

REFERENCE USE

SLAC-73  
UC-28, Particle Accelerators  
and High-Voltage Machines

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report

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## INTRODUCTION

## INTRODUCTION

This is the nineteenth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the thirteenth Quarterly Status Report of work under AEC Contract AT(04-3)-515, both held by Stanford University. Contract AT(04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that has as its chief instrument a two-mile-long linear electron accelerator. Construction of the Center began in July 1962. The principal beam parameters of the accelerator in its initial operating phase are a maximum beam energy of 20 GeV, and an average beam current of 30 microamperes (at 10 % beam loading). The electron beam was first activated in May 1966. In December 1966, a beam energy of 19.0 GeV was achieved. Beam currents up to 15 microamperes have been obtained. Also during this quarter, positrons were accelerated through the machine and experiments with the high energy electron beam were begun. The estimated construction cost of SLAC is \$114,000,000.

The work of construction was 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 retained the services, under subcontract, of the firm Aetron-Blume-Atkinson (ABA), a joint architect-engineer-management venture.

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.

Contract AT(04-3)-515, which went into effect on January 1, 1964, provides support for the various activities at SLAC that are necessary in order to prepare for the research program which will be carried out with the two-mile accelerator. Among the principal activities covered in the scope of Contract AT(04-3)-515 are theoretical physics studies, experiments performed by the SLAC staff at other accelerators, research-equipment development programs (such as particle separators, specialized magnets, bubble chambers, etc.), and research into advanced accelerator technology. Contract AT(04-3)-515 also provides for the initial stages of operation of the Center after completion of construction.



In the final phases of construction during this quarter, several continuing construction projects were essentially completed: the Medical Facility in the Administration Building, the extension to the Data Assembly Building, radiation monitoring wells, a stairway from the Klystron Gallery to the Accelerator Housing at Sector 4, electric power remote indicators, the enclosure for the two-meter spark chamber, the building for the 54-inch spark chamber, the liquid hydrogen storage facility, and minor modifications to the Cryogenics Building, the Auditorium control room, the elevator in End Station A, and the vacuum-testing work area in the Electronics Building.

Other construction projects are in various stages of progress: An architect-engineer has been retained for the extension of the Central Laboratory, construction has started on the klystron store room, the General Services Building is in Title II design, design of the Fire Station is 90% completed, conversion work for the Crafts Shop is out for bid, installation has started for a heating system in End Station A, construction of an exterior lighting system for the End Station area has begun, electronics shop conversion is in design, the expansion of the computer facility is out for bid, and minor modifications are underway for adding thermal interlocks in parts of the accelerator water system, insulation of the off-axis alcoves in the Klystron Gallery, and construction of enclosures for the Beam Switchyard service area.

Subcontracts have been awarded for construction of the 82-inch bubble chamber building, for its utilities and its 12-kV-to-480-volt power substation, and for installation of air conditioning for a computer data assembly area in the Fabrication Building.

All equipment except the pulses magnets has been installed in the Beam Switchyard.

Figures 1 - 9 show some of the completed systems installations and new construction items undertaken during the quarter.

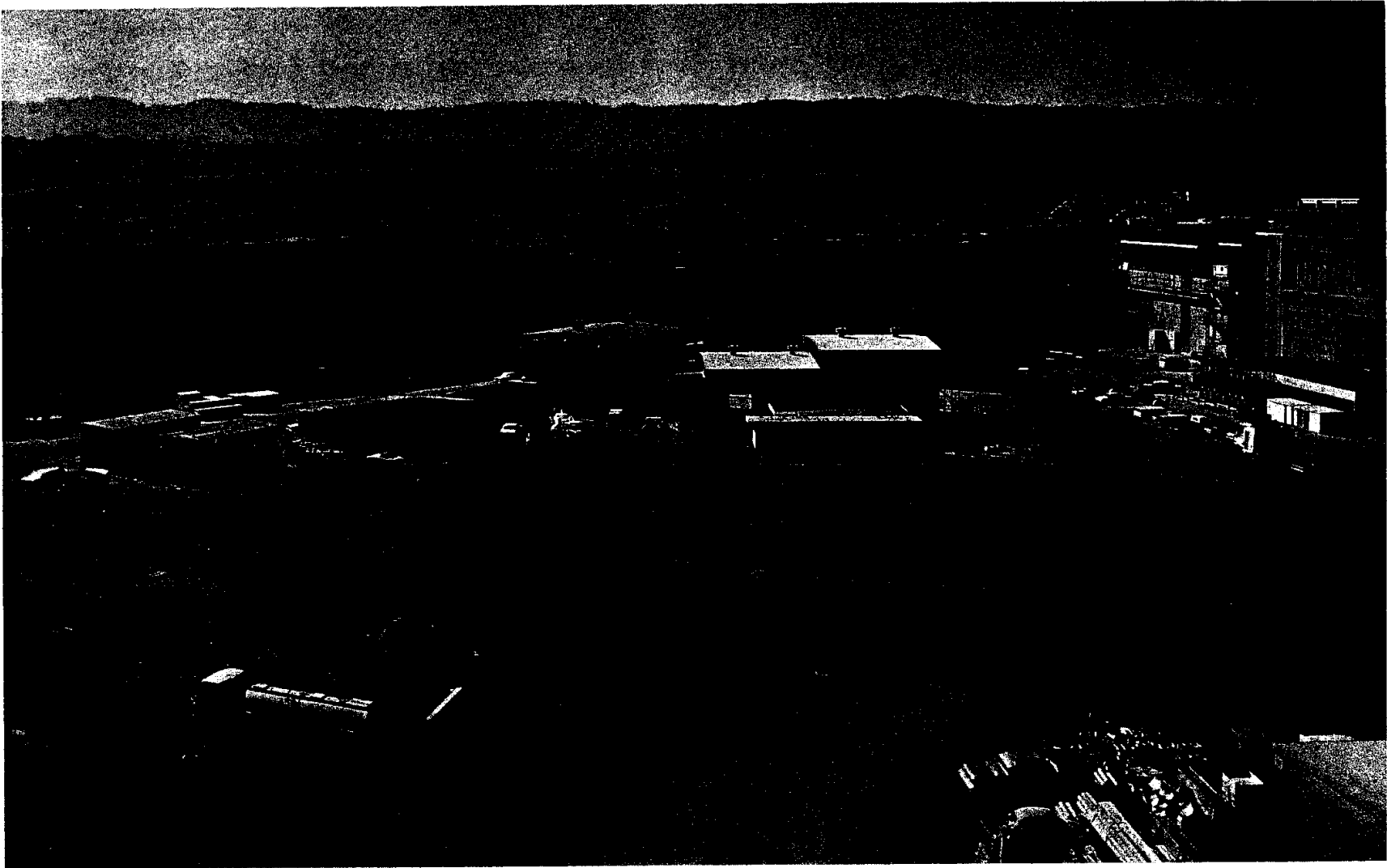


FIG. 1-TARGET AREA; SPARK CHAMBER AND 40-INCH BUBBLE CHAMBER SHELTERS AT CENTER

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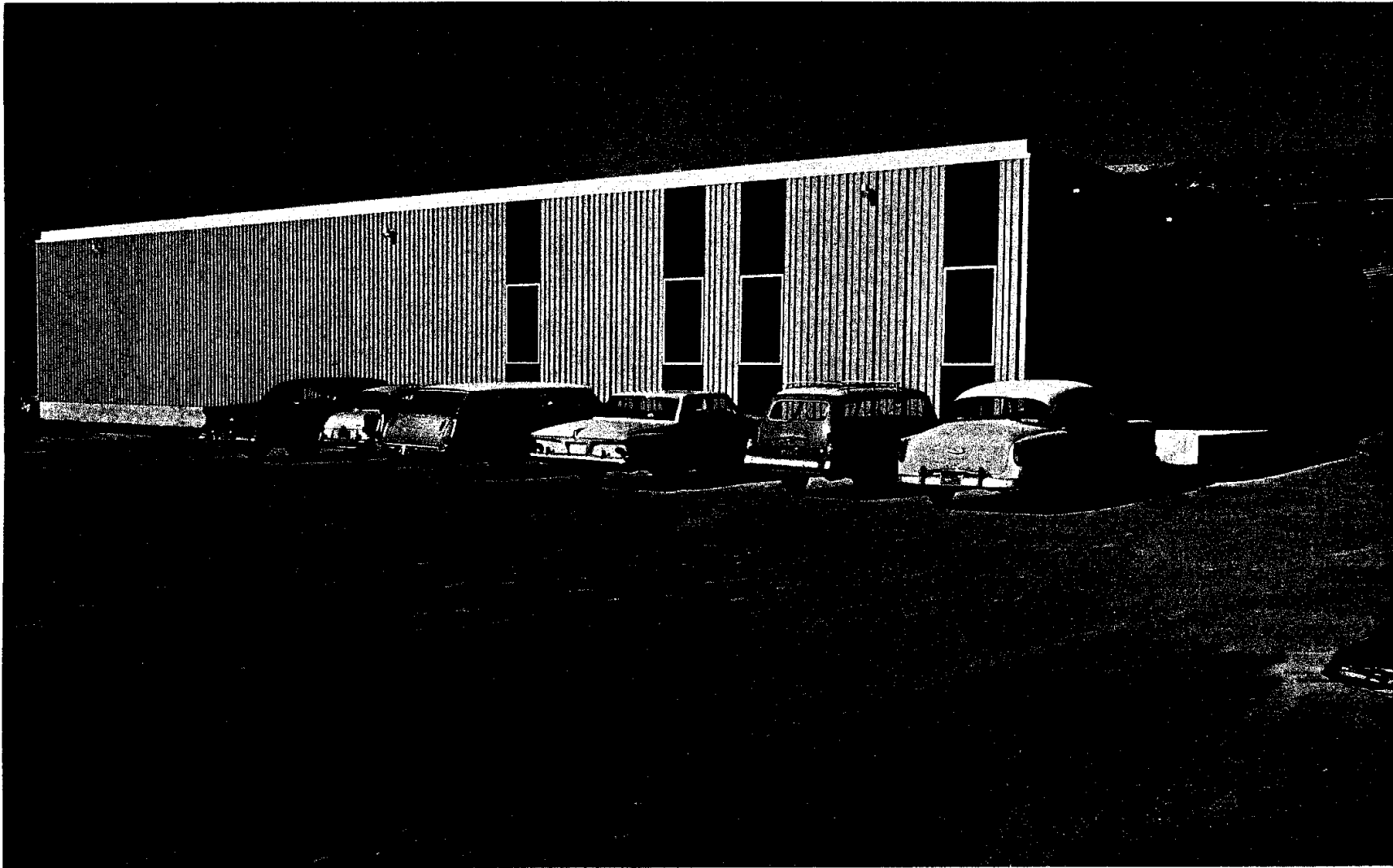


FIG. 2- NEW ADDITION TO DATA ASSEMBLY BUILDING

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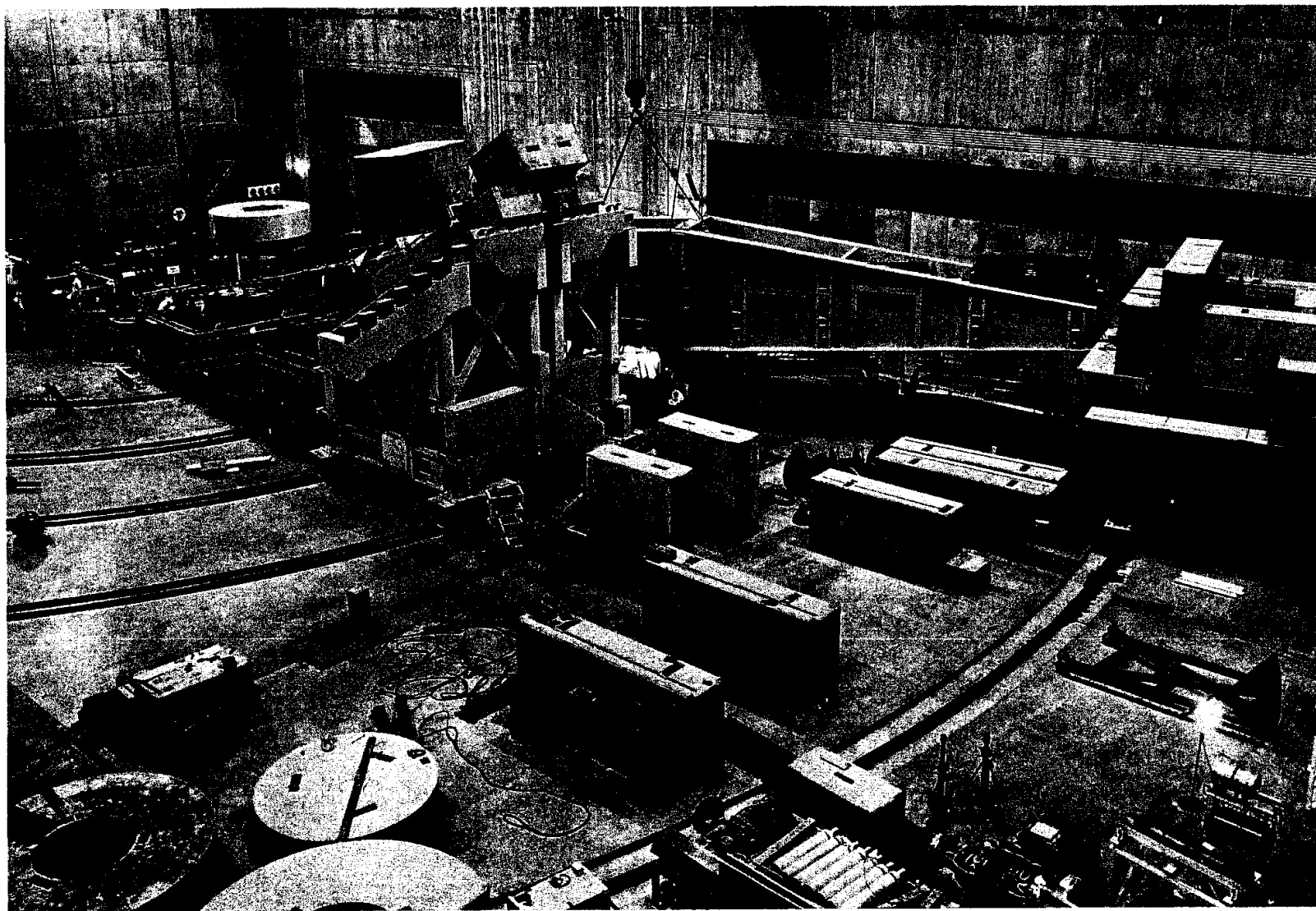


FIG. 3- INTERIOR OF END STATION A

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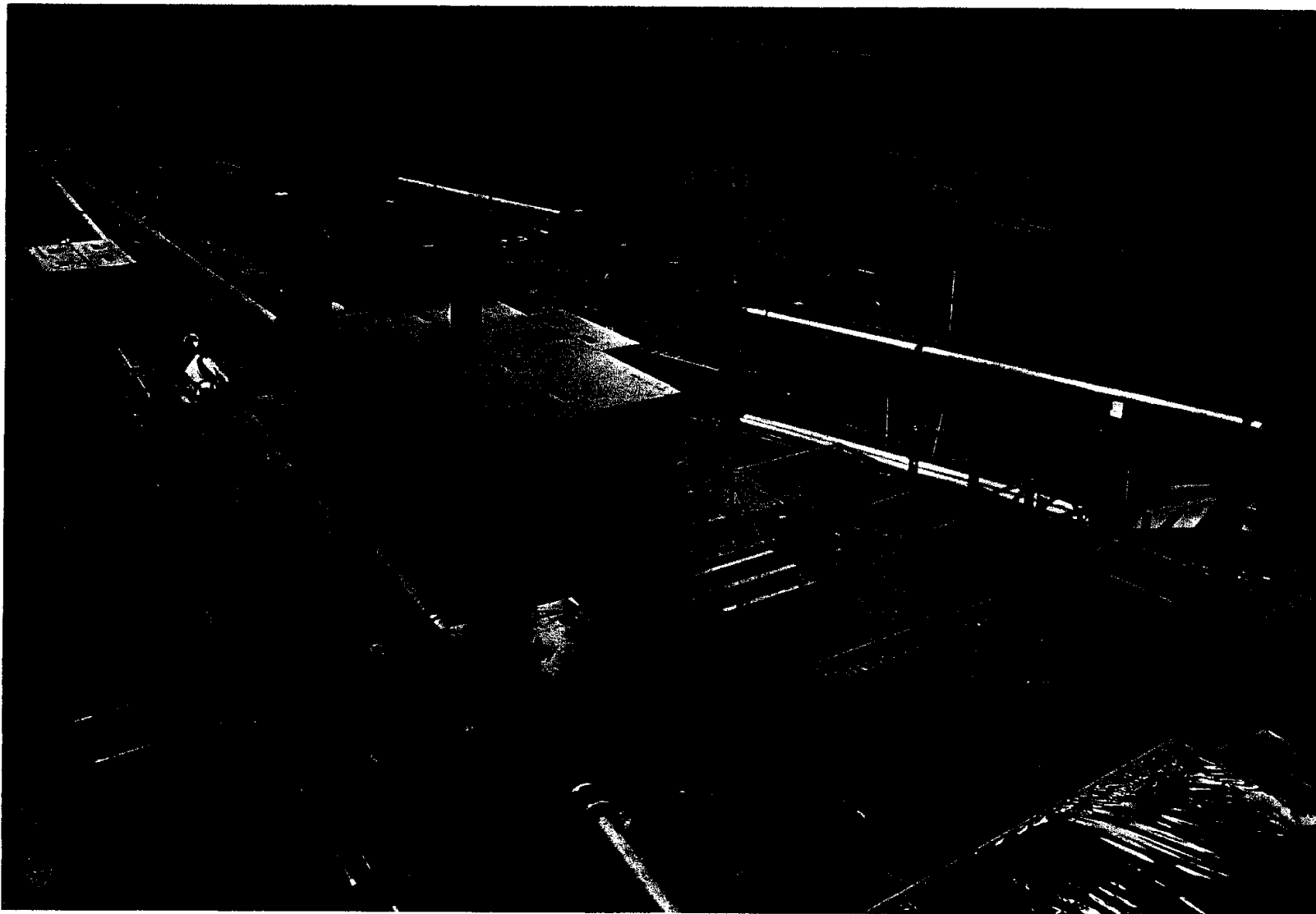


FIG. 4- INTERIOR OF END STATION B

770A4



FIG. 5- BEAM SWITCHYARD HOUSING, UPPER LEVEL, LOOKING EAST FROM MAIN ACCESSWAY; 770A5  
A-BEAM TO LEFT, B-BEAM TO RIGHT, CENTRAL BEAM STRAIGHT AHEAD

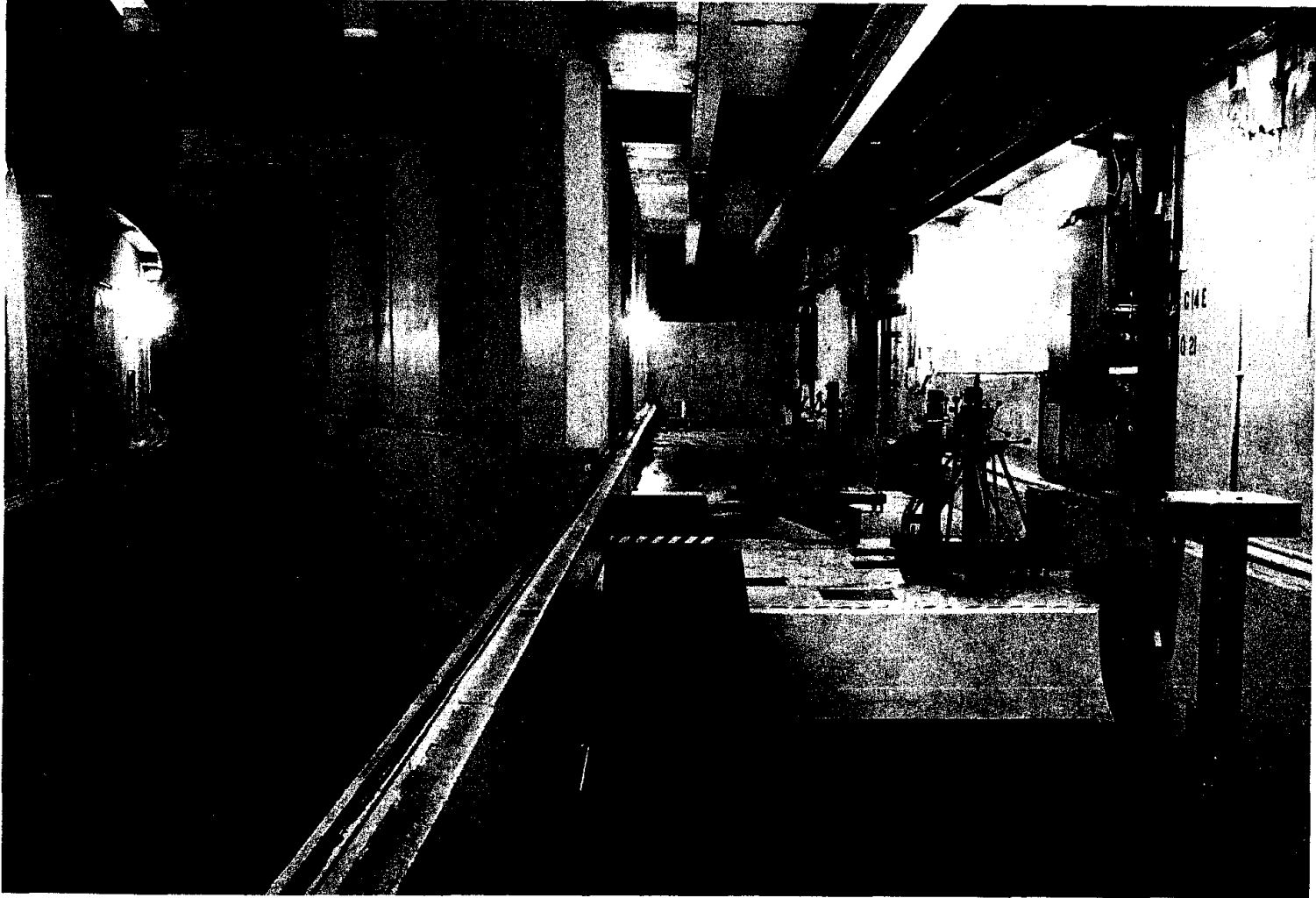


FIG. 6- BEAM SWITCHYARD HOUSING, LOOKING EAST; A-BEAM DUMP IS BELOW  
CONCRETE SHIELDING BLOCKS, FUTURE A' AND A'' BEAMS

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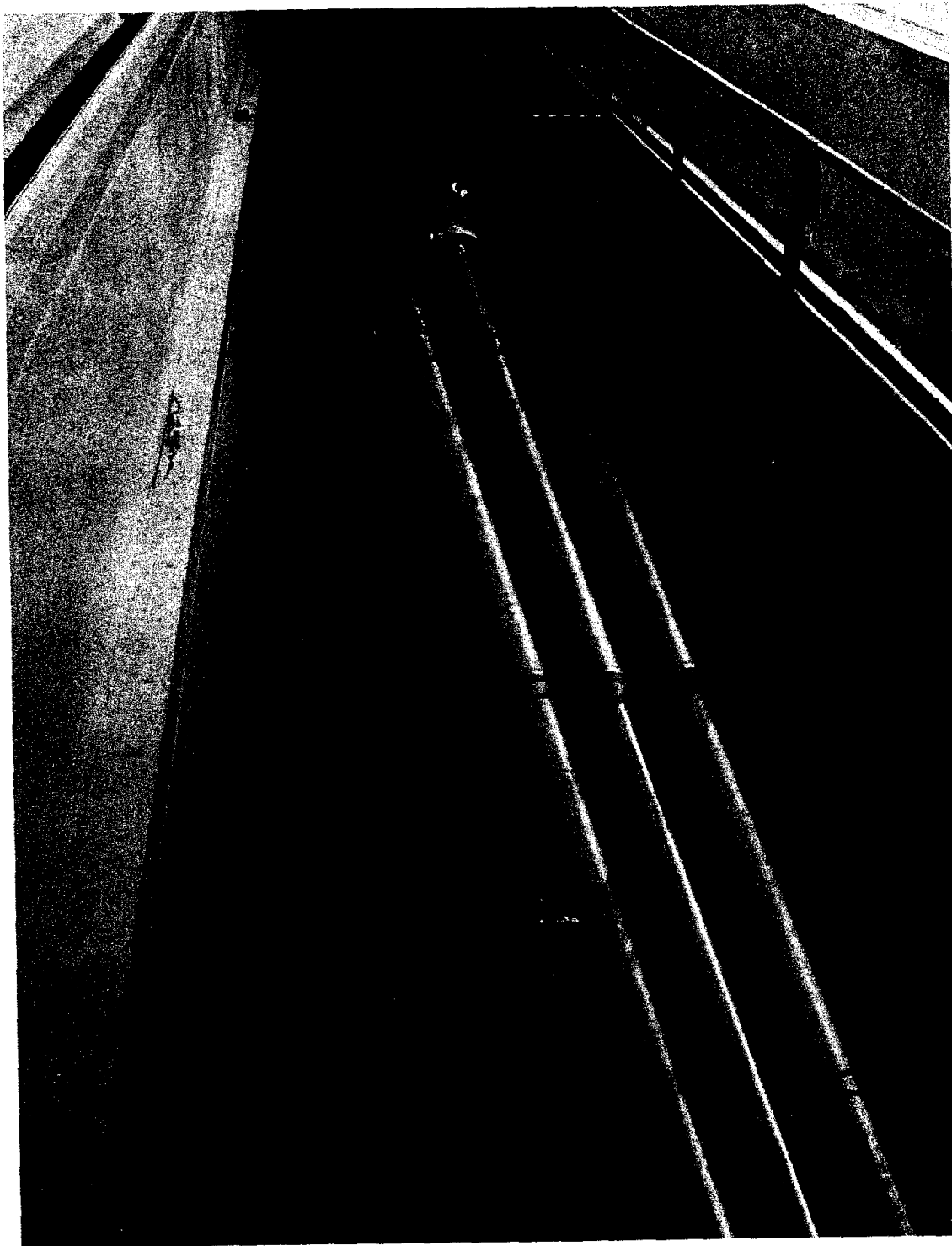
FIG. 7- BEAM SWITCHYARD HOUSING, LOOKING WEST UP CENTRAL BEAM.  
LARGE PIPE SHOWN IS CENTRAL BEAM DIVERGENT BEAM CHAMBER





770A8

FIG. 8- BEAM SWITCHYARD HOUSING, LOOKING EAST AT STEEL SHIELDING AT END OF CENTRAL BEAM



770A9

FIG. 9- BEAM SWITCHYARD HOUSING, LOOKING EAST AT THREE DIVERGING BEAMS ENTERING END STATION B

I. ACCELERATOR AND RESEARCH  
AREA OPERATIONS

## A. OPERATIONS SUMMARY

### 1. Definition of Terms

Correct interpretation of the accelerator performance graphs and charts used in this portion of the quarterly report requires a definition of terms. The following definitions are in use:

a. Useful Beam Hours. Useful beam hours begin when a beam of the requested parameters is first delivered to a scheduled user. Multiple beams do not affect the total; there can be no more than eight "useful beam" hours per shift.

b. Low Energy - High Energy. The dividing line between low energy and high energy beams has arbitrarily been set at 3 GeV.

c. Klystron Hours. The number of klystron hours accumulated in a given period is found by summing the running time meters for each klystron station in the Klystron Gallery and subtracting the klystron hour total at the end of the previous period.

d. Manned Operation Hours. Hours of manned operation were recorded as those periods in which Accelerator Operations provided a chief operator and an operating crew for machine operation. These periods include those shifts in which the machine was open for maintenance but do not include those periods when the accelerator was open for extensive installation.

e. Machine Physics Hours. Machine physics work (i.e., studies of accelerator or switchyard performance or operation) was usually accomplished by Accelerator Physics (AP) or Research Area Department (RAD) personnel as scheduled in the weekly beam planning meetings. Time recorded as machine physics hours began when a useful beam was obtained and ended when the experimenters were finished with their tests. The useful beam hours during a machine physics run may be much less than the number of machine physics hours charged to the experiment.

In accounting for machine physics hours, multiple beam runs during a machine physics run were recorded as if there were only a single beam.

f. Particle Physics Hours. Hours accumulated in multiple beam runs with more than one particle physics experiment in operation (i.e., an experimenter in End Station A and one in End Station B) were recorded as the sum of the hours each beam was on.

g. Machine Down Time - Search/Shutdown. The time required to search the Accelerator Housing prior to turn-on of the klystrons and the time required to turn off equipment at the end of manned operations was classified as search/shutdown time.

h. Machine Down Time - Maintenance (scheduled). Maintenance periods (requiring the klystrons and the beam to be off) which occurred during manned operation were classified as scheduled maintenance. Those "hot" maintenance periods (defined later) where beam operation is not possible are also included under scheduled maintenance.

i. Machine Down Time - Accelerator Failure. Accelerator failure time was recorded when it was not possible for Accelerator Operations to deliver a beam of usable quality to the Beam Switchyard. Short trip-outs of less than five-minute duration were not recorded as accelerator failure during this quarter.

In multiple beam operation, inability to provide a scheduled beam was noted in the log book, but was not recorded in the weekly summaries of operation as "Accelerator Failure" time, as long as at least one beam was produced.

j. Machine Down Time - RAD/AP Request. In Accelerator Operations' log books and reports, a beam-off period requested by RAD or AP was classified in this category. This included any failures in the Beam Switchyard or experimental areas which shut off all beams.

k. Machine Down Time - Tune-Up. Beam tune-up time was recorded when a beam was being steered, focused, or adjusted in some way and, as a consequence, was not usable by an experimenter or RAD. Small changes in beam conditions (energy or current) which were made while the experimenter was using the beam were not classified as tune-up.

## 2. Work Schedules

During the quarter, the accelerator was open for two periods, each of one-week duration, to permit installation work in the positron source area and in the Beam Switchyard. Except for these periods, the machine was manned 15 shifts per week (0800 Monday to 0800 Saturday) to give a total of 156 shifts of operation.

Shift #2 on Mondays (i.e., day shift) continued to be an "accelerator housing open" maintenance period. An additional day shift every other week was scheduled for "hot" maintenance to allow work to be done on stations in the area of the injector and Sector 1. Maintenance work on these stations usually interfered with beam operation; however, it was sometimes possible to do machine physics studies at the same time.

It was typical to schedule 10 shifts per week for high-energy work and three or four shifts for low-energy work. The distribution of scheduled operating shifts between low energy and high energy, and between machine physics and particle physics runs, is given in Table I. The schedule for the shifts was prepared each week in a beam planning meeting conducted by the Technical Division and attended by representatives from the various experimental groups, maintenance and operations.

### 3. Accelerator Operation

Operation Efficiency. One may calculate from the distribution of scheduled shifts (Table I) a number of percentages which relate actual performance to scheduled performance. These percentage numbers are useful in measuring from quarter to quarter any improvement in operating efficiency.

The relatively poor operating efficiency achieved during machine physics runs may be attributed to several factors, such as scheduling, the nature of machine physics operation, short time duration of a typical run, etc. The first "turn-on" shift during each week of the quarter was scheduled as a machine physics run. Housing searches, equipment turn-on, last-minute modification of newly installed equipment to make it operative, etc., have made this shift very poor from the standpoint of beam production. However, some improvements were made during the quarter to increase beam-on time during this shift. (See Fig. 10).

It was possible to provide useful beam 85% of the scheduled time during particle physics runs, compared to only 51% for machine physics runs. During runs at low energy, a useful beam was achieved 63% of the scheduled time compared to 59% at high energy.

A number of hours of low energy useful beam were accumulated during periods scheduled for high energy. In October, for example, low energy beam was scheduled for 104 hours and was achieved for 74 hours during the scheduled time. However, low energy beams were provided at non-scheduled times during high energy runs for an additional 33 hours. The total low energy useful beam time for October is, therefore, 107 hours.

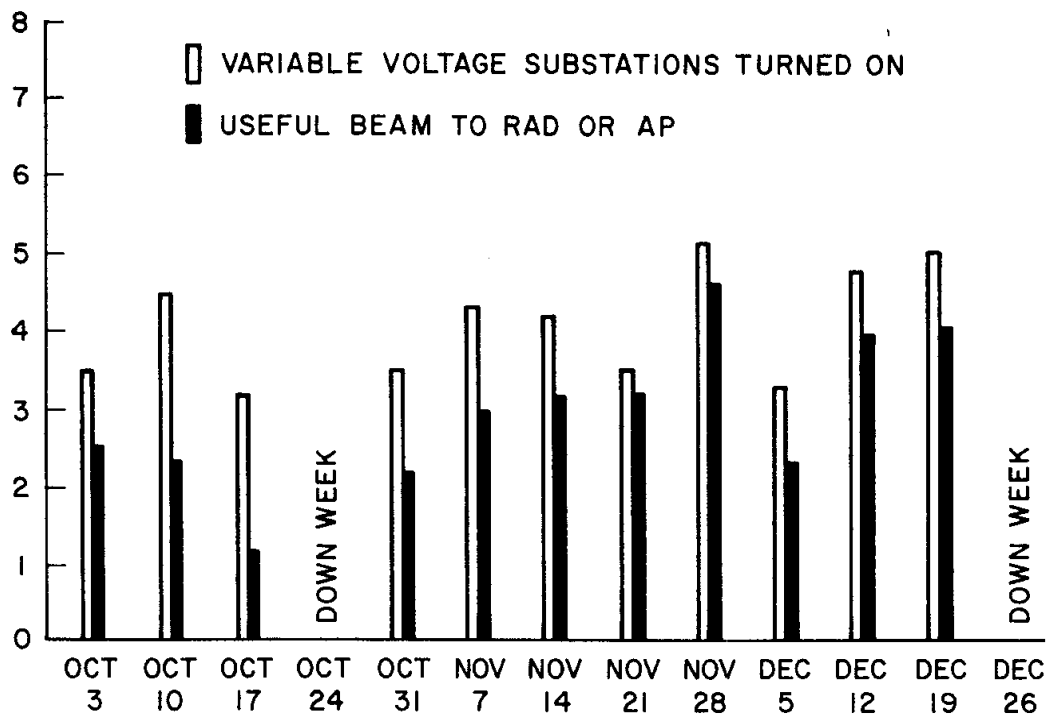
An analysis of the percent of useful beam time during the quarter as a function of day of the week (see Fig. 11) shows a noticeable dip on Thursday. Thursday had several "hot" maintenance shifts and a number of machine physics runs

Table 1  
Distribution of Scheduled Shifts

	October 1966			November 1966			December 1966			Quarter Totals			Percent(b)
	Scheduled		Actual Hrs.(a)	Scheduled		Actual Hrs.(a)	Scheduled		Actual Hrs.(a)	Scheduled		Actual Hrs.(a)	
	Shifts	Hours		Shifts	Hours		Shifts	Hours		Shifts	Hours		
Useful Beam:													
Low energy	13	104	74/107	16	128	70/123	7	56	38/46	36	288	182/276	63/93
High energy	27	216	109	48	384	203	31	248	190	106	848	502	59
Total	40	320	216	64	512	326	38	304	236	142	1136	778	68
Manned Shifts	45	360	360	69	552	552	42	336	336	156	1248	1248	100
Machine Physics	31	248	133	30	240	149	25	200	70	86	688	353	51
Particle Physics	9	72	83	38	304	205	32	256	252	79	632	540	85

(a) As cited in the text, a number of low energy runs were made at the experimenter's request during scheduled high energy runs. These additions to the scheduled low energy run totals are reflected in the second number which appears in each "Actual Hours" column above (e.g., 74/107 . . . etc.).

(b) Percentages listed reflect actual operating hours compared to the scheduled operating hours.



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FIG. 10- USEFUL BEAM HOURS AVAILABLE DURING THE QUARTER ON THE "TURN-ON" SHIFT (THE FIRST BEAM SHIFT AFTER A WEEKEND SHUTDOWN)



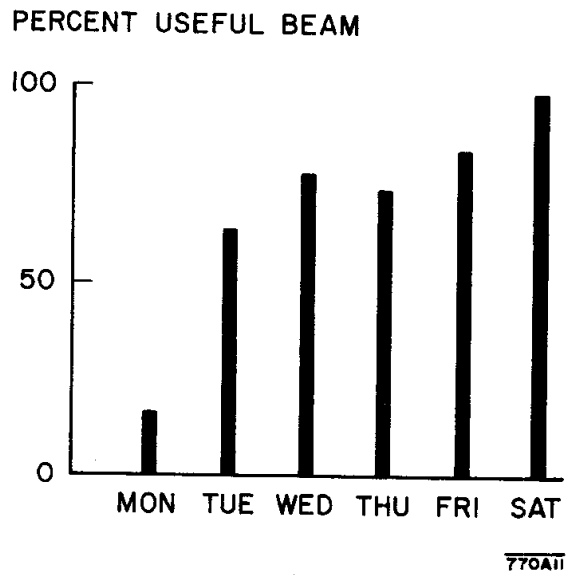


FIG. 11- USEFUL BEAM AS A PERCENT OF MANNED SHIFT TIME AVAILABLE, FOR EACH DAY OF THE WEEK

scheduled which may account for the dip. A histogram of percent of useful beam time as a function of shift of the day was made (see Fig. 12). The dip on Shift #2 is due to scheduled beam-off maintenance. Shift #3 is lower than Shift #1 partly because of the weekly turn-on problems during Monday, Shift #3, and partly because most Shift #1 runs continue unchanged from the preceding Shift #3 run, whereas major changes in beam are usually necessary at the start of Shift #3.

The histogram in Fig. 13 shows the average hours of useful beam time per shift as a function of energy. From this figure one may see that there is little change in operating efficiency at low or high energies even though the effort required to produce the very high energy runs is greater than that for low energy. Figure 14 shows the accumulated total hours (with proper account of multiple beam runs to particle physics experimenters) of useful beam as a function of energy. One may observe that a substantial amount of high energy operation was in the 14- to 18-GeV range.

An important parameter in accelerator operation is the energy gain per station at various klystron beam voltage levels. Accurate knowledge of this value reduces beam down-time in an accelerator that is operating well and is phased properly because the Central Control Room (CCR) operator can provide the Data Assembly Building (DAB) operator a beam of known energy. This reduces the time required by DAB to "search" for the beam. A plot was made (see Fig. 15) of the average energy gain per station calculated from the klystron acceptance data, the average beam voltage versus reference voltage (i.e., the level the operator sets in CCR), and from the formula  $E = 20 \sqrt{P}$  where E is in MeV, and P is in megawatts peak power. The number 20 was determined experimentally for the accelerator. The crosses on the plot show four checks of the curve at different reference voltages. The agreement is well within experimental error.

The division of machine down-time into various categories such as tune-up, maintenance, etc., is shown in Fig. 16 as a bar chart versus weeks in the quarter and as a pie chart for total percentages. The accelerator was operated for a total of 166,295 klystron hours during the quarter.

#### 4. Problems

A brief summary can be made of the major problem areas:

a. Phasing. It is always necessary to phase klystrons when setting up a beam after a shutdown (e.g., Monday night). It is often necessary to phase klystrons when a new beam is being set up that differs considerably in energy from the

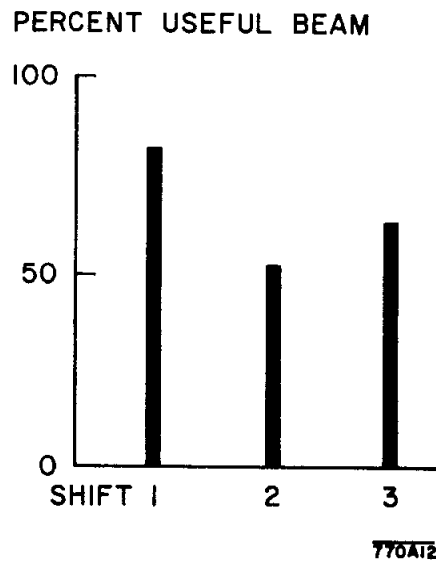


FIG. 12- USEFUL BEAM AS A PERCENT OF MANNED SHIFT TIME AVAILABLE, FOR EACH SHIFT

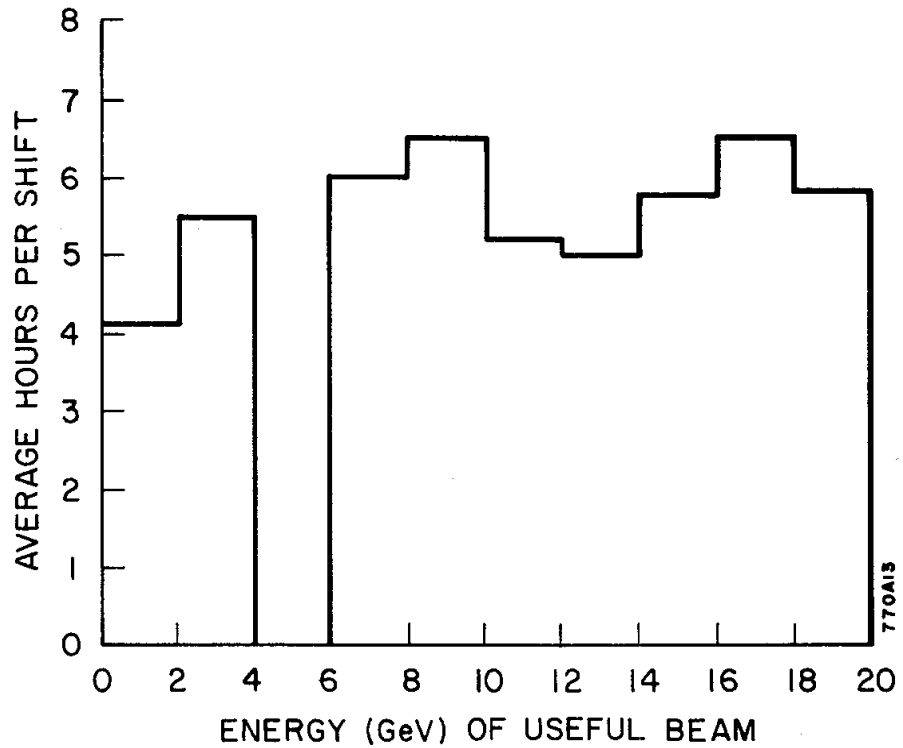


FIG. 13- AVERAGE USEFUL BEAM HOURS PER SHIFT VERSUS ENERGY OF BEAM IN 2-GEV INCREMENTS

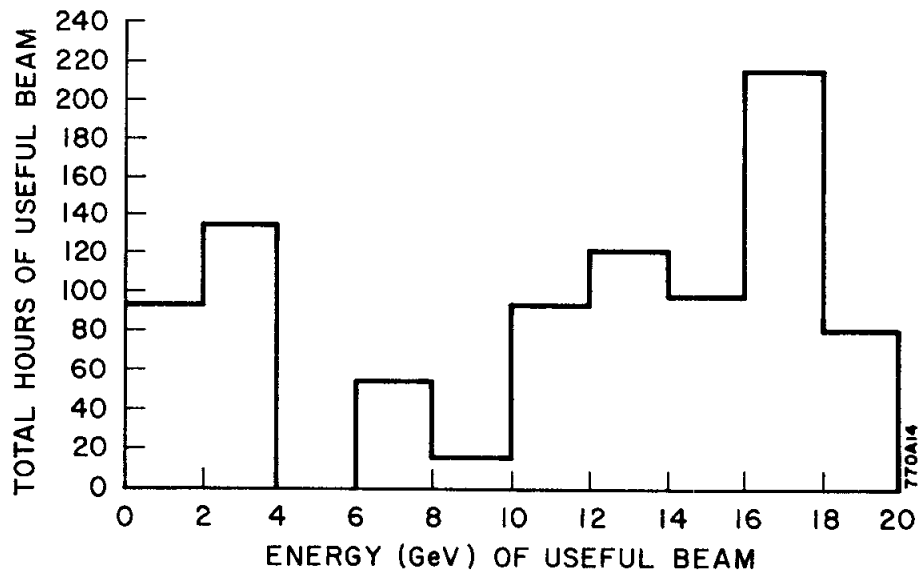


FIG. 14- TOTAL HOURS OF USEFUL BEAM DURING THE QUARTER AS A FUNCTION OF ENERGY OF BEAM IN 2-GEV INCREMENTS

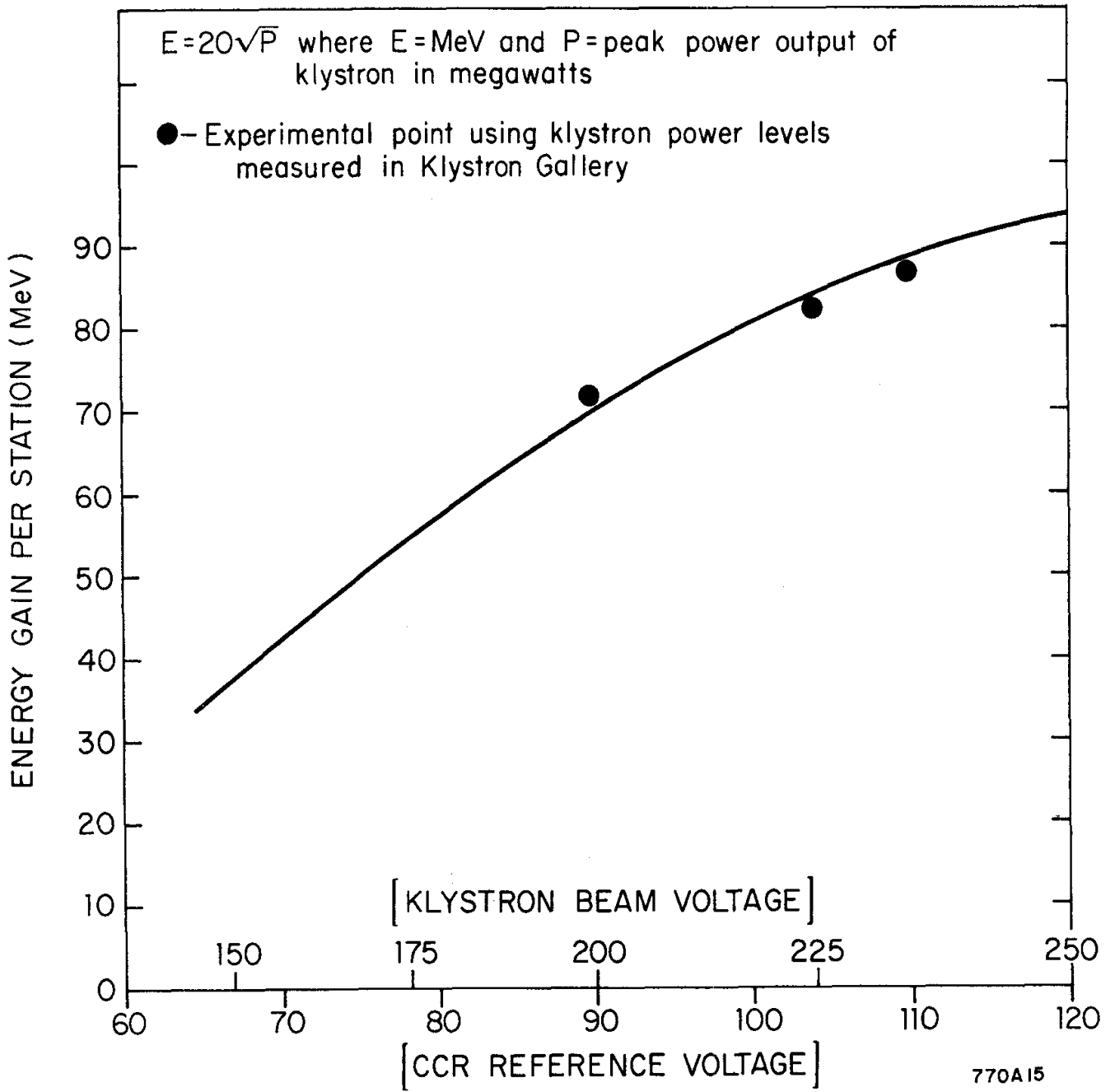


FIG. 15- ENERGY GAIN PER STATION AS A FUNCTION OF KLYSTRON BEAM VOLTAGE AND CCR REFERENCE VOLTAGE



previously run beam, or after a machine physics run. A station-by-station energy check (if time pressure is not too great) will then show the operator which stations have not phased properly. The number can vary greatly, but with operating experience and improvements to the phasing equipment, the system is showing steady improvement.

b. Jitter. The accelerator is a very "young" machine, and made up of a great deal of electronic, electrical and mechanical equipment. Consequently, it is not surprising that instabilities arise in pieces of this equipment. These often show up during operation as "jitter," either in beam energy, intensity, or position. It is often an instability in the measuring equipment rather than the beam. There have been instabilities within the pulse, pulse-to-pulse jitter (regular and irregular), and long-term drifts. With the large amount of equipment, and its interactions, tracking down the problem would be difficult at best; it has been made even harder by the fact that the effects have been small enough that the experimenters, while annoyed, did not allow time for trouble-shooting.

c. Personnel Protection. Noise pick-up and cross-talk in the personnel protection system equipment degraded performance to the point where it was felt necessary to rework the system. (Operation was never allowed when there was any question as to personnel safety; the system is completely redundant, and each half has a very large safety factor.) The system was rebuilt and is now well over the minimum specifications.

## 5. Achievements

a. Interlaced Beams. The quarter was marked by an increase in operating flexibility, as additional equipment and circuitry were completed. Multiple (interlaced) beams were run for the first time. The first run used dc bending magnets; these two beams, one of 8 GeV and the other of 12 GeV, were detected in the A-beam line and the tune-up dump, respectively. Later, as the pulsed bending magnets became available, multiple beams became common, with unrelated experiments going on simultaneously in End Stations A and B.

Up to four interlaced beams have been run, going respectively to the A-beam line, D-10, D-2, and the B-beam line. Operation with beam energies differing by 12 GeV (one beam of 15 GeV and the other of 3 GeV) has been achieved. This was done for two scheduled experiments, not as an attempt to determine the maximum spread available (the limit should be determined by steering and focusing effects).



b. Positron Source. The first successful operation of the positron source took place. With a 3-GeV electron beam to the wand at Sector 11, positrons were generated and steered as far as the end of that sector. Positron yield was of the order of 1%, as had been hoped. This work was done toward the end of December; further work is scheduled for early next quarter.

c. High Energy and High Power Beams. New records were achieved. Though not a planned effort, a new high in energy, 19 GeV, was attained when a few free minutes were available at the end of an 18-GeV run. (Considerable effort continues toward the planning for a 20+ GeV run, which is scheduled to take place early in the next quarter.)

A beam of 72 kilowatts (average) was set up and run for several hours. Although this is the highest power yet achieved, it is only one-fourth of the 300 kW that should be available at full energy, 360 pps, and the maximum current (as limited by beam break-up).

d. Mu and K-Survey Beams. The mu and k-survey beams became operational in early November, with the former continuing throughout the remainder of the year. The k-survey beam was disassembled in late December and its components were used for the arrangement of a neutral beam experiment.

The k-survey experiment successfully measured the absolute yields of electrons, pions, kaons and protons from an 0.3-radiation-length beryllium target placed in the electron beam. Two- and three-degree production angles were surveyed.\* In addition, measurements of the bunch structure of the secondary beam were made using microwave gated photomultipliers (DCFEM's)\*\* to produce separation ratios  $\geq 10^3:1$ .

e. Low Beam Current Studies. A series of measurements were made to determine the feasibility of accelerator operation at very low beam current, and to estimate the electron beam charge per pulse produced by accelerator components when the injector was turned off. A dc ion chamber and a glass Cerenkov radiator with a photomultiplier tube were used to measure the electron beam

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\* S. M. Flatté, et al., Phys. Rev. Letters 18, 366 (1967).

\*\* J. J. Murray, "Recent Progress in the Development of a Microwave-Gated Photomultiplier - the DCFEM," Proc. of the 1966 Int. Conf. on Inst. for High Energy Physics, Stanford Linear Accelerator Center, September 9-10, 1966; p. 157.

current in the deflected beam path at BAS II. It was found that the so-called dark current, measured with the injector off, fluctuated from pulse to pulse, ranging up to about 3000 electrons per pulse, and averaging about 300 epp. Similar tests were made at BAS I with dc and pulse ion chambers in the deflected beam path.

During the period when the BAS I tests were done, improvements were made on the injector system, making possible smooth charge-per-pulse adjustments throughout the range from the dark current level up to maximum. The dark current was found to exhibit a very broad spectrum at BAS I, peaking at about 30 MeV, and with a tail extending well above 100 MeV. The charge per pulse was measured to be about  $5 \times 10^4$  epp in a 15% energy bite at the spectrum peak. The total dark current into the BAS I dump was estimated to be about  $5 \times 10^5$  epp. For these measurements, V1A, the klystron modulator reference voltage, was set at 80% of maximum, or 90 volts.

A series of dark current measurements were made for higher and lower klystron pulse voltages, with the reference voltage set at 70%, 75%, 80%, 90% and 95% of maximum. For each measurement, the BAS I magnet was adjusted for maximum ion chamber signal. The signal increased very rapidly with V1A voltage level, agreeing within experimental error with the results to be expected if the current were due to field emission.

f. Annihilation Beam. Installation of hardware continued for the annihilation gamma beam in the center of End Station B.

g. Spectrometers. The 8-GeV Spectrometer has now been completely assembled in End Station A and mechanical testing has begun. The first magnetic element of the 20-GeV spectrometer has been put in place.

h. Machine Physics Experiments. About 40% of the operating time was devoted to machine physics experiments. These include beam break-up experiments, beam energy experiments, beam loading experiments, phasing experiments, Beam Switchyard optics tests and equipment calibration, and preparation for positron operation. The beam break-up experiments consumed the largest fraction of experimental time under this category. General progress was made in this area to consolidate the knowledge on the variation of the beam break-up threshold as a function of length, current, time, focusing strength, initial noise, steering at the beginning of the accelerator, etc. The information collected is too copious to be summarized here and will be published in a separate report. \*G. A. Loew, "Electron Linac Instabilities," to be presented at the 1967 U. S. National Particle Accelerator Conference, March 1967. Report in preparation.

## B. SYSTEM AND COMPONENT PERFORMANCE

In addition to the performance of various components and systems, discussed below are experiments which, although they may have required an operating beam, involved a specific system rather than beam operation as a whole.

### 1. Injector

During the quarter, the injector operated satisfactorily and only minor problems were uncovered. These included phase jitter in the injector klystron, timing jitter in the injector trigger generator, and loss of one of the two beam current control channels in the gun modulator. Immediately after phasing the entire accelerator and with no special tuning of the injector, the spectrum is often 0.2% at full width half maximum. This indicates that the bunch width must be less than  $7^\circ$ . At the end of the quarter, the original gun was still operating satisfactorily. It had approximately 4700 operating hours at that time.

### 2. Main Drive Line

Using the automatic phasing system, with the beam as phase reference, the phase shift of the main drive line as a function of input power was measured. It was found that changing the input power from 16.9 to 17.6 kW (0.2-dB change) increased the phase shift between Sector 2 and Sector 18 by 7 degrees.

The phase shift as a function of frequency was measured in the same way, and it was found that a frequency change from 2856.0012 MHz to 2856.0690 MHz increased the phase shift by 4 degrees. This represents about ten times the phase shift versus frequency sensitivity which was deduced from reflection measurements on the main drive line. The discrepancy is not yet understood.

### 3. Phasing System

The reliability of the system has improved considerably during the quarter, as is shown by the reduction in the number of trouble reports from 32 during October and November to 1 during December. The changes made are described in Section II of the Status Report.

During the next quarter, work will begin on the CCR video display system, which will facilitate the location and diagnosis of klystron or phasing system faults.

#### 4. In-Line Beam Position Monitors

Performance of these monitors was satisfactory during the quarter. The beam position detector panels were the subject of eight trouble reports, all of which concerned thermionic diode balance or sensitivity.

#### 5. Positron Source RF Deflector\*

The positron source rf deflector was phase adjusted by indenting the input rectangular waveguide and then beam tested. The rf input power used was 0.304 MW and the resulting transverse momentum was found to be 0.46 MeV/c, which checks reasonably well with the theoretical predictions.

#### 6. Linear Q System

A noise problem exists in the accelerator toroidal charge monitoring system. The source of the noise has been traced to vibrations of the ferrite toroid in its housing, which is excited by the motion of the accelerator cooling water. Strong noise components were observed at around 5 kHz.

The noise levels observed are as much as 20 to 50 times the ambient noise level of the system. A brief study has been made to determine the feasibility of adding a passive filter at the output of the preamplifier. This appears difficult; an approach using an active clamping technique is now being pursued.

#### 7. Magnet Power Supplies

a. 360-kW B-Beam Transport Power Supplies. The modifications to minimize interaction (as mentioned in the previous Quarterly Status Report) were fine when the power supplies worked into quadrupole magnets, but not when used with bending magnets; the power supplies would not furnish full voltage to the bending magnets. This problem can be solved by making two minor modifications. By the end of the quarter, we were in the process of making these modifications on all power supplies.

b. 1590-kW Power Supplies for Spectrometers, Group A. The transformer problem mentioned in the previous report was solved by the installation of standard oil-filled utility transformers outside the power supply building. At the end

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\*G. A. Loew and O. H. Altenmueller, "Design and Applications of RF Separator Structures at SLAC," presented at the Fifth International Conference on High-Energy Accelerators, Frascati, Italy, September 9-16, 1965 (SLAC-PUB-135).

of the quarter, 12-kV power had been turned on in power supply No. 2, and it was being tested.

c. 567-kW Power Supplies for Spectrometers, Group A. The balance of these power supplies were delivered this quarter and were undergoing debugging and test.

## 8. Modulators

a. Main Modulator. The operation of the main modulators continued to improve this quarter. The most important problems were pulse-forming network capacitors, main rectifier failures, and occasional tripping of the main circuit breaker during switch tube faults.

Pulse-forming network capacitors continued to fail. We replaced 207 capacitors this quarter, as compared with 150 during the previous quarter. In order to keep our supply of spare units at a satisfactory level, we improved our liaison with the manufacturer. This has resulted in an improvement in quality and quantity.

The main rectifiers, which had not caused trouble for six months, began failing again. During November and December, there were four failures, three in Sector 5 and one in Sector 4. It was thought that the increased humidity during November might be responsible for at least some of these failures, because the Gallery is essentially unheated, and most of the failures occurred during the early morning hours when the air was most humid. The situation is aggravated because the cooling air intakes for the modulators are near the floor, and only a few feet away are louvers, also near the floor, which feed cool, moist air into the Gallery.

This theory was tested on several rectifiers in an environmental chamber. The tests revealed that corona is increased under humid conditions as one might expect, and that arc-over from card to card across the surface of the phenolic side panels (particularly if they are somewhat dirty) can occur. We have noted, in our inspections of failed units, that in this type of failure there are at least two cards involved, and the damage is symmetrical about a point midway between the two cards. In order to combat this type of failure, the relative humidity of the cooling air in the modulators was reduced by partially blocking off all the air intakes in the power supply cabinet, thus warming the air and reducing its relative humidity. Before this was done, tests had been performed on a modulator in the Test Laboratory, in which it was found that under full power operation there was

an increase of  $10^{\circ}$  C in the air temperature in the region of the rectifier. Partial blockage of the air intakes should help to reduce the rate of these failures.

Another type of failure appears to be due to an open circuit in the current-carrying path, either within a diode or in the circuit connected to it. One possible cause is fatigue in the junction or elsewhere in the diode, as borne out by our inspection of many failed diodes. In order to further check this mode of failure, a thermal cycling test has been set up whereby 30 diodes are heated and cooled using a low voltage power supply. At the end of the quarter some 4000 cycles had been run with no obvious evidence of fatigue.

Another program which we are pursuing is to place at least one rectifier in an oil tank. This should solve any corona problem in the rectifier as well as alleviating any fatigue problem, because the diode temperature excursions should be reduced.

The problem of occasional main circuit breaker tripping during switch tube faults is a result of the magnetic trip settings on the circuit breakers being set on their most sensitive position. (The reasons for this were covered in the previous Quarterly Status Report.) Shunt trip coils are being installed in these circuit breakers, and a circuit has been developed which will be a little slower than the normal contactor circuit and yet fast enough to protect rectifiers in case of contactor hang-up.

In order to decrease the possibility of contactor hang-up, we modified the modulator-klystron packages and the modulator interlock chain in Sectors 5 and 6 so that the trigger to the modulator is interrupted for all external faults while the contactor is operated only for internal faults. Most faults are external to the modulators. Reducing the number of operations of the contactors will reduce the erosion of their contacts, which is a major source of hang-up trouble.

Fire alarm circuits are being installed in all modulators in the Gallery. Such circuits will turn off the high voltage and fans and turn in an alarm in the event of a fire. At the end of the quarter six modulators were thus equipped.

b. Switch Tubes. During this quarter four large single tubes and five GL-7890 thyratrons failed. The total number of tubes lost on the accelerator is 21 large ones and 13 dual ones.

In all operations to date, including two-mile accelerator, Mark IV accelerator, and test stand operations, 70 tubes have failed. The average life of the failed tubes has been about 1900 hours on I. T. T. tubes and 1500 hours on Tung-Sol tubes.

At the end of the quarter, there were 135 spare tubes, and a procurement cycle on a new set of tubes had been initiated.

Failure of 28 small trigger thyratrons during the quarter brought the total to 56 failures.

9. Pulse Transformer Tank Assemblies

Construction of the spare pulse transformer tank assemblies was completed during this quarter, and maintenance work on those on which klystrons failed continued. Only one failure was experienced, a pulse cable which failed in about 1000 hours running time.

10. Main Booster Amplifiers

Both amplifiers operated satisfactorily in the voltage regulation mode of operation. The rf regulation mode of operation has not been satisfactory, and work to improve it is in process.

11. Klystrons

During the quarter a total of 176,000 operating hours were accumulated on high power klystrons. The total number of failures for the quarter was 23, giving a cumulative total of 76 tube failures since the beginning of operation of the machine. We have in excess of 100 spare klystrons, including 20 mounted in magnets and on tanks ready for installation.

Driver amplifier klystrons accumulated 38,000 hours in the Gallery and 3000 hours in the Test Laboratory. A total of seven failures occurred in the Gallery. No major problems were encountered with the two main booster klystrons, which accumulated 2765 hours.

a. High Power Klystron Operation. The following table gives a summary of tube usage and failures in the Gallery since the beginning of operation.

Table 1. Klystron Usage and Failure

Dates	Operating Hours		Quarter		Cumulative	
	Quarter	Cumulative	Number	Avg. Life at Failure	Number	Avg. Life at Failure
To 12/31/65		27,000			10	297
To 3/31/66	11,000	38,000	13	252	23	272
To 6/30/66	118,000	156,000	16	234	39	256
To 9/30/66	127,000	283,000	15	594	54	350
To 12/31/66	176,000	459,000	23	1070	76	575

Please note that the cumulative failures figure at the end of this quarter is one less than the sum of failures for the quarter and the previous cumulative number. One tube which had been declared failed during the previous quarter was returned by the vendor after examination indicated that the tube had indeed not failed but that the load side of the window needed cleaning.

The causes of the 23 failures can be tabulated as follows:

<u>Number of Failures</u>	<u>Cause</u>
2	Window
2	Pulse breakup or droop
8	Tube vacuum
11	Arcing cathode

It is probable that both pulse instabilities and cathode arcing are induced by tube gassiness. However, at this time it is not known what causes loss of vacuum in tubes which are operated reasonably regularly.

It is interesting to note that the average tube life at failure is approximately 1070 hours, whereas the mean age of tubes now in use is 1630 hours. Figure 17 gives the history of klystron operating experience (life at failure, number of failures and average hours of operation) per quarter. The age distribution of the tubes installed in the Gallery is shown in Fig. 18. It is also interesting to note that the mean number of operating hours between failures is approximately 6000 counting all operation, and 7500 counting the last quarter of operation. On the basis of information available to date, it appears that the mean time to failure (MTTF) of klystrons can be predicted at between 3000 and 4000 hours at the present operating levels. However, since there are only three tubes to date which have more than 3000 hours of operation, the prediction may be optimistic if we should encounter a major cause of failure which has not yet been observed.

b. High Power Klystron Maintenance. The total number of trouble reports checked during the quarter was approximately the same as that during the previous quarter in spite of an increase in total number of operating hours. The total number of tubes replaced from the Gallery was 38 for this quarter, corresponding to approximately 1-2/3 replacement for each klystron failure. Overall, the relatively small increase in the number of trouble reports and the decrease in the ratio of tube replacements to tube failures indicate a substantial improvement in the effectiveness of the overall station maintenance program.



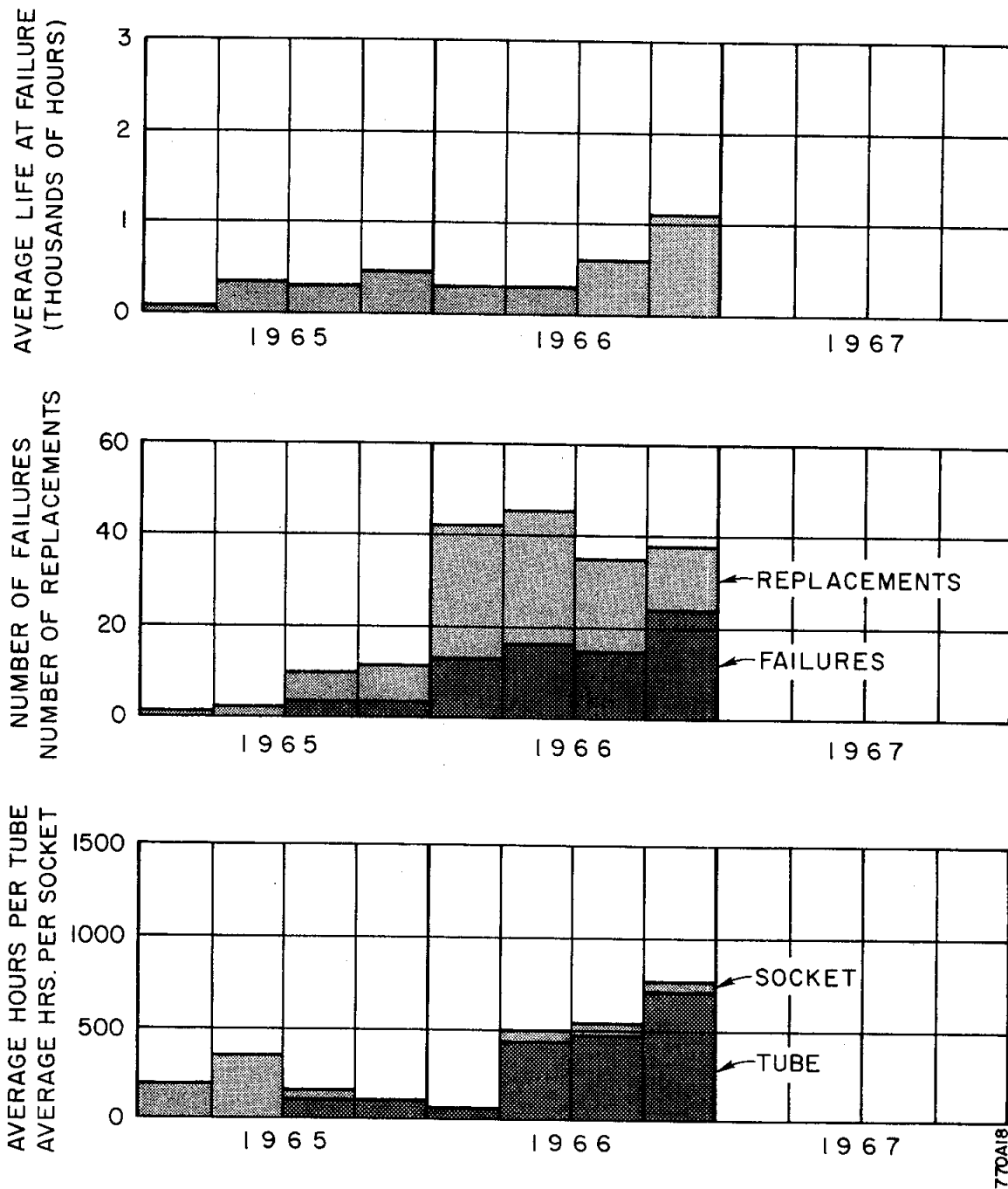


FIG. 17- KLYSTRON QUARTERLY OPERATING EXPERIENCE - ALL HIGH POWER KLYSTRON VENDORS

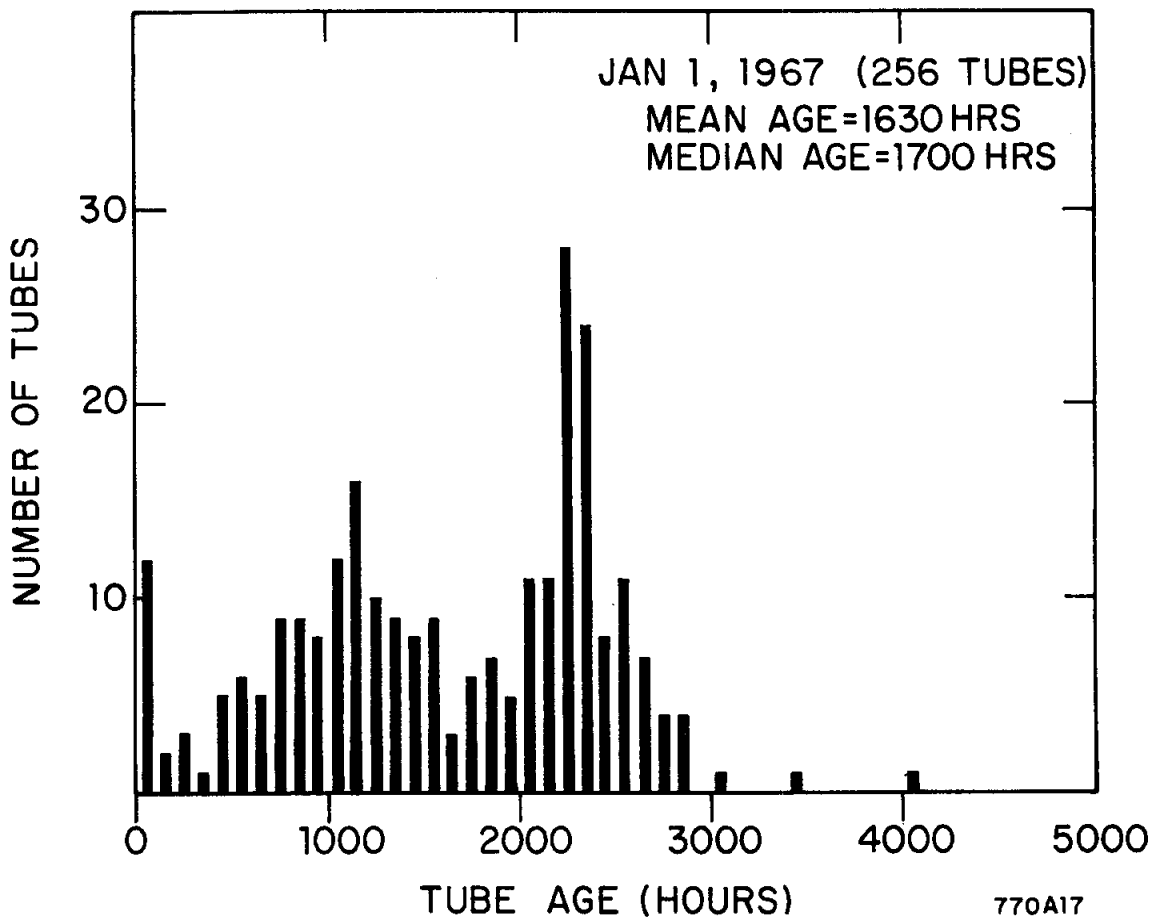


FIG. 18 - KLYSTRON AGE DISTRIBUTION (ALL VENDORS)  
 IN 100-HOUR INCREMENTS

Of the 38 tubes removed from the Gallery, seven klystron pulse transformer tank assemblies were returned because of oil leaks, one because of water leak, and the others because of either tube or pulse transformer problems. As mentioned previously, only 23 tubes failed during the quarter.

Preventive maintenance has continued throughout the quarter, during which careful measurements were made to determine whether a tube is reaching end of life and to take appropriate steps if possible to increase its life. Approximately 10% of the tubes tested showed an indication of approaching or having reached cathode-temperature-limited emission, and the heater power was increased where appropriate to enable achievement of additional operating hours from these tubes. During these tests, checks are also made on beam voltage settings, inverse beam voltage, and timing adjustment of drive and cathode pulse. Again approximately 10% of the stations were found to be out of tolerance for each of the above-mentioned criteria. Checks on rf instabilities indicated that 5% of the tubes were getting critical from an rf stability standpoint, but could be operated by careful adjustment of the drive.

c. Driver Amplifier Klystrons. During the quarter the driver amplifier klystrons ran a total of approximately 41,000 hours: 38,000 hours for 31 sockets in the Gallery, 3,000 hours for three sockets in the Test Laboratory. The cumulative hours of operation now stand at approximately 90,000 in the Test Laboratory and 127,000 in the Gallery.

During the quarter, seven driver amplifier failures were experienced (including tubes removed the previous quarter and retested this quarter). All failures occurred in tubes which had been in the Gallery. The total number of operational failures on driver amplifiers stands at 34. Six of the seven failures experienced during the quarter seem to have been caused by gassiness. Figure 19 gives the history of the quarterly operating experience for the Eimac driver amplifiers used to date. Please note that although the main life at failure is only between 2000 and 3000 hours at present, the overall operating experience (217,000 hours and 34 failures) would tend to indicate a much higher MTTF. Figure 20 indicates that the mean age of tubes now in use is 3725 hours.

Maintenance aspects of the driver amplifier have been mostly concentrated on phase problems encountered at the input to the drive sub-line. In spite of all our efforts and those of Electronics and Accelerator Physics in tuning up the sub-booster modulators, the average pulse length during which the phase shift does

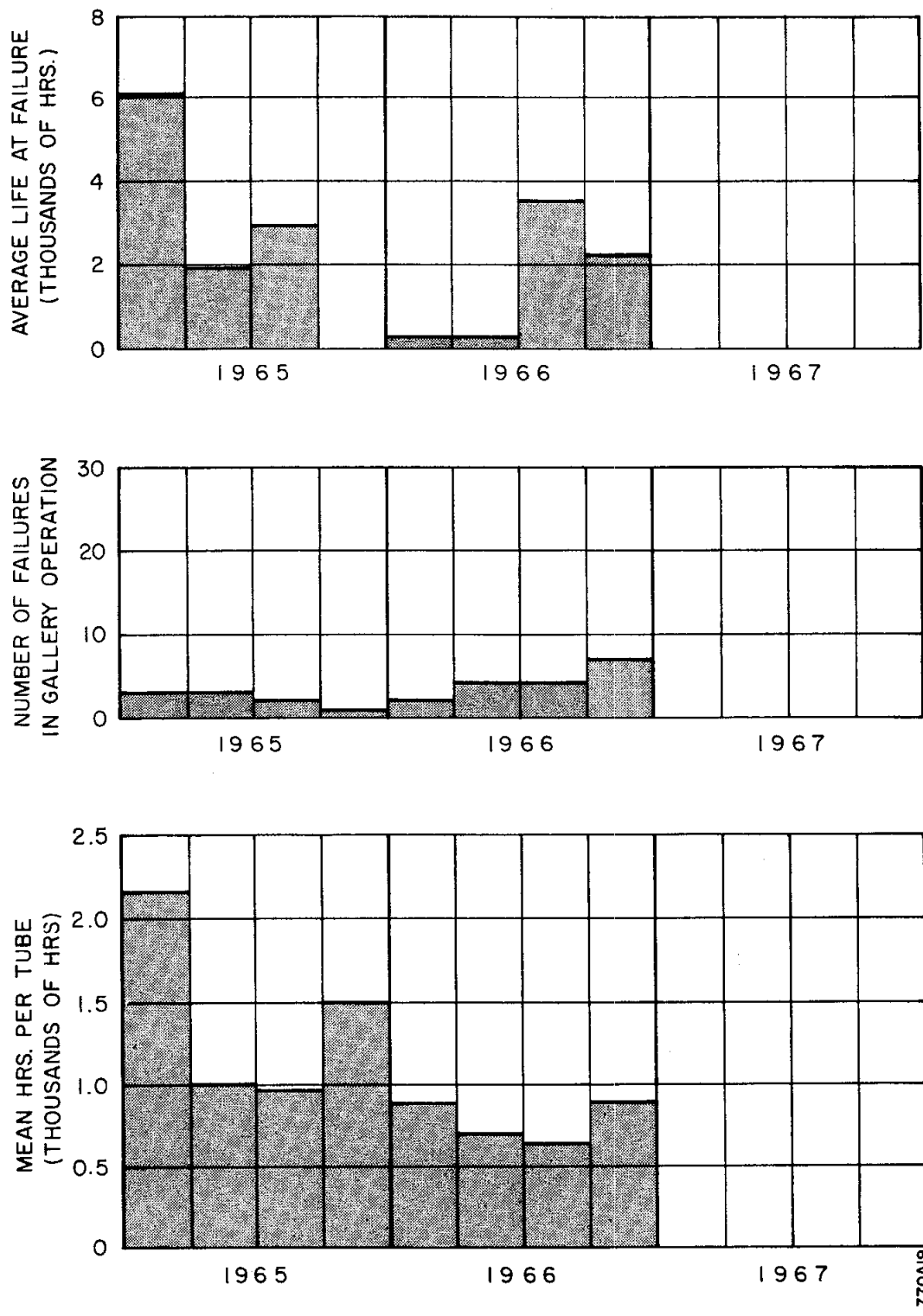


FIG. 19-KLYSTRON QUARTERLY OPERATING EXPERIENCE - DRIVER AMPLIFIER KLYSTRON

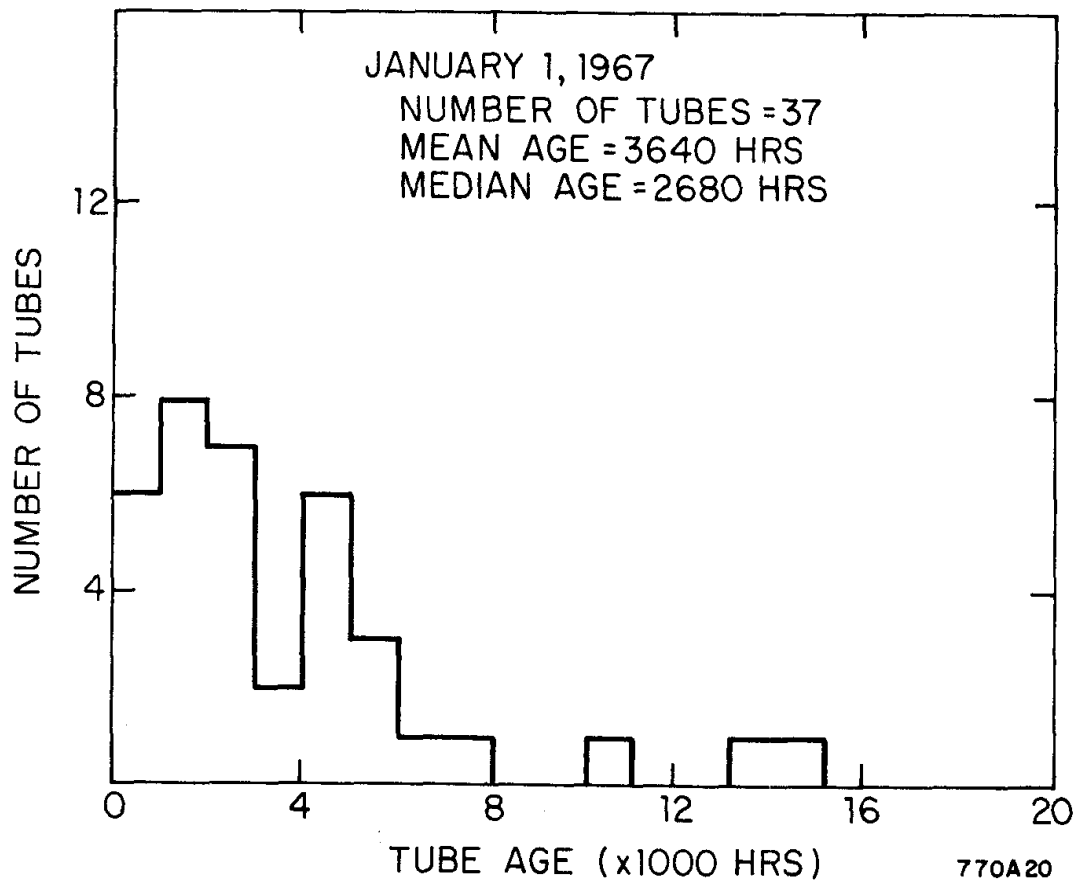


FIG. 20 - DRIVER AMPLIFIER KLYSTRON AGE DISTRIBUTION  
IN 1000-HOUR INCREMENTS

not exceed  $\pm 1^\circ$  for all Gallery stations is only 2.1  $\mu\text{sec}$ , with a range from 1.4 to 2.3  $\mu\text{sec}$ . In general, the driver amplifier does not seem to be contributing to the excessive phase shift; where it does appear to contribute, it is replaced and after further checks, is either declared failed or reused in another station.

d. Main Booster Klystrons. There were no failures and no replacements of the two main booster klystrons, which operated a total of 2765 hours. One of the two tubes had erosion in the input cavity gaps during the previous quarter which prevents tuning of the input cavity for optimum gain. As a result, the drive requirement is somewhat higher than normal, but the power output is adequate and the stability appears as good as that of the other station.

## 12. Vacuum System

In general, the performance of the accelerator vacuum system has been excellent, with a continuing slight improvement in the majority of base pressures. Drift section letups were continued during the quarter to modify the quadrupole focusing, and the operation of the cryosorption roughing pumps has been very successful.

We have installed three manifold gauge assemblies to which all-stainless-ceramic thermocouple gauges were added. It is anticipated that there will be no vacuum problem created by the thermocouple gauges, but that they will be a considerable help in monitoring pressure in case of accidental letups and during roughing. It is planned to equip all manifold gauges with a thermocouple gauge assembly. Two Westinghouse valves (one 3-inch and one 6-inch) required a bellows assembly change. A waveguide valve was also changed because of a suspected leak across the indium seat.

Vacuum system maintenance continued smoothly.

## 13. Beam Switchyard - Research Area Instrumentation

a. Beam Monitoring. The beam monitoring equipment installed in the Beam Switchyard and End Stations has, in general, operated reliably during this period.

The question of misalignment of some of the Beam Switchyard beam position monitor assemblies was not resolved because of lack of sufficient beam time to investigate the problem, and to some extent because of uncertainty about the alignment of adjacent instruments used for comparison. Although the monitors are functioning to the present satisfaction of Data Assembly Building operators, calibration work has not been completed and it is known that low beam current

operation using tunnel diode detectors is unnecessarily restricted because of poor video amplifier characteristics.

The End Station A beam position monitor was installed and tested during the quarter. With one exception, it performed well. The monitor sensitivity is very high. Using a single-channel output, a beam peak current as low as  $3 \mu\text{A}$  can be detected. The differential output of the two channels will detect a 0.1-mm displacement of a 0.1-mA peak beam.

The one trouble encountered was a spurious resonance which spoiled the pulse response of the monitor, producing a tail which was particularly noticeable at the outputs of the logarithmic amplifiers. We were unable to establish the origin of the resonance while the monitor was installed in the end station. Again, the work was hampered by insufficient beam time. After the monitor assembly had been removed from the beam line and returned to the Test Laboratory, it was discovered that the resonance was excited in a 4-inch-diameter tube adjacent to the monitor. Cold tests showed that the resonance could be damped by inserting a small ring of lossy material in the 4-inch tube. It is planned to coat the inside of the tube with Kanthal. If cold tests show that the lossy coating removes the resonance, the monitor will be ready for re-installation as required.

The single (flap) phosphorescent screens in front of the energy-defining slits, which were originally intended to be used primarily as vertical beam position indicators, have been found to be useful for beam tune-up and are constantly used for this purpose. Since they have a limited life, it is planned to replace both of these monitors with multiple screen devices.

b. Ionization Chambers. Initially, ionization chambers used as beam interlock detectors were argon-filled for high sensitivity. The gas has now been changed to helium and time is being devoted to calibrating individual ion chambers and increasing the beam interlock trip-off points to proper levels.

c. Non-Intercepting Station. A non-intercepting beam monitor observing synchrotron light, located in the A-beam line, was used with a standard vidicon camera and lens which was installed temporarily in the upper housing of the Beam Switchyard. Results were promising; at 7 GeV and 60 pps, a beam with 0.1-mA peak current was clearly visible. A more permanent installation is in progress.

d. High Power and High-Z Slits and Collimators. During October, calibrations of the actuation and remote read-out systems were completed. During December, the collimators were in-line calibrated using the electron beam and

current monitors as survey tools. Jaw closure, position, and rotation data were obtained. These data should in the future close the loop formed by optical alignment data and laser beam survey information.

e. Beam Dumps. The highest average power deposited by the electron beam during the period was 74 kW into the A-beam dump. Both the window and dump performed successfully.

f. Radiolytic Gas Evolution. Two high power runs were made into the A-beam dump. Hydrogen detection instrumentation was installed on a sample loop analyzing the gas space on top of the dump water system surge tank. Hydrogen was detected during the power run. It is, however, too early to attach a quantitative figure of the rate of evolution of H<sub>2</sub> as a function of power deposition in the water.

The gases were also analyzed for radioactive isotopes by the Health Physics group. Work has started to develop a system for safe disposal of the hydrogen. Two systems are presently under consideration: (a) a catalytic recombination system and (b) a dilution-chemical removal-hold-up-venting system.

g. Radioactive Water Systems. Corrosion samples were installed in the radioactive water systems of the high power collimator and slits. The samples are aluminum alloy 6061 and are located in a bypass loop upstream of the demineralizer. A valve and flow meter allow simulation of water velocity conditions as they exist in the aluminum modules of the collimator and slits.

#### 14. Beam Switchyard - Research Area Electronic Systems

a. Machine Protection Interlock System. The principal activities have been the calibration and shakedown of the machine protection interlock systems in the Common, A-, and B-beams. Calibration has included trip level adjustments on all temperature sensor interlock detectors and ion chamber detectors.

Experience gained in the early phases of machine operation has resulted in modifications, mostly minor, in several of the chassis which are either an integral part of the interlock system or feed directly to the system. Such modifications have involved the following chassis: a beam interlock selector, beam interlock relays, digital temperature readout, TC-20 control unit, beam stopper control, and, most important, the summary interlock. With respect to the latter it was learned, again during early operation, that interlaced A- and B-beams could only be run safely by locking off all beams when any interlock in any beam tripped.



This has the effect of making all beams a common beam with regard to the interlock system, a most inflexible mode of operation. The modification which implements this mode was made in the summary interlock.

Several new blocks of interlocks have been incorporated into the overall system, notably the End Station A summary, the End Station B summary, and the beam current monitor interlock chassis, which derives its input signals from toroid sensors in the A-beam and permits certain photon beam operations.

As further operational experience was gained, it became apparent that the present interlock system is insufficiently flexible to permit the various modes of machine operation which will soon become necessary. It was decided to rearrange the interlocks with respect to their detector chassis and to redesign the entire interlock selection and logic system.

b. Spectrum Instrumentation. The base band transmission system is complete and satisfactorily checked out. Twelve additional channels have been added for transmitting spectrum signals to End Stations A and B. The noise on the video spectrum electronics was narrowed down to two sources. One source is the trigger system in the Data Assembly Building (DAB) and the other is pick-up in the video cable run from the foils to the DAB. Tests to define the cable problems and investigate solutions are being planned.

c. Computer. The Beam Switchyard computer system was used during this quarter, and certain operational problems in both the programming and hardware were discovered and corrected. The link to the SDS 9300 computer in End Station A was wired and cabled. A few bugs remained at the end of the quarter. Troubles arose in the digital-to-analog converters which provide computer control of the magnet power supplies, causing temporary loss of control of certain magnets. The problems have been alleviated by transferring the units to less important power supplies, but a definitive solution has not yet been found due to the intermittent nature of the trouble.

d. Magnet Control (Manual). Minor modifications were made to some chassis to allow more convenient operation. Troubles arose in the readback circuits for magnet currents; the problems were traced to a defective multiplexer, which has been temporarily patched up pending a shutdown long enough to return the unit to the vendor for complete overhaul.

15. Data Systems

A book of tables, consisting in general of instrument readings or settings versus beam energy, was completed for use by the Operations Group in the Data Assembly Building. A procedure was implemented to utilize punched data cards for keeping the times for which experimental equipment is committed.

16. End Stations Personnel Protection System

The End Station B personnel protection system became operational during this quarter. Most of the period was devoted to maintenance and repair of the entire End Station Area system. However, during the latter part of the quarter, it was decided to extend the system to include placement of radiation monitors and "emergency beam stop" units. A design concept and cable layout were approved and installation is expected to start in early 1967.

II. ACCELERATOR AND RESEARCH AREA  
EQUIPMENT DEVELOPMENT

## A. ACCELERATOR PHYSICS

### 1. Injection

a. Main Injector System. No major changes were made in the injector during the present quarter. The injector system as a whole has functioned satisfactorily during the entire period.

b. Electron Guns. In September, the gun laboratory was relocated to a permanent location in the Test Laboratory. A clean environment was provided for the assembly of guns and associated vacuum components. Adjacent to the clean room, there is a small laboratory for gun tests using several gun modulators or the beam optics analyzer.

During the quarter, emittance measurements were made on the gun used on the Mark III linear accelerator when operated with 1-, 10-, and 100- $\mu$ A dc beams. These measurements were made to determine the suitability of this gun for use on a superconducting accelerator. The emittances were found to be of the order of  $10^{-2}$  m<sub>0</sub>c-cm.

c. Gun Modulators. Breadboard tests of the pulser amplifier have been completed and the final unit is under construction. Construction is also proceeding on parts of the bias switching chassis and on the status and control chassis. The contract for the gun modulator cabinet has not yet been placed.

d. Beam Knockout System. The 39.667-MHz rf driver has been installed in position and has operated successfully. The resonant circuit for the deflection plates has been constructed and tested at high power. It will be installed in the Accelerator Housing and used to deflect the beam during the next quarter. A new set of deflection plates has been constructed with a coating of low emissivity material to reduce secondary electron loading. This set will be installed in the machine during the next accelerator shutdown period.

### 2. Drive System

a. Main and Sub-Drive Lines. The main drive line extension was completed during the quarter but has not yet been pressurized. The extension to End Station B was used during the quarter for the K-meson survey. The drive system constructed and used in End Station B operated satisfactorily.

During the quarter, in response to a request from Experimental Group F, a high power and a low power diplexer were developed to allow the main drive line to serve as a transmission system for a beam knockout reference signal at 10 to 40 MHz. The high power diplexer was installed at the beginning of the main drive line and the low power diplexer was delivered to Group F to be installed at the end of the main drive line extension at End Station A. The diplexers are 3-port devices, where the main drive line signal at 476 MHz is transmitted between ports 1 and 3. Port 2, the coupling port, is isolated from port 1 by a 70-dB band rejection filter centered at 476 MHz. A low pass filter (3-dB cutoff at 270 MHz) connects ports 2 and 3. An additional 700-MHz low pass filter is connected to port 2 to prevent propagation into the low frequency signal source of harmonics of 476 MHz from the main booster.

It has been ascertained that the varactor multipliers are not affected by spurious inputs in the frequency range 0 to 60 MHz if the levels are more than 26 dB below the 476-MHz signal. The coupling of the main drive line couplers increases by 6 dB per octave. This means that, for example, the multipliers will not be affected by a 20-MHz signal on the main drive line if the ratio of its power to the power at 476 MHz does not exceed unity.

The diplexers make it possible to transmit additional signals up to 300 MHz on the main drive line from the injector area to End Station A, provided that the ratio of additional signal power to 476-MHz power is kept within the bounds indicated above, or that suitable high-pass filters are installed at the inputs to the varactor multipliers.

b. Varactor Frequency Multipliers. The varactor frequency multipliers have continued to perform adequately and only a few failures have occurred. Most of the faults are due to diode failure or mistuning of the diode circuit. Repair is usually forthright and no loss of machine time has been incurred since an adequate number of spare units are available.

c. Main Booster Amplifiers. Operation of the two main boosters has been satisfactory during the last quarter. The klystrons and the transfer switch operated throughout the quarter without any signs of failure. Unit No. 2 remains to be modified and updated.

d. Positron Phase Shifters. Booster amplifiers are being installed at intervals along the first 10 sectors to increase the amplitude of the positron phase shifter

drive signal available at the sub-booster isolator-phase shifter-attenuator units. These will ensure that the system functions properly at 360 pps.

In the injector area, a changeover switch has been installed to connect the positron phase shifter drive signal to the on-line sub-booster.

Additional wiring is being installed so that the first two klystrons in Sector II may also be switched in phase.

e. RF Drive System Control Unit. The master oscillator rack work was completed during this quarter. The functions available are: local and CCR control and status of the master oscillators, main boosters, and injector sub-boosters. Automatic switching is also completed and available for the three different pairs of units. Except for a small number of necessary modifications, the units are performing as designed.

f. Sub-Booster Modulators. The failure rate has increased to an average of ten failures and four necessary adjustments of pulse length or voltage per month. However, it is still too early to draw any clear conclusions regarding preventive maintenance. The chief causes of failure were the high voltage switch tubes and the precision power supplies.

g. Sub-Booster Klystrons. At the end of the quarter, Eimac had delivered all but one of the new klystrons under the original contract. A number of warranty replacements were also delivered and about five more tubes are still due.

Under the new contract with Litton Industries, the third klystron is now being tested but still does not meet all specifications. Close scrutiny of the total program is being maintained.

### 3. Phasing System

a. Isolator-Phase Shifter-Attenuator (I $\phi$ A) Units. These units continue to operate reliably and without significant trouble. Transient suppressors have been fitted across all phase shifter motor terminals. This action has effectively stopped the troubles with accidental fast valve closures and phasing programmer erratic stepping. Further suppressors will be fitted across the protection attenuator relays to stop transients from reaching the modulator/klystron protection units.

b. RF Detector Panels. Except for the problem of thermionic diode balance, these units give trouble-free operation. Switched attenuators will be fitted in three more sectors to extend the operating experience with this modification.

The feasibility of making a phase-shiftless PIN diode variable attenuator at 2856 MHz is being investigated.

c. Programmers and Electronic Units. Erratic programmer stepping has been cured by fitting suppressors across the I $\phi$ A motor terminals. Twenty-four VDC supplies along the machine are now well regulated, so that the present design of timing-generator is working satisfactorily.

Preamplifier crossover distortion in the gated voltmeters was found to be due to feedthrough from the switching pulse generator, which was applying low-level pulsed bias to the gate driver transistors, increasing the gain at small signal levels. Additional decoupling between the pulse generator and the video preamplifier cured the problem. To make the decoupling effective, it was necessary to ground the negative line on the PC card. The electronics card cages were partially rewired to accommodate this.

Frequently, failure of the null detectors to close was caused by badly distorted waveforms at the gated voltmeter outputs. The fault was cured by replacing all diodes in the gating bridges by matched and balanced sets.

Gate widths and overall gains of all gated voltmeters have been standardized.

The gains of all servo amplifiers have been adjusted to saturate for a phase error of 30 degrees. This increases system tolerance of small fluctuations on the rf inputs without appreciably reducing phasing accuracy.

The stepping time of all programmers has been increased to 2 seconds to accommodate the variation in servo amplifier frequency response. The latter problem will be tackled during the next quarter.

The video outputs of the rf detector panels in Sectors 1 and 2 have been linked via the injector alcove to the video transmission cables to CCR. This has enabled machine operators to view the phasing system waveforms and detect improper phasing, klystron phase jitter, etc. It has been concluded that such a video display from all sectors in CCR will be very useful for diagnosing machine troubles.

All programmers have been modified to increase the flexibility of CCR control when the video display system is installed. It will be possible to examine the phase stability of any klystron without setting it to standby or changing its phase. Moreover, it will be possible to stop a programmer at any step in either the phasing or nonphasing mode, and to change modes during a program cycle.

This is of practical importance, as it will permit CCR to phase a repaired klystron on standby without disturbing neighboring klystrons on accelerate.

#### 4. In-Line Beam Position Monitors

Installation of the additional monitor upstream of the positron source has been completed.

During the next quarter, work will be started on a simple modification which will permit CCR to rebalance the thermionic diodes in the beam position monitor detector panels. The relay in each sector beam monitoring rack which disconnects the rf position signals to display zero errors in CCR will be used to divert the steering power supply control signal to a motor-driven balancing potentiometer in the beam position monitor detector panel.

#### 5. Beam Analyzing Stations

The two stations operated satisfactorily during the past quarter. No changes were made.

#### 6. General Microwave Investigations

a. Klystron Filters. There is a possibility that beam break-up is being enhanced by the presence of low-level signals at 4140 MHz and 4428 MHz in the outputs of the high power klystrons. To test this hypothesis, a band-stop filter is being designed. This filter will have a minimum of 60-dB attenuation across a 6-MHz bandwidth at both 4140 and 4428 MHz, and will transmit 24 MW at 2856 MHz with low VSWR and no voltage breakdown. Cold tests are almost completed. A prototype will be high-power tested under vacuum next quarter.

Work is also commencing on a low-pass, "waffle iron" type filter.

b. Design of RF Particle Separator for K Beam. The design data of the three-meter particle separator for the K beam was released and machine shop work has started. The pertinent specifications are listed below:



Label		LOLA 4
Mode family		TM <sub>11</sub>
Phase shift per cavity		2 π/3
Periodic length	d	3.5 cm
Disk thickness	t	0.230 inch
Cavity inside diameter	2b	4.580 inches
Beam aperture diameter	2a	1.767 inches
Suppressor holes diameter	2p	0.750 inch
Suppressor holes offset	c	1.457 inches
Length of section (84 cavities + 2 CPLS)	l	301 cm
Cold test frequency (75° F, 42% R. H.)	f	2856.16 MHz
Relative group velocity	v <sub>g</sub> /c	- 0.0193
Couplers:		
Inside diameter	2b <sub>CPL</sub>	4.511 inches
Rectangular waveguide - iris aperture	i	1.100 inches to be opened
End plate thickness	t <sub>E</sub>	2.000 inches to 1.230 inches
End plate hole diameter	2a <sub>E</sub>	1.767 inches

It is expected that with this design, a total attenuation of  $\mathcal{U} = 0.50$  nepers will be obtained. In turn, the expected deflection should be given by

$$p_T c / \sqrt{P_0} = 5.06 \left( \text{MeV} / \sqrt{\text{MW}} \right).$$

For comparison, it is recalled that the coefficient for the LOLA II design was 4.60 and for LOLA III, 5.29. LOLA IV was chosen in preference to LOLA III because the very low group velocity in LOLA III increases the risk of electric breakdown at high input power.

c. Design Studies in Connection with the Beam Break-up Problem. Following the presentation of the report on beam break-up experiments at SLAC by O. H. Altenmueller, et al., "Beam Break-Up Experiments at SLAC," at the 1966 Linear Accelerator Conference, Los Alamos, October 1966, investigations have been proceeding on a wide variety of microwave measurements. These include experiments to measure  $\omega$ - $\beta$  diagrams and transverse shunt impedances of a variety of  $2\pi/3$  and  $\pi/2$  cavity stacks. Exploratory work is also being done in collaboration with the Massachusetts Institute of Technology accelerator design group. This work

includes studying the effect on Q of enlarging the end plate hole of a constant gradient input coupler and the propagation characteristics of the HEM<sub>11</sub> mode for large disk holes (1.200 inches i.d.).

## 7. Optical Alignment System

The second complete realignment of the accelerator was accomplished during this report period. The maximum total excursion since April 1966 is  $\pm 2.5$  mm vertical and  $\pm 1.0$  mm horizontal. The complete results are shown by Figs. 21 and 22.

## 8. Theoretical and Special Studies

a. Beam Break-Up Studies. Analytical work on the SLAC beam break-up study, as described in the previous status report and at the Los Alamos Linear Accelerator Conference, has been continued. An alternate formulation, based on a method suggested by John Rees, has been used in several computer program versions to study the influence on beam break-up of effects such as nonlinear focusing, beam bunch structure, and shock excitation. This model has given added strength to the "shock excitation" mode of beam break-up by predicting that an unexcited beam displaced off axis by 1 millimeter will break up at approximately the right current and position. Further attempts are being made at correlating new experimental data with computer results.

b. Beam Switchyard Studies. Both theoretical and experimental studies were made of the beam optics of the A-beam line of the Beam Switchyard. Using the computer program TRANSPORT, the experimental observation of the focal conditions at the pivot was confirmed. A preliminary set of beam recipes was issued as an A-beam catalogue. The catalogue lists the settings for the seven quadrupole magnets for about 15 different beam conditions. A few of these conditions have been checked enough to show that the results are approximately as expected. A detailed check of the beam optics remains to be made.

Alignment checks, both by beam optics checks and by surveying checks, showed some discrepancies. A realignment routine, such as that being used on the accelerator, is planned for the Beam Switchyard.

## 9. Magnetic Measurements

During the past quarter, magnetic measurements were performed on a variety of beam transport magnets for the K-meson survey beam, muon beam,

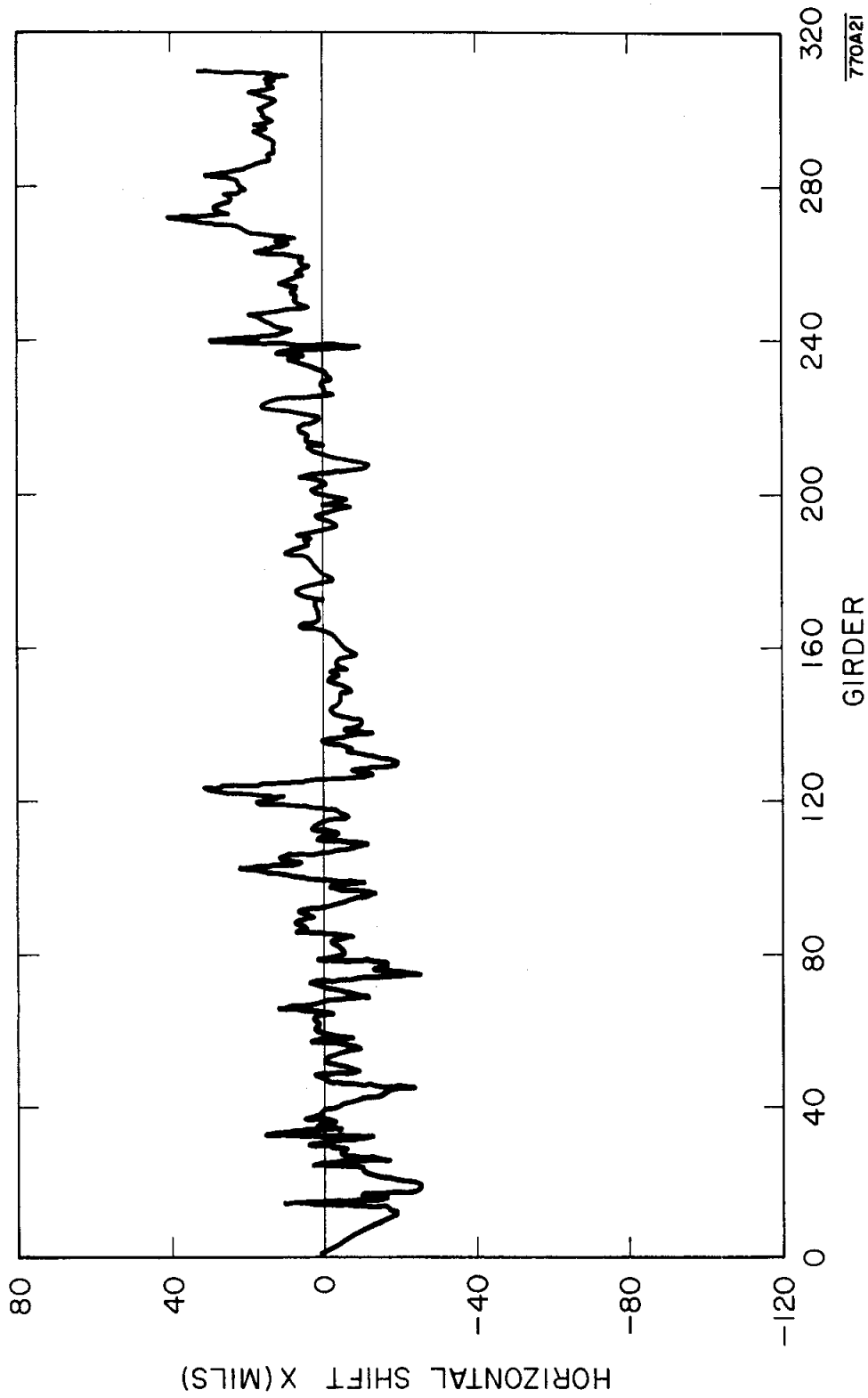


FIG. 21 - HORIZONTAL ALIGNMENT SHIFT SINCE APRIL 1966

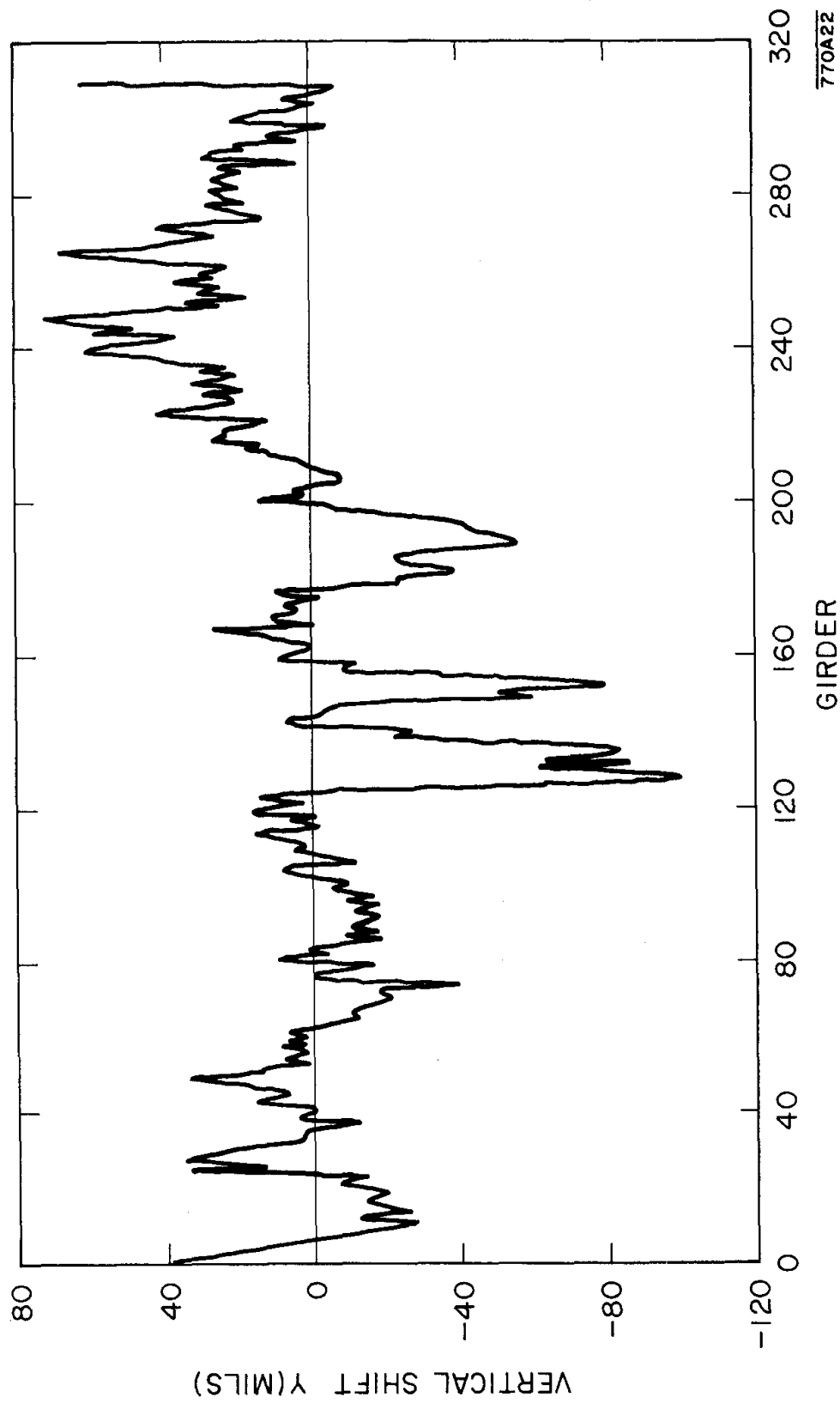


FIG. 22 - VERTICAL ALIGNMENT SHIFT SINCE APRIL 1966

and most of the magnets that make up the 8- and 20-GeV spectrometers. Measurements were made on eleven 8Q48 quadrupoles, two 8Q32 quadrupoles, and seven 18D72 dipoles, all used in the transport systems of End Station B.

The high field tapered section of the positron source solenoid was measured in the Accelerator Housing in order to determine the field distribution that was obtained.

The development of a thin (3/8-inch) nuclear magnetic resonance probe to be used with the Varian model F8a fluxmeter as a permanent installation in the 8- and 20-GeV spectrometer dipoles was completed.

Preparation for measurements that will take place during the next quarters was continued, especially for the rapid mapping of the spark chamber, streamer chamber, and bubble chamber magnets. Computer programs to reduce the resultant data were written and checked.

## B. KLYSTRON STUDIES

Development work is continuing on the main amplifier klystron at Stanford and at our vendors' plants. The majority of the development work is concerned with improving window life, and only a small amount of work was done last quarter to further improve the klystron efficiency.

### 1. Klystron Procurement

a. Sperry Subcontract. No tubes were received from Sperry during the quarter.

b. RCA Subcontract. RCA's deliveries have continued at a reasonably high level in spite of some difficulties experienced at their plant. The major trouble has been in the window area. Whether caused by multipactoring or localized arcing, many windows have not proved satisfactory during tube processing, necessitating a recoating of the window and reprocessing of some tubes two or three times.

A program of improving product design has been initiated to reduce cost and improve klystron operation. Some of the key activities are:

a. Redesigned, demountable collector for improved life and easier replacement.

- b. Improved balance of E-field configuration in the output gap plus a wider gap to reduce tendency toward arcing.
- c. Investigation of removal of stub tuners in output waveguide.
- d. Elimination of mode suppressors and ion pump.
- e. Improvement of cathode seal structure (high failure rate compared to normal).
- f. Investigation into spurious oscillation (reflex type) phenomena.

c. Litton Subcontract. Litton's delivery and acceptance record has been much poorer during the past quarter than previously. Several phenomena (excessive arcing, rf input break-up, harmonic content) were observed at Stanford which necessitated additional engineering at Litton.

After Stanford observed excessive sparking on several Litton tubes, a careful review of the bake and processing schedule was made. Litton also investigated materials used in the gun and has built several tubes using a kovar focusing ring (instead of stainless steel). This change, coupled with improvements on the modulator (end-of-line clipper) and processing to higher voltages, appears to have reduced the problem at present.

The rf input break-up does in some cases result in pulse break-up on the output. After further studies, there is conflicting evidence that some of the output break-up may be caused by multipactoring rather than by actual input seal problems. However, it was discovered that the break-up was sensitive to the position in the magnetic field and further work is being done to minimize the problems in future tubes.

Measurements of second-harmonic content on some Litton tubes showed that the harmonic content was often close to the maximum acceptable specifications, and that it varies greatly from tube to tube. Although there may be some ambiguity in the measurements, it was determined that the second-harmonic content can be reduced by tuning the penultimate cavity at some slight expense in gain.

d. Stanford Klystron Development. The klystron improvement work has been greatly reduced this quarter. However, two additional XM-12 experimental tubes were built and gave power outputs of between 26 and 27 MW in electromagnets at 250 kV. These tubes could not be tested in permanent magnets because of window failure for one and excessive gassing for the second one.

A 1/3-scale beam tester was built to check the rf operation of our beam at voltages much below relativistic velocities. Although the tube performed reasonably satisfactorily, there appeared to be multipactoring in some of the cavities which obscured the data.

Additional work was also carried out in an attempt to improve the permanent magnet fields, but no tubes were tested in the improved magnet during the quarter.

In addition to the experimental tubes built, nine tubes were reworked during the quarter. The yield through test has been poor, partly because of one window failure, one shorted filament, and one high voltage seal failure. Additional investigation of the bake and processing is being undertaken to restore the yield to its previous high values. Five SLAC tubes completed acceptance tests with an average peak power of approximately 23 MW at 250 kV.

## 2. High Power Klystron Windows

As mentioned above, two window failures occurred on tubes processed during this quarter. Based on the window temperature taken prior to failure and on the appearance of puncture marks, it appears that these failures were caused by dielectric breakdown. However, it is possible that one failure was caused by operating the load at an excessively high pressure. Two additional window failures were observed this quarter, one resulting in shelf-life failure of a klystron built in 1965 through a microleak in the window, the other due to excessive loss in the window coating.

Since it is obvious that window stability needs to be further improved, much work is being devoted to understanding the reasons for instabilities. The following tests have been performed to confirm some of the reasons for instabilities.

a. Bake Tests. The old window life test facility has been used during the quarter for complete investigations of baking temperatures on window operations. Five of six windows initially installed on the life test apparatus failed at reasonably low power levels after being baked for 8 to 10 hours at between 500 and 550°C. On the other hand, replacement windows coated under better control conditions appeared to be able to withstand one bake test without failure.

b. Coating Atmosphere. As mentioned previously, an attempt was made to improve the coating stability by using a 98% argon - 2% oxygen atmosphere. To date the results do not appear to be better than those obtained in an argon

atmosphere. One window coated in an oxygen/argon atmosphere and installed on a tube failed after exposure to two successive bake cycles. Three others performed satisfactorily after one bake cycle.

c. Grooved Windows. Because the increase in coating losses appears to be particularly serious on the tube side of the window, other ways of suppressing multipactor on the tube side are being investigated. Several years ago, tests had been performed on grooved windows which indicated a reduction in multipactor. We are now testing ceramics which are grooved on one side (tube side) and titanium-coated on the other side. Initial results have been encouraging; the reduction of multipactor on the tube side is significant, particularly at high power levels.

d. Coating Techniques. Attempts at measuring the absolute value of coating thicknesses have not been successful to date, and there is reason to believe that the crystal technique used to obtain a relative value of coating thickness is seriously affected by the atmosphere in which the window is coated. The most significant measurement to date appears to be one of coating resistance versus temperature as an index of coating stability.

e. Coating Methods. We have begun work to permit coating by rf sputtering. This method should enable us to coat windows with a much greater variety of source materials, including insulators. We hope to be able to test windows coated with films of materials such as boron nitride or titanium dioxide, which should be stable over high temperature vacuum bake conditions.

### 3. Driver Amplifier Klystron

The development work at Litton on this program has been slow during the quarter, and the deliveries of magnets for this tube have not been satisfactory.

In general, the magnet vendor has been unable to meet the transverse field specifications, although the addition of field straighteners and shunts have somewhat improved the situation. Three tubes have been built and tested, and the best results obtained appeared to be approximately 60 kW output at 26 kV. However, there are instabilities in the tube at drive levels close to saturation.

Litton is putting much effort into the improvement of the tube, but it is doubtful that any conclusions can be drawn until better magnets are available early next year.



## C. MECHANICAL ENGINEERING AND FABRICATION

### 1. Positron Source

Assembly of the positron source hardware onto the positron strongback was completed and the strongback installed in the Accelerator Housing. The assembly of the wand positron source was completed and the wand installed in the solenoid housing on the positron strongback. Water, air and electrical connections were made to components on the positron strongback and the wand operation was checked out.

In operation, the wand swings a water-cooled target through the beam, interrupting nine pulses (at 360 pulses per second). The first four and last four pulses are suppressed and the fifth pulse generates positrons in the target. Operation by manually shifting the control valves is satisfactory; synchronized operation will be tested after the circuits are connected to Central Control in February.

Sealing of the vacuum flanges was unsatisfactory, and it was necessary to replace the original V-seal with a solid indium gasket.

A small bellows and cable were added to the original design to allow the target to be held on the beam axis. This feature will be useful until the wheel target is installed.

When the wheel positron source is inserted, it interrupts all beam pulses. It therefore trolls (motion in a circle without rotation) to prevent local overheating. This trolling motion is resisted by eddy currents set up by the magnetic field. The estimated magnitude of the eddy current drag is sufficient to cause torsional deflections of the vacuum bellows that could shorten their life. In addition, sealing experience on the 6-inch vacuum flange indicates that scaling the 10-inch flange on the wheel target during wheel operation may be impossible. Correction of these two faults will require extensive changes in design.

The "flood control system," which was designed to protect the accelerator in the event of a water-to-vacuum leak in the positron area, was installed. The system was checked out and found to operate satisfactorily.

Assembly of twelve positron profile monitor housings was completed and they were installed at the positron quadrupole triplet sections in the Accelerator Housing. Three zinc sulphide profile monitors and actuator assemblies were fabricated for use in the profile monitor housings.

## 2. Accelerator Maintenance

Maintenance of the mechanical components of the accelerator continued throughout the quarter. The more significant accelerator repairs were: (1) replacement of a fast thin valve which had been hit and damaged by beam, (2) replacement of a waveguide 'S' assembly, (3) replacement of an rf load which was found to be arcing, and (4) replacement of a waveguide valve which was leaking.

Difficulty was experienced in getting a reliable vacuum seal with some of the thin valves. Investigation showed that the thin valve springs were taking a permanent set and were therefore not generating the necessary sealing force. The length of some of the springs was changing by as much as 5/16 of an inch. It was found that springs compressed to solid height would take over 90% of their permanent set within 30 days. It was therefore decided to use longer springs, compress them to the solid condition for 30 days, and then cut them off to the right length prior to installing them in thin valves. A program of treating new springs in this way and of replacing springs in thin valves was undertaken. Thin valve spring replacement is expected to be completed during the next quarter.

Polyethylene bellows protectors were installed on all the vacuum manifold bellows, the in-line bellows and the light pipe bellows in the Accelerator Housing.

## 3. Beam Break-Up

A program to convert the quadrupole triplets to quadrupole doublets, thereby yielding stronger focusing, was undertaken. All quadrupole B's on drift sections in Sectors 1 through 9 were removed as well as the quadrupole B's from the positron triplet assemblies, and the remaining quadrupole A's reconnected as doublets. The design of a drift section assembly with a quadrupole B doublet was completed, and seven such assemblies were installed in Sectors 11 through 17 in place of the old-style drift sections which contained quadrupole triplets.

Design of supporting hardware, bellows assemblies, and quadrupole A modifications was completed for installation of quadrupole A's at 40-foot intervals in Sectors 1 through 6. Procurement of hardware for installation in Sectors 1 and 2 was initiated.

## D. INSTRUMENTATION AND CONTROL

The major activities during the past quarter have been (1) completing the Central Control oscilloscope display system, (2) installation of the positron source instrumentation, (3) incorporating new operational requirements into the personnel protection system for Beam Switchyard and End Stations, and (4) continuing the program of updating schematics and as-built drawings of the control system.

### 1. Beam Guidance and Monitoring

a. Quadrupole Doublet Power Supplies. The recent decision to change the configuration of the beam guidance quadrupole system from a triplet into a doublet system necessitated the purchase of 25 current-regulated power supplies having a capability of 60 volts and 15 amps. Delivery of the power supplies is expected in February 1967.

The controllers necessary to remotely program the power supplies are being designed.

b. Beam Monitoring. A modification of the beam monitoring linear Q system was completed. Beam Switchyard signals representing beam charge from toroids  $I_{10}$  (A-beam),  $I_3$  (central beam) and  $I_{30}$  now appear in the same time slot on the linear Q oscilloscope. The profile of beam transmission presented to the operator is now complete from the injector to points well into the Beam Switchyard.

The linear Q circuit is designed to operate over a "60 dB range of charge," from  $10^9$  to  $10^{12}$  electrons per pulse. A complaint that operation is unsatisfactory at the low range was traced to microphonics in the toroid, originating in the water cooling connections to the beam scraper nearby. It has not yet been determined how to correct this fault.

### 2. Trigger System

Trigger generators have been completed and installed in the counting house, End Stations A and B, and Sector 30 (for the pulsed steering magnets in the Beam Switchyard), for gating and triggering various electronic equipment at the respective locations.

A six-channel counter/frequency divider to supply pulses of essentially any desired frequency and/or aperiodic pulse trains to the pattern generator in CCR has been

fabricated and is being installed. The counters will be used primarily to provide low repetition rates for tune-up (such as 10 pps) and to provide special pretriggers and blanking pulses required for the bubble chamber and for wand target operation.

### 3. Central Control

Modulator oscilloscopes have been installed for spectrum and video signals.

Installation has started on the coaxial patching system for CCR. This will enable signals from the accelerator and Beam Switchyard to be rapidly and easily connected to various display devices in CCR.

A display panel for positron signals has been installed on the maintenance console. The positron status signals required an extra decoding cabinet and plug-in units in the CCR status monitoring rack.

After some experience with the beam break-up problem it was decided to augment the SLAC-designed pulse oscilloscopes in CCR with commercial units. The SLAC oscilloscopes are provided with base-line position and trace intensity modulation to facilitate dealing with multiple beam optimization problems. They have, however, a relatively low (3.6-kV) beam accelerating voltage, so that their trace brightness is inadequate for observing short pulses which do not reproduce from one to the next. The commercial units have 14-kV accelerating voltage; the traces are therefore much brighter.

### 4. Control Systems and Data Handling

It was decided that the fire detectors now being installed in the klystron modulators would be connected directly to the fire alarm system instead of being reported by status multiplex to CCR. The decision will result in lower cost and in faster response to fires.

The following accelerator improvement projects were approved for installation during the remainder of the fiscal year: (1) Remote control switching of the video repeater-amplifier inputs will replace the present manual patching. The two cables running the length of the Gallery, with repeaters in each sector, will continue to fulfill the video system needs. Video monitoring of the operation of the phasing system will result from this change. (2) Remote control will be provided for balancing the diodes in the rf position monitor system. (3) Automatic counting of "accelerating" and "standby" klystrons will be installed as soon as possible. Plans for automatically replacing a failed unit will be investigated.

A study was initiated of the cost of making it possible to operate the Beam Switchyard from CCR.

#### 5. Positron Source Electronics

The circuitry required to interlock the positron wheel, namely the wheel interlock chassis and the wheel speed interlock chassis, has been completed and the chassis have been installed in the Gallery, although installation of the wheel target itself has been deferred. The wand drive and positron interlock circuits were installed in Sector 11 and checked out. The system was used on December 20, when the first positron run was made, with the wand stationary in the beam line.

The I/C portion of a protective circuit called "Flood Control" was installed and checked out. The objective of the flood control system is to confine the effects of water leaks to the vicinity of the wand and wheel targets. The system can be set to the automatic or manual state. In the automatic position, the system provides the following protective features.

As pressure at the source rises, the following actions will be taken:

$10^{-6}$ torr	Shut off beam
$5 \times 10^{-5}$ torr	Close fast valves; Shut off wand and wheel water supply valves
$10^{-2}$	Apply dry nitrogen to positron source vacuum chamber; Retract wheel, when in; Shut off wand and wheel water return valves
+20 psia	Shut off nitrogen; Open wand, wheel drain valves; Shut off cooling water pump

The primary sensing element for the vacuum is a gauge in the Accelerator Housing. Failure of this gauge during operation will shut off the beam and close the water supply valves.

In the manual position, water and vacuum maintenance can be done. Complete automatic protection is not provided in this state. In order to minimize the hazard of a water leak, the cooling water pump and the beam are kept shut off until automatic protection is restored.

## 6. Personnel and Machine Protection Systems

a. Personnel Protection System. A number of minor modifications have been made to the personnel protection system, and a new subsystem, the "emergency stop" circuit, has been added in the research area.

Three additional keybanks have been installed in DAB for control of access to heat exchangers, beam dump east, and other fenced areas associated with the Beam Switchyard, End Station A and End Station B.

A radiation monitor was installed in the main Switchyard cooling water loop to shut off the pumps in case of leakage of water from the secondary loops of the radioactive-water heat exchangers. The radioactive-air monitors at the exhaust vents for the Beam Switchyard have been installed.

The "beam on" circuit for the personnel protection system has been installed. This circuit flashes the magenta lights in the Gallery and Beam Switchyard when the gun modulator is in the 'ready' condition, the machine protection receiver has been 'reset,' and when at least one of the injector gun triggers exists.

b. Emergency Stop Circuit. The "emergency stop" circuit for the research areas is designed to shut off the beam and to insert a number of beam stoppers in the beam line when, through some fault of shielding or operational procedures, excessive radiation is observed in the research area outside the End Stations.

The personnel protection system for the Housing and End Stations is designed so that: (1) the machine is totally shut off if a person is known to be in a beam area; (2) a person cannot enter an area unless it is impossible for a beam to exist in that area. The limits of an area are defined by geometry: shielding, gates, beam stoppers. Compromise of the security of an area results in emergency shutdown.

In the research area, there will be locations which are presumably safe from the beam, which must be occupied during an experimental run. Such regions can be made safe by changing the geometry of the beam areas, that is, by inserting beam stoppers farther upstream. This response is less extreme than total shutdown, allows quicker return to normal operation once the fault is corrected, and is, nevertheless, quite absolute in its manner of removing the beam from the area.

In the research area will be a series circuit of "EMERGENCY STOP" switches and radiation monitor alarms. If the circuit is broken, the injector will be turned off and ST<sub>10</sub>, ST<sub>30</sub>, and three beam stoppers at Sectors 20, 21 and 28 will automatically drop into the beam path.

The "EMERGENCY STOP" switches are actuated by two buttons. The "ON" button is key-operated. With the key removed the "ON" button is nonfunctional; the circuit may be tripped by the "STOP" button. The key must be inserted and turned to allow resetting the circuit.

c. Ion Chambers for End Stations Interlock System. The ion chambers are designed after an existing prototype made by Health Physics. Additional design efforts will be devoted to making it more fail-safe. Since it will take some time to finalize the design and to produce it, three copies of the existing model will be made for interim use and to gain experience with the circuit.

The ion chamber itself will be filled with a tissue equivalent gas. A source will be added to the chamber to give a signal of about 2 mrad/hr. Three alarm levels will be provided. One will be a low set point alarm used as an indication of the correct operation of the circuit. The second alarm level will alert the operator that the radiation level is becoming excessive. The third alarm level will be set at about 20 mrad/hr and will turn off the gun and insert beam stoppers. Only the third alarm will be part of the local unit; the other two alarms will be part of the remote metering circuit in DAB.

The logic circuits have already been installed and a push-button, simulating one of the stop switches, has been installed in the K-survey trailer. The prototype monitors will become available for installation in March. The complete installation will be ready in May.

d. Machine Protection System. A new 50- $\mu$ sec protective interlock chassis, which adds the positron interlocks to the 50- $\mu$ sec beam interlock system, has been completed and is being installed in CCR. This circuit will inhibit the gun whenever the wand target is in transit across the accelerator aperture, except when it is exactly on center and ready for a positron beam pulse.

Repeated failures in the heat exchanger instrumentation of klystron cooling, accelerator waveguide cooling, and waveguide drive line cooling circuits necessitated the design of an interlock circuit to shut off the variable voltage substations of the accelerator portion involved. As a result, the water circuits no longer need be interlocked through the 1-millisecond tone network.

The machine protection system has been modified in the same way that the personnel protection system was previously modified; that is, the tone loop is now interrupted by a double break at each tone interrupt unit location. This has improved the ratio of normal received signal amplitude to residual amplitude when the loop is broken.

## E. ELECTRONICS ENGINEERING

### 1. Beam Knockout Modulator

Construction and laboratory tests were completed on the 39.9-megacycle unit. At the end of the quarter this unit was about to be installed on the accelerator for further tests.

A second unit, tunable from 10 to 20 megacycles, has been requested. The circuit is designed, parts are ordered and construction has begun.

### 2. Magnet Power Supplies

The 3.4-MW power supply for the bubble chamber and the 5.8-MW power supply for the spark chamber magnet were delivered. At quarter's end, both were awaiting utilities and loads.

Specifications were drawn up, bids requested, and a contract awarded for construction of the 400-kW magnet power supplies. The beam guidance quadrupole system design was changed from a triplet to a doublet system, which necessitated the purchase of 25 current-regulated power supplies. Specifications were drawn up, the job was bid, and a contract awarded. Delivery of the first units is scheduled early in January.

### 3. Other Electronics Projects

a. Positron Source Electronics. Positron target engineering work was done on the wheel interlock chassis, wheel speed interlock chassis, wand driver chassis, positron interlock chassis, and fifty-microsecond protective interlock chassis. Also, the pattern generator design was modified for use with the positron wand.

b. Hall Probe. Seven Hall Probe chassis were designed and built. They will be used in conjunction with magnet power supplies to regulate magnetic fields.

c. Liquid Hydrogen Target Control System. Two target control systems were constructed, one for the mu beam and the other for the annihilation beam. Design was started on a third system for End Station A.

d. Fast Valve Control. Nine of the existing fast valve controls were modified to include an automatic fast charge initiated by the open fast valve switch, and an independent capacitor voltage monitor.



## F. COUNTING ELECTRONICS

### 1. End Station Charge Monitors

A resonant-toroid integrator containing a digital noise-averaging system has been designed for End Station A. The system was designed for a relative measurement accuracy of  $\pm 0.1\%$ . The three digital outputs of the system, namely the charge per pulse, accumulated charge, and pulse count, can be remotely controlled and read by the SDS 9300 computer.

Some detailed measurements, comparing the instrument against a  $0.1\%$  Faraday Cup measurement, were made recently. The internal calibrator, which tests the system with a simulated beam pulse through the toroid, appeared to agree with the Faraday Cup within  $0.5\%$ . On high ranges, the system stability is presently  $\pm 0.2\%$ , but in high gain positions where noise is large, the noise averaging appears limited by coherent pickup of trigger pulses and line transients. Efforts are being made to minimize this noise, which enters through the ac power and ground systems. The equivalent input noise of the amplifier system is  $2 \mu\text{V r. m. s.}$ ; hence the contribution due to transient pickup must be reduced well below this level in order to perform successful noise averaging. The noise level is equivalent to about  $1 \times 10^8$  electrons per pulse.

The bi-directional accumulator (adder) was built in BCD because of the necessity for decimal readout. The accumulator operates in a parallel-serial fashion, with decade addition being performed in parallel, and each decade added sequentially to share the common decade adder logic.

The accumulator consists of 12 decades of display, and accepts a sign and 4 decades of input information for each beam pulse. Computer output of the information is also provided. It is constructed entirely of commercial logic circuits and performs the complete addition in  $50 \mu\text{sec.}$  The accumulator has been successfully operating for approximately four months.

A system similar to that described above is being constructed for End Station B. The analog portion is essentially identical; however, the digitizer is a gated 1-MHz oscillator which produces a number of counts proportional to the pulse charge. The readout device is a standard 7-decade dual scaler. The system has no bi-directional noise averaging capability. The readout can display either the charge per pulse or the charge accumulated over an arbitrary time interval.

The first of two prototypes is undergoing final testing; construction of the second unit is nearing completion.

## 2. 100-MHz Counter (Scalers) and Readout System

Procurement of 100-MHz dual pulse counters has been completed. Significant features specified were positive and negative dc input coupling, dc gate control compatible with AEC standard slow logic levels, and a gated parallel readout system for ease of data output multiplexing. Detailed acceptance tests were performed on all counters.

A digital scanning system was designed and built to permit readout of these counters into a Hewlett-Packard 562AR parallel printer capable of printing 5 counters per second. The basic scanner unit is capable of accepting 20 channels, but the electronics is provided for 70 channels (capable of expansion to 100). A present count capability is built into the system. Expansion of the system beyond 20 channels is achieved by the addition of connector panels which contain no electronics.

The basic scanner is contained in an 8-3/4-inch  $\times$  19-inch package and uses commercial digital circuits. The readout system is now in use by Experimental Group B.

## 3. Time-of-Flight System

Electronics equipment has been developed for a vernier chronotron time-of-flight system for use with the End Station A spectrometers. In this system, the time of arrival of a particle at a Cerenkov detector is compared with a marker derived from a submultiple of the 476-MHz drive line frequency. Using a mixing process, the real time measurement is made at an IF frequency of about 500 kHz.

The final output is obtained as an analog signal from a time-to-amplitude converter (TAC). Figure 23 shows a multiple exposure of the TAC output for 100-psec increments of delay of the simulated phototube pulse.

The system is due for installation in the A Counting Room in early March.

## 4. Equipment Pool

The Equipment Pool has been steadily acquiring a more complete inventory of 100-MHz logic modules, scalers, digital voltmeters, high voltage power supplies, oscilloscopes, and similar devices. Plans are underway to approximately double the number of logic modules in the Pool during this fiscal year. The new equipment will be purchased to the AEC Standard (NIM) specifications.

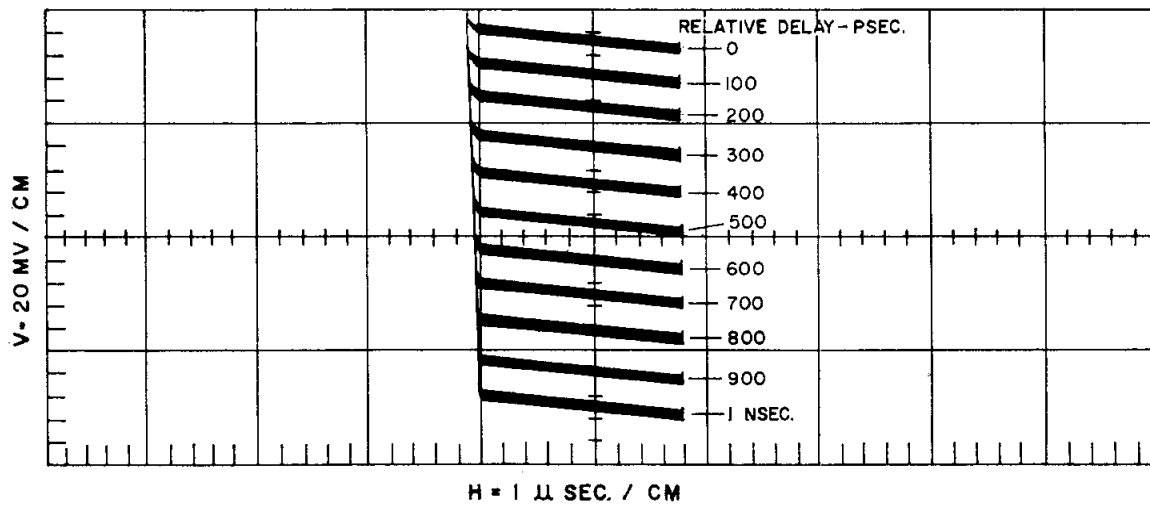


FIG. 23- MULTIPLE EXPOSURE OF TAC OUTPUT FOR 100-PICOSECOND DELAY INCREMENTS OF TEST PULSE

The Pool, besides maintaining complete records for counting electronics at SLAC for loan purposes, presently has full maintenance and spare parts facilities for modules and scalers. Primary activities besides maintenance are new equipment evaluation and procurement, monitoring of field usage problems, overall upgrading of the existing complement of equipment, and providing user assistance on special instrumentation requirements.

## G. RESEARCH AREA

### 1. Annihilation Beam

Beam design layout on the annihilation beam was completed and all major items of hardware have been delivered for installation. A personnel protection system to guard against the accidental delivery of beam to inhabited work areas of the End Station yard was designed and approved by the Radiation Safety Committee.

### 2. Liquid Hydrogen System

a. LH<sub>2</sub> Storage Facility. Facility construction was completed by late October. The 15,000-gallon main storage tank and rolling dewar were filled with LH<sub>2</sub> for a series of performance tests. The tests revealed that the main storage tank had excessive boil-off and that the rolling dewars have faulty gauges. The manufacturers were requested to take corrective action.

b. Beam Targets. The annihilation and mu-beam targets have undergone field tests using LH<sub>2</sub>. Problems encountered with the target liquid level probe have been solved. The mu-beam target flask has been punctured internally to determine the pressure rise in the vent system. A gas-liquid separator was installed in the target reservoirs to eliminate surging during liquid filling.

### 3. Power Supplies

a. Beam Switchyard (BSY) DC Power Supplies. The quadrupole and bending magnets for the B-beam were first energized and found to function properly. The various power supplies for the BSY magnets have developed a few problems affecting long-term reliability. Minor modifications resolved the problems and the units have operated satisfactorily.

b. End Station Power Supplies. The 5800-kW and 3400-kW power supplies for the spark chamber and bubble chamber were delivered. These units will undergo test during the next quarter. The auxiliary magnets for the muon beam were first energized using 16 of the 360-kW silicon-controlled-rectifier current-regulated power supplies. The initial tests on the 360-kW power supplies indicated that the voltage transients generated on the 480-volt, 3-phase power lines were sufficient to cause regulation instability when several of the power supplies operated simultaneously. Four new 400-kW general purpose power supplies rated at 3000 amps were ordered to be used for powering magnets in various experiments.

#### 4. Instrumentation

a. Ionization Chamber. A split-plate ionization chamber with a phosphorescent screen for monitoring the positron beam into the annihilation dump in End Station B has been constructed and will be tested in the beam in early 1967.

b. Special Toroid. Construction of a ceramic-insulated drift section (for Experimental Group F) with a mounted toroidal beam current transformer has been started.

#### 5. Electronic Systems

a. Beam Instrumentation. Principal activities have been the construction and installation of the off-line instrumentation in the End Station B area. During this period, the mu beam and k-survey experiments were installed and checked out. Work was also started on the annihilation beam.

The basic monitoring system and design of all beam switchyard chassis were completed during this time. Some preliminary design was done on the central K-beam equipment.

A chassis to expand the Data Assembly Building toroid monitor system was designed. A delay circuit for the beam triggers was designed and built, and design of a per-pulse integrator for the toroids was started. Design of a digital repetition rate meter was completed.

b. Beam Switchyard Computer. Delivery of the new memory module (expanding the memory to 8192 words) was effected in December, and in anticipation of this, a new version of the main system program was written. The new version allows tighter control of magnet currents than the earlier version and has a considerably expanded instruction set. The new program was undergoing shakedown at the end of the quarter.

## 6. Precision Alignment

a. Laboratory Work. The shop targeting and preinstallation alignment of all the A-Beam equipment and 90% of the B-beam equipment was completed during the quarter. The major components completed were the B-beam quadrupole magnets, target changer, and the photon collimator for the A-beam line.

b. Field Work. Installation alignment of the entire A-beam in the Beam Switchyard was completed, including the A-beam dump, dump magnets, and the high-Z and high power slits.

In the B-beam system, the vertex points (VT-3 and VT-5) were rechecked and the drift lines through these points were established. The drift line through the final vertex point (VT-5) was extended into End Station B and the grid system previously installed was redefined relative to this line. The instrument stands, quadrupoles, and bending magnets for the  $1/2^{\circ}$  and  $6-1/2^{\circ}$  bend lines were installed and aligned in the B-beam transport system. In End Station B, the preliminary targeting of the mu and k secondary particle beam magnets was started and several of the magnets were aligned in their transport positions.

Beam Dump East and the diagnostic instruments on instrument stands in the area were aligned. Because relatively high radiation levels are expected in the dump area, techniques were developed for optically monitoring the dump and instrument stands from a minimum of 100 feet up-beam.

III. PHYSICS RESEARCH EQUIPMENT  
DEVELOPMENT

#### A. 12-INCH-BORE, 70-75 kG SPLIT COIL MAGNET

As reported in the previous QSR, SLAC-71, the turn-to-turn insulation problems for this coil became difficult and required systematic development work. The initial approach, based on square insulated high-resistance strips produced edge-damage during winding of the insulation. The insulation punctures, though microscopic in size, led to a longer charging time of the magnet than predicted by calculation. With randomly distributed shorts across several SLAC-built coils, tests indicated charging times of the 12-inch magnet to be several hundred hours.

Finally, insulation strips composed of multi-filament braids (glass or organic fibers) were prepared and tested. Four coils with a working bore of 2.5 inches, a length of 8 inches and an o.d. of 7.5 inches were built, using various kinds of insulation materials. These magnets produced fields between 27 and 31 kG with a maximum operating current of 655 to 730 amps. Heat transfer coefficients of  $0.4 \text{ W/cm}^2 \text{ } ^\circ\text{K}$  were measured.

From the point of view of cooling, the best performance was achieved with the insulated nichrome strip, where the cool-down time was approximately seven minutes and the boil-off rate of the magnet, once in the superconducting state, was 1.5 liters per hour of liquid helium. However, the charging time for this magnet was twelve minutes, whereas the braided-coil-insulated magnet has a somewhat longer cool-down time of approximately nine minutes but charging times of seven to twelve seconds, which corresponded to the voltage of the power supply (eight volts).

Several glass filaments fractured during insulation and winding. Finally, a polyamide braid, impregnated in silicon, was selected. Polyamides as impregnation materials were tested, but did not uniformly impregnate all filaments and were discarded. The braids were repeatedly subjected to compressive stresses of  $1.25 \times 10^5$  psi, corresponding to the maximum expected compressive stress in the 12-inch-bore magnet between room and  $\text{LN}_2$  temperatures; these proved to be acceptable. A large quantity of this braid has been ordered, and the winding of the two inner coil sections is expected in February 1967.

In addition, a 2000-amp power supply and a 1000-liter liquid helium dewar were acquired. In order to avoid purchasing 700 liters of liquid helium to cool



down the magnet, and in order not to waste the helium gas, four high-pressure helium tanks will be acquired in order to make the operation of the magnet independent of external sources.

### Publications

H. Brechna, "Cabled Magnets," National Superconductivity Information Meeting, Brookhaven National Laboratory, November 9 - 11, 1966.

## B. SPECTROMETER PROGRAM

The 8-GeV spectrometer was essentially ready for optics testing by the end of this period, and the 20-GeV spectrometer followed by about six weeks. Optics testing was scheduled to begin early in the new year.

Four of the six 567-kW power supplies were brought to operating condition, and debugging started on the computer control of the power supplies. The transformers for the 1.59-MW supplies proved to be completely unusable, and were replaced by standard 12-kV distribution transformers which had to be housed in a separate enclosure.

The 8-GeV hodoscope was completed and tested by the MIT group, and the 20-GeV hodoscope and particle discriminator were expected to be ready early in the next quarter.

Alignment stability of the completed 8-GeV magnet frame proved to be better than expected. The electromagnetic pickups which work with a taut wire to indicate magnet movements performed very well. The basic accuracy of the pickups is better than .0003 inch, but the "noise" level on the 60-foot wire limits the resolution to about .001 inch.

The concrete shielding blocks for all three spectrometers reached about 85% completion.

## C. COLLIDING BEAM VACUUM STUDIES

During this quarter work continued on the vacuum chamber design and on testing of materials and fabrication techniques. An order was placed for 10-foot-long, half-size, extruded test models.

## 1. Chamber Design

Preliminary layout drawings and studies of the transition section between the bending magnets and quadrupoles were made. A decision was made to install the ion pumps horizontally. Provisions were made to incorporate removable access flanges which will support the water-cooled beam scraper.

The thermal flux due to synchrotron radiation absorbed on the chamber wall was calculated for the current magnet lattice. As a result of these calculations, the beam scraper in the cavity was modified in order to reduce the peak flux to 150 watts/cm. The calculations also show that the peak flux on the beam scraper in the transition section will be about 275 watts/cm. Calculations of the gas pressure distribution due to these new conditions are now in progress.

A study was initiated on the heat transfer problems involved with the bake-out of the ring. It was found that strip heaters bolted to the side of the vacuum chamber on 1-foot centers would leave a gap of about 0.015 inch. As a result, the temperature differential between the heater and the chamber wall would be about 90°C. The use of four layers of crumpled aluminum foil between the heater and the chamber wall will reduce this temperature difference to about 25°C. This study also indicated that glass cloth would be unsatisfactory as a thermal insulating material. A glass fiber felt was evaluated and found to be satisfactory. Studies of the temperature distribution in the chamber wall are continuing.

## 2. Test Model

An order was placed for five 10-foot-long, half-size, extruded sections to be used as test models. These sections are due for delivery early in the next quarter.

The systematic analysis of in-house aluminum alloy welding techniques was continued and the variables responsible for cracking and porosity are being identified. It has been found that minute contaminants due to handling and storage are largely responsible for porosity. Testing of cleaning techniques and the effects of preheating are being continued.

Dies and jigs for drawing aluminum ports have been built and the first port has been successfully drawn. This technique minimizes the probability of virtual leaks and simplifies the welding operation.

### 3. Aluminum-to-Stainless-Steel Transitions

Some of the aluminum-to-stainless-steel test sections were found to be defective and there was mechanical separation of the aluminum from the stainless steel. Investigations of other suppliers of stainless-steel-to-aluminum bonds are continuing. At the present time it appears that stainless-steel-to-aluminum flanges are the most satisfactory method for the required transitions.

### 4. Stainless-Steel-to-Aluminum Flange Set

Testing of the 8-inch LRL-design flange continued. The flange was assembled with a 0.0015-inch-thick aluminum gasket and baked out at 260°C. It was found to leak after cooling. The flange face was modified and the through bolts were replaced by Heli-coil inserts. Tests were repeated with varying bolt torques. At 140 inch-lbs, there was no detectable leak after cooling. Testing will be continued.

### 5. Insulator Tests

Evaluation tests on the high-voltage alumina insulators were continued. The sample has withstood a maximum of 55 kV after exposure to 30 kV for 4200 hours. Dust and airborne contaminants have discolored the insulator. Testing will continue.

### 6. Electron Desorption Studies

Measurements have shown that by low-energy-electron 'scrubbing' of aluminum we can reduce electron desorption rates to the following low values:

<u>Gas</u>	<u>Desorption Rates at 300 Volts</u>
H <sub>2</sub>	$4 \times 10^{-7}$ molecules/electron
CH <sub>4</sub>	$1 \times 10^{-8}$ " "
CO	$2 \times 10^{-7}$ " "

In the absence of bombardment, ambient gases readsorb on the scrubbed surfaces and the electron desorption rates increase slowly until saturation at rates  $10^4 - 10^5$  higher.

Recent measurements have been concerned with a closer look at the readsorption process while controlling the ambient gas composition. Because of exchange reactions occurring on the chamber walls as any pure gas is introduced, it is difficult to raise the partial pressure of any reactive gas without also increasing the partial pressure of some other residuals. However, in some cases it is

possible to get concentration ratios greater than 100 to 1. Measurements to date suggest that carbon monoxide adsorbs more readily in the presence of larger amounts of hydrogen. Other results<sup>\*,\*\*</sup> also indicate that co-adsorption of carbon monoxide and hydrogen or oxygen may change the binding energy and coverage of carbon monoxide.

Because of its low scattering power, hydrogen has not been considered a serious residual in storage rings. Large amounts of hydrogen may, however, contribute indirectly to high carbon monoxide desorption rates and reasonable efforts should be made to reduce the hydrogen residual.

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\* J. H. Singleton, "Impurity Generation and Pressure Measurement in Hydrogen Using Hot Cathode Gauges," Paper 66-9E1-441-P3, WERL 2823-22 (October 6, 1966).

\*\* P. A. Redhead, "Desorption of CO and O<sup>+</sup> from Polycrystalline MO Surfaces by Slow Electron Impact," Appl. Phys. Letters 4, 166 (May 1, 1964).