SLAC-PUB-55

PROGRESS REPORT ON THE STANFORD LINEAR ACCELERATOR CENTER*

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A. Introduction

This report describes some of the highlights of the present state of construction of the Stanford 20 GeV Linear Accelerator. Comprehensive descriptions, statistics and specifications of the two-mile linear electron accelerator have been given on numerous other occasions[1] and will not be included here. By the nature of progress in our construction schedule, hopefully a substantial fraction of the information and pictures given in this report will soon become obsolete.

B. Building Construction

Figure 1 shows a cross section of the accelerator layout. Two buildings are seen. The lower one, underground, called the accelerator housing, contains the accelerator structure proper, supported by a 24-inch aluminum girder which also provides the optical alignment vacuum pipe to be used to align the two-mile machine. Three jacks are used to adjust the position of each 40-foot girder in the transverse plane. The upper building, called the klystron gallery, is separated from the accelerator housing by 25 feet of earth shielding. The gallery contains all the equipment necessary to power the accelerator and includes the klystrons, their associated microwave equipment, the modulators, vacuum equipment, utilities and over-all instrumentation. In Stage I of the construction program, there will be 240 klystrons with their individual modulators, each feeding four 10-foot long accelerator sections. The vertical tube connecting the two buildings, shown in the picture, is one of the waveguide runs which feeds two accelerator sections. Extra modulators in the gallery are shown to illustrate the configuration foreseen for Stage II when there will be one klystron per accelerator section, hence 960 klystrons and modulators. Plans for this expansion are not firm at this date.

Initial excavations on the SLAC site for the housing started in December, 1962. The construction of the accelerator housing began in June, 1963. Figure 2 shows the concrete slab and the beginning of the

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accelerator housing construction. Figure 3 shows the same building after completion of the concrete housing, on July 3, 1964. The first parts of the water-cooling system installation can be seen. The Klystron Gallery construction was started in November, 1963 and Fig. 4 illustrates the first few hundred feet of construction of that building. Figure 5 shows the inside of the klystron gallery with some installed utilities as well as the klystron supporting frame structure.

C. Accelerator Structure

Figure 6 illustrates some of the slow-wave structures investigated three or four years ago to optimize the accelerator structure of the two-mile machine in terms of shunt impedance, pumping speed and ease of construction. This figure is included here only because of the renewed interest in more complex accelerator structures for high energy proton accelerators, such as the cross-bar structure, the slotted-disk structure and the cloverleaf structure. It should be restated here that for a phase velocity equal to the velocity of light, the highest shunt impedance was obtained with the simple disk-loaded structure operating in the $\frac{2\pi}{3}$ mode. Although a higher vacuum pumping speed could be obtained with the so-called ventilated structure, it was not adopted because of the difficulties in maintaining tolerances on the ventilating holes.

The specific design of the disk-loaded waveguide accelerator structure has been described in detail elsewhere.[2] The accelerator sections using the constant-gradient design are presently under fabrication at SLAC at the rate of about two sections per day. Figure 7 shows the layout of the waveguide circuitry, from the 24 MW klystron through a window, a vacuum pumpout, a waveguide valve, a 3-db coupler, the waveguide feeds, two additional couplers, the input to the accelerator sections, the accelerator sections themselves and the output loads. The configuration of the waveguide as it is shown in the lower part of this figure has recently been modified because the need was found to feed the accelerator sections alternately from right and left. This alternation, called "operation flip flop", was found necessary because it was not possible to cancel entirely the asymmetry in the longitudinal electric field present in the first and last cavities of each section. Microwave measurements showed that both an amplitude asymmetry in the field as well as a phase shift of this field exist across the cavity in the transverse plane. Since the net effect of this residual amplitude and phase asymmetry is to create a transverse force on the electron beam, it was believed safer to alternate coupler inputs. The final result of "operation flip flop" was the building of sections such as the one shown in Fig. 8 with input and output couplers on the same side. However, the mode of coupling into successive sections is to follow

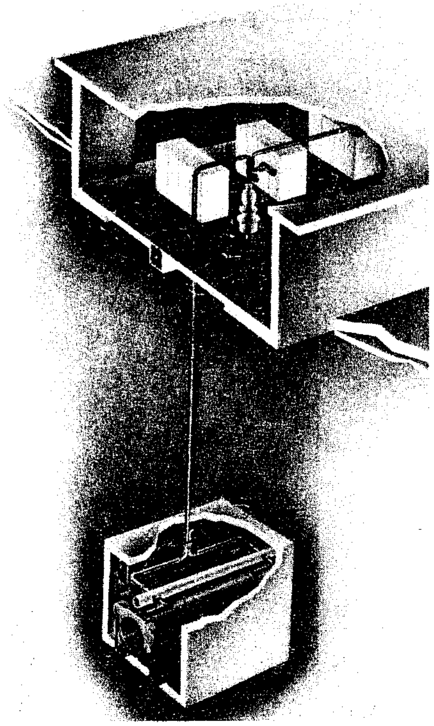


Fig. 1 Cross-sectional layout of klystron gallery (top) and accelerator housing (bottom).

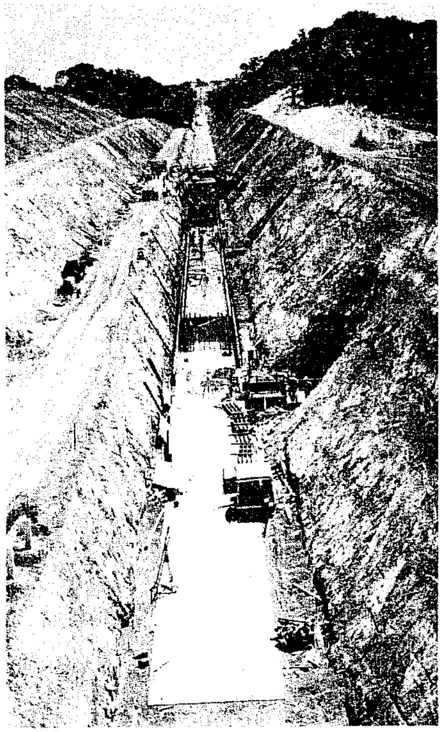


Fig. 2 Beginning of accelerator housing construction.

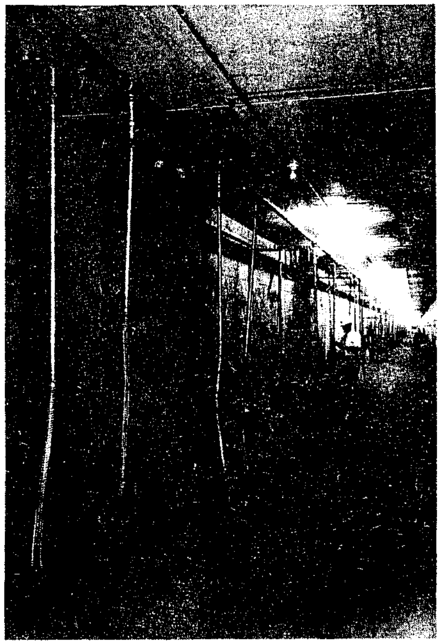


Fig. 3 Inside of accelerator housing shortly after completion.

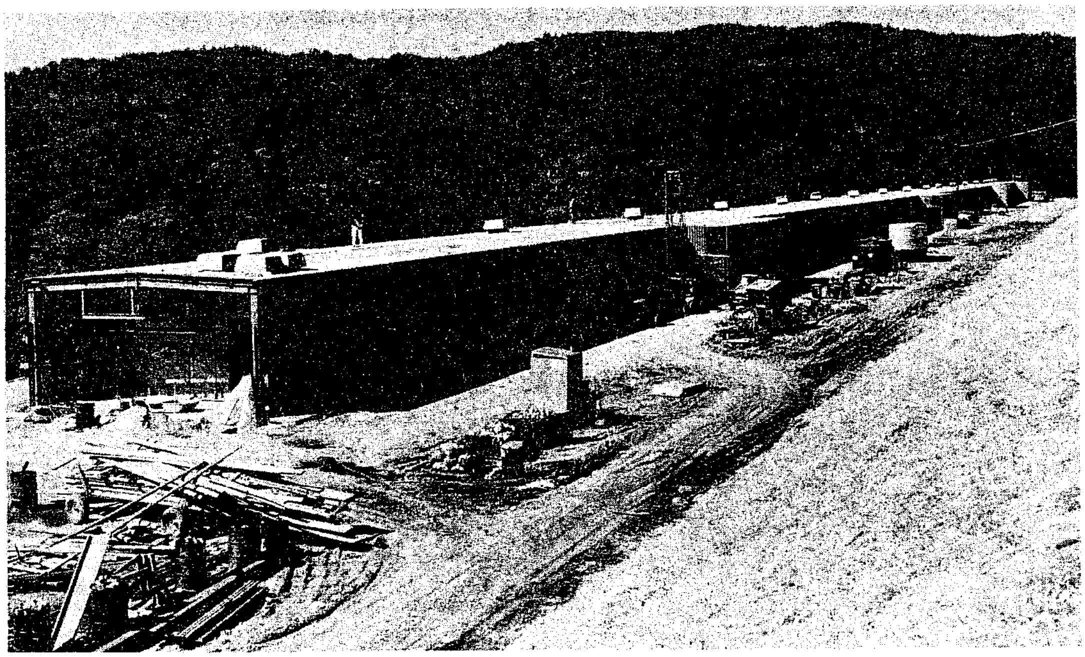


Fig. 4 Beginning of klystron gallery construction.

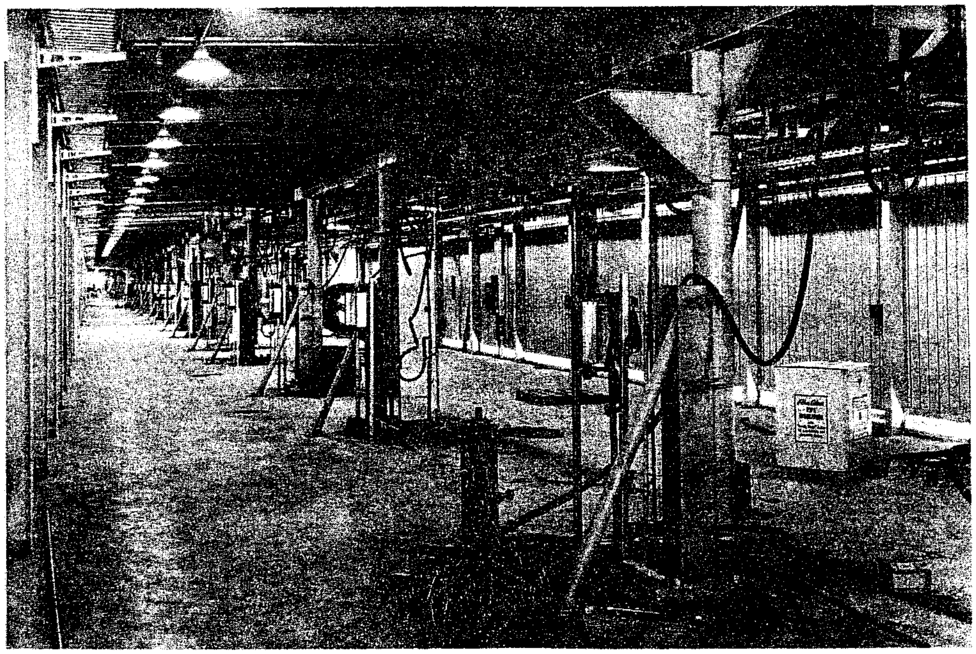


Fig. 5 Inside of first sector of klystron gallery showing utilities and klystron frame supporting structures.

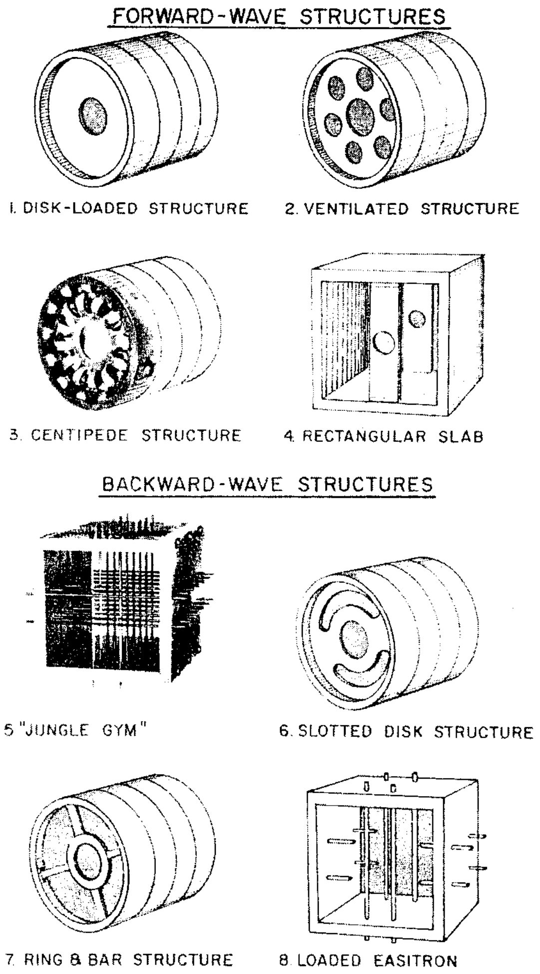


Fig. 6 Museum of forward- and backward-wave structures originally examined for use in the SLAC accelerator for $v_p = c$.

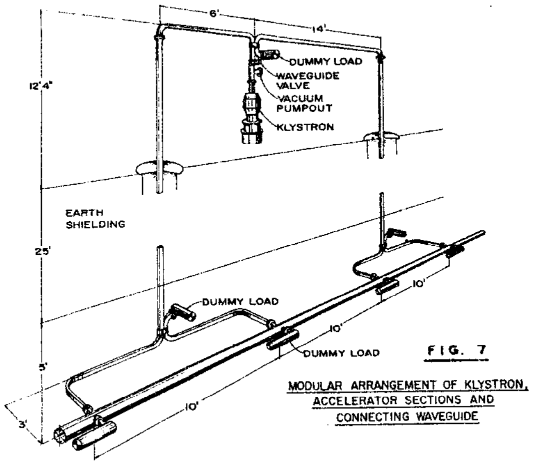


FIG. 7

MODULAR ARRANGEMENT OF KLYSTRON, ACCELERATOR SECTIONS AND CONNECTING WAVEGUIDE

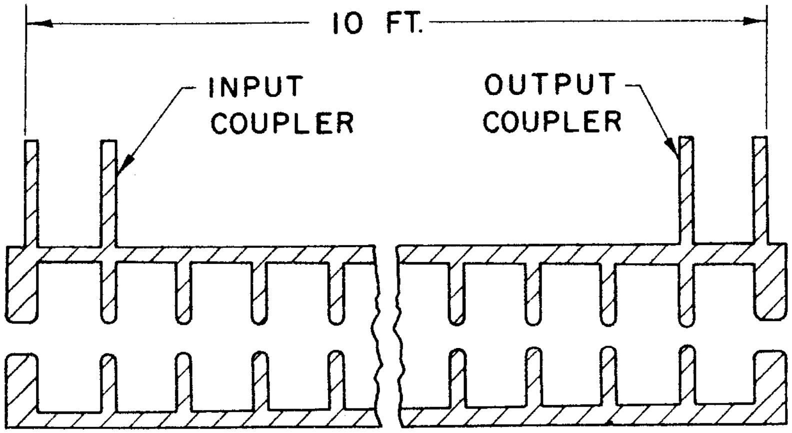


Fig. 8 Constant-gradient accelerator section.

the pattern right-left-right-left, followed by left-right-left-right. This is accomplished by rotating successive sections by 180 degrees. By this method, transverse deflections should cancel out. Over an 80-foot length, then, the beam should be back on axis and parallel to it without any increase in transverse phase space.

D. Drive and Phasing Systems

Figure 9 illustrates the microwave drive system from the master oscillator to the high-power klystrons. One main booster amplifier at 476 Mc/sec fed by a master oscillator powers the entire two-mile length of the drive system by means of a 3-1/8" coaxial line. Each of the 30 sectors into which the machine is divided obtains its rf power from a coupler in the main drive line. The frequency of the rf power is then multiplied by 6 by means of a varactor multiplier. The resulting 2856 Mc/sec rf power is then amplified by means of a sub-booster klystron to 60 kW of pulsed output power. Another coaxial line (1-5/8" diameter) feeds this rf power to each of the eight klystrons in a sector. The phase and amplitude of this signal is controlled by means of an isolator, a phase shifter, and an attenuator. A special protection attenuator is incorporated which automatically removes the rf drive power to the 24-MW klystron every time a major gas burst or modulator failure temporarily disables the klystron. The protection attenuator subsequently slowly restores this drive power to its former level, thereby preventing full output rf power from striking the klystron window instantaneously. As has been reported earlier, this procedure should prevent the frequency fractures and punctures of windows experienced in the Stanford Mark III accelerator.

Figure 10 illustrates the principle upon which the operation of the automatic phasing system for klystrons is based. It is known that when a klystron is correctly phased, the phase of the klystron output signal in the accelerator, E_W, is 180 degrees out of phase with the signal induced by the electron beam, E_e. Hence, maximum energy transfer is obtained from the klystron output wave to the electron beam, resulting in the resultant vector, E_R. On the other hand, if E_e is not 180 degrees out of phase with E_W, less than the maximum energy transfer takes place and one obtains a rotated resultant vector E_R as shown in the lower part of Fig. 10. This principle is used as follows: The klystron pulse is momentarily delayed in time, thereby allowing E_e to be compared in phase with a reference signal obtained from the drive line. A so-called "calibrating" phase shifter is used to null the output of a phase bridge under this condition. E_W is then compared with the reference signal and caused to be 180 degrees out of phase with E_e by means of the same phase bridge. This bridge consists of a magic T and is followed by a

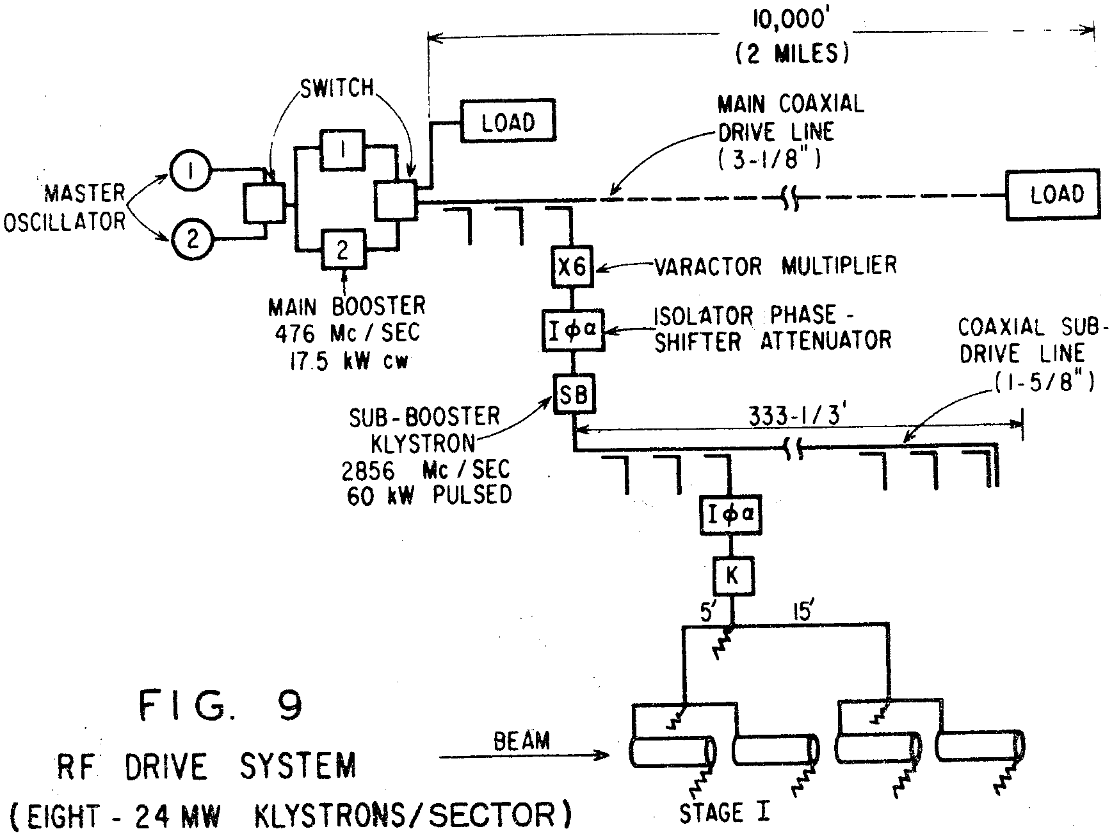
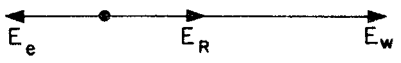


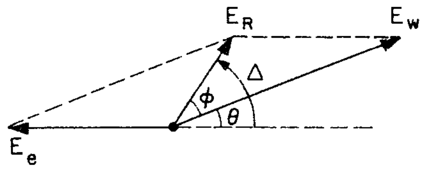
FIG. 9

RF DRIVE SYSTEM

(EIGHT - 24 MW KLYSTRONS/SECTOR)



ORIENTATION OF FIELD VECTORS
WHEN PHASING IS CORRECT



ORIENTATION OF FIELD VECTORS
WHEN PHASING IS INCORRECT

Fig. 10 Principle of automatic phasing system for klystrons using beam induction technique.

pair of linear thermionic diodes, a gated voltmeter, a phase wobbler and two servo amplifiers. These feed into the two windings of an ac motor which controls the rotation of the klystron phase shifter until a null is obtained. An automatic programmer causes all klystrons in a sector to be sequentially and automatically phased according to this technique. The operation should take no longer than one minute per sector.

E. Injection System

Figure 11 shows the main elements of the electron beam injection system to be used at the input to the accelerator. Briefly, this system will consist of a gridded gun, a prebuncher fed with approximately 1 kW of peak rf power and followed by a drift space, a constant velocity buncher ($v_p = 0.75$ c) and finally a standard accelerator section ($v_p = c$). The bunching process which results from this setup is illustrated in the lower part of the figure. An experimental injection system is presently being tested at SLAC and the various parameters including rf power levels, gun modulator settings, and magnetic focusing currents are being studied. It has been found by means of an rf deflector used as a bunch analyzer illustrated in Fig. 12 that 5 degree bunches can be obtained with this system. The structure used for the rf deflector is the same as that proposed for rf separators.[3] By varying the setting of the calibrated variable phase shifter which controls the phase to the input of the deflector, it is possible to study the charge density inside the electron bunch.

F. Beam Guidance

At the end of every sector, i.e. at 30 points along the machine, there will be a special drift space containing special devices to locate and to guide the electron beam. This drift space will include a set of quadrupole triplets, a set of two steering dipoles, a set of beam position monitors, a toroid to measure beam current, an insertable beam profile monitor, a beam scraper to protect the accelerator and to localize the radiation, and two vacuum valves enabling the operator to isolate one sector from the next. The principle of the microwave beam position monitors is illustrated in Fig. 13. The pickup cavity which is shown here as a structure similar to the beam deflector structure shown in Fig. 12, will, in fact, consist simply of a single cavity operating in the TM_{120} mode. Two such cavities will be used, one for x and the other for y position. Depending on whether the beam is up or down, left or right, the phase of the rf induced signal will flip by 180 degrees. This induced signal will be compared with a phase reference signal induced in a third cavity and compared by means of a magic T and two linear detector diodes. The information obtained from each of these drift spaces

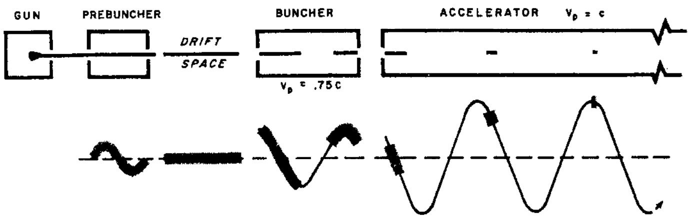


Fig. 11 Progressive bunching of electron beam.

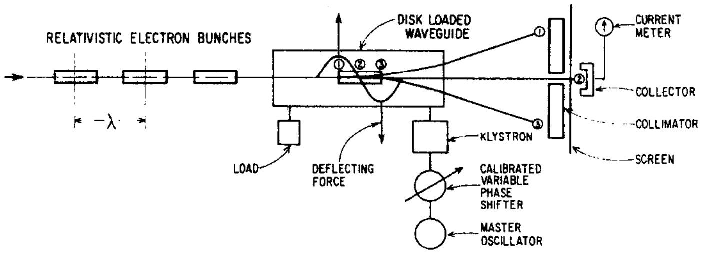


FIG. 12 DEFLECTOR-BUNCH ANALYZER

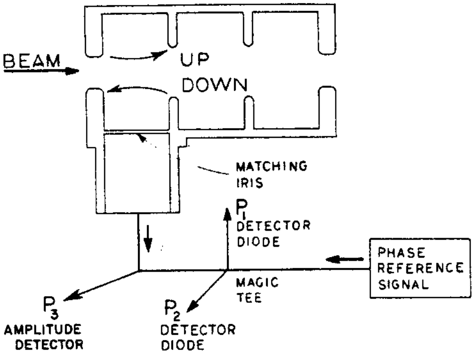


Fig. 13 Beam position monitor using TM_{11} mode structure and magic tee for phase comparison. For example, a maximum for P_1 indicates that the beam is up, a maximum for P_2 that the beam is down. The amplitude of P_3 indicates the distance from the axis.

will be sent to the Central Control Building by means of a base-band telemetry system and an FM system. There this information will be displayed on a set of oscilloscopes, allowing the operator to take corrective action by means of the remotely controllable steering dipoles and quadrupoles.

G. Support and Alignment

Figure 14 shows an expanded view of the support and alignment system. The three jacks which control the position of the beginning of each 40-foot support girder, are shown together with the accelerator tube and a retractable Fresnel lens mounted inside the girder. This Fresnel lens is part of the optical alignment system which will consist of three basic elements: (1) a laser mounted at the injector end of the accelerator, (2) 300 of these retractable lenses consisting of square copper and nickel plated targets perforated with an appropriate Fresnel pattern, and (3) at the end of the accelerator, a light intensity scanner and detector to determine the position of the image center. By determining the coordinates of successive spot centers formed by inserting successive lenses in the light path, it will be possible to measure the misalignment of each lens and hence of each corresponding girder. Corrective action can be taken accordingly. Because the focal length of the Fresnel lenses must change as a function of their position along the two-mile length, the hole pattern must change gradually from lens to lens. A special computer program has been used to determine the pattern pertaining to each lens position and a punched tape has been derived to control the ruling machine used to fabricate each target. Experiments with sample targets have already been conducted in an abandoned railway tunnel, not far from San Francisco, and it has been shown that over a 1,000-foot distance, displacements of a target of the order of 0.001 inch can be resolved.

H. Beam Switchyard

Figure 15 shows the layout of the array of magnets following the two-mile length of the machine which will be capable of switching the beam into the various experimental areas such as End Station A (for electron scattering experiments), and End Station B (for secondary beams, bubble chambers, etc.). A straight ahead beam is also provided. Before entering the beam switchyard, the beam will be steered onto and through an adjustable collimator. Electron energy of the deflected beams is measured in the switchyard by means of several momentum spectrometers.

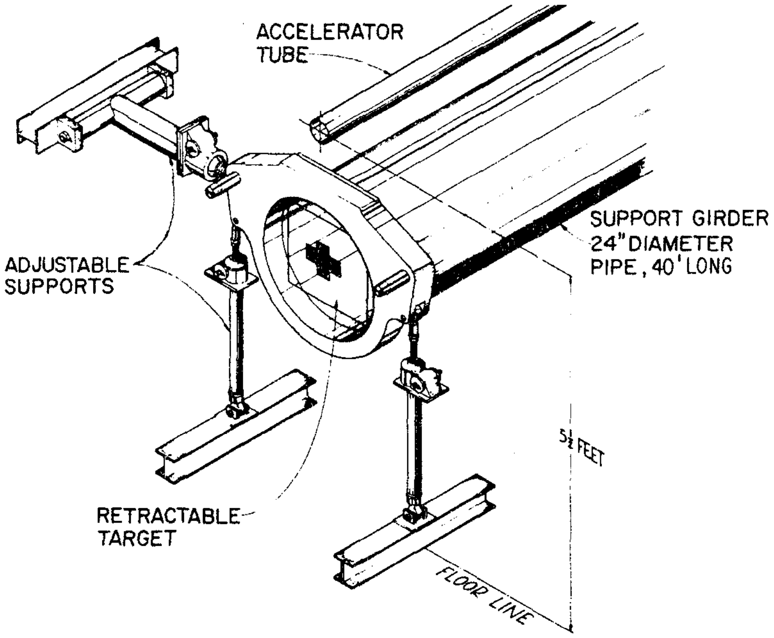


FIG. 14 SUPPORT AND ALIGNMENT SYSTEM

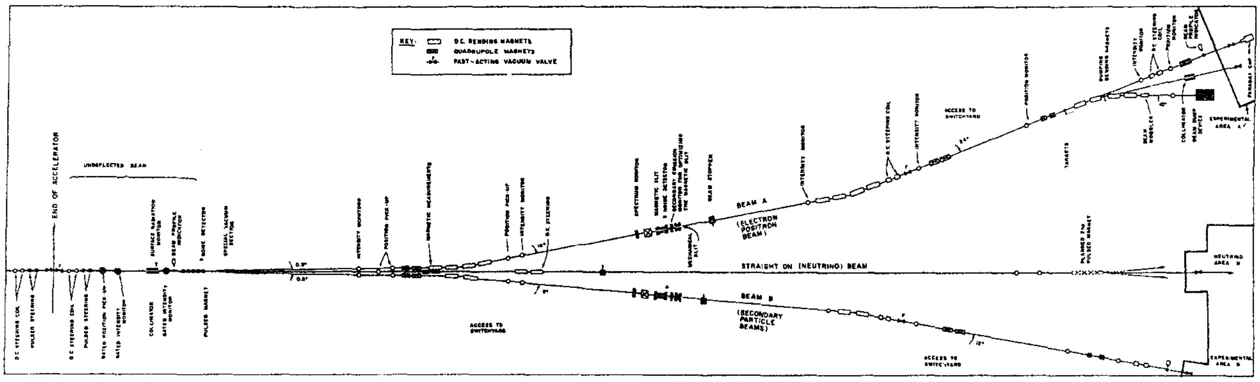


Fig. 15 Beam switchyard layout.

I. Instrumentation and Control

All essential instrumentation and control information will be available at the Central Control Building to be constructed close to the end of the machine. Several systems are being engineered and procured to permit monitoring and control of the accelerator, the switchyard, and some of the essential beam parameters in the experimental areas. These instrumentation and control systems include an "on-off" type status monitoring system based on the time-sharing multiplexing principle, an analog system to transmit information concerning certain analog signals available at each sector, a base-band telemetry system to transmit beam position and intensity information, a more accurate FM system to transmit accurate electron beam charge information and a remote control system consisting of a relay tree enabling the central control operator to actuate a number of devices along the machine, such as trigger delays, steering and quadrupole currents, gain controls, automatic phasing, etc. Because of the complexity of this instrumentation and control system and the difficulties foreseen in operating the accelerator with interlaced beams of different energies accelerated by different complements of klystrons on a pulse-to-pulse basis, it is now being contemplated to acquire at least one small computer to take over some of the control functions and many of the data logging functions which a human operator would not be able to perform. The first computer will be used to set up the magnet currents required in the beam switchyard for beams of specific energies. The next step may be to design a computer system capable of automatically controlling the beam guidance system along the two-mile length. Studies of these computer systems are presently beginning and will develop further in the near future.

J. Conclusion

While it outlines some of the highlights of the present construction status at SLAC, this report is by no means complete and several systems such as the modulators, the vacuum system, the cooling-water system, the variable voltage substations, and others have not even been touched upon. It is believed that the information on these systems can either be found in other SLAC reports or will be forthcoming at future conferences.

YOUNG: Can you tell us briefly what the situation is concerning klystron procurement and delivery.

LOEW: We are making klystrons at Stanford. In addition, we have two contracts, one with RCA and one with Sperry. We are now receiving tubes from these suppliers which are meeting the specifications. To protect the project we have just signed two more study contracts, one with Eimac and one with Litton. These companies will make something like six tubes each in the next year with an incentive plan so that they will receive more for each additional megawatt output.

REFERENCES

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2. A. L. Eldredge, G. A. Loew, and R. B. Neal, "Design and Fabrication of the Accelerating Structure for the Stanford Two-Mile Accelerator", SLAC Report No. 7, Stanford Linear Accelerator Center, Stanford University, Stanford California (November 1962).

3. O. A. Altenmueller, R. R. Larsen, and G. A. Loew, "Investitagions of Traveling Wave Separators for the Stanford Two-Mile Accelerator", SLAC Report No. 17, Stanford Linear Accelerator Center, Stanford University, Stanford, California (August 1963).