

SLAC-85
UC-28, Particle Accelerators
and High-Voltage Machines

TWO-MILE ACCELERATOR PROJECT

Quarterly Status Report
1 July to 30 September 1967

April 1968

Technical Report
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Contract AT(04-3)-515
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TABLE OF CONTENTS

	<u>Page</u>
Introduction	1
I. Accelerator and Research Area Operations	
A. Operations Summary	7
B. System and Component Performance	14
1. Injector system operation	14
2. Drive system operation	14
3. Phasing system	15
4. Beam position monitors	15
5. Beam analyzing stations	16
6. Klystrons	16
7. Main modulators	26
8. Research area experimental activity and support	29
II. Accelerator and Research Area Equipment Development	
A. Accelerator Physics	30
1. Injection	30
2. Drive system	30
3. Phasing system	31
4. In-line beam position monitors	32
5. General microwave investigations	32
6. Optical alignment system	33
7. Theoretical and special studies	34
8. Magnetic measurements	34
B. Klystron Studies	35
1. Klystron procurement	35
2. High power klystron windows	37

	<u>Page</u>
3. Vacuum	39
4. Driver amplifier klystrons.	40
C. Mechanical Engineering and Fabrication	41
1. Positron source	41
2. Accelerator maintenance	41
D. Instrumentation and Control	43
1. Positron source	43
2. Beam guidance	43
3. Machine protection	43
4. Personnel protection	44
5. Central control	44
6. Data handling	48
7. Trigger system.	48
E. Electronics Engineering	49
1. Pattern Generator Modifications	49
2. Trigger system modifications	49
3. 300 kV modulator	49
F. Counting Electronics	50
1. End station charge monitors	50
2. Time-of-flight system.	50
3. Equipment pool	50
4. Module development.	51
5. Rho experiment, Groups B and C	51
6. Multibody experiment, Group D.	51

III. Physics Research Equipment Development	
A. Spectrometer Program	52
B. B-Beam Switching	53
C. Alignment	54
1. Beam switchyard	54
2. Experimental	54
D. Energy Absorbers	55
1. High-power beam dumps	55
2. Hydrogen recombiners	55
E. Research Area Magnet Power Supplies	56

LIST OF FIGURES

	<u>Page</u>
1. Overall view of SLAC as of 1 October 1967.	3
2. Eighty-two-inch bubble chamber building	4
3. Eighty-two-inch bubble chamber being assembled.	5
4. Eighty-two-inch bubble chamber control room	6
5. Particle vs machine physics runs.	8
6. Machine time as percentage of total manned hours	9
7. Weekly operating statistics.	10
8. Klystron quarterly operating experience -- all high power klystron vendors	17
9. Klystron age distribution (all vendors) in 200-hour increments.	18
10. Operating tube performance	20
11. Klystron failure distribution - all vendors	21
12. Eimac sub-booster klystron operating experience	24
13. Driver amplifier klystron age distribution	25
14. Experimental klystron performance in permanent magnet	38
15. Beam shutoff ion chamber location	45

INTRODUCTION

INTRODUCTION

This is the twenty-first Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the fifteenth Quarterly Status Report of work under AEC Contract AT(04-3)-515, both held by Stanford University. The period covered by this report is from June 1, 1967, to October 1, 1967. Contract AT(04-3)-400 provides for the construction of the Stanford Linear Accelerator Center (SLAC), a laboratory that had 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 January 1967, a beam energy of 20.16 GeV was achieved. Beam currents up to 42 milliamperes peak have been obtained. Also during this period, positrons continued to be accelerated through the machine and used in particle physics experiments. Both single and multiple positron beam experiments were performed. The estimated construction cost of SLAC is \$114,000,000, and with approximately 99% of the work performed, it is estimated that the job will be completed within the authorized amount.

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, whose work was completed during the first quarter of 1967.

The terms of Contract AT(04-3)-400 provided for a fully operable accelerator and for sufficient equipment to measure and control the principal parameters of the electron beam; in addition, provision was made for an initial complement of general-use research equipment with which it is 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 were necessary in order to prepare for the research program which is being 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.

Construction that was essentially completed during this quarter included such projects as: a new parking lot north of the Beam Switchyard; the 82-inch Bubble Chamber Building, its utilities and its 12kV to 480 volt power substation; Phase I of the modification of the Temporary Computer facility; extensive interior modifications to the interior of the Data Assembly Building; modifications to the Positron Source Water System; the construction and installation of a permanent front entryway sign; and an extension of the Target Area Fire Alarm System.

Other construction projects were in various stages at the end of the quarter. Engineering was underway for Phase II of an expansion to the Temporary Computer facility, and extension of the End Station A Counting House, a Sand Blasting Facility for the Craft Shops, and an extension of the Chilled Water Mains to the Central Laboratory Addition. Construction was proceeding and the percentages of completion on other projects at the end of the quarter were as follows: a Welding Shop Addition at the Heavy Assembly Building was 18% complete; the permanent Fire Station at the SLAC site, 63%; the installation of a water-cooled, dc power cable in the Research Yard, 50%; interior modifications in the Electronics Building, 50%; and the installation of Shur-Flo sensors in the Klystron Gallery water system was 40% complete.

Invitations had also gone out to bid on two large projects. These were for the General Services Building and for the Central Laboratory Addition. Construction on these will begin in the next quarter and they will be finished in the late fall of 1968.

Experiments continued using all three particle spectrometers in End Station A and the first photographs were taken in the 40-inch bubble chamber by the end of the quarter.

Some of the buildings and equipment discussed are shown in the photos that follow.

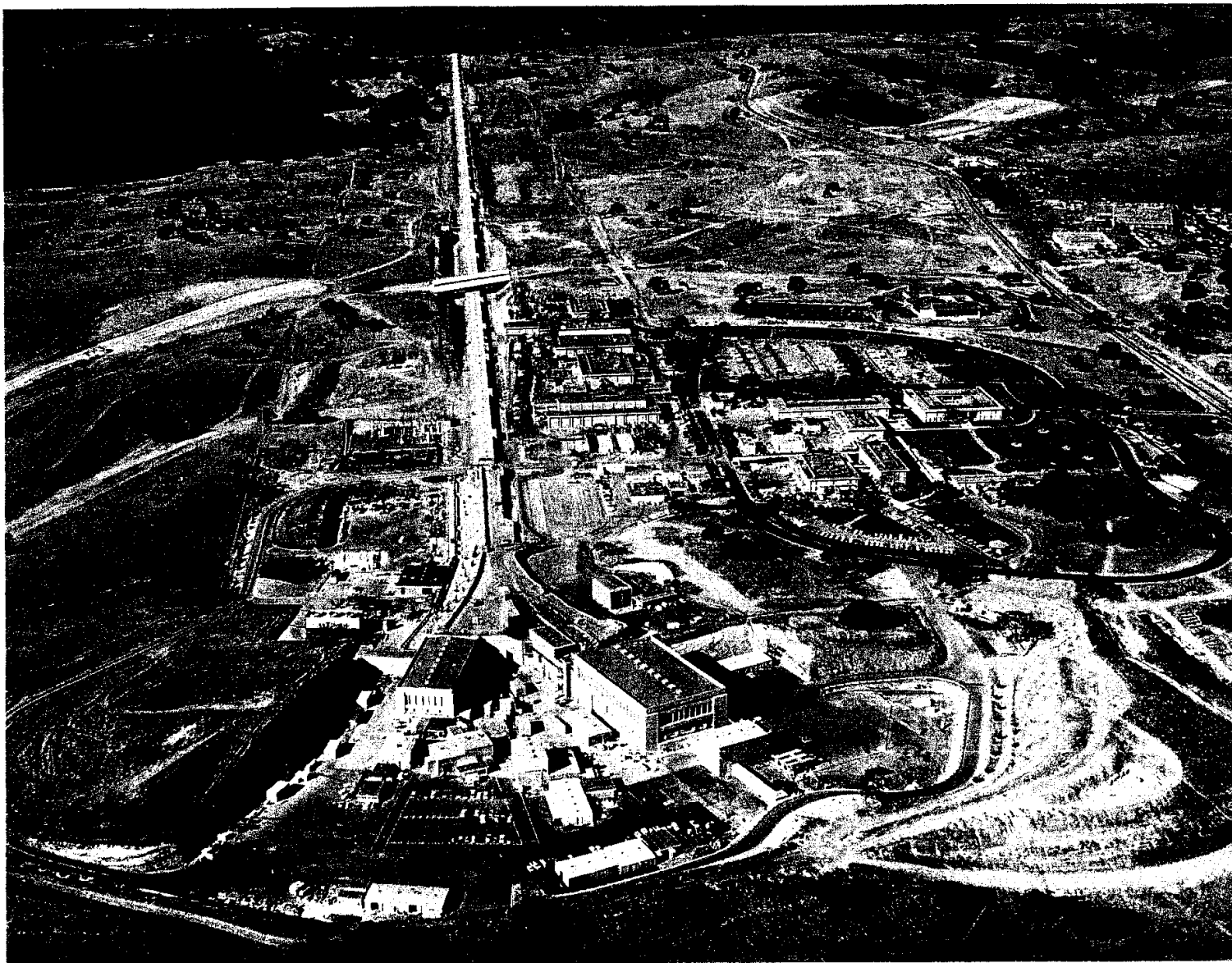


FIG. 1--OVERALL VIEW OF SLAC AS OF 1 OCTOBER 1967

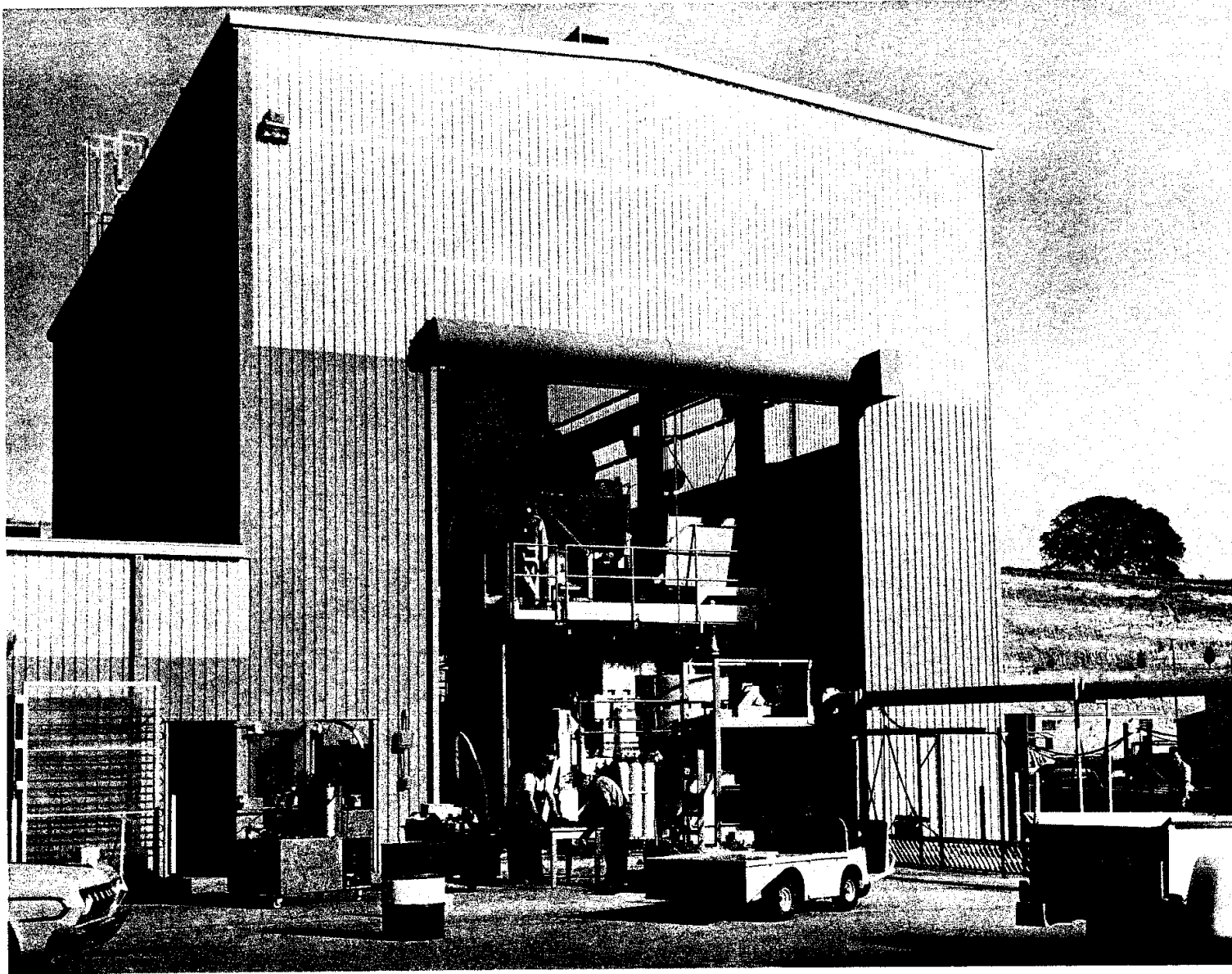


FIG. 2--EIGHTY-TWO-INCH BUBBLE CHAMBER BUILDING



FIG. 3--EIGHTY-TWO-INCH BUBBLE CHAMBER BEING ASSEMBLED

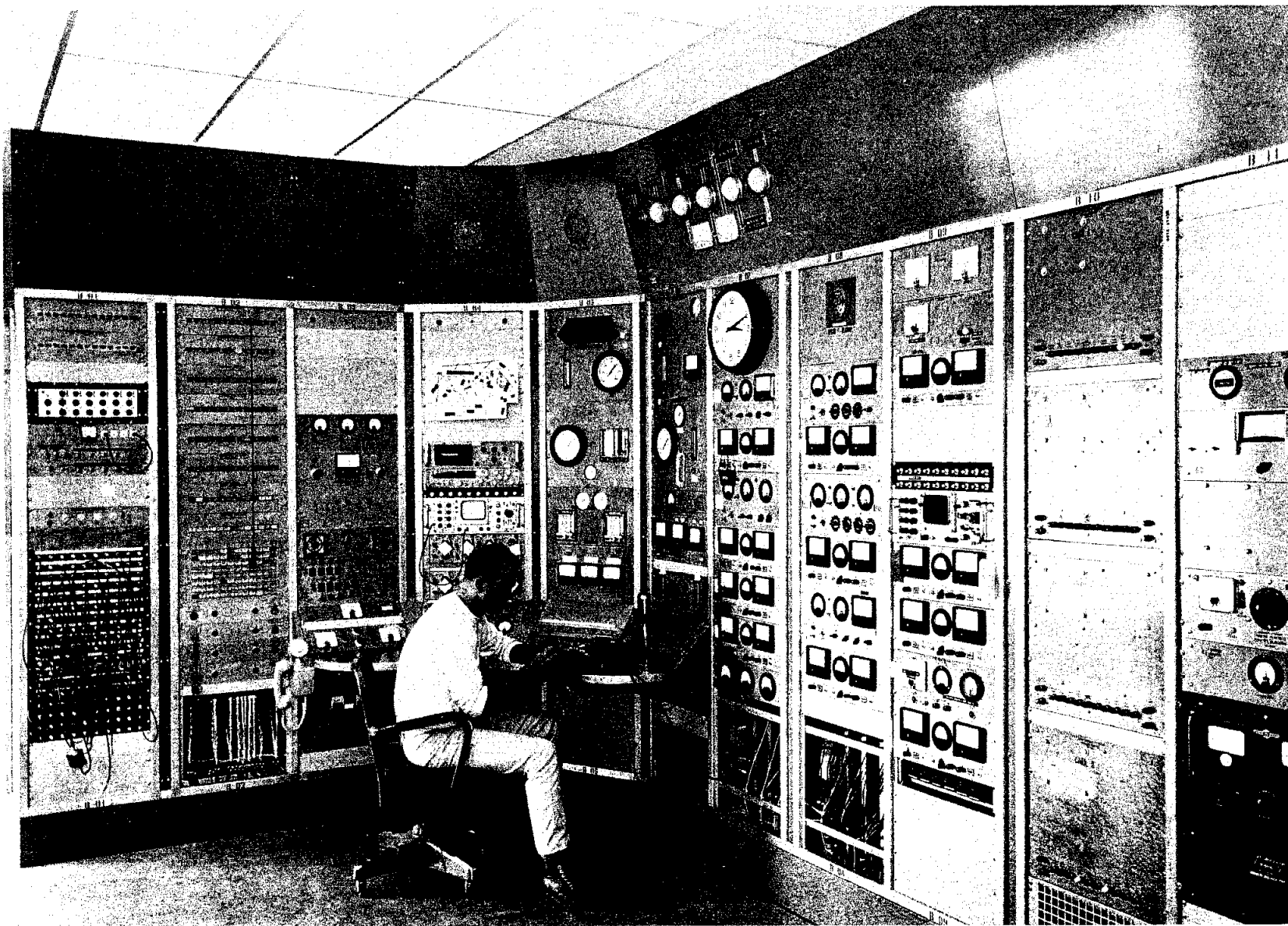


FIG. 4--EIGHTY-TWO-INCH BUBBLE CHAMBER CONTROL ROOM

I. ACCELERATOR AND RESEARCH
AREA OPERATIONS

A. OPERATIONS SUMMARY

The accelerator operating schedule continued relatively unchanged from the pattern established earlier in the year and reported in the previous status report. The housing was open the first shift each Monday, to permit eight hours installation and maintenance work in the housing, gallery and the Central Control Room. (Because of the emphasis on positron operation during the quarter, it was necessary to extend the eight-hour period several times to complete work in the positron source area.) Following housing search, a four-hour period was devoted to hot maintenance. (Literally, hot maintenance refers to maintenance work on "in-operation" modulator/klystron systems throughout the accelerator. The housing must be secured during this work because of the possibility of radiation. Actually the term hot maintenance has become more restricted, and applies here to work on modulator/klystron systems near the injector where the work would affect beam operation. Taken in the broader sense, hot maintenance goes on continually farther down the machine while the beam is running.) Following hot maintenance, the beam is turned on and is in operation--barring troubles--until the end of the day shift on Saturday.

This quarter differed from earlier quarters, in that there were no week-long shutdowns. Consequently, there was a total of 203 shifts or 1624 hours of manned operation. Of this total, 18 shifts were scheduled for maintenance, and the remaining 185 for beam operation. A further breakdown shows 30.5 shifts scheduled for machine physics experiments, and 154.5 shifts for particle physics. Figure 5 shows the comparison of this breakdown with that for previous quarters. A slight reversal of the trend toward a lower percentage of machine physics time can be explained by the much greater emphasis on positron operation this quarter.

In spite of the emphasis on positron operation, and the to-be-expected problems encountered with the associated new equipment, the percent of delivered beam time continued to rise, though only slightly. The breakdown of the operating time as devoted to tune-up, failure, etc., is shown in Fig. 6. The categories have been defined in previous quarterly reports. A similar breakdown, on a weekly basis, is shown in Fig. 7.

A major consideration in the operation of the accelerator is its efficiency--the time it is actually delivering beam to experimenter(s). This has shown a steady but small increase over the past year. The two areas directly related to operation of the accelerator, where the efficiency might be improved, are "tune-up," and "accelerator failure." The first should improve to some minimum value, as the operators gain experience. There are changes and improvements possible to the machine control system that could also make tune-up procedures simpler and more rapid. However,

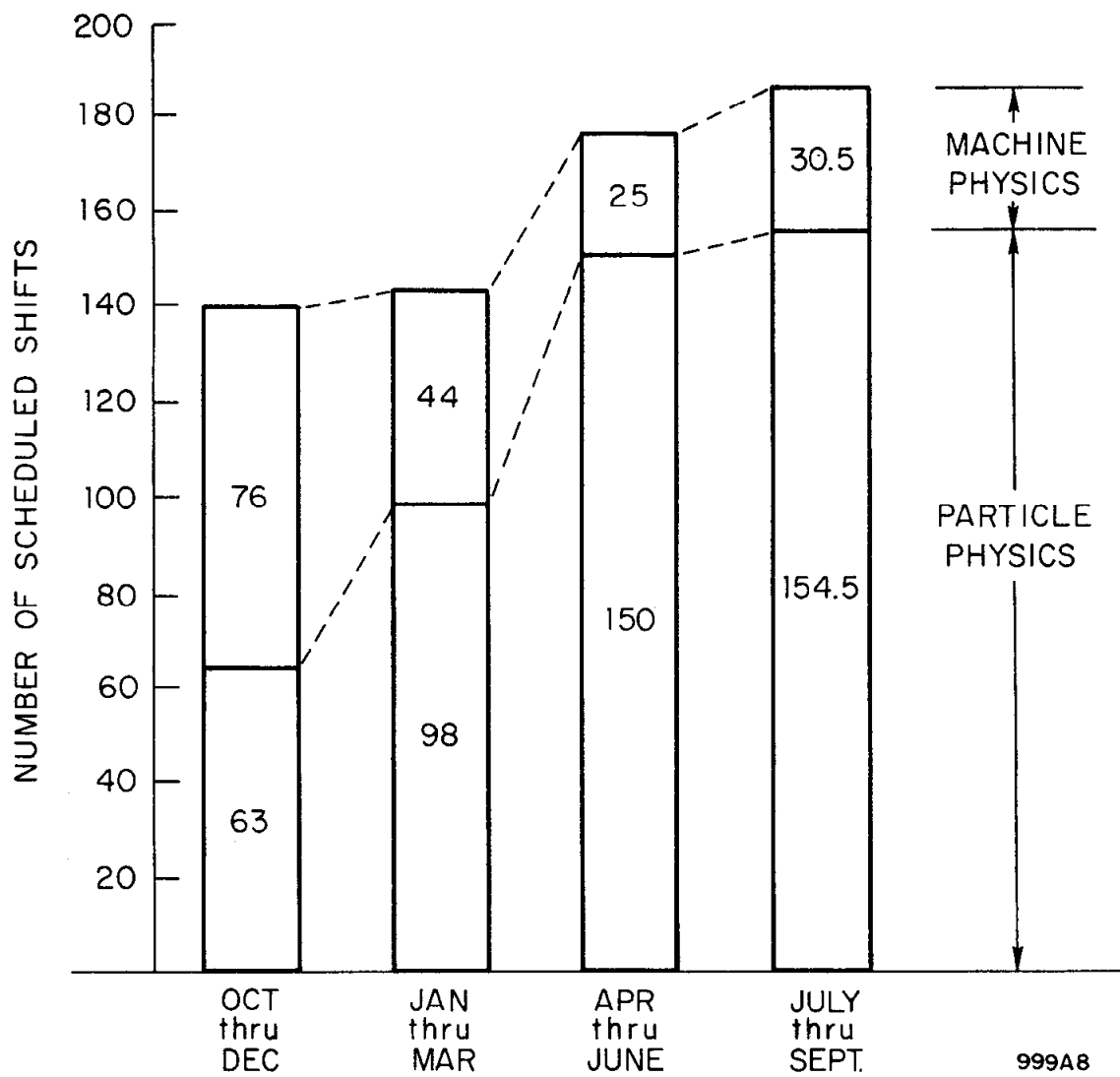
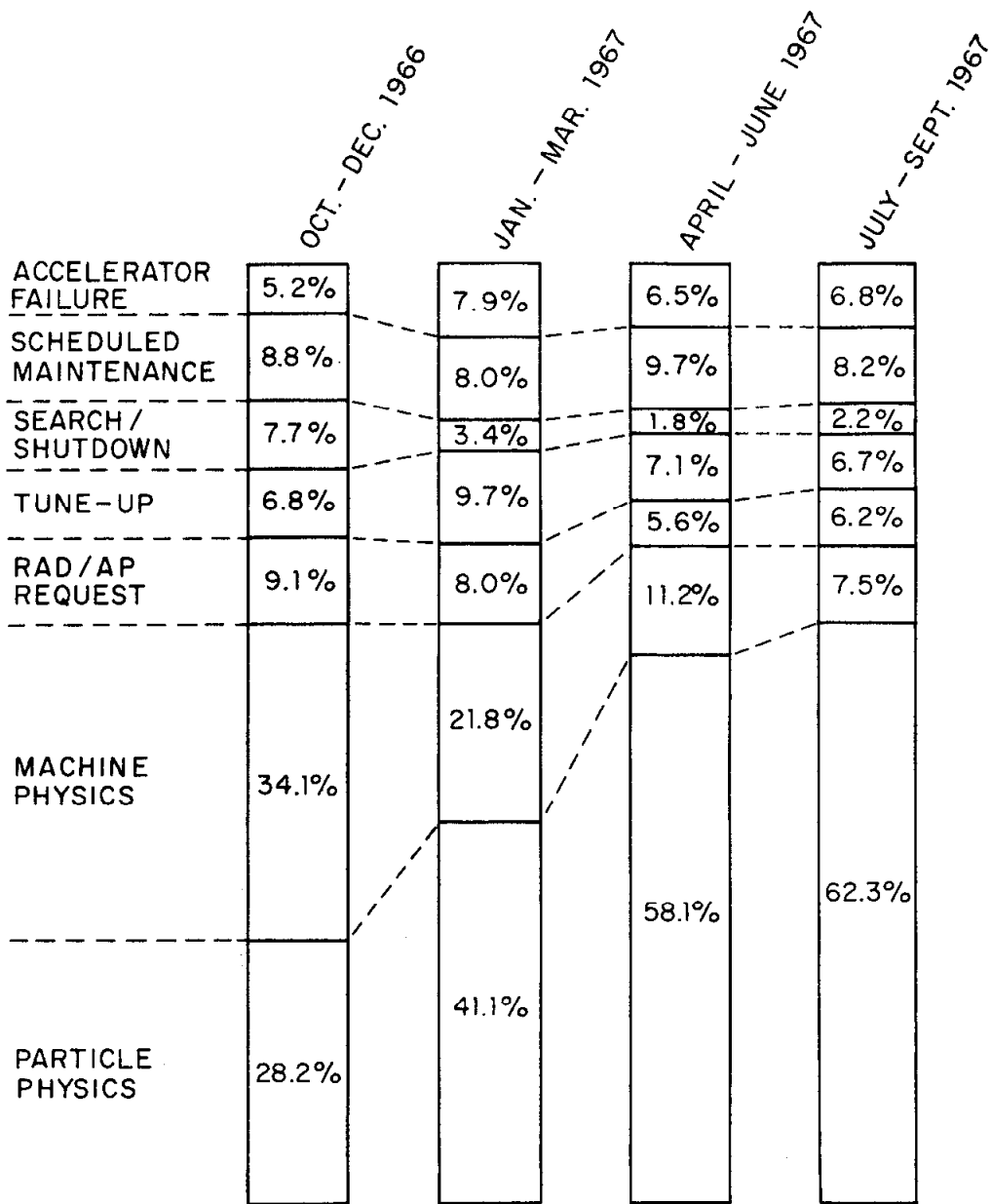


FIG. 5--PARTICLE VS MACHINE PHYSICS RUNS



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FIG. 6--MACHINE TIME AS PERCENTAGE OF TOTAL MANNED HOURS

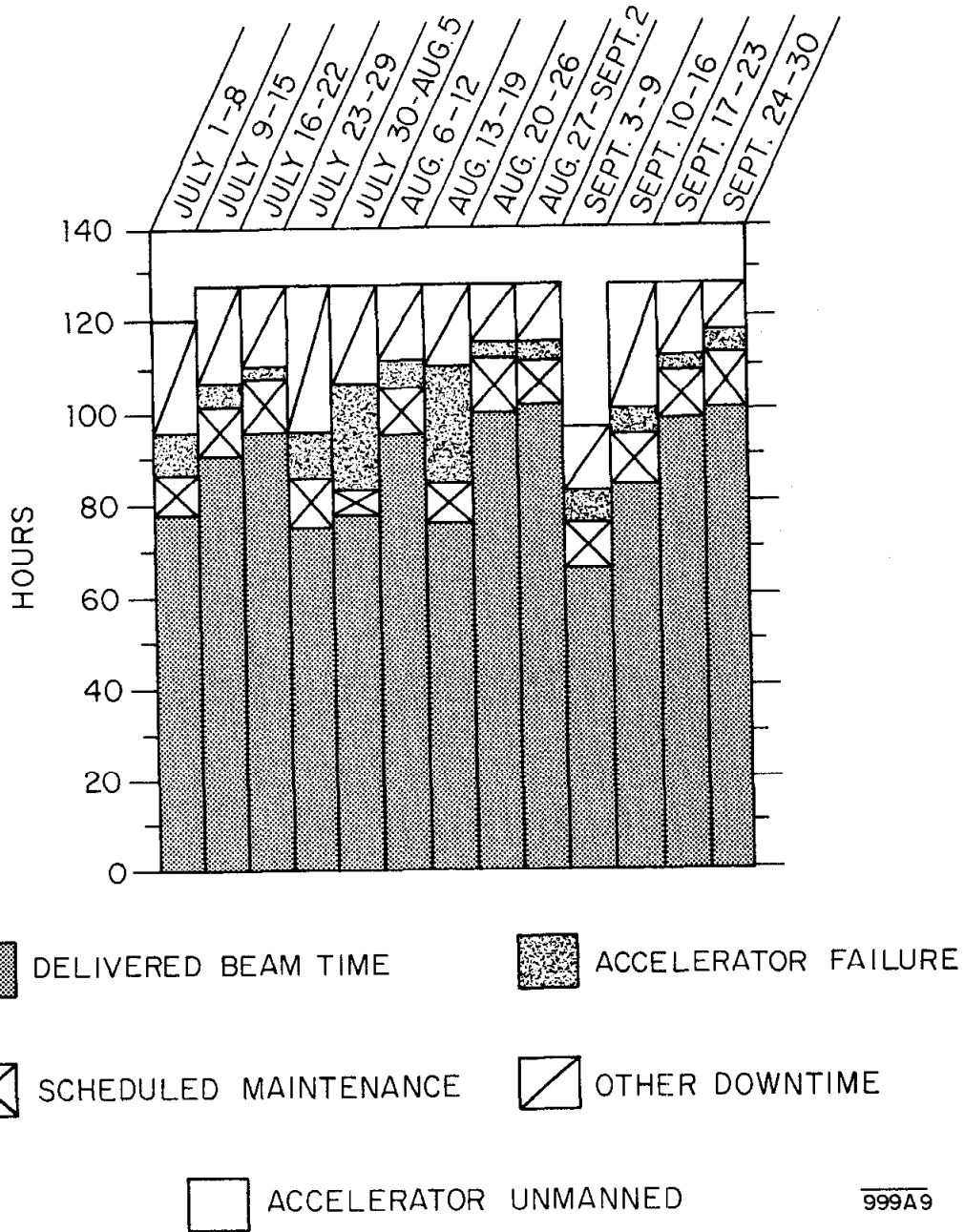


FIG. 7--WEEKLY OPERATING STATISTICS

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there is one factor working adversely. Positron operation is preceded by a rather lengthy and meticulous tune-up procedure. So far, much of the positron tune-up time has been included under machine physics experimental time. Tune-up time can be expected to increase somewhat with transfer of operation of the positron area from Accelerator Physics to the operators, with the time being charged directly to "tune-up."

Accelerator failure has changed very little over the past year. In examining the records, it is apparent that there is no major area of troubles; rather, the time is divided among many different systems. It is of interest to note that many of the accelerator equipment problems contribute little or nothing to the tabulated machine downtime. Few runs are at maximum energy, so there are nearly always spare klystrons available. Consequently, loss of a klystron or any of its associated equipment will generally cause no downtime--it is simply replaced immediately by a spare. The same is often true when a sector is lost, as when the rf drive to that sector fails. However, these losses (often referred to as short trips) may result in considerable lost time to an experimenter if they occur during a critical period of data-taking.

Failures of the gun modulator and the main boosters can be listed among the troubles that have affected accelerator operation this quarter. During positron operation, all three high current power supplies for the solenoids at the positron source have given a great deal of trouble. Instabilities in the beam, both energy and current, are still bothersome at times. However, with experience, the operators are now often able to recognize differences in the instabilities and can more easily track down the different types when their source is known. The most common instabilities come from variations in rf power level, either widespread--traceable to the main- or sub-boosters or the master oscillator--, or local--to an individual klystron; from trigger variations--either the master trigger generator, sector trigger generator or the permissive pulse; troubles with the pulsed magnet power supplies in the Beam Switchyard; variations in the steering or quadrupole power supplies along the accelerator; or troubles with the gun modulator.

The problems with the phasing system, prevalent earlier in the year, have shown a marked decrease.

A new and interesting trouble has been building up; now that it has been recognized it has been traced back and seems to have started early last quarter. For some sectors where there is a very low pressure at the upstream pump, there have been gas bursts, with the pressure rising high enough to turn off two to four stations at the end of the

sector. Recovery is rapid, with all stations back on in about two minutes. The rate of occurrences, and number of sectors has been increasing slowly; gas bursts now occur on an average of about once a shift. They occur whether the beam or rf is on or off, and it has recently been determined that at least in one sector they do not occur if the first ion pump in that sector is valved off. So far the problem is only mildly irritating; if the frequency continues to increase it could seriously effect operation.

Changes to the accelerator and its associated equipment, to improve operation, or upgrade reliability, are continually underway. This quarter was no exception although there were relatively few major changes or additions with most of the effort spent on upgrading the weak links. There was a large amount of work done in the positron source area, however, tied in with the increased emphasis on positron production.

One long-awaited improvement was achieved in the CCR control system. This was the individual klystron control for Sectors 27 and 28, where phase and trigger controls are available for each klystron rather than on a sector basis as in the rest of the machine. This control is of particular advantage when operating with multiple beams.

As usual, a wide range of beam parameters was required to satisfy the experimenters' requirements. Energies from 1.3 GeV (for optics tests of the 1.6-GeV spectrometer) up to 17 GeV and currents from beam breakup levels down to a few microamps (peak) were supplied. With the latter currents the operator has insufficient monitoring facilities along the accelerator; only the generally excellent stability of the accelerator makes such low current operation possible.

There were 12 particle physics experiments in progress this quarter, getting useful beam from 10 to 175 hours each. In addition, there were four areas where SLAC facilities (i. e., the 82-inch bubble chamber) received beam time for equipment checkout, as well as the time used for machine physics experiments. In all, there were 1134.5 hours of useful beam. This figure does not take into account pulse rate, or the use of multiple beams. A more detailed account of the effective hours as assigned to experiments, checkout, etc., may be found elsewhere. To continue a concept started the last quarterly report, if multiple beams are taken into account, there were a total of 1824.5 hours of useful beam for an enhancement factor $= \frac{1824.5}{1134.5} = 1.61$.

There was a great deal of emphasis on positron operation this quarter, with a total of 34 hours of beam time charged to accelerator physics and 309 hours of positron beam delivered to the particle physics experimenters. (This includes some time when

electrons generated in the positron source were used for an electron-positron comparison experiment.)

There was no positron wheel operation during the quarter. Shortly after installation of the wheel late in July, a leak developed in the bellows and removal was necessary. However, a satisfactory test was made of the power capacity of a prototype wheel installed in the central beam line and exposed to up to 300 kW of 17 GeV electrons.

Positron wand operation was more encouraging although successful operation was not achieved until the end of August. Several useful shifts of interlaced positron and electron beams were then attained, although attempts to get two electron beams of rather different parameters while running wand-generated positrons met with little success.

By far the largest share of positron operation was with the slug, a water-cooled positron radiator, fixed in the beam, with limited power capability. Following the rather lengthy tune-up period, slug operation was generally quite stable and trouble-free, although there were a number of problems with the high current power supplies associated with the positron source solenoids. Most of this positron operation featured multiple beams, with positrons going to both ESA and ESB.

A large fraction of machine physics experimental time was spent on positron source operation, both in debugging the system, and in determination of optimum parameters. Nearly all the remaining time was devoted to a continuation of BBU studies. No further improvement was been achieved in this area, with a beam current of 43 mA still the maximum available (full pulse width of 1.6 μ sec, and current delivered the length of the accelerator).

B. SYSTEM AND COMPONENT PERFORMANCE

For this quarter, again, the contributions of the Accelerator Physics Department to the operation of the accelerator could be divided into three categories:

1. General assistance to the operations departments to set up the accelerator for a variety of experimental conditions.
2. Specific accelerator experiments conducted under the leadership of an Accelerator Physics engineer with the purpose of solving a particular accelerator problem.
3. Experiments which, although they required an operating beam, involved a specific system rather than beam operation as a whole.

1. Injector System Operation

During this period, the injector system operated without any major breakdowns. Some modifications in the low-level grid pulser circuitry now make it possible to obtain 3-channel operation capable of yielding three interlaced beam currents. The 10-MHz Beam Knockout system was tested, put into operation and used for accelerator experiments. Some initial arcing in the resonant step-up transformer was isolated and cured.

2. Drive System Operation

a. Main and Subdrive Lines. During the past quarter, the main and subdrive lines operated without problems. The main drive line switch repaired during the previous quarter operated satisfactorily. Methods of improving the life of the switch were still being investigated.

b. Main Booster Amplifiers. Operation of the units has been very good. No klystron failures occurred during the quarter. The arc detection scheme being planned should be installed during the next quarter.

c. Varactor Frequency Multipliers. Operation during the past quarter has been excellent. The major improvement seemed to be accountable to better preventive maintenance.

d. Switchable Phase Shifters. The phase shifters in Sectors 1 through 10 designed for use in positron acceleration were all adjusted to give 165° of phase when in the "positron" mode. In addition, one of the Sector 1 Sub-Booster I ϕ A units was further modified so that the switching circulator controlled by the positron pattern could be used to switch the Fox phase shifters in and out of the rf circuit. This means that it

is now possible to independently adjust phase closure for the positron-generating electron beam.

Installation of analogous phase shifters in Sectors 11 through 30 was completed. These devices and their actuating circuits are being tested but have not yet been utilized for multiple beam acceleration and deceleration.

e. Sub-Booster Modulators. The failure rate during the last quarter increased to about 10 failures per month. However, the failures, other than switch tubes (3 failures per month) and high voltage power supplies (3 failures per month), were of very minor character. Thus, in spite of the failure increase, operation has been quite good.

3. Phasing System

Twenty trouble reports were written during the quarter. The breakdown is as follows:

Type of Fault	Number Reported During Quarter	Remarks
Programmer wiring	4	Connector tabs worked loose.
Spurious triggering	3	Corrected by improving grounding.
Diode unbalance	3	All diodes rebalanced weekly.
Power failure	2	Fuse loose in I/C Alcove.
Phase shifter stuck	1	Dust cover jammed.
RF Dector Panel inoperative	1	Loose connector.
No CW Reference Signal	1	Cable disconnected.
Undetermined	5	Systems functioned normally when trouble reports were investigated.

4. Beam Position Monitors

a. In-Line Beam Position Monitors. These monitors continued to operate satisfactorily during the quarter.

b. Beam Switchyard Beam Position Monitors. The system continued to perform satisfactorily.

5. Beam Analyzing Stations

The two stations continued to operate satisfactorily.

6. Klystrons

During the quarter, a total of 335,000 operating hours was accumulated on high power klystrons. The total number of failures in the gallery was 27, giving a cumulative total of 157 failures since the beginning of operation of the machine. There were approximately 120 spare klystrons including 20 ready for immediate installation as of the end of the quarter.

Driver amplifier klystrons accumulated 62,500 hours in the gallery and 3000 hours in the test laboratory. There were five failures this quarter.

There were no failures of main boosters during the quarter, in spite of the slight increase in operating hours.

A gas burst problem affecting a few sectors began to develop during the quarter, and is still under investigation.

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

Table I -- Klystron Usage and Failure

Dates	Operating Hours		Quarter		Cumulative	
	Quarter	Cumulative	Number	Avg. Life @ Failure	Number	Avg. Life @ Failure
To 6/30/66	118,000	156,000	16	234	39	256
To 9/30/66	127,000	283,000	15	594	53	350
To 12/31/66	176,000	459,000	23	1070	76	575
To 3/31/67	228,000	687,000	28	1670	104	860
To 6/30/67	303,000	990,000	26	2166	130	1130
To 9/30/67	335,000	1,325,000	27	2881	157	1433

As mentioned previously, there were 27 failures for the quarter, and 70 replacements.

The general statistics of all tubes are now considered. Figure 8 gives the general operating experience (number of hours per tube and per socket, number of replacements and number of failures, and average life at failure), since the beginning of operation of the accelerator. Figure 9 gives the klystron tube age distribution

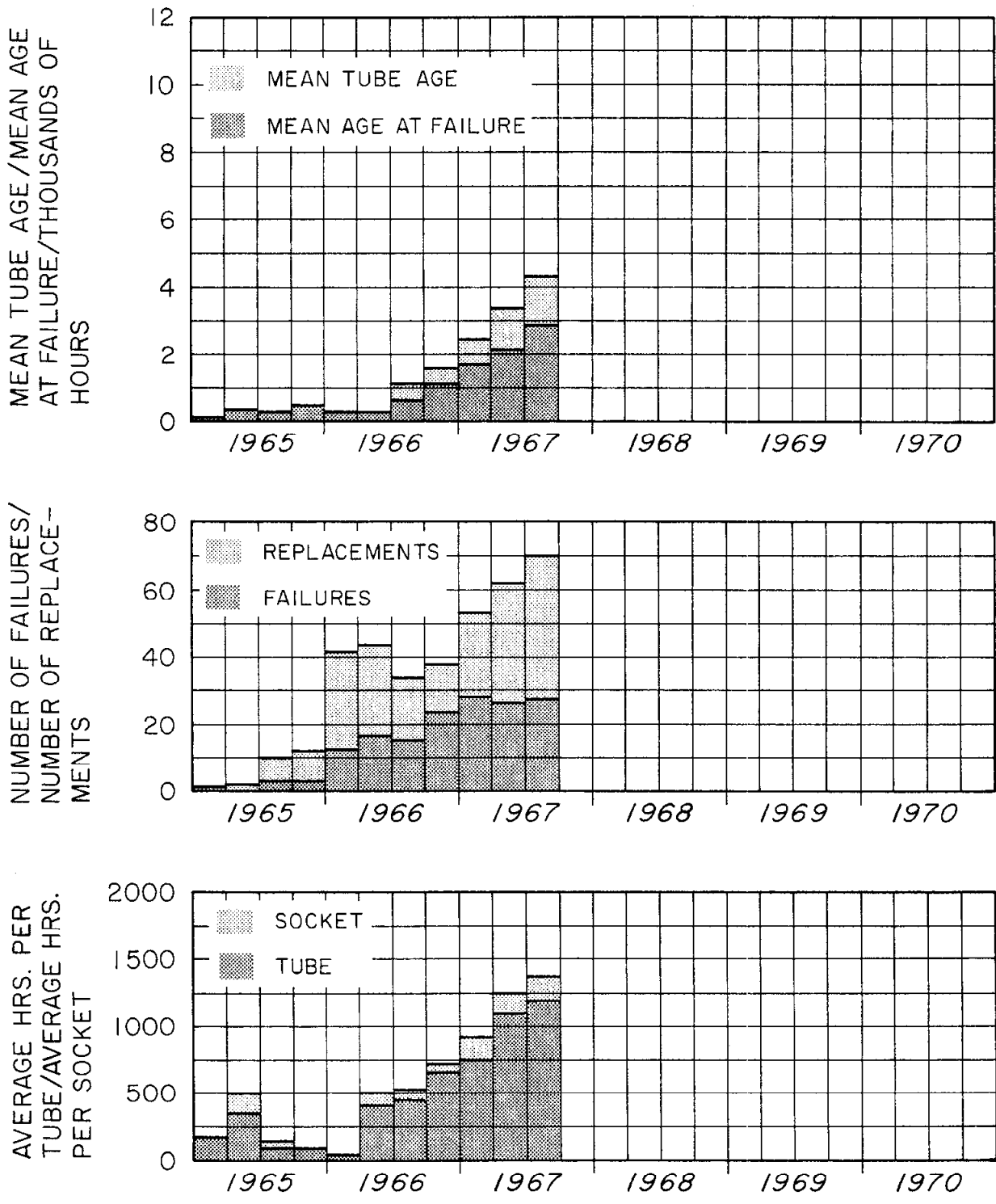


FIG. 8--KLYSTRON QUARTERLY OPERATING EXPERIENCE-- ALL HIGH POWER KLYSTRON VENDORS

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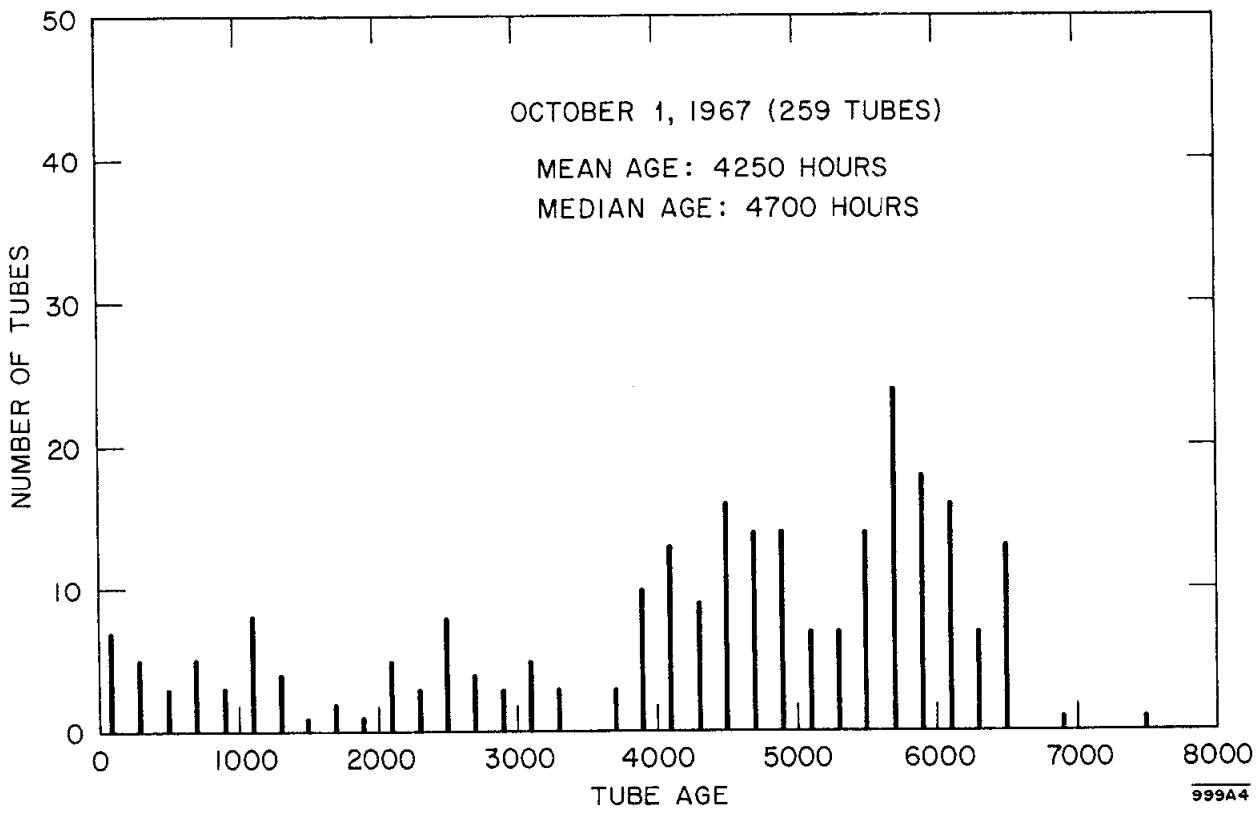


FIG. 9--KLYSTRON AGE DISTRIBUTION (ALL VENDORS) IN 200-HOUR INCREMENTS

on October 1, 1967, indicating a mean age of 4250 hours, a median age of 4700 hours. There are now 38 tubes with an operating life in excess of 6000 hours. Figure 10 gives the mean time between failures (number of operating hours per quarter divided by number of failures per quarter), the mean operating tube age, and the mean age at failure for the past two years. Figure 11 is a plot on probability paper of failure distribution as a function of age at failure (Sperry failures not included).

The mean-time-to-failure predicted from the probability plot is about 5500 hours. This number is much lower than the mean time between failure (see Fig. 10). One would expect that eventually the mean time between failure, mean operating tube age, and mean age at failure would equal each other except for random statistical variations. Therefore, it is possible that the mean-time-to-failure will be higher yet than predicted by probability paper on the basis of failures to date.

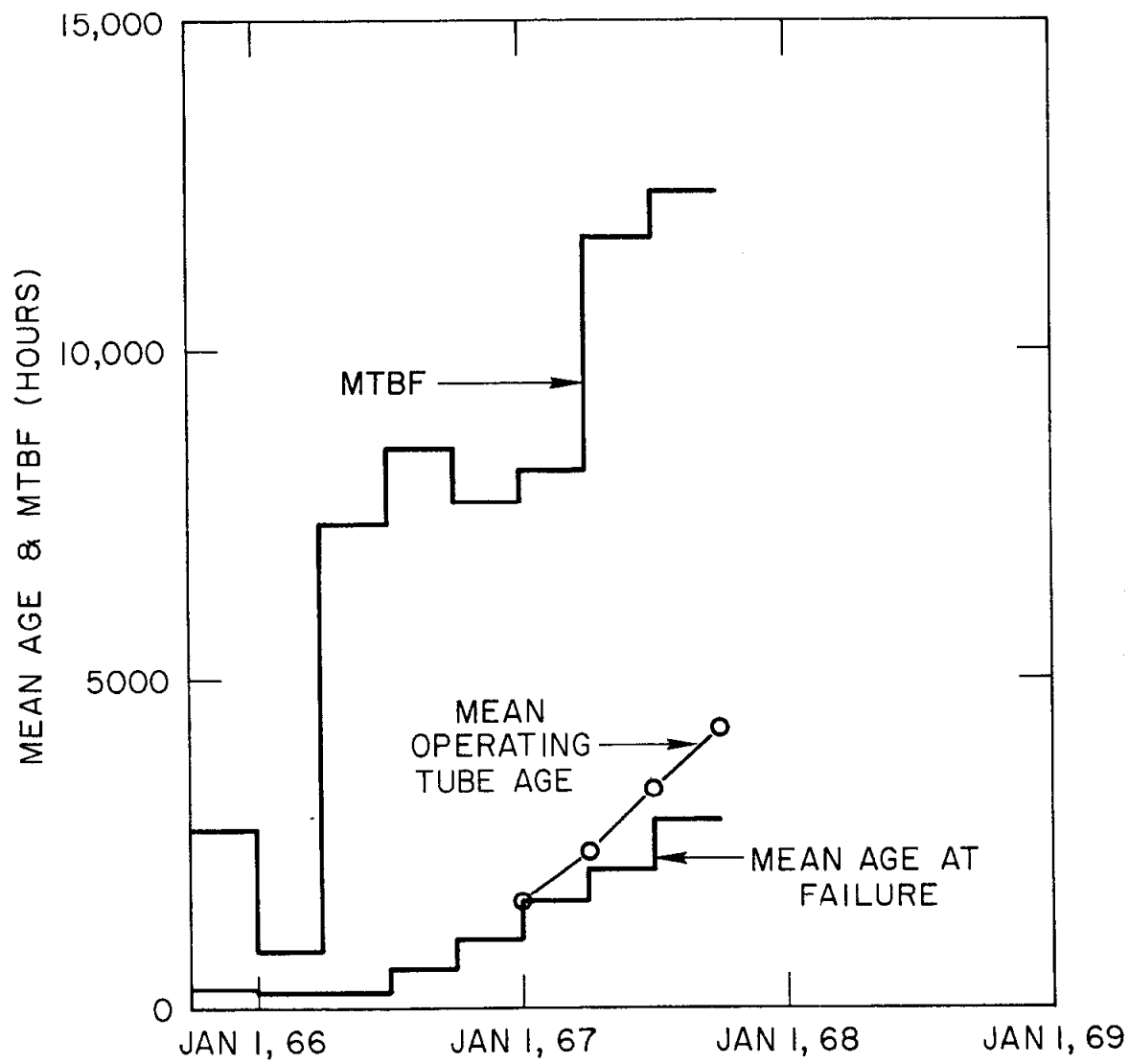
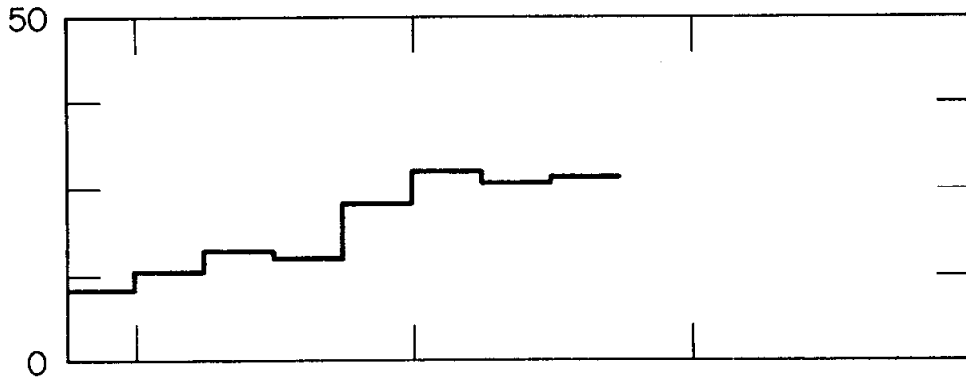
1. Causes of Failures. The failures experienced this quarter were reasonably evenly distributed between RCA (12) and Litton (10). Of the 12 RCA failures, 8 were failures which occurred at varying times from a few hours to 5000 hours of operation. Tube gassiness accounted for 3 more RCA failures, and a high voltage seal puncture for the last one. Two of the Litton failures were caused by window problems, 4 were tube vacuum gassiness problems and the remainder were caused by cathode problems.

As can be seen, the major failure mechanism is quite different for our two vendors. Some of the problems experienced by Litton in the cathode area are peculiar to Litton tubes which will, under some conditions, exhibit sudden variations in perveance (for instance, when the pulse forming network is being tuned), and also inverse conduction resulting in inverse voltage breakup. This phenomenon has been observed and is probably similar to the cathode "burning" reported on a few SLAC tubes.

2. Effect of Operating Levels. During the quarter, four sectors have been operated at a beam voltage of approximately 254 kV, 18 sectors at approximately 236 kV, the remainder at approximately 217 kV. There appears to be a substantial difference in the number of replacements and failures as a function of sector operating level. The following table gives the number of replacements and failures as a function of sector operating level:

<u>No. of Stations</u>	<u>Oper. Level (kV)</u>	<u>No. Fail.</u>	<u>No. Replace.</u>
69	217	0	4
144	236	20	45
32	245	7	21

NUMBER OF FAILURES



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FIG. 10--OPERATING TUBE PERFORMANCE

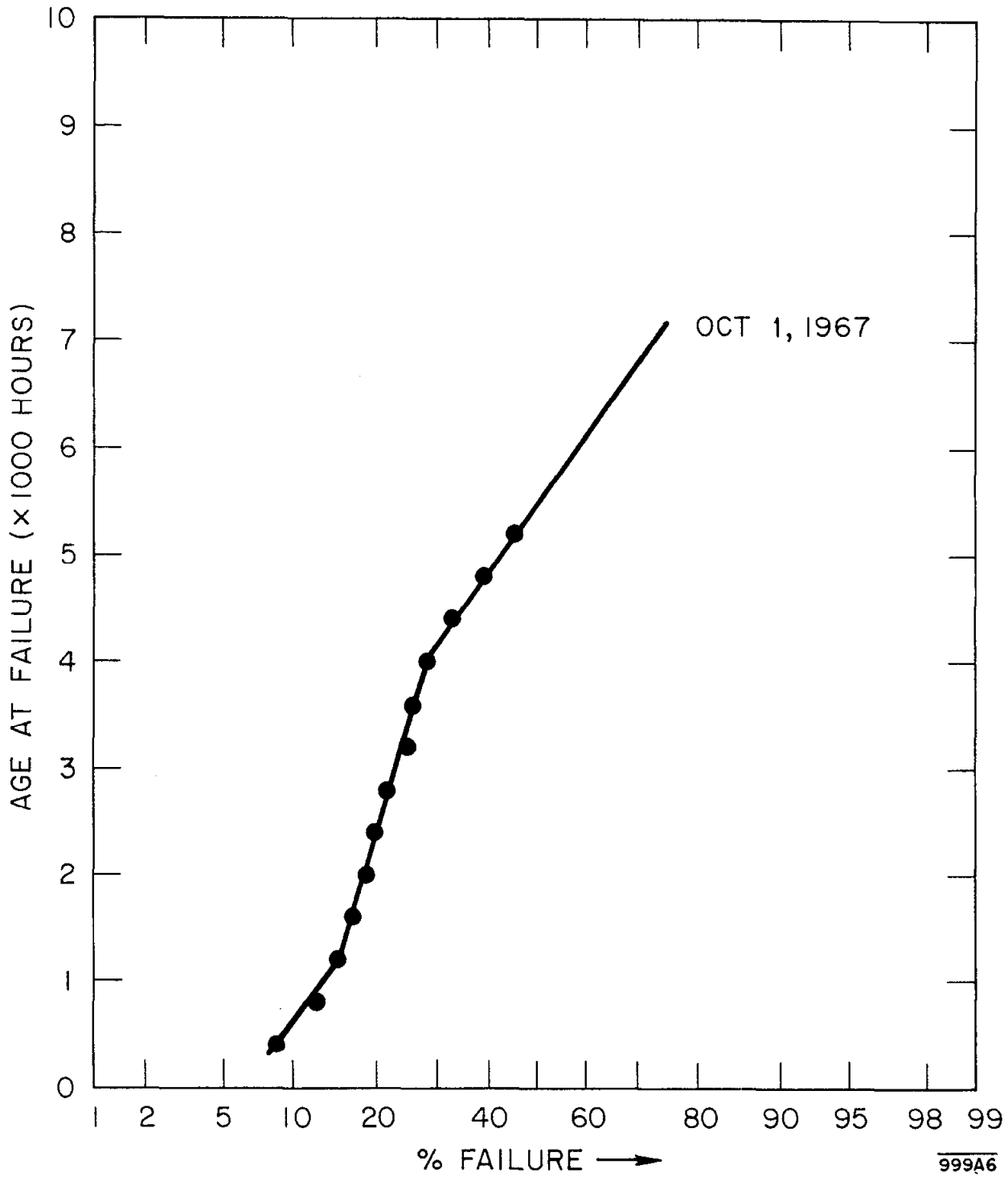


FIG. 11--KLYSTRON FAILURE DISTRIBUTION - ALL VENDORS

The number of failures and replacements per socket, per quarter as a function of operating level can be tabulated as follows:

<u>No. of Stations</u>	<u>Oper. Level (kV)</u>	<u>No. Fail.</u>	<u>No. Replace.</u>
69	217	0.00	0.058
144	236	0.14	0.310
32	245	0.22	0.660

Hence, there appears to be a substantial increase in both failures and replacements as a function of operating level. It must be remembered that the total sample was small, however, and that during the previous quarter there seemed to be little or no difference in failure or replacement rate between the 217 and 236 kV operating levels.

The average on-time per station appears to decrease as the operating level is increased, but the difference is only a few percent decrease from 217 to 236 kV and from 236 to 245 kV. The fault counts similarly seem to indicate an increase of faults as a function of operating level. For sectors running at 217 kV, the average fault count is probably close to 20 faults per day, per sector. For sectors running at 236 kV, the average fault count is probably close to 25 faults per day, per sector; for sectors running at 245 kV, the average fault count is probably close to 40 faults per day, per sector.

b. High Power Klystron Maintenance. The number of trouble reports for klystron maintenance increased since the last quarter partly because of the increase in number of operating hours, and possibly because of increasing tube age and operating levels. The mean time between trouble reports is now 490 hours of klystron operation. Preventive maintenance is continuing at a rate of approximately one check per 640 hours of operation. In addition to previous measurements taken in preventive maintenance, the increase in window failures has led us to install thermocouples on most tubes now being installed, and to monitor the window temperature as a routine maintenance problem. The hope is that if there is a significant change in this parameter, it would be possible to save the window by cleaning and recoating the window surface towards the load before actual failure occurs.

The total number of replacements increased to 70 for the quarter. Almost 50% of these were caused by either oil leaks between the pulse transformer tank and the klystron, or by tank problems. On the other hand, the number of replacements because of suspected tube failure decreased and accounted for approximately 40% of replacements.

Emission problems on Litton tubes continued to require a high proportion of the total maintenance time available. At least 10% of all trouble reports were related to the Litton cathode problems (high perveance, varying perveance, inverse voltage breakup or clipping, and end-of-line clipper faults). Solutions to the problems included adjustments of filament power and/or shunting of the magnets. There are still cases where a tube cannot be stabilized in the gallery; is brought back in the Test Lab for retest, where it performs satisfactorily; and is then returned to the gallery where the same problems reappear.

c. Driver Amplifier Klystron. Indicated running time for driver amplifier klystrons was approximately 62,500 hours, but the actual running time was probably close to 50,000 hours. This is because the modification of the running time meter circuitry to start the meter only when high voltage is applied to the klystron had not been completed until late in the quarter.

Four sub-booster klystrons failed in the gallery, including one which had only one hour of operation. All failures were caused by pulse droop, probably associated with gassiness in the tube. The average age at failure was approximately 4700 hours, including the early failure. In addition, one tube failed in the Test Lab. When attempting to reactivate a station which had not been operated for a year, the tube was found to have failed. Its previous life was slightly over 5000 hours.

Figure 12 gives the usual operating experience on driver amplifier klystrons since the initial turn on of the machine, and Fig. 13 gives the tube age distribution at the end of the quarter.

d. Main Booster Klystron. Main booster operating hours increased approximately 10% over the previous quarter. No failures occurred.

The dc filament supply for the No. 2 station was installed and operating satisfactorily. The regulated focus coil supplies are ready for installation and a prototype arc detector was completed and is undergoing tests.

e. Vacuum System. In general, the operation of the vacuum system continued to be very satisfactory with an ion pump pressure averaging close to 1.5×10^{-8} . The number of weekly letups for modification for the accelerator pipe has decreased. One minor problem arose in one station in Sector 30, resulting in a gradually increasing pressure as a function of rf power so that the station could not be maintained in operation. The klystron was not replaced because one of the valves leaked and we were waiting for a long shutdown scheduled for the end of October to replace the tube.

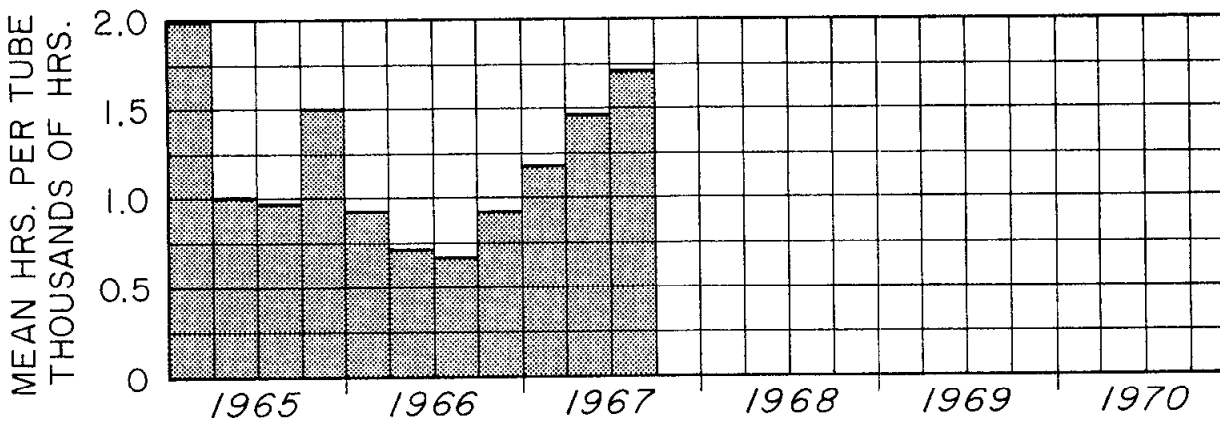
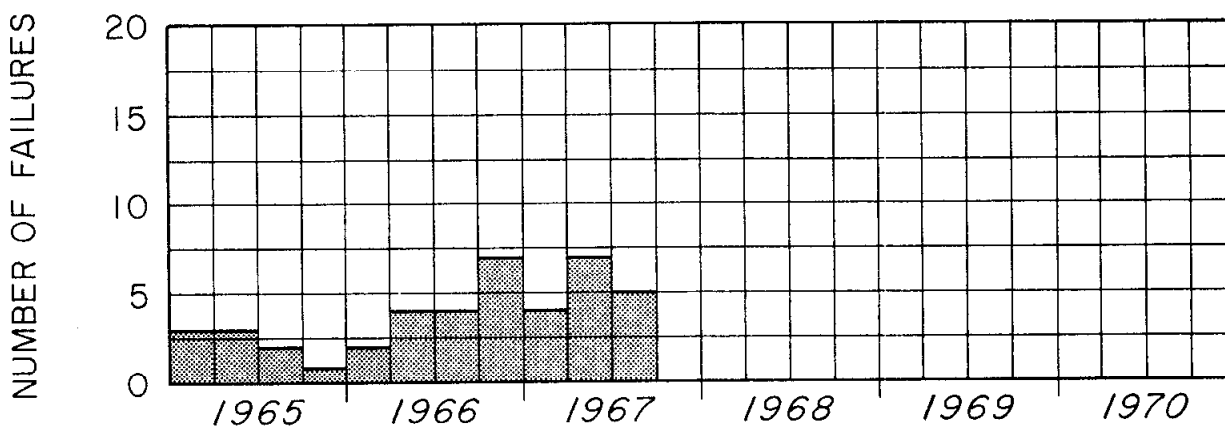
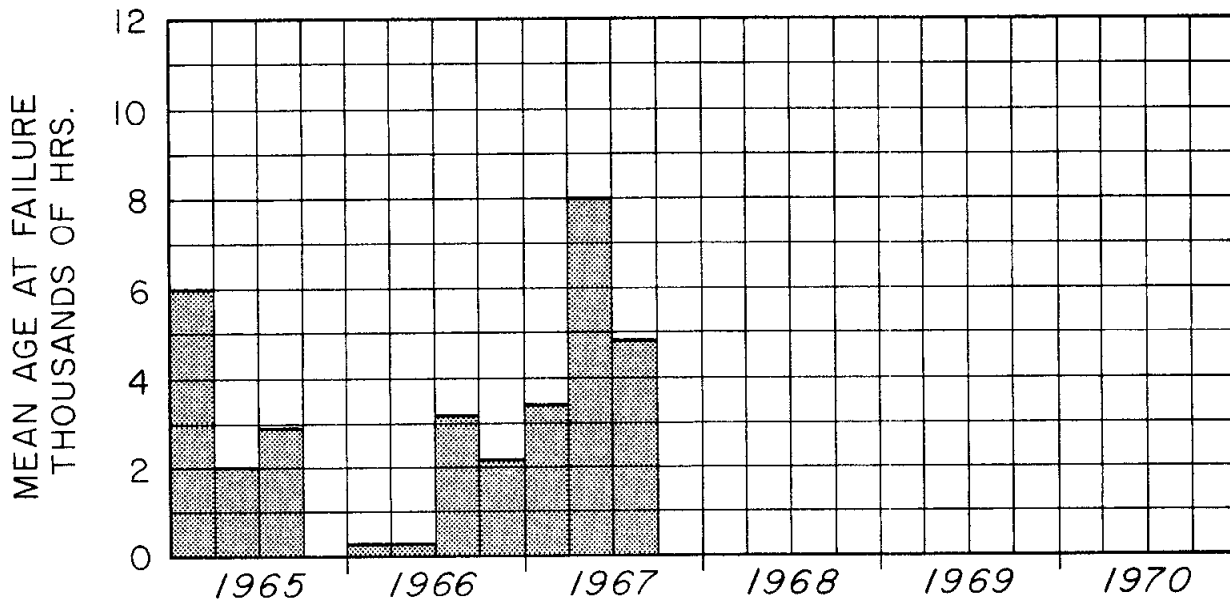
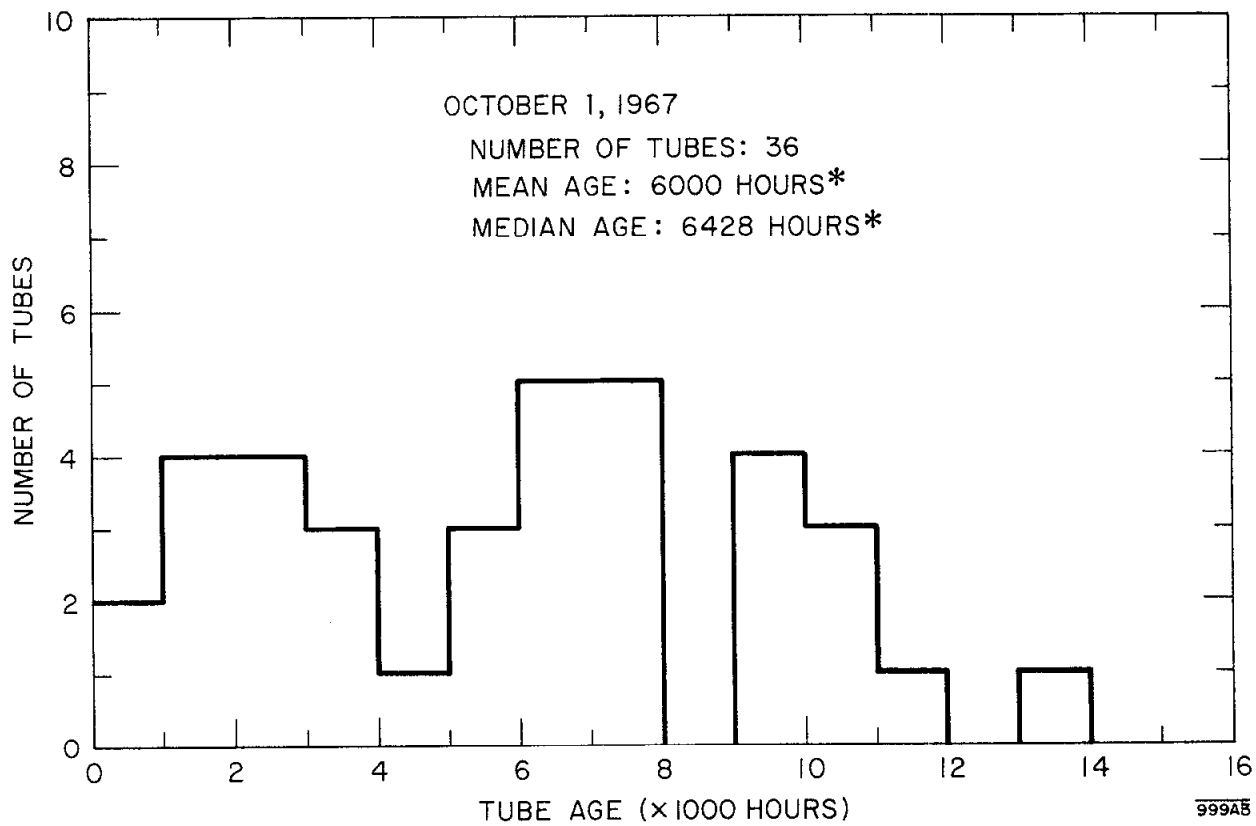


FIG. 12--EIMAC SUB-BOOSTER KLYSTRON OPERATING EXPERIENCE



*THE ACTUAL HOURS ARE PROBABLY BETWEEN 500 - 1000 HOURS LESS THAN INDICATED

FIG. 13--DRIVER AMPLIFIER KLYSTRON AGE DISTRIBUTION

A gas burst phenomenon which developed in five of the sectors has, to date, not seriously affected accelerator operation. The gas bursts are usually short, with the ion pumps bringing pressure back to normal in about 2 to 5 minutes. The pressure rises at the pump to about 1×10^{-5} Torr, but is not high enough to stall the pumps or trip the fast-acting valves.

The following observations and data regarding the gas bursts have been accumulated so far:

1. The bursts always occur at the upstream end of a sector, usually starting in order of klystron stations.
2. Bursts have been observed in Sectors 7, 10, 12, 14 and 17.
3. Most (but not all) bursts have been observed with both klystrons and beam turned on.
4. In two cases (Sector 12), the pressure at the first two klystrons was seen to rise slowly for about two hours before the burst occurred.
5. The pressure in the troublesome sectors is generally much lower on the upstream end.
6. No significant burst has occurred with the first ion pump in a sector "valved-off."
7. Bursts occur under all beam conditions and any hour of the day (although most have occurred during daylight hours).

Multi-channel recorders are being used to monitor the pressures of as many troublesome sectors as possible. A residual gas analyzer will be installed on one or more sectors to determine quantitatively and qualitatively the gases in the system during a burst.

7. Main Modulators

The main modulators operated satisfactorily this quarter in spite of problems, such as: pulse capacitor failures, main rectifier failures, de-Q'ing SCR failures and main rectifier transformer oil leaks. No modulators were down any appreciable length of time because of these problems.

a. Main Rectifiers. Five rectifiers burned out during this period as compared with four the previous period and three the period before that. In each case damage was confined to only two or three cards out of a total of 60 in the rectifier because of the prompt action of the fire alarm circuits installed in the modulators. The fire trucks respond to the alarms but they are not required because the alarm circuit removes power, stops fans, and the fire extinguishes itself. In this regard, since

most fire alarms do not require the services of the fire department, and such calls are expensive, we plan to change the system to notify CCR operators instead of the fire house. The CCR operators can, in turn, alert the maintenance technicians who must repair the damage anyway and thus save unnecessary fire department calls.

The backup source rectifiers continued to operate satisfactorily.

b. Pulse Capacitors. These units continued to be our main problem this quarter. One hundred and two failed this quarter as compared with 116 last quarter. The manufacturer continued to supply us with sufficient spares. Analysis of failure data revealed that the failure rate was six times higher for capacitors manufactured in the early part of the contract than during the balance of the contract. This indicates that design of the capacitor and manufacturing techniques improved.

The main problem at the early stages of the contract appeared to be leaks in the capacitor cans which resulted in air bubbles in the capacitors. Corona, which occurred in such bubbles, in turn, released more gas because of decomposition of materials surrounding the bubble. This, of course, eventually resulted in swollen capacitor cans.

The backup source capacitors* which were ordered last quarter began to arrive near the end of the quarter.

c. De-Q'ing SCR Assemblies. The failure rate among these units was improved considerably this quarter by: 1.) removal of the RC transient suppression networks across the SCR's, 2.) changing the low voltage gate transformers to ones with higher voltage rating, and 3.) changing the gate resistors to higher quality units.

The manufacturer has been cooperating with us very nicely and still feels there may be a problem in connection with running the units without RC circuits across the SCR's. They plan to conduct further experiments with us and, hopefully, arrive at a better circuit.

In connection with de-Q'ing, we ran into a problem months ago whereby some voltage dividers, which divide pulse forming network voltage down to a level where the comparator circuit operates, would develop small voltage spikes on an otherwise smooth waveform. This caused jitter in de-Q'ing operation with resultant jitter in the modulator output pulse. This problem was solved by the insertion of small, low-pass filters in the signal line between the voltage divider and the comparator.

d. Rectifier Transformers. Many of the main rectifier transformers have developed oil leaks, particularly around the high voltage bushings, during the past

* See SLAC Report No. 80.

year. The manufacturer repaired them until recently when we decided to do the repairing ourselves as we could do it faster, using their techniques and not having to be concerned with shipping and handling.

e. Hydrogen Thyratrons. During this quarter, we had a total of 62 failures, or an average of 21 per month, of large single thyratrons or pairs of smaller ones. A total of 161 failures have occurred in all our operations, including test stands, giving us an overall average age at failure of 3196 hours. The three original tube manufacturers had average tube ages at failure of 3284, 3928, 2888 hours. The average age at failure is increasing steadily with time.

One manufacturer, who has experienced rather short life with its tubes, redesigned its cathode so as to increase its size and, hopefully, its life.

Both of our current suppliers experienced problems in manufacture of their tubes. Element spacings were drifting around again and some tubes required excessive aging. However, we had plenty of spares so there was no immediate problem, but deliveries were slowed down during the quarter in order to allow additional time for them to work out their problems.

Our handling of these tubes has improved inasmuch as the technicians are now better trained in ranging techniques and we have employed a computer to keep track of reservoir voltages. Ranging information is fed into the computer and plots of all previous ranging points come out of the computer. The technicians doing ranging have this information and if the new center point is not the same as the previous point or slightly higher, the ranging operation is repeated. Also, a ranging instrument was developed in this group which operates on the amplitude of radio frequency noise, at 24 MHz, generated by the thyatron. We have found that the amplitude of this noise is at a maximum when the tube is at the center point of its range. This instrument has been checked against the old, tried and true, hot ranging technique and found to be reliable. It has helped tremendously in speeding up an otherwise slow operation.

f. Pulse Cable Assembly. During the past year of accelerator operation, we have experienced 24 failures of these assemblies. The major troubles are arcing in the finger stock, poor clamping of the braid in the first shield termination, and arcing between the first shield termination and the corona ball. We have been able to repair 50% of the failed units, and have enough spare assemblies to last many months (at the present rate of failure); however, in order to be safe, we ordered more cable and drew up new improved specifications as a result of our experience, and prepared to order 50 spare assemblies.

8. Research Area Experimental Activity and Support

a. Experiments in the End Station B Area. The study of μ -p inelastic scattering had a total of 464 hours of scheduled experimental beam time by the end of this quarter. This experiment is to continue on into the coming quarters. The set-up of this experiment is located on the north side of End Station B.

Instrumentation check-out for the use of a monochromatic photon beam to study photon interaction in the 40-inch hydrogen bubble chamber was continued this quarter. Considerable rearrangement of and addition to the shielding was required to reduce background. Actual experimental time scheduled for this quarter was 200 hours. This experimental set-up occupied the center channel of B-Beam.

The study of photoproduction of boson pairs was scheduled for 216 hours of beam time and was to be continued on into the coming quarters. This experiment also utilizes the center channel of the B-Beam.

The study of K^0 decay completed one phase of several phase experiments early in the quarter. The experimental set-up is to be dismantled and the area prepared for a new experimental set-up.

b. Experiments in the End Station A Area. The 1.6-GeV, and 20-GeV spectrometers have been successfully used for research during this quarter. Various experiments were conducted in the End Station A area in this quarter exceeding 1200 hours of experimental beam time.

These proposals were electron-proton elastic scattering; electron-proton inelastic scattering; comparison of positron-proton and electron-proton elastic scattering ratio; multibody photoproduction study; forward photoproduction; backward T^0 photoproduction; and, the study of cross sections of π , η , ρ , ω and ϕ mesons.

c. C-Beam Experiment. The ex-LRL 82-inch hydrogen bubble chamber is scheduled to run in the next quarter. Beam optics and shielding check-out for this beam line were conducted to prepare for the coming run.

d. Accelerator and Beam Switchyard Study. Experiments conducted for accelerator study included behavior of the positron source, theory of beam break-up, and accelerator optics. In the Beam Switchyard, beam optics study was conducted on the A and B beam transport systems. Various instrumentation was being checked out and calibrated during this quarter.

II. ACCELERATOR AND RESEARCH AREA
EQUIPMENT DEVELOPMENT

A. ACCELERATOR PHYSICS

1. Injection

a. Electron Gun. The SLAC Model 4-1c gun continued to operate satisfactorily on the main injector. The operating time for its cathode was 9,832 hours as of September 30, 1967. Construction of parts for three additional guns was about 25% complete.

Beam profile experiments on the SLAC Model 1-3 gun (Mark III design) are in progress. Emittance measurements were being made for two modifications of the gun: 1) without normal grid mesh, 2) with the grid hole diameter reduced from 0.200-inch to 0.090-inch. During these experiments, it was discovered that the radiation shield was inadequate and a more effective shield against x-rays is being constructed.

The gun design program has been translated to PL/1 and operates satisfactorily with the new third release of the PL/1 compiler. There is no PL/1 plot package available so that current activity requires adopting the Fortran plot package to PL/1.

b. New Gun Modulator. Much work was done during this quarter on the new modulator design. Satisfactory operation of the Manson modulator on the accelerator has permitted design improvements and further expansion in scope on the new modulator. All hand-wired electronic circuits have been laid out for printed circuit fabrication. Most were assembled and tested. The increase in scope arose mainly from the decision to use accelerator patterns directly to generate the height and width for the gun pulse rather than having the injector trigger generator supply trigger pulses as is done presently.

c. Sector 27 Video Instrumentation. The three-toroid system described in the previous status report was practically completed. Early operation of the system was satisfactory.

2. Drive System

a. Drive System Control Unit. This system was completed and checked out during this quarter and has been in operation. It controls the substitution of an on-line by a standby unit of the master oscillators, main boosters and sub-boosters in the injector area. The control consists of remote, local and automatic switching.

b. Sub-Booster Klystrons. The EIMAC klystrons have been performing satisfactorily during the quarter and only 4 tubes failed. These had over 3,000

hours of operation. Progress on the Litton sub-booster contract has been slow, and the problems associated with power, gain and stability have not yet been solved.

3. Phasing System

a. Isolator, Phase-Shifter, Attenuator (I ϕ A) Units. Installation of the system giving CCR individual phase control of each I ϕ A unit in Sector 27 was completed. Each phase-shifter may be coupled through an electromagnetic clutch to a stepper motor. All motors are driven from a single supply, making it possible to synchronously rotate the phases of selected klystrons in either the same or the opposite directions. The system works well and is frequently used for vernier energy control.

b. RF Detector Panels. Work is progressing on the design and evaluation of a fast-latching ferrite circulator which will be used to switch a phase-compensated attenuator into and out of the rf line between the accelerator section and the phase bridge. A switching time of less than 20 μ secs was achieved, but insertion loss and VSWR have still to be improved. The aim is to incorporate two fast circulators into an integrated stripline package. The circulators will be used as coupled SPDT switches, providing alternative paths through an attenuator and an adjustable phase-shifter, which are also contained in the stripline package.

The completed unit will be a fast-acting, phase-shiftless attenuator capable of decreasing the required dynamic range of the phasing system diodes by 20 or 30 dB. This device will make it possible to increase the sensitivity of the phasing system, so that the machine may be phased on 1/3 mA or less with the present thermionic diode detectors. Moreover, reducing the required dynamic range will make it possible to consider tunnel diodes or hot-carrier diodes as replacement detectors. Use of these devices would reduce maintenance and further improve the phasing system sensitivity.

A video amplifier was designed for installation in the rf Detector Panels. This amplifier will be used to feed the phasing video waveforms onto the video transmission system to CCR. The printed circuit card on which the amplifier is built will contain the diode balancing network. A prototype unit was built and installed in Sector 27. It performed very satisfactorily.

A separate output from one diode load will also be sent to CCR. This signal is intended to provide the operator with a rough, comparative indication of klystron power level. This comparison can be made only if the attenuations of all phasing cables are equalized. Simple, inexpensive mismatch attenuators have been designed and are being fitted in all sector phasing systems.

c. Programmers and Electronics Units. The beam detector described in the last report was found to change sensitivity as the temperature was varied. The design has been modified to give the necessary stability. It was also found that additional preamplifier gain is required. This will be corrected during the next quarter.

d. Phasing Control Panels in CCR. These panels are in the process of being redesigned to incorporate the additional "Phase/Don't Phase," "Auto Advance/Hold" controls which the sector programmers were modified to accept. The new panels will also display the number of the klystrons being phased or examined. The information will be transmitted to CCR in the form of a dc-level analog signal generated in each programmer. A zener diode circuit has been designed to convert this signal to a numerical readout in CCR:

4. In-Line Beam Position Monitors

A new decision to proceed with the remote balancing system independently of redesign work on the steering supply controllers was reached. A suitable motor-driven potentiometer was found and tested. The unit has adequate torque when driven by the steering control pulse train in sectors remote from CCR. Prototype units with a suitable gear ratio were ordered. A dynamic braking circuit will be necessary to stop the motor from overrunning.

5. General Microwave Investigations

a. Klystron Filters. Quarter-wave resonant strip filters were built, tested at up to 20 MW at 2856 MHz, and installed on one injector klystron and on klystrons 1A, 1B, 1C, 2, 3, 4 and 5 in Sector 1. No significant increase in BBU threshold has been observed.

b. RF Separator. Authorization to proceed with the rf Separator was obtained during the quarter and the entire installation of the system in the Central Beam is presently being prepared. Fabrication of the rf structure is being resumed. The rf drive for the separator system was completed and installation of the entire system including cables, control system, phase shifters, etc., will take place during the next quarter. An extra high power klystron and modulator are being reserved for the system. A moderate amount of preparation and repair of the existing modulator is taking place.

c. Experimental Studies Related to Beam Break-Up. Experiments are in progress to study the feasibility of changing the beam break-up frequency (4140 MHz) by about 2 MHz by indenting the first few cavities of a typical SLAC constant-gradient 10-foot

section. The effect will first be studied in the laboratory using screws, inserted in each of the first 10 accelerator cavities, as tuning devices. If successful, this tuning technique will be put into practice by dimpling these cavities with an external tool and the dimpling will be applied to the first and second sectors of the accelerator.

Attempts to change the diameter of these front-end cavities by heating them using an external tape failed because the local heating can not compete with the heating produced by the water flowing through the cooling pipes.

6. Optical Alignment System

a. Alignment. The Beam Switchyard laser mount was found to be jammed and the adjusting gears were stripped. To survey the switchyard, it was necessary to remove and rebuild the mount. Further alignment of the accelerator was suspended pending completion of this work which will enable the target at Sector 30, girder 9, to be placed on-line between the west end of the accelerator and BSY target 14. This operation is normally performed before each alignment cycle.

A paper titled "A Laser Alignment System For the Stanford Three-Kilometer-Long Accelerator" by W. B. Herrmannsfeldt, M. J. Lee, J. J. Spranza, and K. R. Trigger was presented to the First International Conference On Laser Applications, during July 1967, in Paris, France. A more complete paper titled "Precision Alingment Using a System of Large Rectangular Fresnel Lenses" by W. B. Herrmannsfeldt, M. J. Lee, J. J. Spranza, and K. R. Trigger was accepted for future publication by the Journal of Applied Optics.

Measurements of the short-term mechanical stability of the accelerator were made. Using continuous recording of the output from the detector with a sensitivity of 0.0005 inch, there has been no observable motion that could not be explained by such minor effects as faulty actuator adjustments or, in the case of the monument targets, by slight girder expansions.

b. Geophysics. A proposal to build an optical interferometer with a six kilometer light path making use of the SLAC alignment system was prepared and presented at a SLAC seminar. After this presentation, the proposal was slightly revised and is being prepared for submission to an appropriate sponsoring agency.

As part of the preparation of this proposal, a study of the light pipe vacuum system was made. It was found that it was possible to add suitable pumping to reduce the pressure to 2×10^{-4} torr from the present 2×10^{-2} torr. Ten small pumping stations spaced along the accelerator should give the above expected result.

7. Theoretical and Special Studies

Further computations on beam break-up were carried out. Many of the theoretical and experimental results were presented at the Sixth International Conference on High Energy Accelerators, Cambridge, Massachusetts during September, in a paper titled, "Progress Report on Beam Break-up at SLAC," by E. V. Farinholt, R. H. Helm, H. A. Hogg, R. F. Koontz, G. A. Loew, and R. H. Miller.

In general, comparison between experiments and computations has been fair. One of the interesting results of these computations, which has prompted the experimental work mentioned earlier in this report, is that an improvement factor of approximately 1.3 in the beam break-up threshold would result if the 4140 MHz resonance were detuned by 2 to 3 MHz in Sectors 1 and 2.

8. Magnetic Measurements

During the past quarter, the two-meter streamer chamber magnet was mapped using the rapid magnet mapper. The mapping operation consisted of obtaining the three components of magnetic field for a current of 2500 amperes for a grid of 2 inch \times 2 inch \times 4 inch. Approximately 200,000 data points were taken over a period of two weeks. Since that measurement, preparation has been made for a system capable of measuring the three field components simultaneously. This system, including a new mechanical support system, new electronics and slightly modified logic, should become available in early 1968.

The 54-inch streamer chamber magnet for Group E was mapped in three components at one current, with some additional data taken at a second current. This measurement consisted of a 2 inch \times 2 inch \times 4 inch grid and a total of 130,000 points.

The 40-inch Hydrogen Bubble Chamber magnet was mapped by essentially manual methods. About 4,000 points were taken in a period of 48 hours.

In addition to the above projects, several magnets were measured for the new C-Beam and other miscellaneous services were performed for other magnet users on the project.

B. KLYSTRON STUDIES

The vendors continued working to solve some of the production problems which appear to result in tube failures that decrease the average life of the tubes on the line. At SLAC, the emphasis continued to be on work to improve tube efficiency and the development of a tube capable of operation at 300 kV.

The problems have not yet been solved in the Litton driver amplifier tube development program. Although some acceptable tubes were received, the vendor was still experiencing difficulties in achieving full power, gain and stability, simultaneously.

1. Klystron Procurement

a. RCA Subcontract. One of the problems with RCA tubes is still window failures, and a high percentage of all RCA failures were caused by the window, including a number of early failures (less than 1000 hours of operation). The RCA people are fully aware of the problem and have instigated a program to improve hopefully the overall window life. Up to now, RCA had used a compression seal as a vacuum seal between the alumina and a thin copper sleeve. The window sleeve assembly was then brazed onto the tube output after titanium-coating the tube side of the window. The load side of the window was titanium-coated after final bake. Basically, the same method has been used for the past two years. Although statistically there appears to be a difference in window life for tubes built in 1966 compared to those built in 1965--there were more early failures in the 1966 tubes than in the 1965 tubes.

The window improvement program will maintain the same window geometry, but will replace the compression seal by a braze seal from the alumina to a cupro-nickel sleeve. In addition, a redesign of the final assembly has been started so that windows can be heliarced onto the tube instead of being brazed as they are at present. Finally, RCA is investigating better coating methods. They have built an rf, plasma sputtering machine which promises to produce a more adherent coating and a more coating thickness than their present evaporation technique. Basically, RCA is modifying those window fabrication and assembly techniques which are different from the SLAC or Litton techniques. Although there is no definite proof that their techniques were detrimental to window life, the total percentage of RCA tube failures because of window failure is much higher than that of either Litton or SLAC tubes. If after these modifications there is still a substantial difference in window life between RCA, SLAC and Litton tubes, the window geometry or electrical design would then probably be to blame.

RCA is also continuing a program of tube improvement. In a test last quarter, a special tube achieved a power output of approximately 26 MW at 250 kV, and 30 MW at 272 kV in a permanent magnet. The main difference between this tube and standard RCA tubes was in the tuning of the output cavity and output coupling.

b. Litton Subcontract. The Litton tube "burning" problem mentioned in the previous quarterly report¹ was still present, and a number of Litton tubes had to be adjusted prior to acceptance. A number of their tubes also required considerable maintenance attention during operation, particularly because of the "burning." This results in changes in perveance and makes the tuning of the pulse-forming network for pulse flatness extremely difficult, if not impossible.

Litton is well aware of the problem which they believe to be related to a similar problem experienced in some of their high voltage switch tubes. Their main engineering effort at the present time is being directed to a solution of this "burning" problem with the help of the engineer in charge of the switch tube program. At the present time, no final solutions are in sight. However, speculation indicates that a change in materials or processing technique is involved in the problem since the tubes initially delivered by Litton did not exhibit such difficulties at least for the first several thousand hours of operation.

c. SLAC Klystron Development. Gassy tubes which are difficult to process have still been observed at SLAC during the quarter. We believe that the main reason for these problems has been traced back to a batch of bad copper used in drift tube fabrication.

An investigation of cathode problems mentioned in the last quarterly status report² indicated that the cathode temperature was not sufficiently uniform from center to edge, and a new cathode button was designed which, according to our measurements, results in temperature uniformity to within $\pm 5^{\circ}\text{C}$. One of the drawbacks of this improved cathode is a much longer heating time constant. The total time to reach operating temperature from a cold start is approximately 45 minutes. The cathode is more efficient and should operate at somewhat lower heater power.

Our attempts at improving tube efficiency are continuing, and are directed toward improving bunching of the output gap by adjustment of the drift distances between cavities. We believe that both the output cavity coupling and the frequency of the penultimate cavities are almost optimum, but a change of approximately 1/4 inch in the position of the penultimate cavity has produced a remarkable improvement in

¹"Two-Mile Accelerator Project, Quarterly Status Report, 1 July through 30 September 1967," SLAC Report No. 80, Stanford Linear Accelerator Center, Stanford, California.

²Ibid.

power output. Three tubes built to these new dimensions produced power output in excess of 30 MW at 250 kV in an electromagnet. One of these tubes was tested in a permanent magnet and, by adjusting tube position in the magnet and doing some field shunting, we were able to obtain a power output of 30 MW peak at 250 kV with an efficiency of 46%. Measured performance characteristics for the tube are given in Fig. 14.

Ten, old General Electric permanent magnets originally procured for the Sperry subcontract have been modified for operation with SLAC tubes. The field appears to be almost optimum for operation of the XM-12 variety of tube (enlarged drift tubes from number 3 to number 5 cavities). Three of these tubes tested in modified magnets achieved power outputs in excess of 26 MW.

Work continued on the fabrication of an experimental 300 kV tube. All the components were machined and the majority of the assembly had been made. The cathode design slowed down the final assembly of the tube. Because of the observations on temperature gradients across the standard gun, it was decided to redesign the gun mounting and heat shielding completely. Such a gun was tested in a bell jar during September. Although the cathode area was increased approximately 25%, the heater power necessary to achieve operating temperature increased only 10 to 15% over that of our present guns. The temperature uniformity appears to be excellent, and barring unforeseen oscillation or sparking problems, there should be no difficulty in operating this gun at the full rated voltage of 300 kV.

A permanent magnet was modified to give us a field equivalent to that computed as necessary for the 300 kV tube.

2. High Power Klystron Windows

a. Resonant Ring Tests. The routine resonant ring tests prior to klystron installation indicated that the standard titanium coating is now in good control with the quartz crystal monitoring method. However, the tests are still continuing in an attempt to determine the probability that the present window design could operate in a 300 kV klystron at approximately 40 MW peak and 40 kW average. Approximately 30 windows have been tested up to 86 MW peak, 86 kW average, with no detectable evidence of failure.

The tests are continuing on windows coated with boron nitride. Two specimens showed slightly higher multipactor activity than would be expected with titanium coating. However, the operating temperature appears to be satisfactory for good operation, and

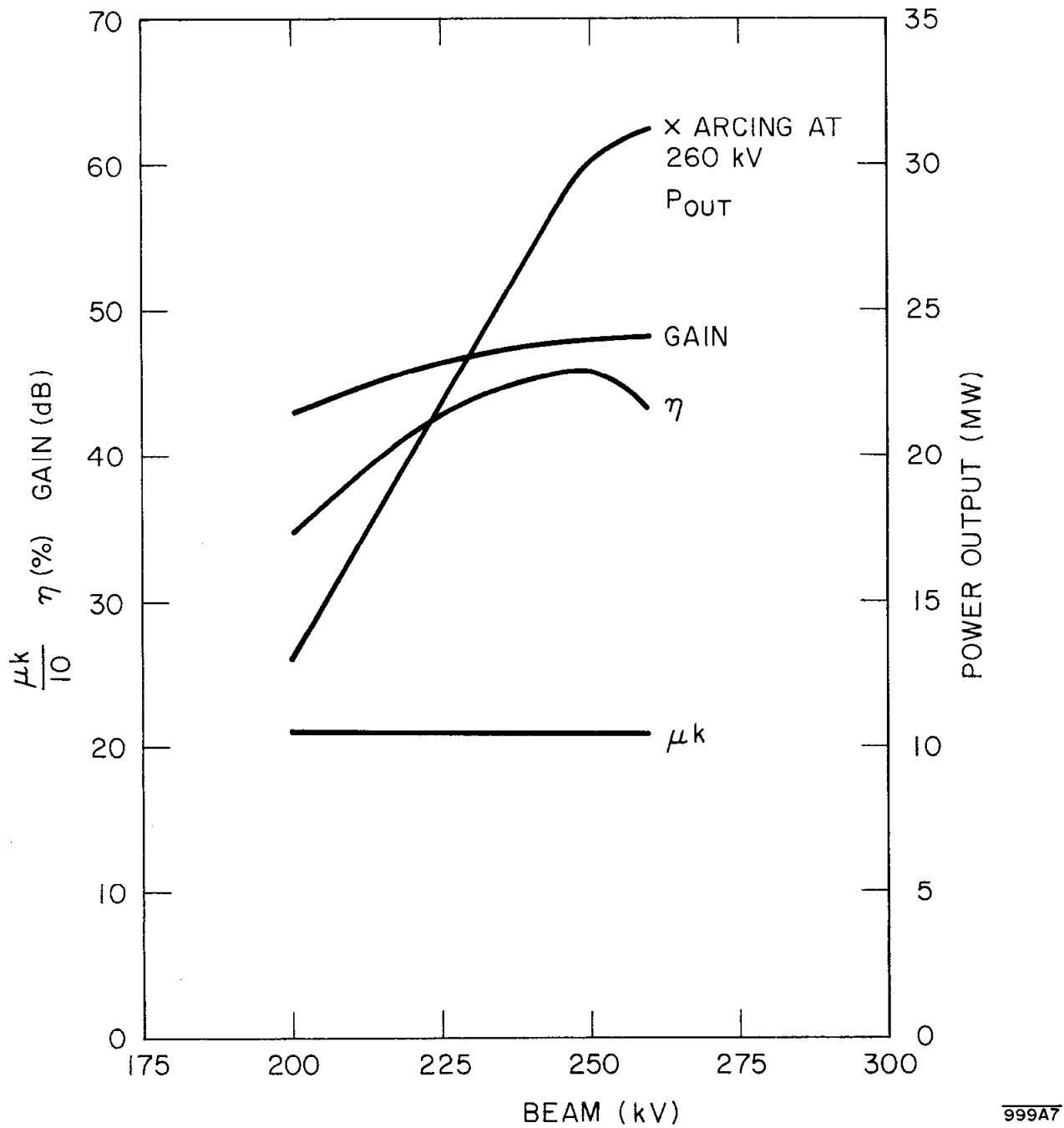


FIG. 14--EXPERIMENTAL KLYSTRON PERFORMANCE IN PERMANENT MAGNET

no deterioration of coating effectiveness was detected after one sample was exposed to two successive vacuum bake cycles.

Tests are also continuing on grooved windows. It appears that with the grooves on the generator side, the window is capable of withstanding higher peak power than with the grooves on the load side. Effects of impurities on coated window operation have also been investigated, but results are so far inconclusive.

b. Window Coating Techniques. Further work is being done on coating techniques to improve the uniformity of coating thickness on SLAC windows. It is suspected that the coating is significantly thicker near the center of the window, and that this thickness distribution contributes to high temperature gradients and thermal window failures. Our measurement techniques of coating thickness do not lend themselves easily to determining variation of thickness across the window, but thickness uniformity has apparently been improved by eliminating the heated filaments from the sputtering configuration. This improvement has been indicated by measurements of coating resistance variation as a function of temperature during the bake cycle of the window.

c. New Equipment. In an attempt to understand the properties of window coatings further, a surplus electron diffraction machine is being reactivated to permit secondary emission studies on klystron windows. This equipment is similar to that used with good success by the Princeton Labs of RCA during the earlier phases of RCA klystron procurement and window troubles.

We also have procured all necessary components to build an electron beam evaporator to be used in preparation of boron nitride or other types of coatings for klystron windows.

3. Vacuum

Work continued on the experimental and theoretical studies of ion pumps, relating the noise generation to pumping speeds, electrode voltages and magnetic fields. Pump speed measurements were continued with a conventional three gauge system and an aperture-dome system. The comparison between systems appears to be generally good, but there appears to be real changes in pumping speed at a given pressure, depending on whether the pressure is increased, decreased, or has been maintained at a steady value for different lengths of time.

Good correlation appears also to have been obtained between sputter ion pumps and noise measurements and computed cyclotron resonance within the cells of the pump for the magnetic fields applied.

4. Driver Amplifier Klystrons

The driver amplifier klystron tubes produced by Litton are being aged at much higher voltage than actual operating level. This has considerably reduced the tendency of arcing during tests at SLAC. General performance also improved during the quarter as a result of changes in cavity aspect ratios, secondary suppression techniques in the collector, and field straighteners in the permanent magnet. The power output is usually acceptable, but a comfortable margin of safety has not yet been obtained. Litton is continuing a tube improvement program to improve the stability further and to increase the power output.

C. MECHANICAL ENGINEERING AND FABRICATION

1. Positron Source

The edge-cooled solenoid coils (Coil 0) at the positron source developed a partial short, limiting operation to approximately 3000 amps. Design of hollow conductor solenoid coils to replace the edge-cooled coils was completed and fabrication began.

A solid copper wand target was fabricated and installed, replacing the laminated target. Because of its greater weight, the transit time for the new target was longer. The increase in transit time was not sufficiently great, however, to necessitate interruption of any more beam pulses.

Construction of a pantograph drive system to troll the 5-inch wheel target was completed and the complete system was shop tested. The new target and drive system was installed, replacing the slug target. The air-to-vacuum bellows failed during system test. The system was removed again and the slug target was re-installed. When the slug target was removed from the positron source housing, a small pit, approximately 1/16 inch in diameter and approximately 1/32 inch deep, with a conical bottom, was observed in the exit face of the target. The pit was located on the beam centerline. When the wheel target drive bellows failed, the slug target was reinstalled in spite of the pit, since the pit was very small and the damage appeared to be localized.

A second five-inch wheel target was fabricated and tested for power handling capability in the Central Beam of the Beam Switchyard. Trolling at 2 cycles per second, the target withstood the maximum available incident beam power of 200 kW. At the conclusion of the trolling test, beam power was reduced and the wheel motion stopped. The stationary wheel appeared to be capable of handling approximately 100 kW of incident beam power.

As a result of the bellows failure, the design of a smaller wheel target, which would decrease the amplitude of the bellows motion, was initiated. A two-inch wheel target was designed and fabrication began. Procurement of bellows for the new motion was initiated.

2. Accelerator Maintenance

Replacement of springs in the manual and fast-acting valves and re-damping of the fast-acting valves was completed during the quarter. Two fast-acting valves in Sector 1 were replaced because repeated remelting of the indium seats failed to

make the valves seal. Remelting of indium seats in the fast-acting valves is continuing as required.

Realignment of accelerator sections on their support girders continued. The accelerator sections on 55 girders were realigned. Approximately two-thirds of the accelerator sections remain to be realigned. This activity is continuing.

Fifteen laser alignment target actuator springs were found to have yielded sufficiently to make the targets inoperable. These springs were replaced. Spring replacement is continuing only when malfunction of the target actuators occurs.

The profile monitor can on the drift section in Sector 27 was removed and three beam intensity monitors installed. The three monitors allow a wider range of beam current measurements to be made near the end of the accelerator.

D. INSTRUMENTATION AND CONTROL

1. Positron Source

A wheel target for the positron source was installed in July. The electrical circuits for control and monitoring appeared to work. Not so satisfactory was the procedure for retracting the target, which required applying brakes as the target passed a pre-determined position so that it would coast to a stop at the proper position for retracting. The wheel had to be removed after about four hours of operation because of bellows problems. The wheel is presently being redesigned; a new control concept is in development; the date for installation is in the middle of the autumn quarter.

The "slug" type target, which was planned to be a temporary substitute for the wheel, will become a permanent standby for the wheel. Separate control and monitoring panels must therefore be provided.

In order to equalize the time required for the up and down swings of the wand, two time-delay channels were modified to provide up to 60 milliseconds delay. The time-delay adjustment was made more accessible by mounting the control potentiometers in back of the chassis. Ten-turn counters were used to make convenient resets of time delays.

Additional pulsed steering supplies, similar to the one used with the rf separator to remove electrons from the positron beam, have been built. They will be used in Sector 11 to ease the problems in steering interlaced electron and positron beam through Sector 11 during wand target operation.

2. Beam Guidance

The increased focusing resulting from adding new quadrupoles in Sectors 1-6 and larger supplies in 15-30 has helped reduce beam break-up but is difficult to adjust correctly since there are now more devices to adjust than positions for monitoring. A system to allow the operator to make zero-set adjustments for the position monitors has been designed. It will allow more precise use of the existing monitors. Fabrication and installation will be delayed by long delivery of parts.

3. Machine Protection

The present amplifier used to display the waveform on the PLIC scope has a switched gain of 1 and 10. A gain of 100 is required to observe the waveform when low energy beams are accelerated. The 100 gain amplifier has been designed and

tested. A new PC card is being manufactured to contain the X1, X10, and X100 amplifiers. Because of the high amount of radiation present in Sector 11 when positrons are being generated, the PLIC interlock needs to be disabled during positron operation. A circuit has been designed to be incorporated in the wand driver chassis to transmit pulses to disable the PLIC interlock during positron runs. Interlock disabling pulses will be sent continuously during wheel and slug operation, and discretely during wand operation. The new circuitry will be installed during the latter part of October.

4. Personnel Protection

Beam shutoff ion chambers have been installed in the research area at locations shown in Fig. 15. They have a failure alarm and a low-level radiation alarm at 25 mr/hr which warns the operator and a high-level alarm at 100 mr/hr which turns off the beam and also inserts beam stoppers as a second guarantee of removing beams from the research area.

5. Central Control

The notion of a computer system for CCR was studied. Such a system could improve operating efficiency by speeding up control responses. It could also keep more nearly complete records on component and system performance. Some of the data would be useful in programs for improvement of equipment.

Among the original guidelines for the design of the control system was its suitability for ultimate computer control of the accelerator. It was intended that such a computer should monitor status changes of the accelerator and its components, provide an operational log and allow analysis of operation. It also was to assist in the programming of the beam, energy control, and beam guidance.

To simplify eventual interface problems with the computer, a limited number of signal formats was specified. There are (1) binary status signals, to be used for logging equipment troubles and, if necessary for initiating corrective action; (2) slowly-varying analog signals, to be scanned as often as prove necessary; (3) pulse-amplitude-modulated signals for monitoring the beam; and (4) control signals, all of which are momentary closures.

At present, whenever experimental beam requirements change substantially, time is lost on activities such as quadrupole current adjustment and pattern switch manipulation. A computer could reduce this time loss in many cases. It could keep

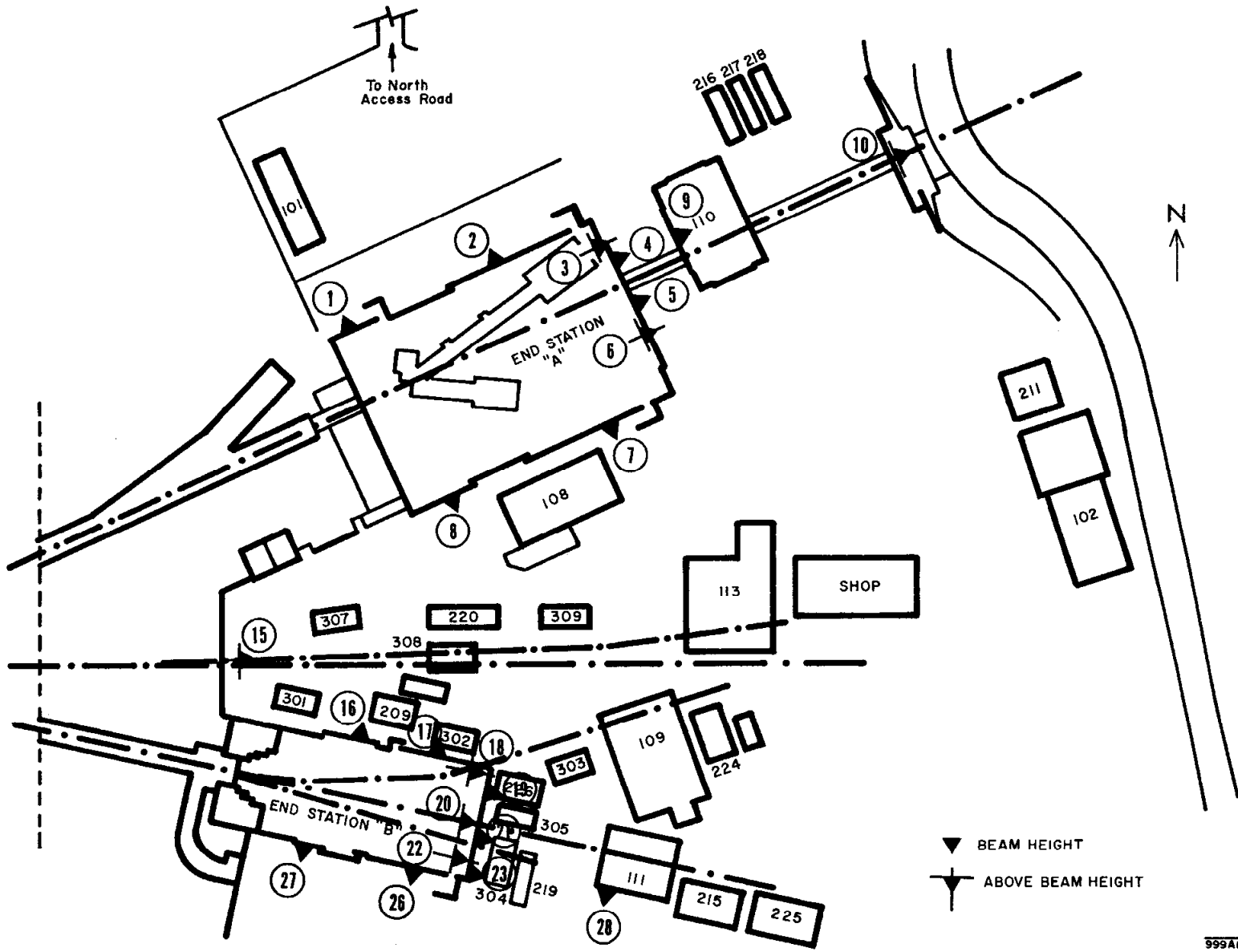


FIG. 15--BEAM SHUTOFF ION CHAMBER LOCATION

on file much of the necessary data, look it up quickly, and operate the necessary controls very much faster than an operator.

When a high power beam is being run, the loss of a single klystron can sometimes cause the beam orbit to shift in the Beam Switchyard (BSY) enough to over-heat part of the BSY beam transport system in a small fraction of a second. With the existing control system, the beam must be turned off by an automatic safety circuit. A computer could evaluate the energy shift, and when appropriate, switch on a spare klystron before the next beam pulse. In many cases, this would eliminate unnecessary loss of running time.

It occasionally occurs that the accelerator operators are pre-occupied with maintaining the proper beam energy and a narrow spectrum and do not notice that something else, say steering, has drifted, until too late. Here again a computer could help by gradually touching up the steering and focusing of the electron beam whenever necessary. It might also sometimes do a better job (quicker, more accurate) of spectrum control than an operator.

A computer in the Central Control Room is not intended to eliminate human operators, or to relieve them of their responsibilities for control and logging operations. It is intended to relieve them of jobs that are tedious and repetitive, and to do some jobs more quickly and accurately. It must always be possible to turn off the computer and resume full manual operation.

An attempt has been made to list all the jobs that a computer might do in the CCR. In general, the CCR control computer must be supplied with information and instructions, and must acquire data. It must process the data and produce signals to operate remote controls and recording, signalling, and indicating devices. These activities are necessary for the primary functions of the CCR data processor. The primary functions include remote control operation and the data acquisition and analysis necessary for proper control of accelerator components.

The study has led to general conclusions concerning computer requirements. The peak data input rates indicate that the computer cycle time should be less than $2.5 \mu s$. The maximum data rates, averaged over a period of 1 second, and the estimated requirements for instructions resident in core, indicate that the core must contain a minimum of eight thousand 16-bit words. There is a considerable variety of jobs to be done intermittently. This indicates that a larger, fairly quickly accessible memory store will become necessary at some stage in the development. A disc file accessible in a fraction of a second would be suitable. It would be prudent to make provision for further expansion of the disc file, as well as of the core memory of the computer.

The projected system would contain 10 or 11 output terminals and eight input terminals, of which only one at a time would be connected to the processor. For the purpose of this discussion, a data terminal is a transmitting or receiving unit capable of sending or receiving 16-bit binary words at a rate of about one word per computer cycle. Probably only one input terminal would actually handle data at the highest possible rate. It would receive digitized beam monitoring signals at 8 μ s intervals. There exists a possible requirement to receive data from two or three such rapidly changing sources in rapid succession. The other terminals would receive data at intervals ranging from tens of microseconds to some fraction of a second.

The output terminals would be largely constrained to operate at lower speeds to accommodate relay actuation. None would be required to respond in less than one ms. Most of the output terminals would contain pulse stretchers, so that the processor would require only a few machine cycles to complete each control operation. It would thus be possible for the computer to produce the effect of operating a number of remote controls continuously and simultaneously.

In the course of acquiring the information necessary for control responses, the CCR computer would process much of the data which is required for permanent records of machine performance. One approach would be to record the machine state once on a disc, and then record all significant changes in state as they occur.

It would be desirable to check certain analog signal levels for a significant change at intervals of 1 to 10 minutes. When the computer is adjusting a parameter represented by one of these signals, it would be necessary to read that level move often, say at 0.1 to one second intervals, with the signal selection being made under program control.

Signals from beam intensity and position monitors constitute by far the largest source of data input for the processor. Some 150, pulse-amplitude-modulated beam monitoring signals are generated for each beam pulse, representing perhaps 75 computer words of data per pulse. The computer throughput rate would, however, be limited by the accelerator control system response, so that it would probably never be useful to process more than a small fraction of the beam monitoring data.

Most remote control functions are performed by relays located along the klystron gallery. Relay actuations require time intervals ranging upwards from a few milliseconds for some on-off actions to many seconds. The longer periods will be required, for example, to run up quadrupole currents. By and large, the practical speed of computer control actions will be governed by these time periods.

6. Data Handling

Design work for the remote video switching system was completed. The shop has modified and tested one prototype unit. Progressive modification of the remaining sector repeaters was started. Sector and CCR wiring will be completed within the next two months.

Installation and check-out were completed for two independent video channels. This system allows selection from the CCR of any two video signals available in the DAB and provides an alpha-numeric readout in CCR of the signal name. Design was completed and CCR installation started for a TV presentation and nixie tube identification of profile monitors from the DAB.

7. Trigger System

A special trigger pattern system was installed for Sector 27 and 28 klystrons. The trigger system in these sectors was modified to provide separate accelerate/standby mode control of each klystron, thereby making possible finer control of beam energy than could be achieved when only control of an entire sector's klystrons was available. With the new arrangement, it is possible to assign any of these klystrons independently to any beam or combination of beams, by means of switches on the beam operator's console in the CCR. This arrangement provides a means for quick step-wise energy adjustments for multiple beams. At the same time individual manual phase controls were installed for the Sector 27 klystrons. The phase controls permit convenient multi-beam fine energy adjustments, and facilitate the maintenance of proper relative phase between the electron bunch and the accelerating electric field vector.

The master trigger generators have been modified to increase the main trigger pulse delay with respect to the pre-trigger from 25 to 1000 μ s. This permits different pulsed steering magnet currents to be obtained (at beam time) by shifting the phase of the magnet current sine wave with respect to the main trigger pulse. This is simpler and less costly than changing the peak voltage of the magnet capacitor. Although not yet fully evaluated at the time of this report, operation has been quite satisfactory for several weeks and preliminary results appear favorable.

E. ELECTRONICS ENGINEERING

1. Pattern Generator Modifications

The operation of this system was improved by the addition of large capacitors across dc power sources to eliminate cross-talk between channels and a larger power supply. The old power supply became inadequate when power requirements exceeded the power supply ratings because of continual expansion of this system.

2. Trigger System Modifications

The trigger system in two sectors near the CCR (27 and 28) has been modified to provide separate accelerate/standby control of each klystron, thereby making possible finer control of beam energy than could be achieved when only control of entire sectors was available. This is discussed in greater detail in Section II, D.

The injector trigger generator was modified to provide a beam knockout standby pulse automatically whenever the beam knockout system is not in use. This was done to keep the beam knockout radio frequency amplifiers more stable with respect to phase shift by maintaining them at as constant temperature as possible.

Also, as discussed in Section II, D, the master trigger generator was modified to increase the main trigger pulse delay with respect to the pre-trigger from 25 to 1000 microseconds.

3. 300 kV Modulator

A 300 kV, 100 megawatt - modulator for a developmental, 40-megawatt klystron is required to increase the energy of the accelerator. Design work was undertaken, specifications for large custom made parts were written and some construction work was done.

F. COUNTING ELECTRONICS

1. End Station Charge Monitors

Previous severe pickup problems cited with the End Station B unit (μ -Beam) were such that the only practical solution was to place a transistor preamplifier physically close to the toroid. The improvement in total system operation was dramatic, although magnet power supply transients are still bothersome. The possibility of additional cable shielding is being studied as a method to improve performance.

Preamplifiers near the beam have been avoided up to this time because of the uncertainties of the effects of radiation damage. After one month of operation, the first unit showed no observable degradation; hence a second remote preamplifier was installed on the toroid serving the digital averaging monitor in End Station A. Previous pickup problems immediately improved by a large factor; moreover it was no longer necessary to use a special isolated ac power supply to run the amplifier chassis. The noise averaging now appears to behave properly without significant uni-directional drifts. That is, a run of N samples (beam pulses) is seen to reduce the rms noise, on the average, by a factor of \sqrt{N} .

2. Time-of-Flight System

Measurements were made using a test pulse of the electronics alone. By deriving a reference signal for the mixer from the test pulse itself, the dispersion of the electronics alone, for a 5-nsec test pulse, was shown to be less than 50 psec, full width at half maximum.

Measurements were begun using fast, solid-state light pulsers as sources to test the scintillator-phototube front end. Initial measurements on the detector used previously in the spectrometer showed poor resolution. It was found that this was partly due to incorrect wrapping of the scintillator. Measurements aimed at defining resolution of the system for a given number of available photoelectrons, and the degradation due to reflections in scintillators, are continuing.

3. Equipment Pool

The logic module contract was re-negotiated during this period because of delivery problems with the original contract recipient. About 90 percent of the new equipment was received from the alternate suppliers. Part of the need for the equipment still outstanding is being met by the loan of nearly equivalent units from one of the manufacturers.

Several measurements were carried out on EG & G OR100, OR102, C104, and C102A logic modules. An evaluation of the LRS161 discriminator revealed difficulties which required factory modification of the SLAC units.

4. Module Development

A special modular 8-channel buffer storage unit was designed during this quarter. The unit accepts standard logic pulses from a discriminator or coincidence unit and stores the information until reset. Six units were supplied to the Rho Experiment (Group B), where they are used for reading picket fence counters into the IBM 1800 computer.

5. Rho Experiment, Groups B and C

The computer interface for TSI scalers was built and installed during this period. This system was designed to read in 19 channels of scalers to the IBM computer and also includes preset count capability for experiment control.

Later, the system was expanded to read in 39 scaler channels. Some problems were experienced with the cable connectors.

6. Multibody Experiment, Group D

An interface unit was built and installed during this period which permits printout of LeCroy scalers (integrated circuits) on the Digital Data Scanner. The system is capable of accepting 40 channels of LeCroy scalers, and includes a LeCroy converter to permit decimal printout of the binary LeCroy scalers.

In addition, a Scaler Display Unit was built to permit visual readout of a LeCroy scaler channel. This unit was designed as a general purpose instrument that can be used to checkout LeCroy and TSI scalers.

III. PHYSICS RESEARCH EQUIPMENT
DEVELOPMENT

A. SPECTROMETER PROGRAM

An accident on the 20-GeV spectrometer in the previous quarter damaged the coils of one of the quadrupoles, and a spare set of coils was wound by the Magnet Assembly Group. They used the technique of winding bare copper coils and then wrapping the conductors with stage B epoxy glass. Coil splices were done by copper-argon arc welding.

Another hodoscope was completed for the 8-GeV spectrometer. It was placed as far ahead of the p-focus as possible in order to get additional information on the ϕ of the particle. Along with this, a set of independently operated slits was built at the entrance to the magnet system. These slits allow the solid angle to be closed down in both θ and ϕ to any required setting.

The secondary emission monitors (SEM), which are used as an additional method of measuring quantity of beam incident upon the target, were further improved in stability during this period. The most recent design uses 500 Å of gold plated on the thin aluminum foils. The SEM is "wobbled" over a square pattern about six beam widths in size. Preliminary data indicated that the efficiency remains constant within 1% for a run at fixed energy.

B. B-BEAM SWITCHING

All operating parameters and criteria were finalized in this quarter. The deflection of the switching magnets was set at 0.351° to optimize the beam path through the magnetic slit. A new vacuum chamber was built and installed in the magnetic slit to accommodate this new beam path.

The design of all components, with the exception of the power supplies, was completed. A contract was awarded for the fabrication of two pulsed steering magnets, and work on the magnets began. All effort was directed toward having all components ready for installation by the end of the fourth quarter.

C. ALIGNMENT

1. Beam Switchyard

Beam surveys disclosed discrepancies in the location of the beam position monitors. A recheck of the coordinates was made. It was discovered that an error had been made in the calculation of the instrument stand coordinates. The stands were moved to the correct locations.

Bending Magnet B-14 was found to be incorrectly positioned. It was moved to its true location. However, it is still necessary to use magnet A-10 in the A-Beam and A-30 in the B-Beam to steer the beams, indicating that the transport magnet positions are incorrect.

2. Experimental Area

The laboratory and field alignment for the components of the central K-Beam were completed during this quarter. The field alignment was completed to the 82-inch bubble chamber.

The spark chambers, target wheel collimators and counters were targeted and installed in the Annihilation Beam in End Station B.

A continuous alignment check was maintained on the 8- and 20-GeV spectrometers both before and after experimental beam runs to determine any shifting of equipment. If necessary the magnets and targets were realigned to the theoretical beam center-line.

D. ENERGY ABSORBERS

1. High-Power Beam Dumps

During the previous quarterly period, it became apparent that the Beam Dump East setup had severe shortcomings. Particularly, the radiation level outside the shielding in the research yard was excessive during beam operation, mainly because of beam loss on protection collimator PC-400. The latter, in turn, was needed to protect the beam dump window flange from high-power beams.

The problem was solved by removing PC-400 and the associated instrument section and by replacement of the existing Beam Dump East (D-400) with a new dump.

This new dump is not beam-position sensitive. Its whole front face (dump diameter = 152 cm \approx 60 inch) is the window. The latter has a hemispherical shape. Thus, no protection collimator is needed and thick radiation can be installed up-beam. The dump vessel material is aluminum alloy 5083 and the power absorption medium is water. This will keep induced radioactivity levels low and thus simplify maintenance work in the area. The power absorption capacity was set at 500 kW, which is equivalent to the present Stage I power expectations. At this power level the window can handle any beam size.

The length of the dump vessel (including the water) is equivalent to 20 radiation lengths. The vessel is followed by a 30-radiation length-long (56 cm) iron block to further attenuate the remaining power leaking out of the dump in the forward direction.

2. Hydrogen Recombiners

A full-size, catalytic hydrogen recombiner was built during the quarter. It is capable of recombining all the hydrogen produced in the radiolysis process of water for average beam powers up to 2 MW. This unit will be installed in the A-Beam Dump radio-active water loop.

E. RESEARCH AREA MAGNET POWER SUPPLIES

All activity relating to the design, procurement, and operation of magnet power supplies is now being coordinated within the Research Area Division.

Some improvements were made in the existing eighteen, 360 kW power supplies, including the installation of facilities to allow switching of some supplies into any of several magnets. Four new, 400 kW power supplies were put into operation, and bids for the procurement of an additional eight, 400 kW power supplies were obtained.

The 3.4-MW power supply, with some deficiencies that need correction, was operated into its magnet loads. Because of transformer failures, the 5.8-MW power supply either did not operate at all, or was capable of delivering only 75% of its rated output during most of this quarter. Replacement of the dry-type power transformers with oil-cooled units was explored.

Installation of a 15,000 ampere tie-line was begun and was about 80% complete at the end of the quarter. The purpose of the tie-line will be to allow greater flexibility in the use of the existing and future large power supplies with the various large magnet loads.

A group of power supplies brought to the laboratory from LRL and intended for the Central Beam magnets were installed and put into operation.

Design and construction of two additional pulsed switching supplies for B-beam switching was also begun.