, one sub-booster received late last quarter was tested. Of the total of fourteen sub-boosters tested, two were reworks of tubes initially not acceptable because of insufficient band width. A total of twelve sub-booster klystrons has been accepted by Stanford during the quarter.

G. HIGH-POWER KLYSTRON WINDOWS

1. All-Metal Cavity Tests

Four smooth disks were tested in a cavity 3/2 wavelengths long, with the windows placed at the voltage maximum. Three failed before loading tests could be done. The fourth showed some loading at pressures above $10^{-6}$ torr, but much less than that shown by rough disks. Two rough disks were tested in this configuration and showed loading similar to that reported previously.* These tests show that the loading effect is not due to the viewing hole or matching iris in the cavity. Two disks were also run in a one-wavelength cavity with the disk placed at a voltage minimum. The behavior exhibited was similar to that of disks placed at the voltage maximum, although the equivalent power at the disk was less than 1 percent of the peak power in the cavity.

2. All-Metal Ring Tests

The all-metal ring is operating satisfactorily, although at higher powers heating of the phase shifter produces some pressure rise. Powers of 125 Mw peak, 115 kw average has been obtained using a 5 Mw drive. Seven alumina disks have been tested in the structure used on the current model of the Stanford klystron. Four were as built for tube uses, brazed vacuum tight; the other three were shrunk-in models. Some of these windows were given a thin coating of titanium. The results are shown in Table II.

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

TABLE II

HIGH VACUUM RESONANT RING WINDOW TEST RESULTS

(Samples Are Listed In Order Tested)

| Sample No. | Surface | Window Mount | Failure Power Level | Highest Peak Power | Loading[a] |
|---|---|---|---|---|---|
| 1 | Uncoated | Brazed | 2.2 Mw, 2 kw | 80 Mw, 12.5 kw | Normal[b] |
| 2 | Uncoated | Brazed | 6.6 Mw, 6 kw | 100 Mw, 16 kw | Normal[b] |
| 3 | Coated | Brazed | No failure | 91 Mw, 14 kw | Normal |
| 4 | Coated | Brazed | No failure | 110 Mw, 100 kw | Normal |
| 5 | Uncoated | Shrink-Fit | No failure | 120 Mw, 110 kw | Normal |
| 6 | Coated | Shrink-Fit | No failure | 84 Mw, 78 kw | Very heavy |
| 5 (Repeat)[c] | Coated | Shrink-Fit | 40 Mw, 37 kw | 40 Mw, 37 kw | Heavy |
| 7 | Uncoated | Shrink-Fit | Still under test | 120 Mw, 110 kw | Normal[b] |

[a] The "normal" gain of the ring with a window is about 14 db corresponding to a loaded Q of about 5000. "Heavy" loading is about 12 db gain or $Q_L \approx 3000$ and "very heavy" loading is about 10.5 db gain or $Q_L \approx 2000$.

[b] These windows have heavy loading around 10 Mw where the gain was about 12 db. Well above and below this level the gain was about 14 db.

[c] This test may not be representative as doubtful procedures were involved during test.

Although this sample is small, Table II shows that brazed uncoated assemblies show heavy loading and failure at low levels, but coated assemblies do not. The uncoated assemblies show a bright glow; the coated ones are nearly dark, although this varies from sample to sample. It is also noteworthy that shrunk-in uncoated assemblies did not fail. This may be an accidental result, since the later disks were run more carefully to avoid the "mode" of excessive loading at about 10 Mw observed on some disks. In this mode the pressure rises, the glow pattern becomes brighter, the radiation increases and the disk temperature* may rise several hundred degrees in a few minutes. In one test (#7) there seemed to be a tendency for the effect to be less as testing continued over a week. A systematic study of the effect of coatings has now been started.

3. Resonant Ring Tests

(a) Heil Windows

Tests on windows designed by Dr. Oskar Heil of Eimac were extended. A grooved $Al_2O_3$ window (Wesgo AL-300), coated with pure $SiO_2$ by sputtering from silicon in an oxygen atmosphere, has been tested. Four grooved quartz windows were tested, two of which differed from previous grooved quartz windows in that their grooves were more narrow and more shallow (1/32-inch spacing and depth, and 0.015-inch spacing and depth). Two disks, both with 1/16-inch spaced grooves and both previously tested without failure, were retested. One was destroyed when reoriented with its grooves parallel to the electric field; the other was retested without damage after both surfaces had been fire-polished. Table III below is an extension of the tabulation of tests in the previous Status Report.**

(b) Internal Damage Test

In order to determine the validity of the mechanism of internal failure suggested by RCA, an experiment was devised to eliminate any contribution to window damage from electron multipactor. This was done by mounting the window to be tested in a pressurized atmosphere (Freon-12)

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*As measured with a 1-R detector.

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

TABLE III

WINDOW TEST RESULTS

| Window No. | Material | Surface | Coating | Max Peak Power | Max Avg. Power (360) | Failure |
|---|---|---|---|---|---|---|
| 15 | $Al_2O_3$ | Grooved | $SiO_2$ | 91 Mw | 44 kw | Puncture and internal damage |
| 16 | $SiO_2$ | Grooved[a] | None | 88 Mw | 44 kw | None |
| 17[b] | $SiO_2$ | Grooved[c] | None | 65 Mw | ----- | Destroyed |
| 18 | $SiO_2$ | Grooved[d] | None | 88 Mw | 44 kw | None |
| 19[e] | $SiO_2$ | Grooved[f] | None | 86 Mw | 44 kw | None |

[a] 1/32-inch spacing and depth

[b] Formerly #9 (not damaged by highest available peak and average powers)

[c] Grooves parallel to electric field direction

[d] 0.015-inch spacing

[e] Formerly #11 (not damaged by highest available peak and average powers)

[f] Fire polished

confined between two vacuum-tight model A windows (Fig. 15). The window structure mounted in the pressurized environment was the "short-taper" structure for one-half wavelength alumina windows, chosen because of its consistent history of window failure at a power level of $\approx 28$ Mw.* The Freon-filled portion of the test structure withstood up to 50 megawatts without a half-wave window. Four half-wave windows of Coors AD-96 were tested. Two windows failed at about 28 Mw, the failures being definitely internal with no detectable surface punctures (see Fig. 16). The exact moment of failure could not be determined because of the nature of the test structure, but the failure levels were definitely less than 34 Mw and 31 Mw, respectively. Neither the third nor the fourth test piece was damaged during identical tests up to power levels of 42 Mw and 36 Mw, respectively. Because a suspected contribution to past failures in the $\lambda/2$ test structure is tilting of the flanges causing one side of the window to be slightly cocked, the fourth window is presently being retested after being cocked slightly more than in its original test.

These tests show that internal breakdown does take place without surface damage even though the field is less than at the surface. Surface punctures have also been found in other windows which do not result in any apparent internal damage. It now appears that at least three modes of failure may occur: (1) cracking due to thermal shock caused by excessive heating (multipactor), (2) internal dielectric breakdown due to excessive gradients, and (3) surface punctures, perhaps due to multipactor or local discharges. How these may interact is not clear.

(c) Surface Roughness

Testing has continued on the effect of surface roughness on windows. A smooth window (35 microinch finish) received in the latest shipment of Wesgo windows failed at 52 Mw peak power level. Damage appeared to be

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*See "Linear electron accelerator studies and proposed two-mile accelerator project, Combined Status Report, 1 July to 30 September 1961," M Report No. 280, Stanford Linear Accelerator Center, Stanford University, Stanford, California; pp. 28-31 (October 1961); and "Two-mile accelerator project, January 1962," M Report No. 294, Stanford Linear Accelerator Center, Stanford University, Stanford, California; pp 36-38 (January 1962).

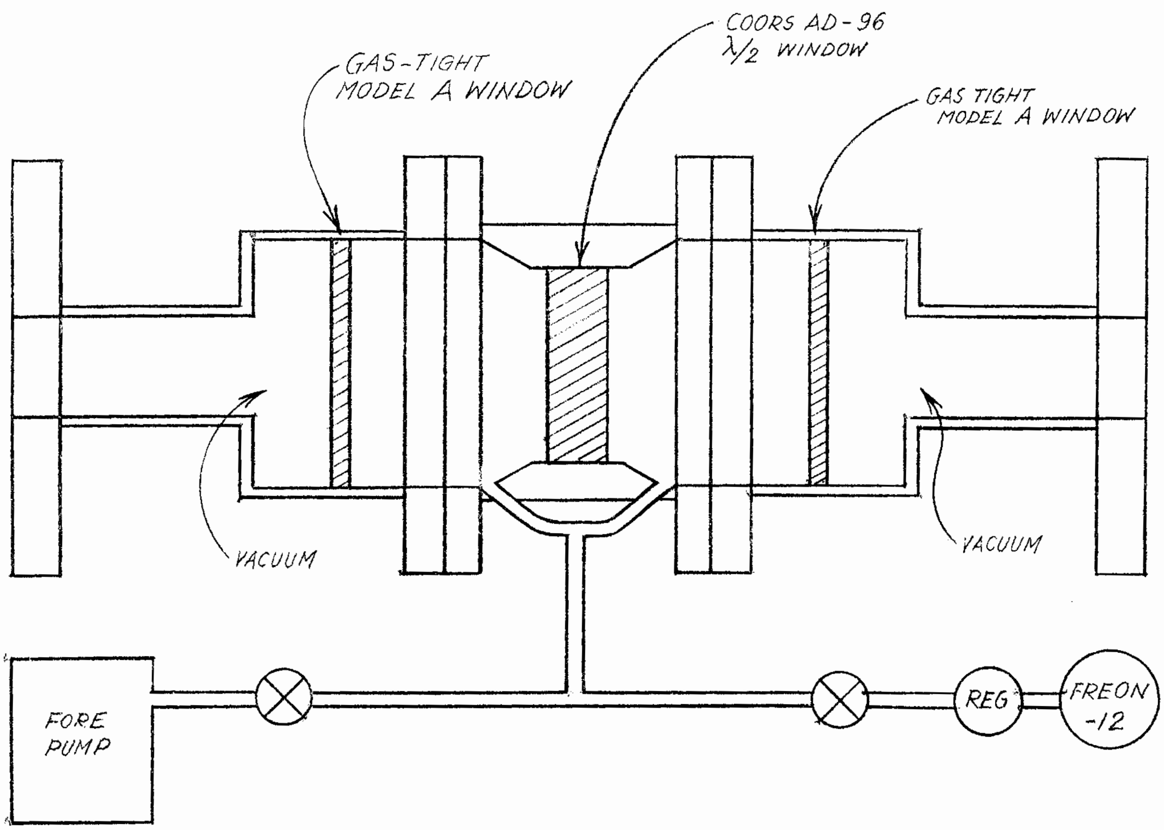


FIG. 15--Window internal damage test setup.

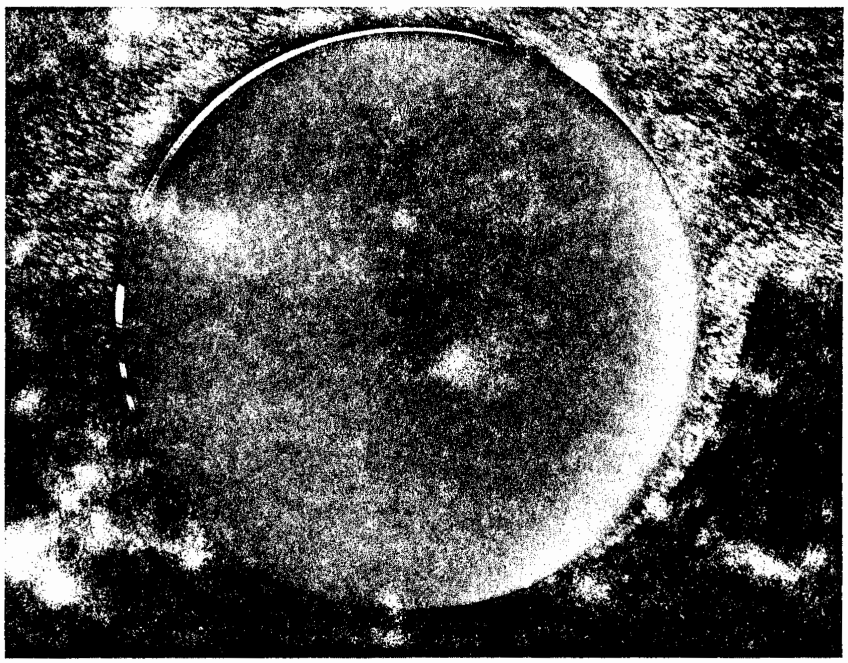

FIG. 16--Half-wave window with internal damage (illumination from rear).

solely internal. Otherwise, the operating characteristics of the window were similar to those of other smooth-surfaced windows.

Surface roughness measurements were made on all the flat alumina windows tested in the ring during the past year in an attempt to uncover some correlation between surface roughness and window performance. No easily recognizable correlation was evident, but there does seem to be some tendency for smoother windows to behave more erratically. An alumina window "roughened" to $\approx 240$ microinch finish by sand-blasting its surfaces with aloxite has been tested. It failed at 65 to 70 Mw with punctures and internal damage after having an operational behavior surprisingly similar to that of the smoothest windows.

(d) Other Ring Tests

A Zirconia window (Norton Refractories) has been tested in a symmetrical structure and has failed at 10 Mw ($\approx 2$ kw average) because of extreme overheating at its center, apparently due to the poor thermal conductivity of the material. Calorimetric measurement showed a negligible amount ($\approx 1/2$ watt) of dissipated power being conducted to the window sleeve, while an optical pyrometer showed the window center temperature to be greater than $1200^{\circ}$C.

A 1/16-inch quartz window mounted in model A geometry was tested and was destroyed at 35 Mw. Of possible interest in this test was a cyclic process of heating to visual thermal activity in expanding concentric regions. The visible phenomena were accompanied successively by intervals of violent electric breakdown followed by an increase in ring gain. The behavior probably indicates a change in the nature of the window material, most likely the loss of water previously absorbed by the quartz.

4. Electron Motion Calculations

An exact solution for electron motion for a plane wave has been obtained. This shows the expected drift toward the load with an oscillatory velocity having a frequency slightly less than twice the driving frequency. The velocity parallel to the E field has a dc and an oscillatory term; the latter has a frequency slightly less than the driving frequency (one-half of the frequency of the forward motion). The amplitude and frequency shift are, of course, a function of the field strength.

# V. MODULATORS

## A. THYRATRONS

Efforts to ascertain the best thyratron for use as a switch tube in the main modulators continued during this period. A summary of operating data from each tube follows:

### 1. General Electric Z-5212

This tube was operated for 849 hours in the RCA modulator before it failed. Upon investigation it was found that one of the heater leads was so oxidized that no heater current was able to flow. This was probably caused by a faulty connection at the tube's installation.

The log on this tube indicates an average run of two hours between kickouts over a 465-hour sampling period. Such a kickout rate on this tube is not inordinately high, however; the tube was weakened by the oxidized heater lead, and the system as a whole experienced problems with the water load, pulse transformer, and the pulse transformer tank cable connector.

This tube showed anode time delay variations of 0.35 microsecond at constant plate voltage. The repetition rate was varied from 60 to 360 pps. Holding the repetition rate constant, it has a 0.4 microsecond variation. Because our modulator pulse width is only 2.5 microseconds, time drifts of this magnitude cannot be tolerated without additional and undesirable circuit complications.

Another disadvantage of this thyratron is that operation must begin at approximately 3/4 full voltage for the instantaneous application of anode voltage to take place. Also, this tube is water-cooled, which is a more troublesome system than air cooling due to maintenance problems with the water hoses.

### 2. Kuthe KU 275A

The first KU 275A thyratron we received was installed in Ling modulator No. 11, where it was operated for a total of 271 hours. Because these thyratrons are run with a load impedance greater than the network impedance (positive mismatch), almost 250 kv output from the pulse transformer into a load impedance near 1000 ohms can be obtained, even though the power supply voltage is only 18 to 20 kv. The pulse is shorter than it would be using a higher power supply voltage, but approximately 2.5 microseconds on the flat top of the pulse is still attained.

When this tube was first installed in the modulator many kickouts occurred, due to bad capacitors. After replacing the faulty capacitors the tube ran satisfactorily.

It has operated a total of 1250 hours, including 140 hours at the Kuthe factory, 271 in Ling modulator No. 11, 794 hours in the RCA modulator, and 45 hours in our prototype modulator. The average time between kickouts (including those caused by modulator and pulse transformer tank troubles) in the RCA modulator over a period of 351 hours has been 4.1 hours.

The KU 275A tube has several advantages over the Z 5212; specifically, it utilizes air cooling as opposed to water, no bias is required, and its operation may be initiated at full plate voltage.

Anode time delay variations are present, not as great as those in Z 5212, but still much larger than can be tolerated without compensating for them in the triggering system. The anode time delay drift start-up is 0.35 microseconds (this is at full power and repetition rate, after the tube has been resting with heater and reservoir power applied). With respect to anode voltage variations, the anode time delay variation is 0.15 microsecond (about three times better than the Z 5212). The tube varies 0.25 microsecond within the 60 to 360 pps repetition rate.

A second KU 275A thyratron was obtained and installed in Ling modulator No. 2, where it has operated satisfactorily for 789 hours and is still running well. The usual capacitor troubles have caused kickouts, as have the loss of a charging choke and coaxial cable connector troubles at the pulse transformer tank, but in spite of these problems the tube seems as good as the first KU 275A.

3. Edgerton, Germeshausen and Grier HY-5

The first HY-5 thyratron was obtained and installed in the RCA modulators, where it was run for several days; it was then transferred to Ling modulator No. 2. Its total life span was 548 hours. The tube was operated satisfactorily at 40 kv anode voltage with long periods between kickouts, but it degenerated very quickly. Toward the end of its life the HY-5 tube showed serious anode time delay drifts with respect to repetition rate and anode voltage; changing from 60 to 360 pps caused a 0.7 microsecond shift in time delay in the tube.

Two additional HY-5 thyratrons were tested in Ling modulator No. 2; they failed after 32 hours and 60 hours running time, respectively. The tubes were returned to the E. G. and G. people for evaluation and were found to be leakers. They will be replaced shortly with two new tubes.

The HY-5 thyratron does not seem to be powerful enough to operate in SLAC modulators. It is reported to have a cathode area of 400 $cm^2$, but, due to back heating, the heater voltage must be cut back at higher powers in order to extend the life of the tube.

4. Kuthe KU 274

Two KU 274 tubes were installed in Ling modulator No. 11 on May 22, 1963. They were operated for 48 hours before they died prematurely due to a water hose rupture. Although analysis is difficult after this short a running period, they appeared to be fairly good tubes. Some noticeable disadvantages were a limited reservoir range and a probable high kickout rate. The KU 274 thyratron seems to be fairly stable with respect to anode delay time variations according to measurements made at Evans Signal Corps Laboratory, Fort Monmouth, New Jersey.

5. General Electric GL 7890

A pair of GL 7890 thyratrons has been operating in Ling modulator No. 6 for almost 200 hours and is still doing well, although this modulator has experienced trouble with pulse capacitors, the charging choke, the charging diodes, and pulse transformer arcing. In spite of this the tubes operated for 57 hours at full power without a kickout. The GL 7890's are rated at 40 kv, but they seem to equal some of the 50 kv tubes with respect to hold-off voltages. These tubes were later shifted to Ling modulator No. 11, which was in better operating condition. They turned in the longest run of all our thyratrons, 110 hours, without a kickout, before the modulator was shut down manually for other tests.

The split line setup used with two switch tubes is capable of a flatter pulse than can be obtained on a single line setup, because ripples on one line can cancel those on the other line. A ± 0.3% flatness, as compared with ± 0.5%, has been obtained with a single line. Total operating time on these tubes is 478 hours.

In June another pair of these tubes was obtained and installed. These tubes seem to be as good as the first pair, with a total operating time of 460 hours.

These tubes have a low anode time delay variation, 0.1 microsecond maximum, which was verified at SLAC and at Evans Signal Corps Laboratory. If this small amount of variation can be tolerated without compensating for it in the triggering system, a pair of these tubes may be the answer to the switch tube problem. Possible disadvantages are the rather conservative 40 kv rating of the tubes and the additional complexity of the system necessitated by the use of the tubes in pairs. However, a flatter pulse can be obtained with this tube, the internal inductance of pulse capacitors problem is lessened because split lines have higher impedance, and the similar General Electric GL 7890, Kuthe KU 274, and Tung Sol 7890 thyratrons afford good competition. The GL 7890 is also an older tube, having been on the market about two years.

6. M. O. Valve

The M. O. Valve Company's E2986 has been operating intermittently in the "purple coffin" modulator for several months at reduced power. The power level is held at about 50 percent due to rf testing power limitations. The M. O. valve is reported to be a very good switch tube, having great carrying capacity and very little anode time delay variation (less than 0.1 microsecond).

7. General Electric 7004

In June General Electric brought out a new tube for SLAC evaluation. It is an air cooled hydrogen thyratron with a gradient grid and a cathode area of 400 sq. cm. Its hold-off voltage capability is better than the KU 275A but not as good as the GL 7890. Anode delay time variations were comparable to the KU 275A. The longest full power run between kickouts was 93 hours in the RCA modulator.

B. SPARK GAP

Spark gaps were studied during this quarter to investigate the possibility that their use would result in a lower operating cost than the use of thyratrons.

A simple three element spark gap using 1/2-inch copper electrodes was built and operated. The highest voltage at which it would operate without frequent kickouts was 15 kv at the modulator power supply. After three hours operation at 360 pps the erosion on each electrode was about 1/8 inch. Such an intolerable amount of erosion could probably be reduced considerably by using larger electrodes and by oscillating the elements to distribute the erosion over a larger area.

The main problem is that the allowable deionization time is short due to our high repetition rate, so that the gap fails to deionize between pulses and kickouts result. Also, the voltage range over which such a spark gap operates is too limited for our type of operation.

C. PROTOTYPE MAIN MODULATOR

The prototype main modulator was finished, except for doors, in June. It was started up on a 6-ohm water load and began working satisfactorily immediately.

A new dissipative de-Q'ing circuit has been designed. This circuit is much superior to any type of ac regulation because it protects against overvoltages due to premature switch tube breakdowns, and it is faster than an ac regulator since it is faster than an ac regulator since it can correct amplitude variations from pulse to pulse.

Drawings and specifications on the basis of this prototype were begun. These drawings and specifications, including any future changes, will become part of the bid package for procurement of the modulators.

A decision was made during this period to procure modulators on a drawings basis. This type of procurement allows us to draw from our experience with the modulators purchased so far and the prototype now under test. It also permits maximum flexibility in the substitution of various types of switch tubes or spark gaps.

Because the present prototype was hurriedly built in a welded angle iron framework cabinet which is satisfactory only temporarily, and because changes involving de-Q'ing, etc., are necessary, a second prototype modulator in a production type of cabinet will be constructed. Such a cabinet was ordered and the ordering of parts was begun.

### D. PULSE TRANSFORMERS

During this period sample pulse transformers from four companies were tested. Two of the transformers passed all tests; the other two companies are rebuilding their units for resubmittal.

A prototype pulse transformer tank containing a pulse transformer has been improved to the point that it is now a fairly satisfactory operating unit. Problems with the small overall size of the tank and the high pulse voltages involved were rectified.

### E. SUB-BOOSTER MODULATOR

Two sub-booster modulators have been installed and tested for operation in the test stands. Three additional units were completed and are ready for testing and installation, and another sub-booster is still under construction.

A program has been set up for evaluation of alternate switch tubes which can be used in the sub-booster to replace the 4 PR 1000 tubes presently utilized.

The Machlett ML 7003 is a shielded grid triode containing a unipotential oxide cathode with relatively modest drive requirements. It features special construction to prevent damage by transient arcs. The unipotential cathode does not need a dc heater power supply to eliminate the hum present with the 4 PR 1000's. Because it is a triode, small "horns" on the output pulse caused by the space charge effects associated with tetrodes should be eliminated.

The ML 7003 has a peak plate voltage rating of 50 kv and a peak current rating of 200 amps. These ratings are far in excess of our requirements and are reflected in the cost of the tube.

A dc filament supply has been constructed and installed in the sub-boosters to eliminate the hum observed at the top of the output pulse, which was caused by the ac-fed thoriated tungsten filaments of the 4 PR 1000's. Microwave equipment must be installed before tests can be undertaken to determine if this problem has been solved.

The high voltage regulator circuitry has been completed and evaluation will soon get under way.

Two different solid state recharge diodes to replace the vacuum diode have been purchased and will be installed for evaluation of their reliability.

A new driver circuit for the Machlett ML 7003 is still in the design stage. Evaluation of the Tung Sol secondary emission multiplier tube for use in the drive circuit had to be postponed until a new tube is available.

A high voltage regulated power supply, John Fluke Model 430 A, will be made available for test and evaluation purposes to SLAC on a loan basis. This unit is not able to deliver the 35 ma required for the sub-booster at 720 pps pulsed pair operation, but the current rating can be increased in future models if this unit is basically suitable for our needs.

A design for an improved version of the present prototype sub-booster modulator was drawn up. An investigation to obtain an RFI cabinet with enough flexibility inside to make changes in the layout of components for this prototype unit is underway.

# VI. MICROWAVE ENGINEERING

## A. INJECTION

### 1. Injection Test Stand

All waveguide components for the injection test stand have been machined and will be assembled early in the next quarter. The waveguide phase shifters and power attenuators have been received. The phase shifter has been tested and appears satisfactory; the power attenuator will be tested shortly. The coupler cavities for the 0.75c buncher and the two-foot accelerator section have been received and are ready for testing.

The design of the deflection magnet for the beam momentum spectrometer has been completed and parts are being fabricated. This will be a C-type magnet with a field intensity of 1 kilogauss. A prototype of the bunch monitor to be used on the two-mile machine is being designed for testing on the injection test stand. It will be calibrated by measuring the bunch size with the rf beam sweeper described in the previous Status Report.*

The fabrication contract for the radiation shielding has been awarded and the shielding assembly is now 80 percent complete. The focusing coil form is ready and will be wound shortly. Number 9 square wire will be used.

Preliminary design of the vacuum system layout has been completed, and the waveguide pumpout components are in the Machine Shop.

The control, monitoring and interlock wiring design is 80 percent complete. Design of the control system chassis is 90 percent complete and 60 percent of the fabrication has been accomplished.

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

2. Electron Guns and Modulators

The procurement specification for the electron gun pulse modulator Model 4-1 was released on April 4, 1963. Of the four responsive bidders, Manson Laboratories, Stamford, Connecticut, was selected. Approval to purchase two units was received and the contract was signed effective on June 21, 1963. Two electron gun modulators should be available by the end of December, 1963.

On April 1, 1963, Gun Model 2-2 (an oxide cathode triode purchased from Quantatron, Incorporated) was installed on the Mark IV accelerator. Prior to its use on the accelerator, it was pulse tested at a filament power of 30 watts and a cathode voltage of 60 kv. This resulted in a 1.7 amp peak pulse beam current for a 600 volt grid voltage. During this test the gun valve was closed. Subsequently the valve was opened and exposed to a vacuum of approximately $10^{-6}$ mm Hg. Under these conditions the gun current fell rapidly to below 0.5 amp peak. The gun cathode was baked out at a filament power of 40 watts, which improved the peak current to 1.64 amps. Unfortunately, exposure to the accelerator vacuum drove the emission down to below 0.5 amp peak.

In the belief that foreign material in the magnetic lens area could be poisoning the cathode, the lens was baked out to above 250°C on May 9 with the gun valve closed. After bakeout, however, the emission could not be improved. Subsequently the gun emission improved during use, varying from 0.18 amp to 0.86 amp. On May 14th, the gun and the accelerator were accidentally exposed to a vacuum worse than $10^{-3}$ mm Hg for over 15 minutes. After recovery, gun emission was less than 0.08 amp. On May 29th the gun was removed and sent to the Gun Shop for recoating of the cathode.

While preparing Gun Model 2-1 (a similar gun also purchased from Quantatron) for installation on the Mark IV accelerator, a significant leak developed at the gun filament ceramic braze. Therefore, the Hughes gun, Model 3-1 (a triode with a Phillips B Cathode), was baked out and converted for installation on the machine. Gun Model 3-1 was installed along with a differential pump, a scheme by which it was hoped to isolate the gun from the accelerator vacuum. This differential pumping technique was not effective because the two diffusion pumps on the machine were replaced by an ion-getter pump, and the high vacuum manifold vacuum was worse by a factor of ten.

Gun Model 3-1 was tested on June 6 with its valve closed. With a filament power of 25 watts, a cathode voltage of 8 kv and a grid voltage of 6 kv, a gun beam current of 2.55 amps peak was obtained. On June 13 the gun valve was opened to obtain an accelerator beam. The nearest ion-gauge pressure reading was $3 \times 10^{-6}$ mm Hg but the gun current dropped from 1.2 to 0.6 amps in less than two minutes. Gun emission was then recovered and remained steady at 1.4 amps peak for a filament power of 35 watts with a cathode voltage of 17 kvdc and a grid voltage of 4 kv. The loss of emission at 25 watts is greatly attenuated at 30 watts, but steady emission can only be obtained at a filament power of 35 watts. This temperature dependence was still present on June 26.

On June 17, 1963, the differential pumping throttle was removed in an attempt to discover the reason for the low accelerator current caused by undue beam interception. It was also thought that the waveform distortions of the first klystron output could have been caused by detuning of the accelerator coupler cavity to which the throttle was affixed. However, removal of the throttle had no effect on either one of these difficulties. Further gun studies are presently underway to discover the causes of poor beam transmission from the gun to the output of the accelerator.

Ninety-five percent of the mechanical parts for the beam analyzer were in the shop for fabrication by the end of the quarter. Instrumentation is 50 percent complete and purchasing of components is 95 percent complete. Completion of all schematic drawings in July should result in final assembly and operation by the middle of August. A vacuum station for gun processing was designed and built this quarter. Purchasing and design of the oven and instrumentation for this system is 50 percent complete.

3. <u>45° Inflection System</u>

The addition of a sextapole correction to reduce chromatic aberration in the center quadrupole has succeeded in cancelling the debunching that was found in second order calculations. The best system studied to date is still the three-element system with rotated pole faces, which was described in the previous Status Report. The beam parameters are shown in Table I.

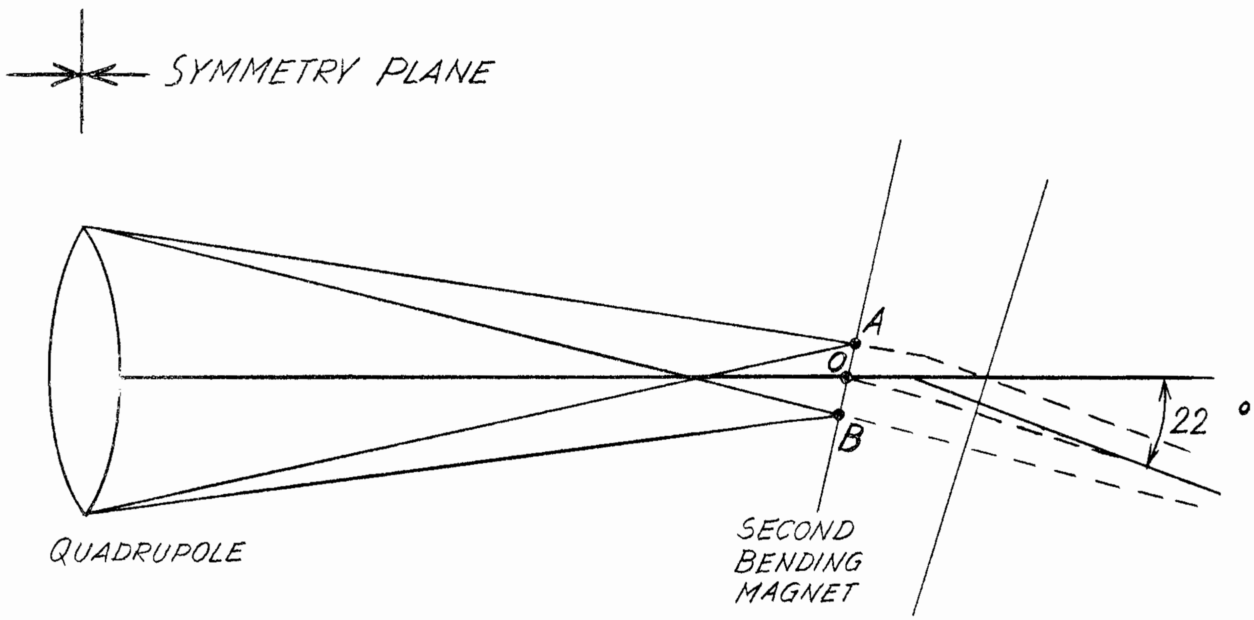
TABLE I

BEAM PARAMETERS, 45° INFLECTION SYSTEM

| Parameter | Input | Output | | |
|---|---|---|---|---|
| | | First Order | Second Order | Sextapole Corrected |
| x (width) | ±0.5 cm | ±0.5 cm | ±0.64 cm | ±0.65 cm |
| $x' = dx/dz$ | ±0.33 mrad | ±0.33 mrad | ±0.83 mrad | ±0.83 mrad |
| y (height) | ±0.5 cm | ±0.5 cm | ±0.53 cm | ±0.53 cm |
| $y' = dy/dz$ | ±0.33 mrad | ±0.33 mrad | ±0.37 mrad | ±0.37 mrad |
| z (bunch) | ±0.8 mm | ±0.81 mm | ±1.9 mm | ±0.82 mm |
| $\Delta p/p$ | ±5.0% | ±5.0% | ±5.0% | ±5.0% |

The sextapole effect is only required in the horizontal plane. The need for it arises from the fact that both high and low momentum trajectories are defocused to the same side of the central trajectory by chromatic aberration in the quadrupole. By slightly overcorrecting the above effect with a sextapole element, the high and low momentum trajectories are allowed to go through the second bending magnet on the inside of the central trajectory, thus reducing their path length and cancelling the debunching which resulted from the longer path these rays took through the quadrupole (see Fig.17).

The exact method by which the sextapole correction will be added has not been determined. Suggestions have been to include shims on the quadrupole pole-pieces, shunts on the quadrupole windings, shims on the pole-faces, iron screws on the sides of the quadrupole return pole, or a pair of separate sextapole elements. The actual amount of sextapole correction does not appear to be very critical. Over a 10 percent change




Point O – Central trajectory and first order focus.

Point A – Uncorrected second order focus.

Point B – Sextapole corrected isochronous focus.

FIG. 17--Diagram of $45^{\circ}$ inflection system.

in sextapole strength, none of the beam parameters changed significantly.

The two remaining undesirable features of the proposed system are the need for special bending magnets with rotated pole-faces and the increase of horizontal phase space. These features are related in that this system was chosen because the transverse phase space spread is about four times smaller than in any other system. A few other systems remain to be investigated.

## B. DRIVE SYSTEM

### 1. Overall Design of the Drive System

During this quarter, major emphasis was again placed on testing the various component prototypes to be used in the drive system. The details are described below. The following individual specifications and procurements for the drive system have been let or will be let in the early part of the next quarter.

a. Main Drive Line System, including drive line, directional couplers and expansion sections

b. Sub-Drive Line System, including lines, directional couplers and flexible sections

c. Master oscillator

d. Main booster amplifier (contract let to Radiation at Stanford on June 10th, 1963)

e. Varactor frequency multipliers and ovens

f. Sub-booster klystrons (let to Eimac on July 19, 1962, with ten tubes delivered to date)

g. Sub-booster klystron modulator (activity handled by the Modulator Group)

h. Isolator-Phase Shifter-Attenuator for the sub-boosters and the 24 Mw klystrons (see section concerning this assembly)

### 2. Varactor Frequency Multipliers

During this quarter, a Criteria Report and a rough draft of the purchase specifications for a varactor frequency multiplier were prepared.

Two ovens were purchased from the Syntax Corporation, Palo Alto. Harmonic generators are being installed in these ovens and an evaluation of phase stability has started. These assemblies constitute prototype units for the two-mile machine.

3. Main Booster Amplifier

In addition to the contract for this unit with Radiation at Stanford, the corresponding Criteria Report was prepared and published during the past quarter.

4. Stable Test Stand Drivers

The OS-2 test stand stable drivers have been delivered to their users. All six units have been modified by the addition of a ferrite isolator in the output line. Operation has been satisfactory and only a few minor maintenance repairs have been necessary.

5. Tunable Test Stand Drivers

All four units are complete and ready for delivery.

6. Master Oscillator

A rough draft of the purchase specification for the master oscillator has been prepared and an analysis of the short term frequency stability requirements is presently up for review.

7. Mark IV Driver

One request was received from the Mark IV group for major maintenance on the rf driver. Failure in this case was caused by the switch tube, which burned out and caused a number of minor failures in the bias supply. This is the second switch tube failure in one year, and remedies are being sought.

8. SAS-61 Klystron Modulators

The two SAS-61 klystrons ordered from Manson Laboratories for the accelerator structure test stands have been received and accepted. One unit is presently installed in the Tree House; the other unit is being used in the M-1 building.

9. Sub-Booster Klystrons

The first shipments of sub-booster klystrons, as specified per contract, were delivered during the last period. The tubes were acceptable except that the nominal operating beam voltage was not entirely as specified. The klystrons had 20 percent more output power at 26 kv than at

24 kv. In order to obtain the benefits of the higher output power, the specifications were negotiated and the remainder of the tubes on the contract will arrive on schedule. Extensive life and operating experienc will be obtained on the five units used in the Test Laboratory.

10. Test Stand Drive Systems

The first part of the test stand drive and distribution system has been installed and will undergo tests as soon as the 24 Mw klystrons and modulators are ready. The second part of the drive system will be installed in July of 1963. It will consist of two lines running parallel to each other, enclosed in insulating jackets, and a water line. Allowance for changing the water temperature will permit testing of the system in a manner comparable to the SLAC drive line.

11. Group Velocity Measurement

In order not to exceed ±1 degree of phase slippage between electron bunches and rf drive wave crests over the operating frequency range of 476 ± 0.017 Mc/sec, the relative group velocity of the main drive line system must remain within the limits $0.99735 \leq v_g/c \leq 1.00265$. This condition must be satisfied by the aggregate assembly of the main drive line, the thirty directional couplers, and the thirty expansion sections.

Similarly, in order not to exceed ±0.104 degree of phase slippage over the operating frequency range of 2856 ± 0.1 Mc/sec, the relative group velocity of the sub-drive line system has to be within the limits $0.99 \leq v_g/c < 1.01$. The average group velocity of various combinations of drive line, couplers, and other discontinuities were measured. The values of the average relative group velocity ranged from 0.92 to 1.02. Further analysis of the data is necessary in order to determine the effects on relative group velocity of the discontinuities and the electrical spacing of the discontinuities.

12. Isolator, Phase Shifter, Attenuator Assembly

Final specifications for this assembly are presently being prepared and will be submitted to the AEC for approval early in the next quarter. A total of 280 of these units will be required. Approximately 25 will be obtained on a pre-production basis in February 1964, and will undergo extensive in-house testing before the final production run is authorized.

## C. PHASING SYSTEM

### 1. Programmer Design for Automatic Phasing System

Two new programmer designs have been completed. The first is a new version of the existing hybrid programmer and the second is a new design to be used with the beam induction technique of phasing (see below). The hybrid programmer was redesigned to meet the new interface requirements proposed by the Instrumentation and Control group and to simplify the original design. Both of these objectives have been attained. A beam induction programmer was designed because this technique has lately come up for active review. Construction of both programmers is scheduled for completion early in the next quarter. Studies on the interface conditions and cable requirements for the automatic phasing system have been completed.

### 2. Sector Simulator

Experiments of the sector phasing simulator have been carried out. Preliminary results which indicated the practicality of an automatic system have been confirmed, and several days of trouble-free operation were obtained, thereby indicating good reliability of the system. Measurements on the accuracy of the system show that an error of $\pm 7°$ in phase between klystrons within a sector could be expected with the present system. This order of accuracy is maintained for a difference in the compared signal levels of 6 db. Improvements in the design of the phase shifter should reduce this error to approximately $\pm 1°$. Further tests with the new programmer are scheduled early in the next quarter. An investigation into the relative merits of an ac versus a dc servo system showed that the ac system is still preferable, mainly because of the reduced motor starting voltage required in the ac system.

### 3. Beam Induction Technique

The advantage of the beam induction technique in giving the correct phase of the klystrons with respect to the beam considerably simplifies the problem of sector phasing. Because of this property, a thorough re-evaluation of this technique is being made. Experimental results from the Mark IV accelerator show that this technique will phase the second klystron with the same degree of accuracy as the energy maximization technique presently used. It must be remembered, however, that the beam induction technique requires conducting phase comparisons for widely ranging signal levels (corresponding to signals induced by beams of 1 to 100 milliamps peak, and 24 Mw klystrons). This difficulty does not arise in the hybrid method where only signals of comparable amplitudes undergo phase comparison. To overcome this difficulty, two alternate systems are being investigated.

(a) An IF system in which the phase comparison is made at an intermediate frequency and limiting is obtained in the mixing action.

(b) An rf system in which the beam or klystron signal is made much greater than the reference signal, under all conditions. If the variable input signal, either from the klystron or from the beam, is phase-wobbled from 0° to 180°, a relatively constant amplitude modulated output should result, provided that the mixing with the reference signal is done through a linear rather than a square law detector. Particular emphasis is presently being placed on the investigation of various types of linear detectors. It is expected that the final phasing system design will be completed early in August 1963.

4. <u>360° Continuous Phase Shifter</u>

As discussed in the previous Status Report, a 360° continuous phase shifter is an important component in the automatic phasing system. For this reason, preliminary specifications were prepared and a product survey was conducted throughout the industry to determine whether such a unit could be built to SLAC specifications. Fourteen manufacturers indicated their interest in producing this unit in the quantity required. In addition, design of a unit is being undertaken within the Microwave Engineering Group to obtain better understanding of the problems involved. Two different approaches have been adopted: one uses a strip-line configuration, and the other consists of two helical antennae (one transmitting, the other receiving) enclosed in a circular waveguide.

5. <u>Magnetic Deflection System Design</u>

Preliminary design has started on a magnetic deflection system to be located both in the position of the fourth section of the first sector and in the fourth section of the eleventh sector. These systems, consisting of a magnet, analyzing slits, and a Faraday cup, will be used to phase the main injector and the off-axis injector located upstream of these points.

D. GENERAL RF STUDIES

1. C-Band to S-Band Coupler

The C-band to S-band coupler was completed and installed in the Mark IV accelerator. Beam breakup studies using the C-band power to launch the $TM_{11}$ mode for currents lower than the usual blow-up threshold will be attempted.

2. RF Particle Separator

This program continues to be carried out in cooperation with the Research Division and this quarter all information on the subject will be reported in the section pertaining to that division.

# VII. SYSTEMS ENGINEERING AND INSTALLATION

## A. ACCELERATOR RESEARCH AND DEVELOPMENT

### 1. Vacuum System

a. Gauge Evaluation

Tests were conducted with Hughes and General Electric cold cathode gauges and power supplies. Hughes gauge readings were linear over a range of $6 \times 10^{-5}$ to $4 \times 10^{-8}$ torr and agreed closely with a calibrated nude gauge within a factor of 1.5. The General Electric gauge readings were not linear over the same range and varied up to a factor of four higher than the nude gauge in the lower range and slightly less than a factor of two at $1 \times 10^{-6}$ torr.

b. Valve Evaluation and Test Program

Preliminary proposals from vendors on SLAC valve designs were received, and costs appear to be within the anticipated budget. A prototype of the 6-inch valve is being fabricated and will be installed in the Test Tower for testing. An all metal 3/4-inch bakeable valve with removable operator was received from Cryolab Company for evaluation and a similar valve will be furnished by RCA.

c. Roughing Systems Study

A turbomolecular pump is being evaluated on the Test Tower.

d. Mark IV Program

Getter-ion pumps are in use continuously on the Mark IV accelerator to provide data on pumping with this type of pump. System pressure is approximately a factor of two higher than with diffusion pumps. Transient variations of pressure observed with diffusion pump operation do not exist with ion pump operation. Isolating valves for diffusion pumps are being modified to incorporate Viton "O" rings for effective shutoff.

e. Vacuum Piping

The ion pump test system was completed in May, and results of outgassing studies made on three samples of pipe are as follows:

| | Cleaning Process | Final Outgassing Rate at Room Temperature |
|---|---|---|
| (1) | chemical cleaning only 16 hours bakeout at 400°C, 8 hours at 200°C. | $1 \times 10^{-12}$ TL/sec-cm$^2$ |

| Cleaning Process | Final Outgassing Rate at Room Temperature |
| --- | --- |
| (2) chemical cleaned, glass bead honed, 24 hours bakeout similar to (1). | $4 \times 10^{-13}$ TL/sec-cm$^2$ |
| (3) chemical cleaned hydrogen fired at 1000°C for 20 minutes, bakeout similar to (1) | $4 \times 10^{-12}$ TL/sec-cm$^2$ |

f. Test Tower Vacuum Test

The Test Tower system was in operation during May with the mechanical and ion pumps only pumping on the system. The ion pump was turned on at 50 microns. The time necessary to reach $1 \times 10^{-6}$ torr was approximately two hours, as contrasted with 1-1/2 hours for the diffusion pump. A five minute Argon treatment of the ion pump changed the indicated pumping speeds from 270 to 370 liters/second. Gas analyses indicate that hydrogen is the principal gas evolved from the copper waveguide during rf processing and gas bursts. Insulation of the pipe exposed to the sun did not appreciably affect system pressure. Heating of copper locally by means of a torch does not change system pressure, but heating of the stainless steel has a significant effect. RF power increases the system pressure by only ten percent. Ambient temperature fluctuations affect the pressure considerably; a 20°C rise doubles the pressure in the system.

2. Supports

Free vibration tests were made by John A. Blume Associates in May on the 12-inch sight tube truss. These tests indicated that increased Y-Y moment of inertia was needed. Work is progressing on the extension of the mockup, and three sections (two 40 feet long and one 10 feet long) will be set up for final checkout of target actuators, motorized jacks, and free vibration testing of complete units.

3. Alignment

New, simplified target positioners were designed, fabricated and installed at the Brisbane Tunnel. Final evaluation of the alignment system is underway. A stretched wire has been installed above the pipe to eliminate the possibility of systematic error. Instruments have been installed on isolated towers above the stretched wire to permit accurate alignment of three targets distributed over 1000 feet of the evacuated system.

4. Cooling Water

The Test Tower cooling water system was installed and is in operation. A larger in-line heater for the Test Tower accelerator tube cooling water system will be installed in July.

Final design of the water treatment corrosion test circuits was completed, and materials and equipment have been received and are being assembled. Investigation of water chemistry tests are underway.

Constant water temperature system components for the test stands have been received and are being assembled.

## B. ACCELERATOR ENGINEERING, DESIGN AND INSPECTION

1. General Design

a. Design Coordination

Drift sections are being reviewed. The waveguide vacuum penetration spacing is under study. Drawings showing general arrangements of machine services and equipment were updated to reflect the latest project design changes and ABA Title II 50% Klystron Gallery drawings information. Complete sets of plans were issued to all project groups for review and comments. A new full-sector model of the Klystron Gallery and Accelerator Housing is underway.

b. Standards and Specifications

General updating of the Standards Manual was accomplished during June. An increasing number of preliminary and final specifications are being reviewed and issued for various project groups.

2. Installation Drawings

Drawings for sectors 1, 2, 3, 4, 5 and the main injector station were printed for project review. Flow diagrams are being finalized for vacuum, cooling water and ac electrical systems. A design report describing the installation drawings program is being prepared for project reference.

3. Vacuum

A decision was made to use getter-ion pumps as the primary vacuum pumping system, and specifications are being prepared. The 4-finger piping scheme, which has an 8-inch manifold above in the Klystron Gallery and a 5-inch manifold below in the Accelerator Housing, was approved.

Preliminary design of the vacuum plumbing connecting to machine components was completed. Specifications for bellows, spinnings and piping were started.

Decisions were made to eliminate (1) valves on the Klystron Gallery manifold that had been provided for Stage II convertibility without accelerator shutdown, (2) valves on gauges at waveguide pumpouts near klystrons, and (3) gauges on the horizontal run of waveguide pumpouts downstream of waveguide valves.

4. Supports

Major design changes were effected for the support system. The support girder will be a 24-inch pipe, and specifications are being established. Inter-girder seals and connections are being redesigned. Design of the klystron system (klystron tube-waveguide-vacuum manifold) support frames was completed and procurement of one unit for checkout was started.

5. Alignment

Various remote jack actuating systems are being investigated. The design of the monument supported targets, physically isolated from but contained within the 24-inch-diameter light pipe, is underway.

6. Special Material Handling Equipment

Each component or system group will provide their own installation and initial maintenance requirements. A centralized system can be initiated later if needed.

7. Cooling Water

The heat exchanger-blending valve system will be the method used to control the temperature of the machine cooling water circuits, in accordance with a project decision of April 9, 1963. Pump and heat exchanger specifications have been started. Cooling water circuits were deleted for ignitron switch tubes, which are no longer being considered. Flow diagrams are being revised to reflect these changes as well as the new waveguide configuration.

8. Electrical

The Variable Voltage Substation specification was approved and issued for bid in June. Preparation of the installation subcontract was started. Work is continuing on the machine ac services.

9. Auxiliary Machine Shielding

A design report covering all phases of required auxiliary shielding will be issued for project review in July.

## C. ACCELERATOR INSTALLATION

1. Test Stands

An expanded three-phase test stand program was developed. Plans and specifications for the Phase II test stand installation were completed, and bids were received June 20, 1963.

A floor plan layout of equipment for the high power rf test stands in the Fabrication Building (Phase III) was prepared.

2. Installation Management

Detailed planning for installation of the SLAC machine is underway, based on significant decisions made during this quarter, i.e., the four-finger per sector vacuum system and the installation of a variable voltage substation to be made by SLAC. A report covering the installation program for the two-mile accelerator was reviewed with the AEC. Segregation of installation subcontract work items and critical path work is underway.

# VIII. INSTRUMENTATION AND CONTROL

## A. TRIGGER SYSTEM

Because of the increased requirements for flexibility of beam repetition rates in physics and the requirement that the klystron-modulators operate only at regular rates, the trigger system has been modified somewhat from the report in the Quarterly Status Report of a year ago.* A master clock generates clock pulses which are transmitted through a master trigger cable to a trigger generator at each sector and at all other locations where trigger signals are required. The trigger generator contains a gate which selects the appropriate clock pulses for a particular piece of equipment and rejects the rest. In the earlier system, the gate operated by a preset local rate generator. In the present system, the gate is operated by a "pattern control signal" generated at Central Control and transmitted directly to the trigger generator as an audio-frequency signal. The pattern generator at Central Control allows setting arbitrary repetition rates for each beam. Combinations of the beam patterns are separately combined into appropriate pattern control signals for each sector, the injector, the switchyard magnets and the research areas.

In order to provide a regular pattern for the klystron-modulators, a delayed (standby) pulse is generated at each sector. If the pattern control signal for a sector does not call for klystrons to accelerate the beam, the klystrons will automatically be triggered by the standby pulse, so that their repetition rate is independent of the actual beam pattern. Provision is being made to operate the klystrons at a reduced rate (60, 120, or 180 pps) when such a rate is compatible with the beam acceleration requirements.

The beam transport and the experimental physics equipment are incorporated in this system to ensure the distribution of the electron beams of suitable energies to their respective experimental areas. Pre-triggers ensure the establishment of quasi steady-state conditions of the pulsed magnetic fields in the beam switchyard during the interval

*"Two-mile accelerator project, Quarterly Status Report, 1 April to 30 June 1962," SLAC Report No. 1, Stanford Linear Accelerator Center, Stanford University, Stanford, California; p. 63 (July 1962).

of the passage of the electron beams through the pulsed portion of the beam transport system; verification signals guarantee that a predetermined level of the magnetic field has been reached at a given time interval. Electron magnetic resonance measurements of time varying fields, under development, ensure an accuracy of 0.1 percent. In the absence of the proper verification signal, the electron gun of the accelerator is suppressed for protection of the transport system.

It is mandatory to ensure the continuing operation of the master clock in order to prevent sudden load changes of the order of tens of megawatts in the primary ac supply line. A method of reliability via redundance is applied, using three identical master trigger generators and a comparator circuit with a fail-safe feature. The status of the four instruments is monitored continuously. The loss of a single pulse from any one of the master trigger generators causes a relay to switch over to a properly functioning generator in a time interval less than the interpulse period (2.78 milliseconds).

Problems of the distribution of the primary pulses to the 30 sectors and the individual modulator-klystron sets have been investigated. A high impedance level take-off from the main trigger line was found to be feasible. The degradation of the pulse rate-of-rise and the reflections from the take-off discontinuities were well within tolerable levels. Directional couplers are now under investigation for pulse distribution under (impedance) matched condition.

The trigger system and sub-systems are in the final stages of design, incorporating the presently known input information. Engineering design reports are in preparation. Detailed circuit design is progressing in those areas where input-output characteristics can be frozen. This includes the master generator, comparator circuit, sector generator, pulse pattern generator, rate generator and active precision time-delays as well as driver amplifiers to be used as standard circuit elements in the trigger system.

## B. BEAM GUIDANCE AND MONITORING

The resonant type of beam position monitor was brought to completion. The fabrication of prototypes using "Ceram-temp" wire, wound on ceramic forms, is proceeding. Electronic circuits have been developed for the test of the coils in a high noise environment originating from electromagnetic and nuclear radiation sources.

A different magnetic pickup device for beam position monitoring is under development. It will operate in a broad-band mode. Sensitivities of 0.25 volt/amp-cm have been achieved to date.

The electronic circuitry for the beam guidance is under development. The integrated output from the magnetic pickup coils undergoes a second integration to achieve a quantity $q \cdot \Delta x$, for example, where $q$ is the total charge passing through the sensor at a distance $\Delta x$ from the accelerator axis. The wide dynamic range of the quantities involved demands the use of a logarithmic amplifier for scale contraction. The following advantages are thus derived: (1) remote gain control is obviated, (2) the signal excursions of ±2.5 volts match the data transmission handling capacity, and (3) normalization is easily achieved to obtain a quantity proportional to the displacement only. The analog operation of the normalization is:

$$\log \left\{ V_1 + \frac{V_2}{2} \right\} - \log \left\{ V_1 - \frac{V_2}{2} \right\} \approx \frac{V_2}{V_1}$$

where $V_1$ = signal proportional to the charge $q$

$V_2$ = signal proportional to the product of $q \cdot \Delta x$.

The output from the normalization circuit is thus proportional to $\Delta x$ with an error of about 3% when $V_2 \leq 0.5\ V_1$.

## C. BEAM SWITCHYARD INSTRUMENTATION

A major effort has been initiated in the study of beam steering and beam interlock problems peculiar to the beam switchyard. The principal purpose of the study is to establish more precisely the characteristics of the beam monitors (intensity, position, profile, etc.) which must be developed. The destructiveness of the high power beam and the high radiation levels to be found in the beam switchyard provide the most serious complications to be resolved.

D. DATA HANDLING

Design Criteria Reports have been prepared describing the proposed features of the Signal Battery Plant and the Personnel Communications System. Revised cost estimates were included with each report. These reports are being circulated throughout the project for comment before initiating a design freeze. Similar reports for elements of the Data System have been started.

The Engineering Design Plan for the Operational Telephone Intercommunication System and the Design Criteria Report of the Control Cable Plant have been approved and initiation of procurement authorized. The Installation and Assembly Plan for the Cable Plant has been prepared.

Concept evaluation testing of various system and equipment designs was accelerated during the period with extensive testing of status monitoring and analog measurement sub-systems. All evaluation to date has been favorable in that no test results have precluded use of any of the control techniques presently contemplated. These tests are expected to continue until all proposed technical features are evaluated.

Tests were completed on measurements of environmental noise in a 130-ohm balanced, shielded video-pair cable at the Mark IV accelerator under "Beam On" operating conditions. These tests were part of a series conducted to determine the best method to transmit the beam position and beam intensity signals from the accelerator pipe to the amplifier rack in the klystron gallery.

Field measurements and a survey of the background level for all frequencies from 30 cps to 3000 Mc/sec have been completed and documented for reference purposes and correlation to any RFI or EMI problems that might arise during the operation of the accelerator and supporting operations. Eight peripheral sites surrounding the SLAC installation were fixed as reference points for future measurements to maintain a monitoring of SLAC modification to the ambient environment before SLAC installation.

## E. MEASUREMENT AND ACTUATION DEVICES

The Criteria Report for the modulator-klystron protection system was issued and is currently under study by Project management and interested parties. Sub-system optimizing was achieved by Boolean algebra methods.

The following instruments constituting the measuring and actuation devices for the modulator-klystron pair are under development.

1. A klystron impedance fault detector, which measures klystron cathode impedance within each pulse has been developed. It has been shown that deviations from normal, detected by impedance measurements, approximate the deviations measured by perveance measurements within a few percent. The simplification achieved promises high reliability of the circuit, which is to be used in conjunction with 240 klystrons. The analytical design is complete; experimental evaluation of the breadboard is nearing completion.

2. An instrument to measure the presence of the rf drive to the klystron is being developed. RF window protection demands a gradual increase of the rf drive power when the modulator is triggered after a comparatively long shutdown. The integration of this circuit in the logic design of the modulator-klystron protection is complete.

3. An instrument to measure rf power at the output of the klystron is under development. The ratio of incident to reflected power is also derived from the circuit. It has been proposed that biased coaxial neon switches serve as power indicators.

## F. TEST STAND INSTRUMENTATION

Instrumentation and Control equipment racks for Test Stands Nos. 03, 05, 07 and 09 were installed in the new Test Laboratory Building. Test Stands Nos. 09, 07 and 05 have been checked and tested, using resistive or diode loads on modulator output. Sub-booster modulators were installed in Test Stands Nos. 07 and 09.

The Test Stand Instrumentation and Control Group was moved from the M-2 Building to temporary quarters in the Test Laboratory Building, and work on the remaining racks is continuing with installation of Stands Nos. 02, 04, 06, 08 and 13 scheduled to start the first week of July and to be completed by August 22, 1963.

G. GENERAL PROJECT SUPPORT

1. A gated wideband amplifier for the energy spectrum analyzer to be mounted in the beam switchyard is under development.

2. Measurement and actuation devices for the test stands were completed. Additional trigger and delay generators are being designed. The timing pulse distribution system is in its final stages of completion.

3. A trigger generator for the synchronization of the Lynch Status Monitoring of the Data Handling equipment was completed.

4. A gated amplifier for the Tone-Generator protection line is in the stage of analytical design.

5. A double pulse (2 x 360 pps) generator for testing of the sub-booster modulator was completed.

6. A list of preferred electronic components is in preparation, the primary consideration being reliability combined with budget realities.

7. Support was provided to the Research Division in evaluation and design of magnetic field measuring devices. A low field electron magnetic resonance instrument was completed; an integrating method of field measurement is nearing completion.

# IX. MARK IV PROGRAM

## A. OPERATION

A fairly substantial amount of operating time was logged on the Mark IV accelerator during this quarter.

Temperature control of the acceleration sections continued to be provided by the heat exchanger-blending valve system. This was partly because of its satisfactory operation, and partly because the design of the water jacket on the first section prevents the use of a wall temperature sensing device in a separate closed loop temperature control system.

The Research Division carried out further experimentation at Mark IV on secondary emission, shower production in several materials, the effects of radiation on coaxial cable performance, and, in collaboration with the Microwave Group, on a microwave particle separator.

In addition to the separator work just mentioned, the Microwave Group carried out a considerable amount of work with their equipment for monitoring and control of phasing of acceleration sections.

Radiofrequency interference measurements were carried out by the Instrumentation and Control Group on interference levels produced on the cable contemplated for use on the two-mile machine. These measurements were made with the cable placed for estimated maximum noise pickup and with the Mark IV machine in operation.

Vacuum system operation was carried on largely by means of getter-ion pumps, and was as satisfactory as in the previous quarter.

It was discovered that the valves used to shut off the diffusion pumps in the trench had not actually closed, as was reported last quarter, so that the getter-ion pumps were not connected alone to the machine at that time. During the present quarter the diffusion pumps were removed and their connecting parts on the machine were blanked off. Under these conditions no significant change in vacuum operating conditions has been noted except that the machine base pressure is higher by a factor of about two. However, this is not necessarily to be attributed to the change in pumps, in view of the many other changes and additions to the machine which were made concurrently.

Operations continued with the use of klystrons produced at SLAC. In socket No. 1, klystron F-6A has been in service during the entire quarter. In socket No. 2, klystron E-13C developed heater and/or getter difficulty and was replaced by E-14C, a tube which had previously been in service on the Mark IV machine and which was reworked and reinstalled. Klystron E-14C then developed trouble with oscillations and was replaced by F-9B.

The automatically operated waveguide flap attenuators installed in the klystron input drive lines during the preceding quarter operated satisfactorily this quarter and relieved the operators of much inconvenience.

Although the installation of Ling equipment in the modulator firing circuits improved the reliability of operations, by the end of the quarter it was decided that the ignitrons on the Mark IV accelerator should be replaced by thryatrons. This will be done as early next quarter as the thyratrons and associated components can be obtained and packaged for installation.

## B. MACHINE MODIFICATIONS

In addition to the modulator firing circuit changes mentioned above, the following modifications were completed.

Three high power Faraday cups were fabricated and delivered. Two have been placed in service, although not completely debugged. Installation of the third Faraday cup, the collimators, alignment hardware, and support stands will require a major shutdown of the machine. It is expected that this can be accomplished next quarter, probably when the present acceleration sections are replaced by a pair of new constant gradient sections.

The two high power beam sampling collimators were delivered, but without final mechanical drive power equipment. Development of a drive system is being carried out by the Systems Installation and Engineering group as part of a requirement for an alignment adjusting drive on the two-mile machine, and components will be supplied to adapt the Mark IV collimators.

The support stands for beam line components were completed and delivered.

Installation of improved water connections and components improved the klystron collector water flow to an amount sufficient for immediate needs, but with little, if any, safety margin for the more severe operating conditions expected as further power increases are attained. Therefore, a new water pump for the main heat exchanger and water system has been ordered. It has been necessary to run the standby water pump in parallel with the regular one in order to meet present requirements; the single large pump is expected to increase both the water flow rate and the efficiency of the heat exchanger.

The retainers to prevent shifting of shielding blocks over the trench were installed.

Two new injector guns were installed and used during this quarter: a Quantatron gun and, late in the quarter, a Hughes gun.

The principal weaknesses in the radiation protection interlock system were corrected by the end of this quarter.

## C. PROGRAM FOR THE NEXT QUARTER

A heavy schedule of experimental use of the Mark IV accelerator by various groups of SLAC has been set up.

1. Testing of a microwave particle separator, using several models of the separator
2. Electron beam intensity measurement using secondary emission monitoring
3. Electron beam breakup study
4. Check of beam-induced microwave power in a resonant cavity
5. Check of electron beam energy gain per section versus amount of microwave power fed to the respective section
6. Repetition of microwave phasing experiments using the beam induction method
7. Testing of the performance of a beam position monitor
8. Continued evaluation of the vacuum system and its pumps, gauges and components
9. Collection of data on radiation during machine operation, especially on neutron levels

There will be additions and modifications made to the machine during the next quarter:

1. It is intended to complete the strengthening of the radiation protection interlock and warning system.
2. A stable solid state power supply, along with nuclear magnetic resonance (NMR) detectors and a feedback control amplifier, will be purchased for use with the beam bending magnets.
3. A new pump in the main water heat exchange system will be installed.
4. A cold cathode vacuum gauge will be purchased and installed, and its performance under accelerator operating conditions will be evaluated.
5. Several pieces of electronic equipment for instrumentation and bench testing work will be added.
6. The acquisition of a floor crane for flexible and easy handling of heavy components will be accomplished.
7. Thyratrons and associated circuit components, which are to replace presently used ignition switch tubes in the modulators, will be purchased and installed.
8. The SLAC Accelerator Structures Group will provide two new constant gradient acceleration sections for installation in the Mark IV accelerator.
9. The installation of beam component support stands, the new half-way Faraday cup, and optical alignment components will be accomplished. It is also planned to install high power beam collimators as soon as the necessary drive mechanism parts have been provided.
10. The half-way bending magnet will be remounted.

# X. RESEARCH DIVISION

## A. BEAM SWITCHYARD MAGNETS

### 1. $3^\circ$ Bending Magnet and Power Supplies

The problems described in the previous status report have been largely resolved now, and preliminary magnet specifications have been written. Some additional radiation-damage tests are planned. Two prototype power supplies, each rated at 100 volts and 1000 amps, have been ordered for magnet testing. These power supplies will also be used for the beam switchyard quadrupoles and the field lens.

### 2. Other Magnets

Design has started on the field lens, the beam switchyard quadrupoles, and the switching magnet.

### 3. Beam Stirring

Because of the high density power carried by the electron beam, it may be desirable to use a magnetic device in the beam dump area which can deflect individual beam pulses in different directions so as to spread out the area over which the beam is absorbed. Design of such a "beam stirrer" has begun.

### 4. Pulsed Magnet Program

The capacitor bank and power supply for this magnet have been ordered. The capacitor bank will be rated at 300 kilojoules and 5 kilovolts; and the power supply will be rated at 5 amperes and 5 kilovolts. The capacitor bank is composed of six similar units which can be used independently.

### 5. Pulsed Magnet Modulator

The pulsed magnet circuit has been operated at a repetition rate of 180 cps for several hours at full power. The maximum repetition rate is presently limited by the size of the capacitor storage bank and the driver circuit that is being used for the ignitron switch tubes. A larger capacitor bank has been ordered, and a revised driver circuit is being constructed. A special network is being developed to regulate the voltage on the capacitor bank without the need for a highly regulated power supply.

6. <u>EMR for the Pulsed Magnet</u>

The microwave equipment for the electron resonance magnetometer has been assembled and tested, and electron resonance in fields of 1600 gauss to 2000 gauss has been observed. A helix slow wave structure has been chosen as a resonator and is presently in fabrication, along with its associated feed and matching structures. When these have been received, tests of the resonance apparatus will be conducted in pulsed magnetic fields, and appropriate pulse shapers and amplifiers will be designed and built for the pulsed EMR signal.

7. <u>Gated Integrator for the Pulsed Switching Magnet</u>

Preliminary design and construction of an integrator for the pulsed beam switching magnet have been completed. The integrator uses a high gain operational amplifier with capacitive feedback and low frequency roll-off to eliminate long term drift. A 6-diode gate has been designed and constructed, and tests are being carried out to determine its linearity and crossover distortion. Level detectors and a coincidence circuit have been built and tested; all these components are presently under test as a system (see Fig. 18).

Once the stability of gain of the integrator has been established and linearity and crossover distortion of the gate circuits has been checked, the gated signal will be presented to a multi-channel analyzer to provide a measurement of the amplitude jitter of the model pulse magnet.

8. <u>Effective Length Measurement of Quadrupoles</u>

A special coil has been built and tested and found to be so successful that an improved version is presently being built. Two signals from two sets of coils are taken out through a graph-alloy brush and slip ring assembly that is rotated at 1 cps. The two signals are compared by nulling on a type Z Tektronix Differential Amplifier.

From the initial tests, it appears that this method of effective length measurement could be used easily to measure the effective lengths of a large number of quadrupoles with an accuracy of better than one part in $10^3$.

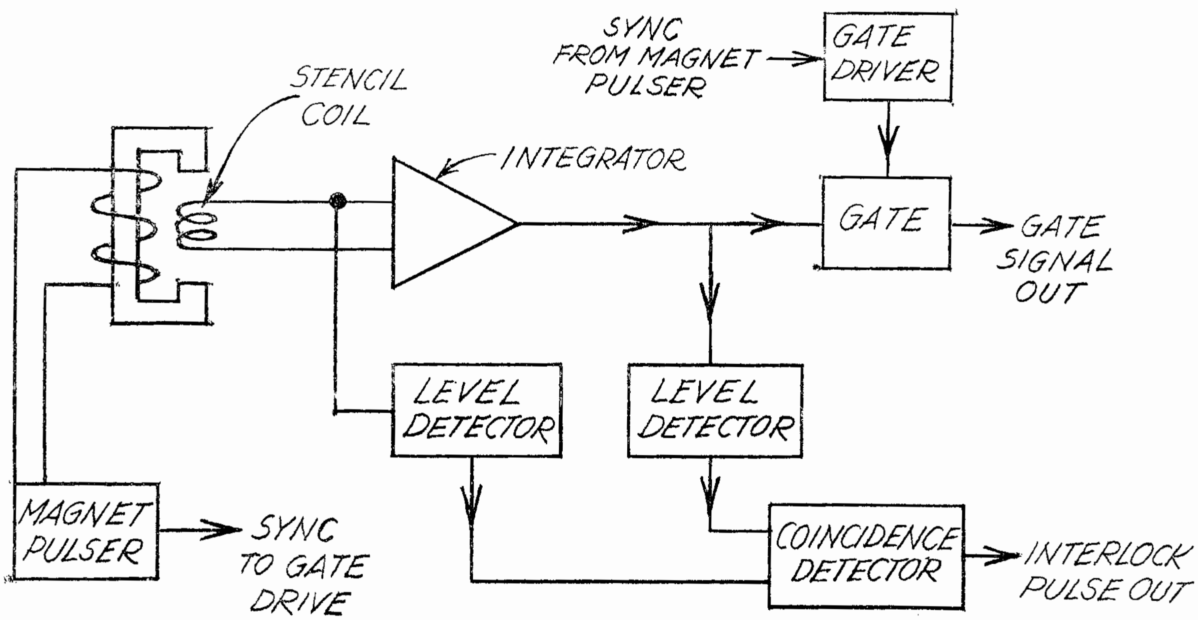



FIG. 18--Gated integrator for the pulsed switching magnet.

9. Quadrupole Harmonic Analyzers

The rotating search coil developed for measurement of the harmonic coefficients in a quadrupole magnet has shown itself to be an extremely accurate device for locating the magnetic center of the quadrupole field. Recent experiments with the coil, using a variation of the technique mentioned in the last Quarterly Status Report, have now determined the magnetic center of the quadrupole to within ±0.00025 inches.

At the present time the limiting factor in determining the magnetic center lies with the positioning equipment. The strength of the dipole signal is strong even 0.25 mils from center. Equipment allowing measurable movements of distances smaller than 0.25 mils would undoubtedly give an even greater accuracy in determining the magnetic center.

Experiments are being carried out at the present time in an effort to develop a practical method of determining the quality of a quadrupole magnet by examining the amplitude and form of the various harmonics as picked up by the search coil.

B. MAGNETS ALONG THE ACCELERATOR

1. Beam Steering Magnets

Two sets of steering magnets are planned for use between the accelerator and the beam switchyard. These would be placed in the 29th and 30th drift sections of the accelerator and before the pulsed magnet. Calculations on these magnets have now been made.

2. Quadrupoles and Power Supplies

The present intention is that accelerator beam focusing will be accomplished through the use of quadrupole triplets in the drift sections of the accelerator. These quadrupoles are designed to have nearly identical magnetic properties and to have their geometric centers aligned to within $10^{-3}$ inch. The design of these magnets is nearly complete. Specifications are written, and a prototype magnet is being built to allow measurement of the magnetic center, the effective length, and the fringing field.

Specifications for the power supplies for these magnets are also being written. These supplies will be rated at 25 volts and 10 amperes each, with a current stability of one part in $10^3$. It appears that modified, commercially available power can be used.

C. MAGNET OPTICS

A set of alignment tolerances giving maximum deviations in position and level for the magnets in system A has been given to the mechanical engineers who will prepare preliminary designs and cost estimates for the magnet support systems. These tolerances were compiled from a revised table of effects of alignment errors prepared with the aid of TRANSPORT; they will be subjected to one further review in connection with the final report on the transport systems.

A study of the optics of a parasite gamma-ray beam was completed. If a radiator is inserted in the electron beam of system A after the first six degrees of bend and the fourth bending magnet is moved nine meters downstream from the third, then the gamma-ray beam created at the radiator will clear the third and fourth magnets. The optics of the electron beam are not changed appreciably by moving the fourth magnet.

Several transport systems utilizing the beam dump magnets were studied. Any one of them would afford a means of bringing a second electron and/or gamma-ray beam into end station A. The final configuration has not been selected, but the most promising arrangement is a system nearly identical to the $24^{\circ}$ system but bending only 16 degrees. The first two bending magnets bend four degrees each and are separated by six meters to allow clearance for a gamma-ray beam. The uncoupled nature of the $16^{\circ}$ system allows a great deal of flexibility for locating the beam as compared to the $24^{\circ}$ system.

D. VACUUM SYSTEM

The critical path scheduling network for the beam switchyard vacuum system has now been completed. Modifications of commercial valves are being undertaken to replace all organic components with metallic seals and gaskets. In addition, a conversion from pneumatic to hydraulic operation of the valve is being made.

## E. BEAM DUMP, COLLIMATORS AND SLITS

Design calculations for the circulating water beam dump followed by water-cooled plates are continuing. Experimental measurements of feasible power density on the water-cooled plates are being made with a heliarc welder in a water-cooled test cell. The data already obtained are being correlated for engineering purposes. An extensive survey of literature has been made to determine available parameters for design of heat exchange surfaces. In addition, some information has been obtained on heat transfer during short time transients.

Concerning collimators and slits, we are presently investigating effects of thermal stress fatigue, general thermal cooling problems, and possible relevance of available radiation damage information in the literature.

## F. SHIELDING AND HEALTH PHYSICS

### 1. Radiation Protection

To supplement the film badge monitoring service, daily monitoring is done of all radiation areas. This work will continue until all groups show the awareness and capability of assuming responsibility for the routine monitoring.

Preliminary neutron surveys have been made of the Mark IV accelerator, with the levels well within tolerance.

### 2. Shielding Studies

The scanning of the track plates from the CERN collaboration experiment has been finished; attenuations have been measured done to $10^{-6}$, with some possibility of reasonable measurement to $10^{-7}$. The thicker nuclear emulsions arrived June 20 and are being scanned for stars with both neutron and charged particle primaries. With the data from these we should have a complete picture of the shielding properties of iron.

### 3. Electron-Induced Showers in Copper

Measurements of the radial and longitudinal electron-induced shower development in copper have recently been completed. These were done on the Mark III accelerator at 187 MeV and at 950 MeV. The transition curves (longitudinal development) are in very good agreement with Zerby and Moran* at both energies. A SLAC report will follow soon containing a complete discussion of these results.

## G. RF PARTICLE SEPARATORS

The two rf separator models (Lola I, without mode rotation suppressors; and Lola II, with mode rotation suppressors) described in the previous status report were fabricated and testing was started. Figure 19 shows a sketch of the separator structures. Notice that the input and output couplers are on opposite sides of the structure to cancel the effect of any coupler asymmetry on the beam. The machining and brazing tolerances on both models were such that the phase shift excursions per cavity never exceeded $\pm 5^{\circ}$. Tuning of individual cavities was therefore not necessary. The matching procedure was carried out by means of the nodal shift technique, both with a detuning plunger introduced into the structure and with a movable short in the output waveguide. It was discovered that a plunger with a 1/2-inch diameter was optimum, while larger plungers, presumably detuning the cavities more drastically, did not give repeatable results from cavity to cavity. The final match was obtained with the movable short technique. Neither one of the two models was optimized in terms of the attenuation, $I\ell$. Lola I had a relative group velocity $v_g/c$ of -0.0311, a Q value of 10,700, and a value of $I\ell$ of 0.047 nepers. Lola II had a relative group velocity $v_g/c$ of -0.0296, a Q value of 9030, and a value of $I\ell$ of 0.059 nepers. A third model, Lola III, is presently being designed for use on the Injection Test Stand as a beam sweeper. Its relative group velocity will be approximately -0.007.

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*C. D. Zerby and H. S. Moran, "Studies of the longitudinal development of high-energy electron-photon cascade showers in copper," ORNL-3329, Oak Ridge National Laboratory, Oak Ridge, Tennessee (October 2, 1962).

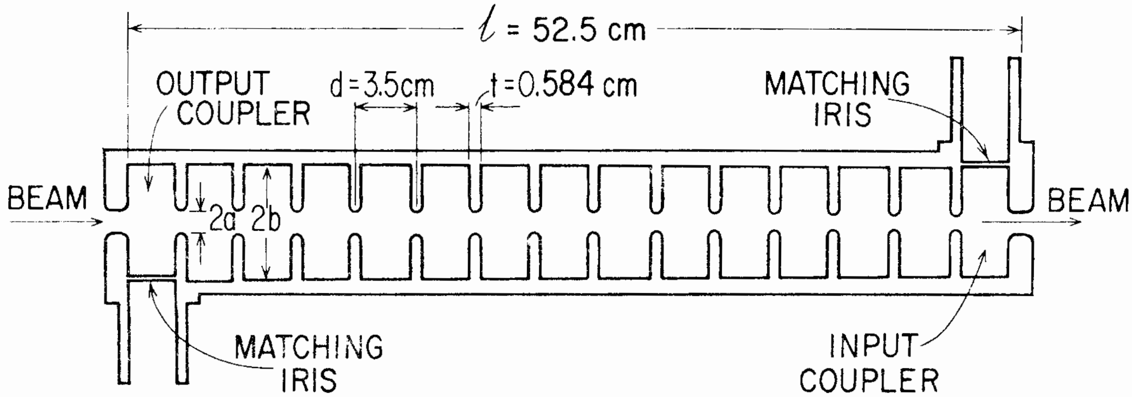


FIG. 19--Sketch of rf separator model with input and output couplers

After the cold test measurements, Lola I was installed in the momentum analyzed beam of the Mark IV accelerator. Figure 20 shows the complete experimental setup. After passing through the separator, the beam drifted over approximately 2 meters and was observed on a ZnS screen. The entire system (separator plus drift tube) was tied to the accelerator vacuum. The momentum was in the vicinity of 40 MeV/c, and the observed beam spot was 1/2 cm $\times$ 1/2 cm with the 1/2 percent slits. Measurements have been made on:

1. Maximum deflection vs. power. A plot of deflection vs. $(\text{power})^{\frac{1}{2}}$ gives a straight line; the slope of the line yields deflection (cm) = $4.72\sqrt{\text{power (Mw)}}$. This number, together with a knowledge of the geometry of the experiment, yields $E = 1.5\sqrt{\text{power (Mw)}}$ Mv/meter for the equivalent electric deflecting field on the axis of the structure.
2. Deflection vs. phase, which was observed to be in good agreement with a sine relation.
3. Aberrations. The beam was made to enter the structure approximately 1 cm off-axis in a plane normal to the deflection direction and was observed to experience the same deflection as an on-axis beam. To this extent the structure has no aberrations.

The experiment is continuing and will include further probing of the aberrations and tests of Lola II on the Mark IV accelerator.

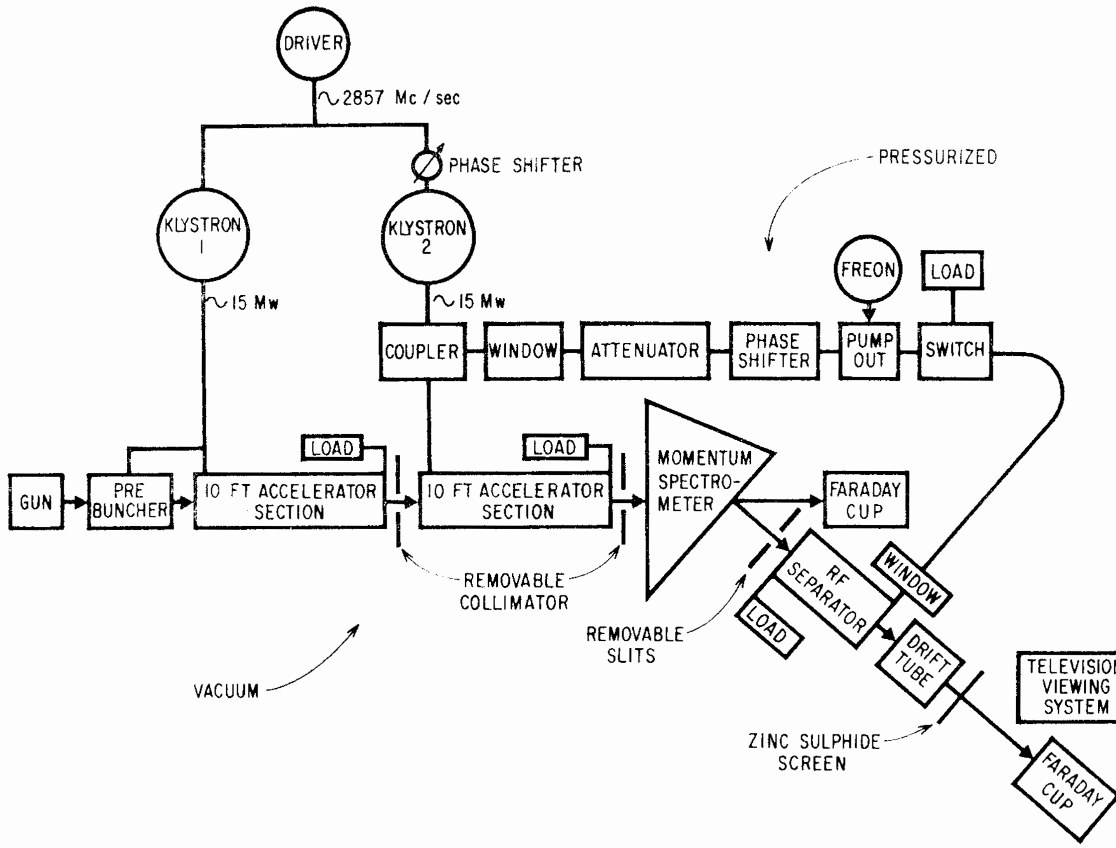


FIG. 20--Mark IV layout showing two accelerator sections with respective klystrons and rf separator with microwave circuitry.

# APPENDIX A

The summary of project activity and developments which follows was written by W.K.H. Panofsky, Director of the Stanford Linear Accelerator Center. This report was prepared for presentation at the 1963 International Conference on High Energy Accelerators, and is appended to the Quarterly Status Report as an item of special interest.

APPENDIX A

# PROGRESS REPORT ON THE STANFORD TWO-MILE LINEAR ACCELERATOR*

W.K.H. Panofsky

Director
Stanford Linear Accelerator Center
Stanford University, Stanford, California

Paper to be presented at the 1963 International Conference on High Energy Accelerators in Moscow, U.S.S.R., August 1963.

*Supported by the U.S. Atomic Energy Commission.

LIST OF FIGURES

## Acknowledgment

This paper is a description of the technical status of the Stanford Accelerator. The work involves the contributions of many members of the staff of SLAC; the author is deeply indebted to them for their devoted efforts. A list of the responsible investigators for the major phases of the Project is appended.

J. Ballam, Research Division
K. L. Brown, Instrumentation and Control
K. Copenhagen, Plant Engineering
H. DeStaebler, Radiation Shielding
A. Eldredge, Mechanical Design and Fabrication
J. Gunn, Mechanical Design and Fabrication
F. Hall, Systems Engineering and Installation
R. Helm, Special Studies
J. Jasberg, Klystron Windows
L. Johnston, Electronics
J. Lebacqz, Klystron Group
G. Loew, Microwave Engineering
R. Miller, Injection
R. B. Neal, Technical Division
C. Olson, Heavy Electronics
D. Porat, Light Electronics
R. Taylor, Beam Switchyard

In this brief summary I would like to report on the status of construction of the two-mile accelerator at Stanford, and on the progress of plans for its use. In general terms the work has progressed at the rate originally forecast when the project was proposed in 1957: Detailed design started in 1961, ground was broken in July 1962, and the beam is anticipated in 1966.

I assume that most members of this audience are familiar with the general specifications of the accelerator; to refresh your memory I am giving the table here (Fig. 1). The accelerator is expected to take its place in the international family of machines as shown in a plot (Fig. 2) giving both the intensity and energy of machines built, under construction, and under design or study. I hope you will forgive me if the parameters of accelerators attributed to members of this audience are not fully up-to-date.

Figure 3 shows schematically the major components and systems of the accelerator. I will briefly indicate the function of each of these on the figure.

Electrons are injected from a conventional electron gun through a bunching section, then through a short low phase velocity ($\beta \approx 0.75$) accelerator section. The accelerator proper is fabricated in 10-foot "sections" of the constant gradient type. By this, we mean a structure designed to propagate electromagnetic waves in a longitudinal electric circularly symmetric mode with phase velocity c, but with a group velocity $v_g$ varying ($0.020\ c \geq v_g \geq 0.007\ c$) such that the electric field will build up to an essentially constant value. This is achieved by varying the cavity dimensions (three disks per wavelength have been chosen to optimize the shunt impedance) for each of the 86 cavities constituting the section. The choice of the "constant gradient" structure has considerable advantages, the most important being a lower peak electric field strength for a given energy gain and also lesser problems with multipactoring and "beam breakup" due to unwanted modes.

We have chosen accelerator dimensions to correspond to a 10 per cent energy drop due to the rated current of 30 μA average at 20 GeV.

After considerable experimentation with alternate techniques, we have chosen to fabricate the accelerator by brazing cylindrical rings and disks of oxygen-free high-conductivity copper. Figure 4 shows the components of this process and Fig. 5 shows a completed section. Brazing takes place in a vertical furnace using a ring-burner traveling along the section at a rate of 10 cm/minute.

## PRINCIPAL M ACCELERATOR SPECIFICATIONS

| | STAGE I | STAGE II |
|---|---|---|
| ACCELERATOR LENGTH | 10,000 feet | 10,000 feet |
| LENGTH BETWEEN FEEDS | 10 feet | 10 feet |
| NUMBER OF ACCELERATOR SECTIONS | 960 | 960 |
| NUMBER OF KLYSTRONS | 240 | 960 |
| PEAK POWER PER KLYSTRON | 6-24 Mw | 6-24 Mw |
| BEAM PULSE REPETITION RATE | 1-360 pps | 1-360 pps |
| RF PULSE LENGTH | 2.5 μsec. | 2.5 μsec. |
| ELECTRON ENERGY, UNLOADED | 11.1-22.2 Bev | 22.2-44.4 Bev |
| ELECTRON ENERGY, LOADED | 10-20 Bev | 20-40 Bev |
| PEAK BEAM CURRENT | 25-50 ma | 50-100 ma |
| AVERAGE BEAM CURRENT | 15-30 μa | 30-60 μa |
| AVERAGE BEAM POWER | 0.15-0.6 Mw | 0.6-2.4 Mw |
| FILLING TIME | 0.83 μsec. | 0.83 μsec. |
| ELECTRON BEAM PULSE LENGTH | 0.01-2.1 μsec. | 0.01-2.1 μsec. |
| ELECTRON BEAM ENERGY SPREAD (MAX) | ± 0.5 % | ± 0.5 % |
| NO. OF ELECTRON ENERGY LEVELS | up to 6 | up to 6 |
| ACCELERATOR VACUUM | $< 10^{-5}$ mm of Hg | $10^{-5}$ mm of Hg |
| OPERATING FREQUENCY | 2856 Mc/sec. | 2856 Mc/sec. |
| OPERATING SCHEDULE | 24 hrs/day | 24 hrs/day |

FIG. 1--Principal specifications of the Stanford two-mile linear electron accelerator.

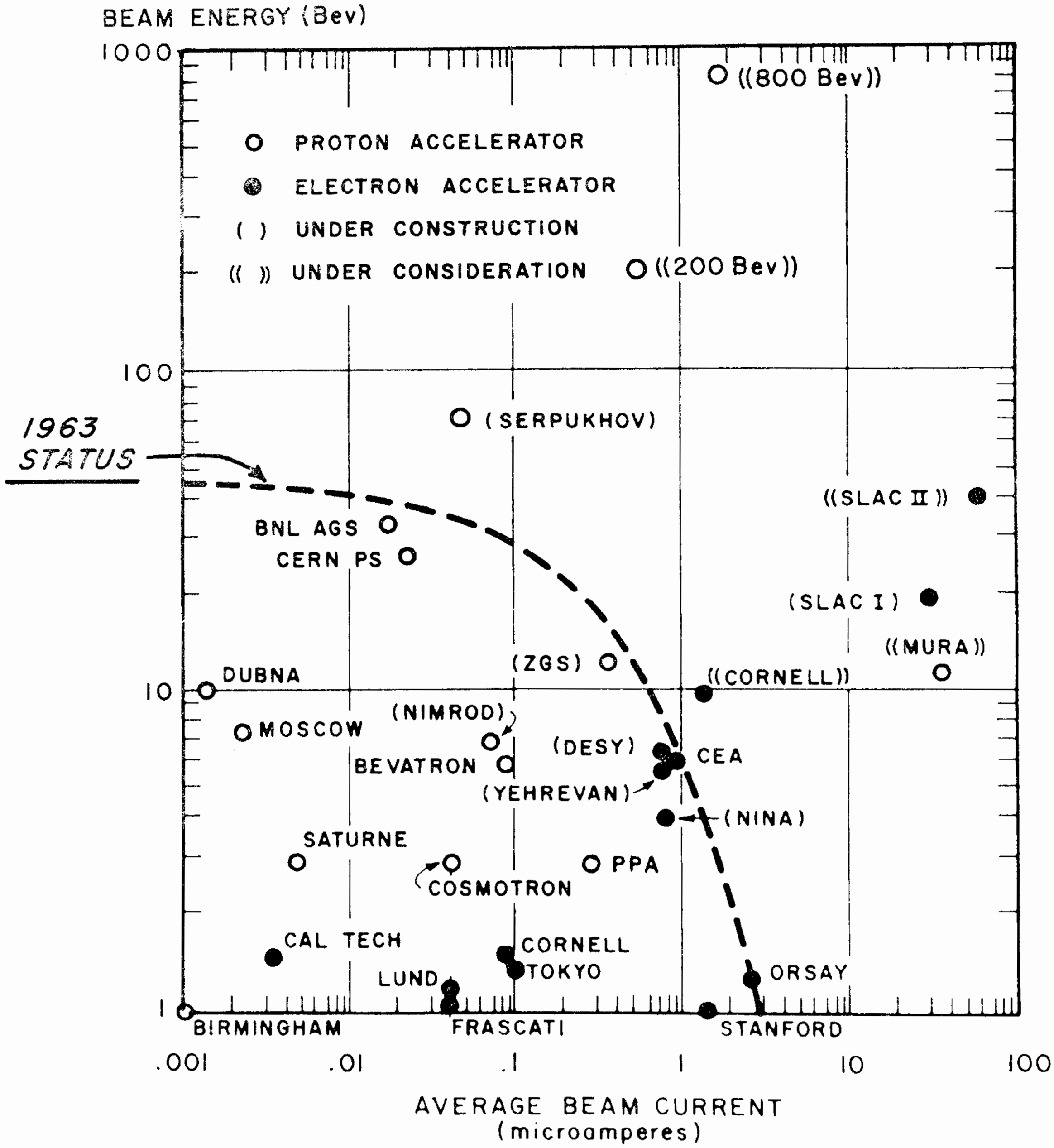


FIG. 2--Comparative graph of various accelerators.

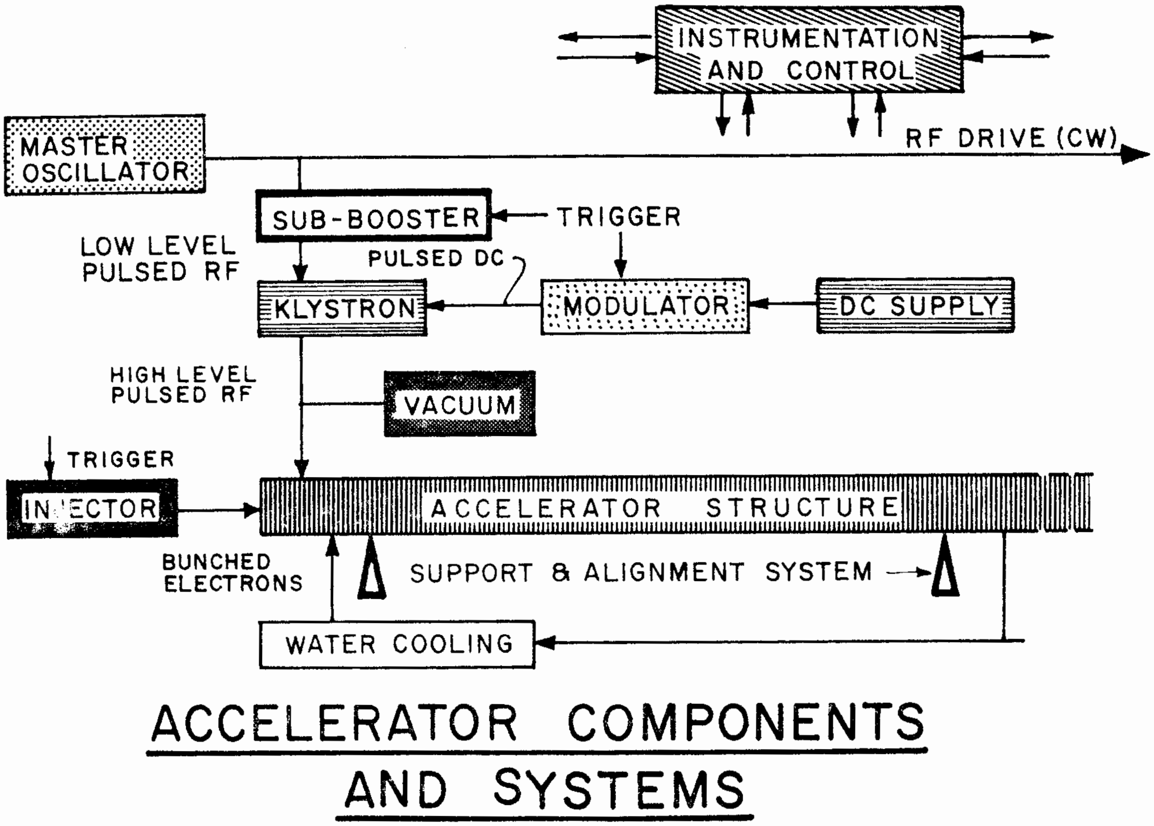


FIG. 3--Schematic representation of the major components and systems of the Stanford Linear Accelerator.

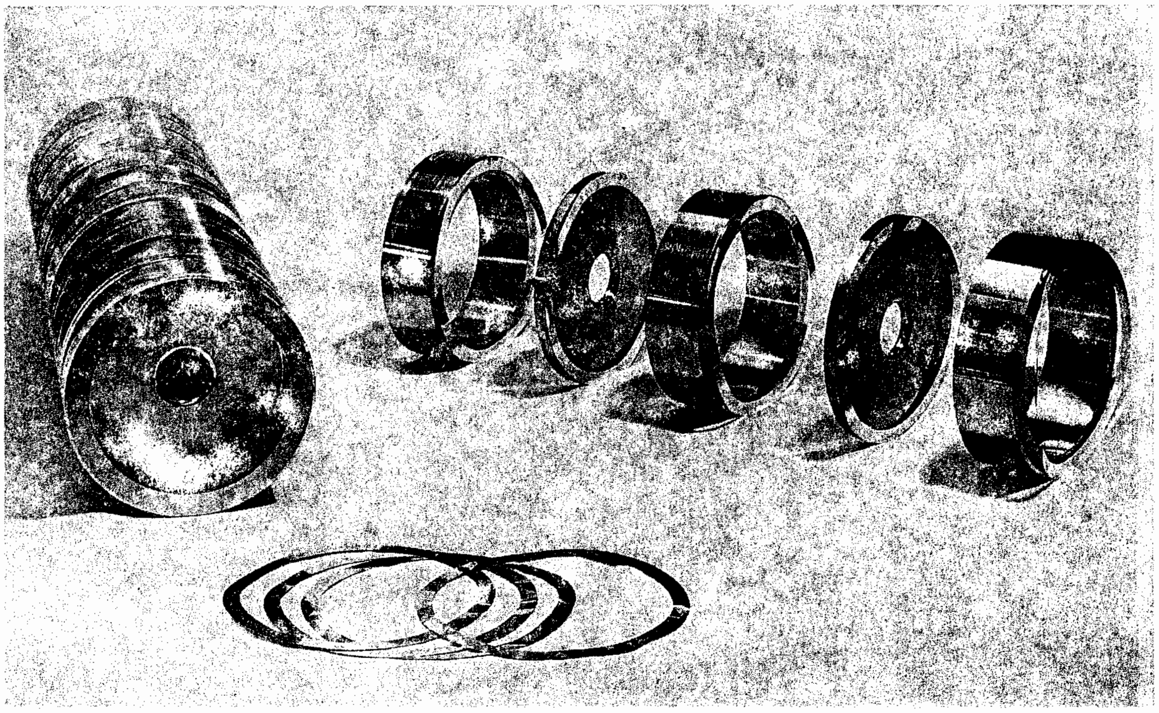

FIG. 4--Components of an accelerator pipe section before brazing.

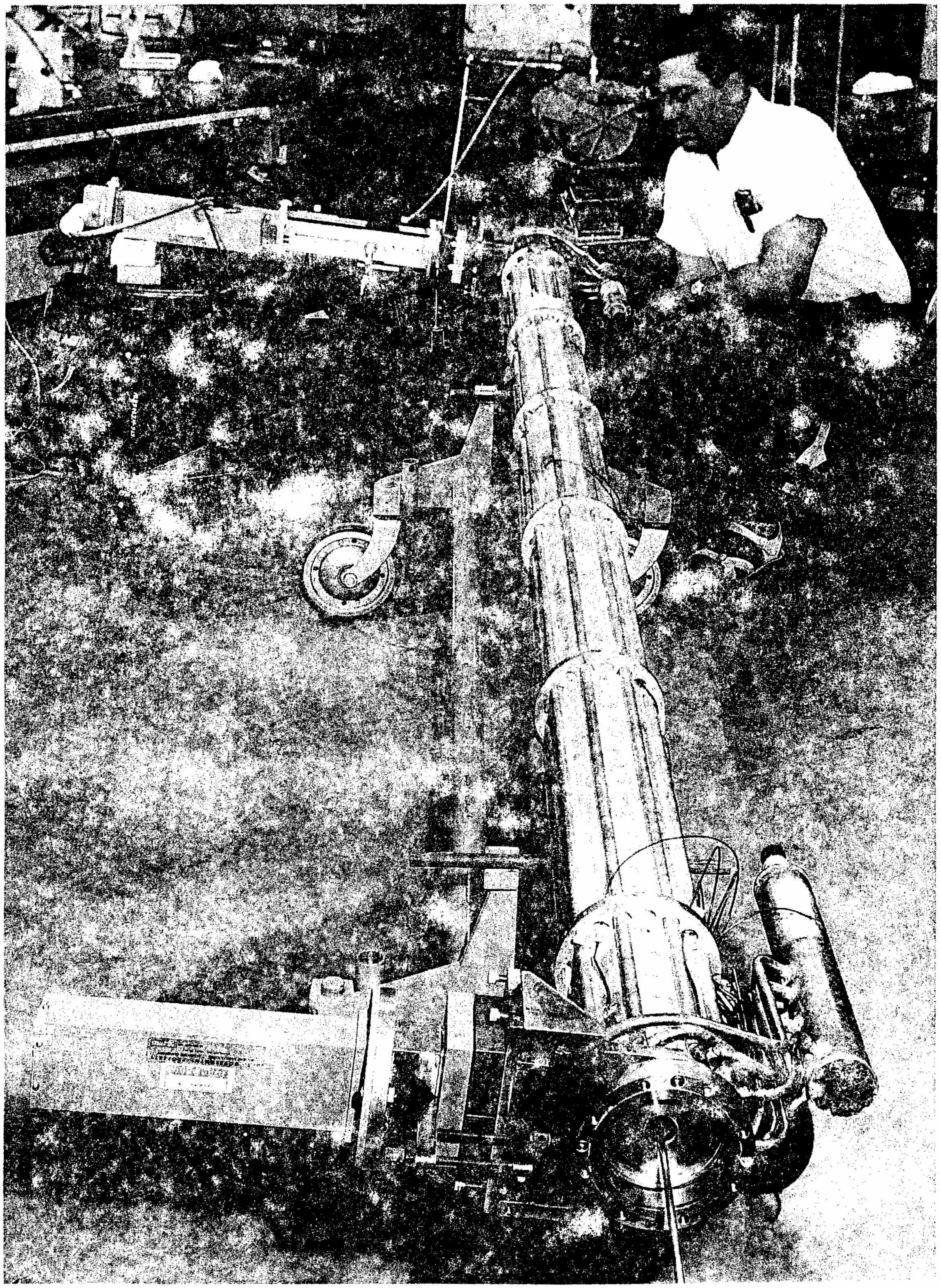

FIG. 5--A completed 10-foot section of the accelerator pipe.

Groups of four sections are assembled on a support beam consisting principally of a 2-foot-diameter aluminum pipe. The resulting 40-foot units are supported by remotely adjustable jacks in the accelerator housing. The aluminum tube serves the dual purpose of accelerator support and as an evacuated sight tube. Alignment through the total two-mile length is accomplished by diffracting the beam from a laser at the injection end of the accelerator by means of "zone plates" which can be introduced by remote control near each of the 40-foot support points; the resulting fringe pattern is analyzed electronically at the target end to yield information as to misalignments. The alignment tolerance is 1 mm but the optical system has a sensitivity of a fraction of this amount; this has been experimentally determined.

Figure 6 shows the arrangement of high-powered waveguide "plumbing" feeding the accelerator sections. This design, now fixed and tested, contains only brazed joints and metal gaskets and is water cooled to avoid waveguide phase shifts.

The specifications of the klystron shown in Fig. 7 are tabulated in Fig. 8 in comparison with the klystron now feeding the Stanford 1 GeV machine. The tubes are in procurement; present tests verifying these specifications use tubes manufactured in our own laboratory.

As you know, the window between the klystron and the vacuum guide is a critical component. This problem appears to be no longer as serious as considered earlier for several reasons. First experiments using the presently operating 1 GeV accelerator indicate that window life can be extended to many thousands of hours by controlling the rate of turn-on of the klystron drive power; means to provide such control are being introduced for the big machine. Secondly, windows coated by a layer of titanium sub-oxide applied by a sputtering technique are being tested at equivalent power levels of 150 megawatts peak and 135 kw average and show very promising results.

The physical arrangement of the accelerator and the power sources are shown in Fig. 9. You will note that the accelerator proper is in a housing of 10-foot by 11-foot dimensions with 2-foot-thick walls; this housing is now in construction. Almost all equipment requiring maintenance is located in the "klystron gallery," a building 30 feet wide, 14 feet high and 10,000 feet long, separated from the accelerator by 25 feet of compacted earth shielding. The gallery contains the klystrons, modulators, vacuum system, the pulsed rf system and most of the instrumentation and control.

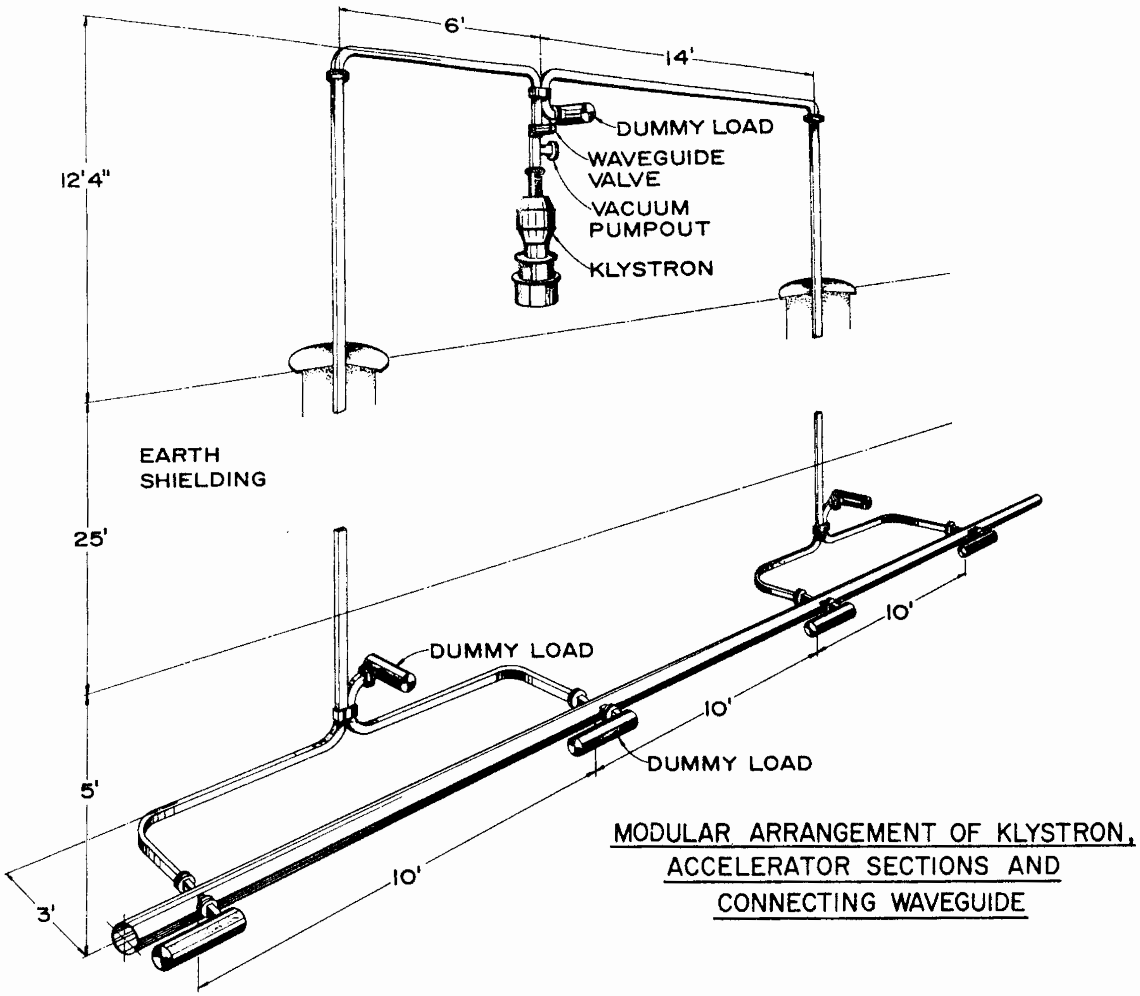


FIG. 6--Modular arrangement of klystron, accelerator sections and connecting waveguide.

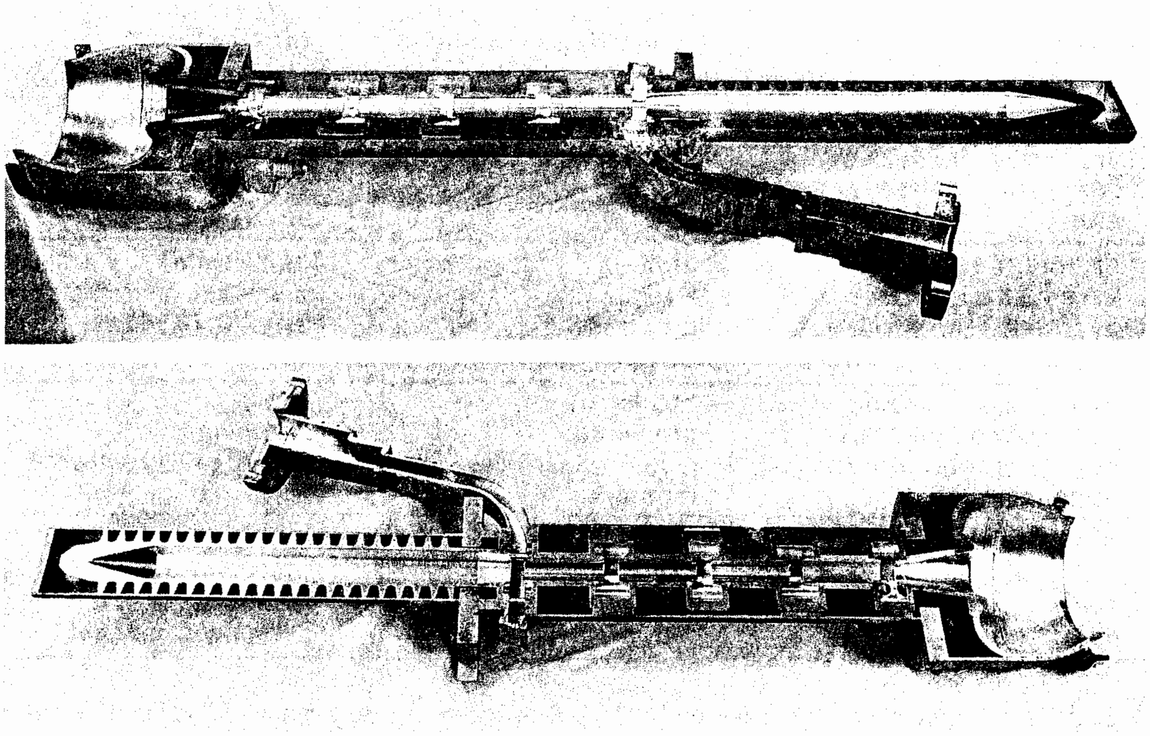

FIG. 7--Cutaway view of klystron tube.