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and High-Voltage Machines
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TWO-MILE ACCELERATOR PROJECT

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INTRODUCTION

INTRODUCTION

This is the nineteenth and twentieth Quarterly Status Report of work under AEC Contract AT(04-3)-400 and the fourteenth 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 January 1, 1967, to July 1, 1967. In the text, the references, "first quarter," and "second quarter" are used to designate calendar periods rather than fiscal. 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 30 milliamperes peak have been obtained. Also during this period, positrons were 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 95% 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 the year.

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.

Installation of the initial complement of equipment for both End Stations was completed during the reporting period. This included the three particle spectrometers in End Station A which were in use for experiments during the period. The 40-inch bubble chamber installation was completed and the chamber was being cooled and filled with liquid hydrogen in preparation for experiments in the next quarter. The two-meter streamer mode spark chamber was also completed and in use during the period. The 82-inch bubble chamber building was completed and the instrumentation for the chamber was being installed. The buildings and equipment are shown in the figures that follow.

Construction began on the Fire Station and it was scheduled for completion during the last quarter of the year. The conversion of the ABA building to house the Crafts Shop was completed and the building was occupied. Design for the extension of the Central Laboratory and for the General Services Building was well along by the end of the period and it was anticipated that both would go out for bid before the end of the third quarter.

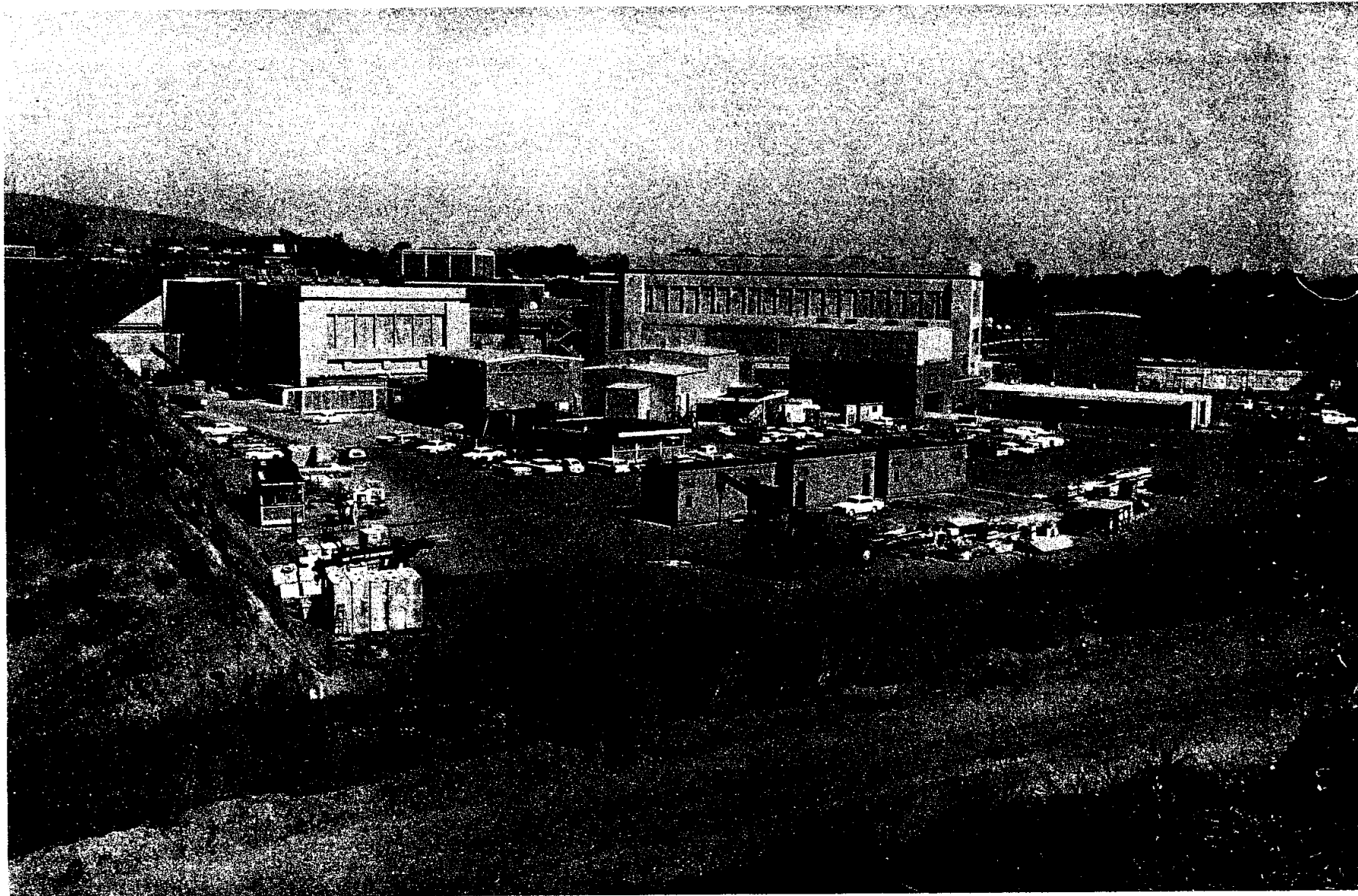
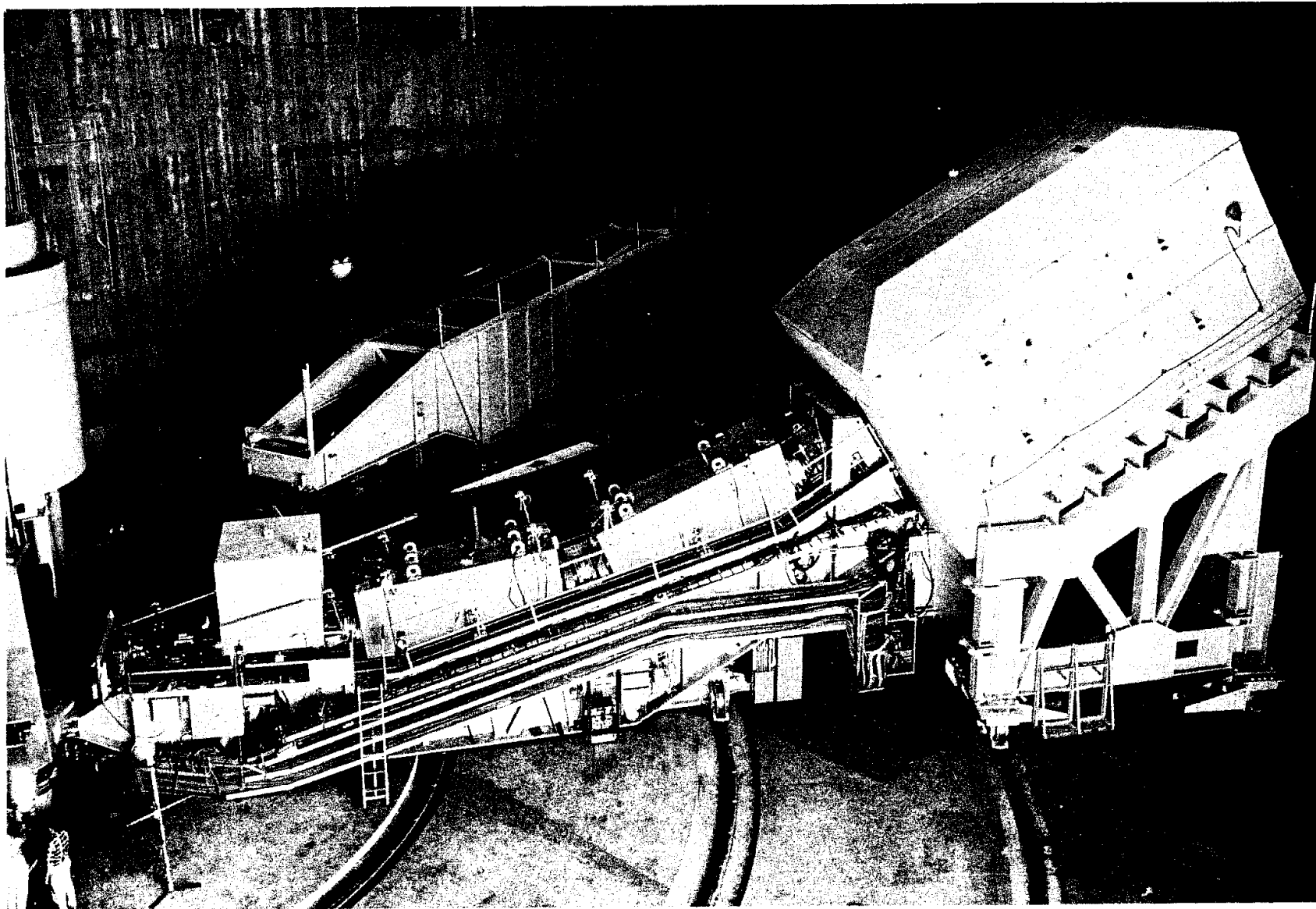
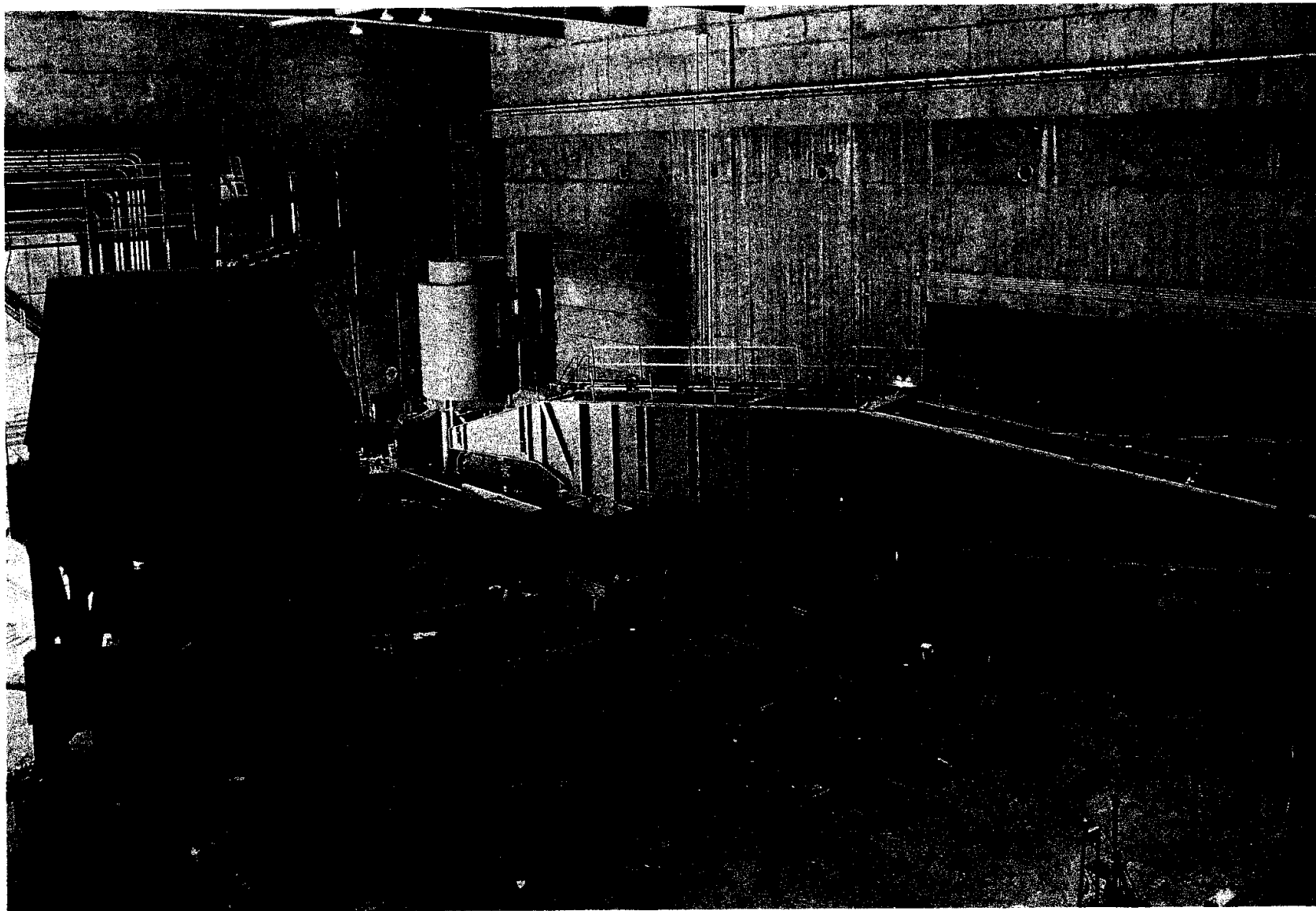


FIG. 1- EXPERIMENTAL AREA IN MID-1967



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FIG. 2- EIGHT AND 20-GeV SPECTROMETERS



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FIG. 3- EIGHT AND 1.6-GeV SPECTROMETERS

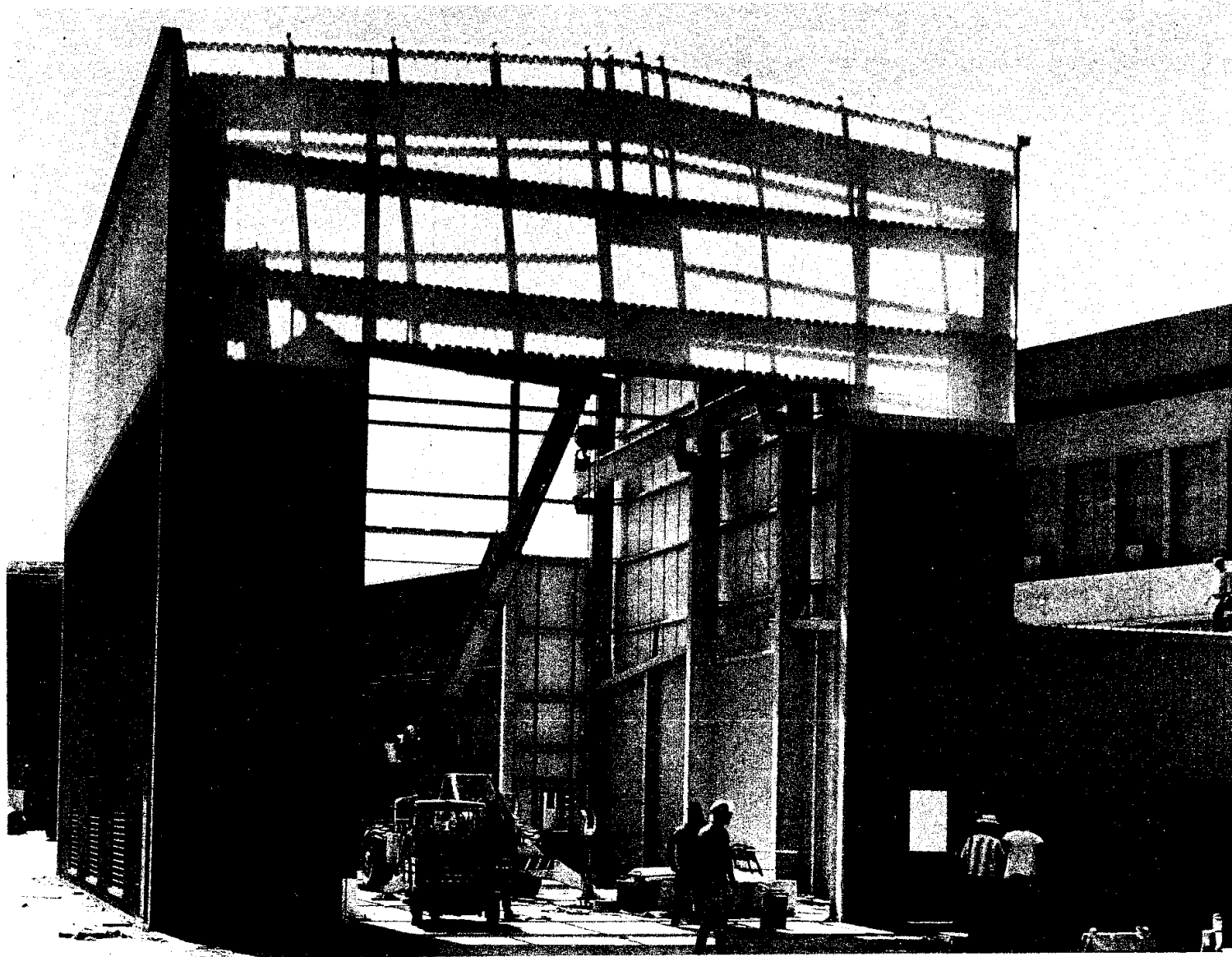
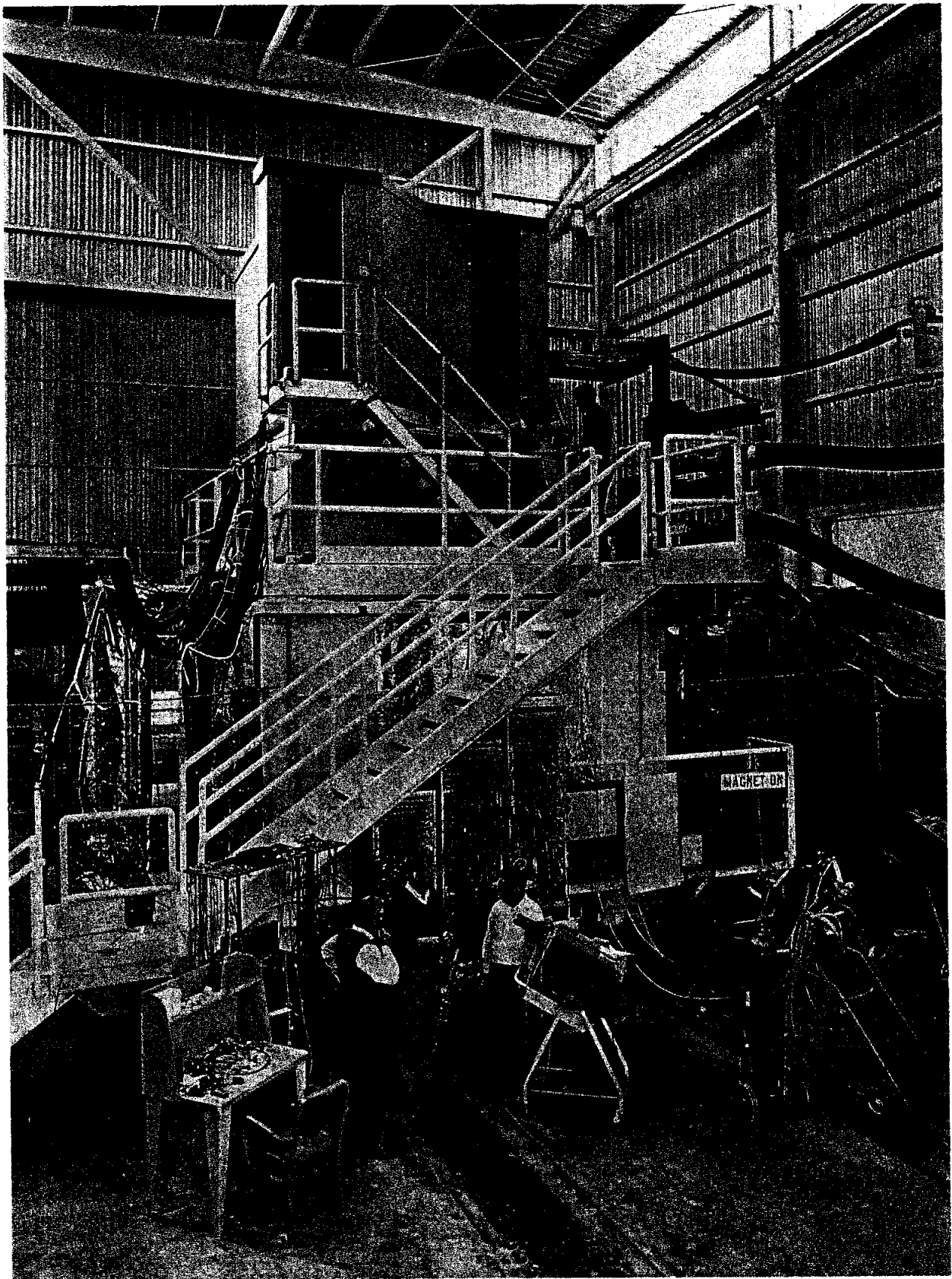
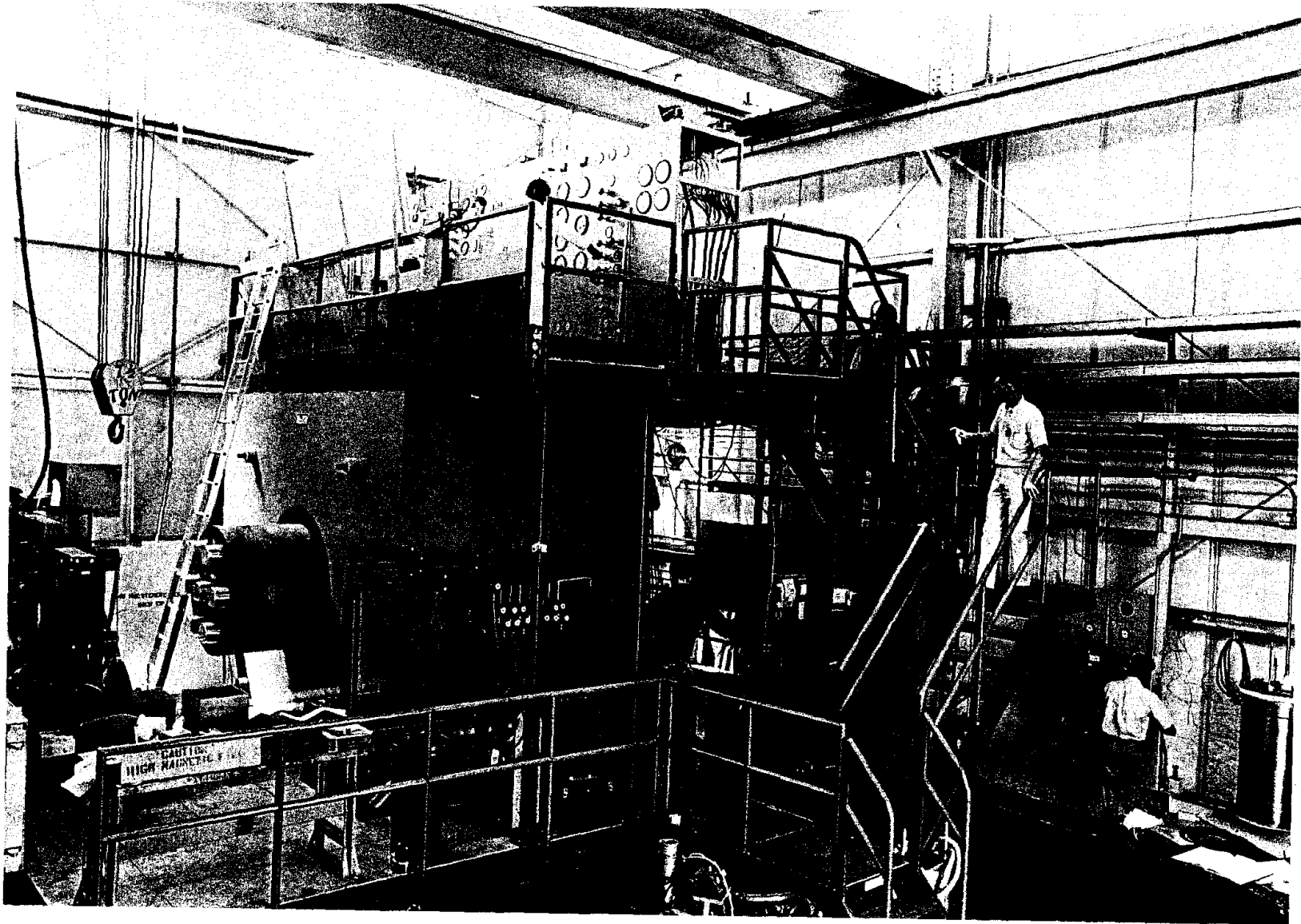


FIG. 4- EIGHTY-TWO-INCH BUBBLE CHAMBER BUILDING



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FIG. 5- TWO-METER STREAMER CHAMBER



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FIG. 6- FORTY-INCH BUBBLE CHAMBER

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I. ACCELERATOR AND RESEARCH
AREA OPERATIONS

A. OPERATIONS SUMMARY

1. General

For a definition of the terms used in this Operations Summary, refer to page 12 of SLAC Report No. 73, the previous Quarterly Status Report.

In comparing the last quarter of 1966 and the first quarter of 1967, it can be seen that there was a significant change in the type of operation. The last quarter of 1966 was largely an accelerator and BSY checkout period. During the first quarter of 1967, there was a much larger share of particle physics experiments. To compare, there were 76 shifts of Machine Physics runs and 63 shifts of Particle Physics runs scheduled for the period, October through December, 1966, as against 49 shifts of Machine Physics and 98 shifts of Particles scheduled in the January to March, 1967, quarter. The actual increase is even greater when it is realized that there were only 26 shifts during the former period that were scheduled for multiple beam runs, as compared with 71 multiple beam runs during the latter, with essentially all multiple beam runs used for particle physics work.

Operation of the accelerator settled into a fairly routine pattern. The accelerator was off for scheduled maintenance on the day shift (Shift 2) each Monday. Beam was scheduled for day shifts Tuesday through Friday to the tune-up dump (TUD) (D-10) or ESB, so that work could proceed in ESA. Other operating shifts generally featured multiple beam runs with experiments going on in both ESA and ESB.

2. Particle Physics, First Quarter

Particle physics runs were used for calibration and checkout of Research Area equipment and for high-energy physics experiments. Optics tests and calibration of the 8 and 20 GeV spectrometers were achieved, as well as checkout of various pieces and groupings of equipment for high-energy physics experiments. Many shifts were devoted to scheduled experiments, including new particle search, fractional charge particle search, K^0 study, μ -p inelastic scattering study, and production of monochromatic photons by positron annihilation. Many of these runs were done "two-at-a-time" by use of multiple beams. While experimental useful beam-on time totaled 540 hours, actual experimental beam hours--taking multiple beams into account--amounted to 780 hours.

3. Machine Physics, First Quarter

Machine physics efforts have largely been directed at a study of the beam breakup (BBU) problem with both a continuing research effort toward an understanding of the problem and an evaluation of the measures already taken to improve operation. Along the latter line, rearrangement of the quadrupole focussing magnets along the accelerator was completed and the effect of this change determined. As a further step, quadrupole focussing magnets were being installed at 40-foot intervals in Sectors 1 through 6. This was completed through Sectors 1 and 2, with the work to be completed in the next quarter. The net result of the changes so far was to increase the maximum peak current before breakup from about 20 mA to somewhat better than 30 mA.

Early in January, a concentrated effort achieved several hours of operation at energies of 20 GeV or more. The maximum energy during this period was 20.16 GeV. To check out BSY equipment, for H₂ evaluation at the beam dumps and for Health Physics measurements, two high (average) power runs were undertaken. The first, with 200 kilowatts into the BSY, achieved 175 kW at the A-beam dump. For the second, a 17.5 GeV, 30 mA 360 pps beam (300 kW) delivered 240 kW to beam dump east (BDE).

4. Particle and Machine Physics, Second Quarter

There were 192 shifts of manned operation this period. Of this number 150 were scheduled for particle physics runs, and 25 for machine physics. The change in emphasis over the past three quarters can be seen in Fig. 7 where the number of shifts devoted to particle and machine physics runs is plotted.

While a great deal of the particle physics time went to experimental data taking, much of this time was also spent on equipment check-out, including both the 8 and 20 GeV spectrometers, the streamer chamber set-up, the 40-inch bubble chamber, etc. Experimental work in progress is described elsewhere in this report.

As has been the case since full accelerator operation first started, much of the emphasis during machine physics runs was on the BBU problem. Quadrupole singlets were installed at 40-foot intervals down the accelerator, in Sectors 1 through 6. The effect of these has been to raise the maximum available peak current for a 1.6- μ second pulse from 25 to 43 mA at 16 GeV. (It should be recognized that the 43 mA figure is the current attained after the careful optimizing of all parameters; a more realistic figure for long-period operation is a current of the order of 35 mA.)

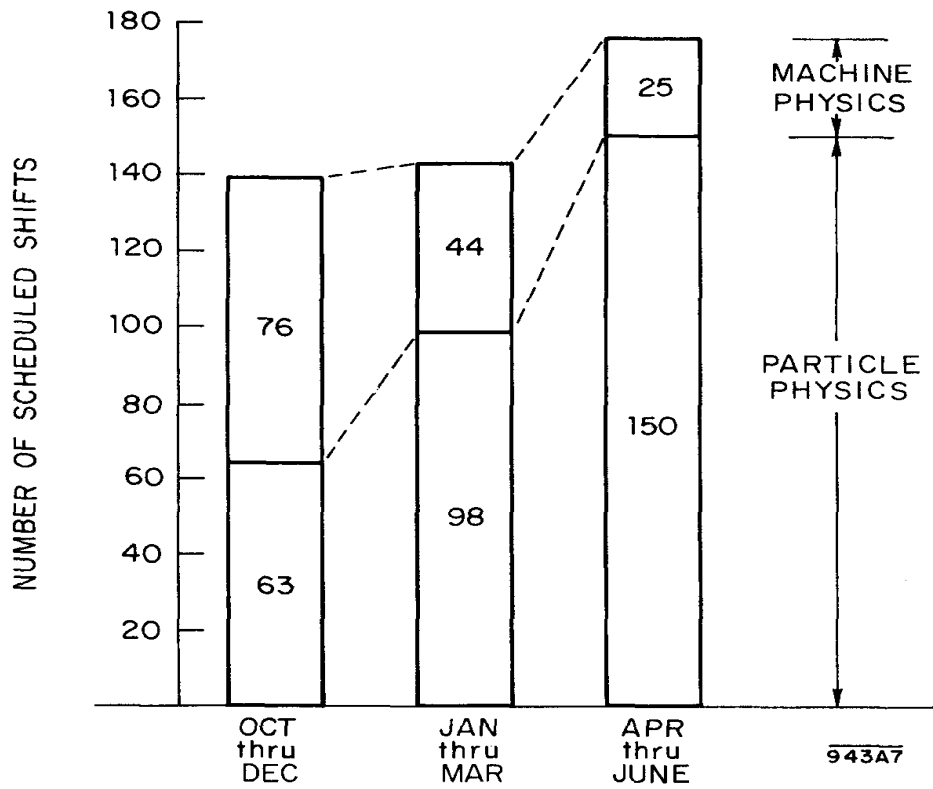


FIG. 7- PARTICLE VS MACHINE PHYSICS RUNS

Other machine physics work has concerned check-out of the beam knockout equipment, translation of positron production from an experimental set-up to routine operation and beam optics determination in the BSY. This work is covered in more detail elsewhere in this report.

5. Positron Operation, First Quarter

This quarter saw the first high-energy physics use of positrons produced at Sector 11. In January, positron operation was limited to set up, testing, and initial production of positrons. By the end of the month, positrons were observed at beam analyzing station (BAS) II.

The next positron run, late in February, supplied 11 GeV positrons at $40 \mu\text{A}$ to ESB; in early March a multiple beam run delivered positrons to ESA and ESB.

A pattern was established for positron operation which was followed each week for the remainder of the quarter. The first 8 to 12 hours of positron operation was reserved for tune up and machine physics; two or three shifts then followed during which positrons were used for high-energy physics experiments in both ESA and ESB.

With 5 GeV electrons to the positron source at Sector 11, at currents up to 30 mA, 10 GeV positrons were available in the experimental areas at currents up to $600 \mu\text{A}$.

6. Positron Operation, Second Quarter

There were 36 shifts scheduled for positron runs. In general, the first 1-1/2 to 2 shifts of a scheduled run were set aside for tune-up and machine physics experiments, with the time largely devoted to optimizing operating parameters. Following the tune-up period, several shifts would then be used for particle physics. In several cases, multiple beams with positrons to ESA and ESB were provided; there were also periods where positrons were used at ESB and either positrons or slug-generated electrons were used at ESA.

Throughout April only slug-generated positrons were used. (The slug is a positron source fixed in place while the run is in progress.) Little positron operation occurred in May, largely because of a vacuum leak in the positron source area that required a long period of positron-off time before the radioactivity was low enough to allow work in the area. Operation in June was again largely with the slug, but toward the end of the month there were successful

periods of wand operation with interlaced beams of positrons and electrons sent to the research areas.

There were a total of 150 hours of delivered positron beam from the accelerator; taking into account multiple beams, the total positron beam time delivered was 195 hours.

7. Accelerator Changes, First Quarter

The klystron life test run, terminated in August, was reactivated in modified form. Ten sectors were selected to run at 360 pps and at several different fixed klystron voltage levels; the remaining 20 sectors were run at selected klystron voltages but at pulse rates determined by the beam requirements. It was hoped that this regime would give information as to the relative cost of different levels of klystron operation.

A new, isolated injector water system was put into operation during the quarter and eliminated some of the instabilities caused by the former sharing of Sector 1 water with the injector.

Improvements in control equipment aided operation in this quarter. A counter and display, which keep a tally of the klystrons operating on each beam, assist in maintaining constant beam energy. The temporary system for producing low pulse rate beams was replaced with an upgraded unit which allows for far more flexible control of the operation.

8. Accelerator Changes, Second Quarter

Changes in the accelerator and its associated equipment were going on almost continually. As the accelerator can be operated with klystrons, sectors, or even groups of sectors off--the number of stations not in service depending on the required energy and current--it is possible to make some of these changes during beam-on time.

The only major alteration undertaken during this quarter was the addition of the quadrupole singlets at 40-foot intervals along the first six sectors--as already mentioned. Other changes included modifications to the modulators for improved reliability, the installation of a positron wand of improved design, installation of a 10-MHz beam knockout system (in addition to the already available 39-MHz equipment), improvements in the personnel protection system (to allow more flexibility and more rapid changeover when shifting operation from accelerator-only-beam to beam to the BSY), and more reliable over-temperature protection for the accelerator and klystron water cooling systems.

9. Accelerator Operation, First Quarter

Machine downtime due to accelerator failure, accounted for nearly 8% of the operation time. There was no one major contributor to this downtime but rather contribution from nearly every area of the accelerator system. Some of the major types of continuing trouble over this quarter were beam instabilities and jitter. These generally do not contribute to downtime as the experimenter would usually rather accept the poor beam than lose his beam time. The source of the instability was traced, when found at all, to the master oscillator, master trigger generator, steering supplies, klystrons, and to the pulsed bending and steering magnets. Improvements were made, but the problem is by no means completely solved.

Communications between the various groups (experimenters, the operating crews and the maintenance crews) continued to be poor. However, improved systems were being designed and tested.

Because the final method of fine energy control has not yet been installed, maintaining a specific energy has been difficult, particularly on multiple beam runs requiring high energy. Instead of single klystron phase control, we must now use one sector for each beam, which cuts sharply into the number of spare klystrons available.

10. Accelerator Operation, Second Quarter

Machine downtime caused by accelerator and equipment problems was somewhat less than the previous quarter (6.5% as compared with 7.9% of the hours of manned operation). As was true the previous period, the downtime cannot be attributed to any one area or machine system, but rather is made up of the sum of many short-lived troubles. Probably the two largest single causes of downtime was vacuum troubles in the positron source area, and the debugging periods after electrical and electronic changes done during the Monday maintenance periods. There was evidence that excessive equipment recycling was associated with high ambient temperatures. The problem may become more acute with the advent of summer, although thermal insulation planned for the injector area should alleviate the problem in the future.

One continuing problem is apparent energy jitter and beam instabilities. ("Apparent" because it is often difficult to isolate the problem to either the accelerator or the energy analyzing equipment in the BSY.) Many of the sources were found and the problem was much alleviated over earlier periods. However, much work remains to be done to track down the more insidious causes of instability that are usually of short duration.

It was generally possible to satisfy the experimenter's request over a wide range of energies and currents. However, there are sometimes problems when widely different energies and/or currents are desired simultaneously for multiple beam runs. A good example is when the wand is used to generate positrons; particularly when the interlaced electron beam is of high current. As the positron yield is of the order of 1%, there is a current discrepancy of nearly two orders of magnitude, as well as a great energy discrepancy following the positron source. Steering and focussing is then a compromise at best, and while it has been possible to operate in this fashion, neither experimenter gets a particularly pleasing beam.

A further problem to the operation has been the requirement occasionally to produce very low current beams--of the order of a few microamperes peak. This is far below the noise level of any monitoring equipment on the accelerator itself so the operator is flying blind--without instruments. Operation under these conditions has been successful only because of the excellent stability of the accelerator.

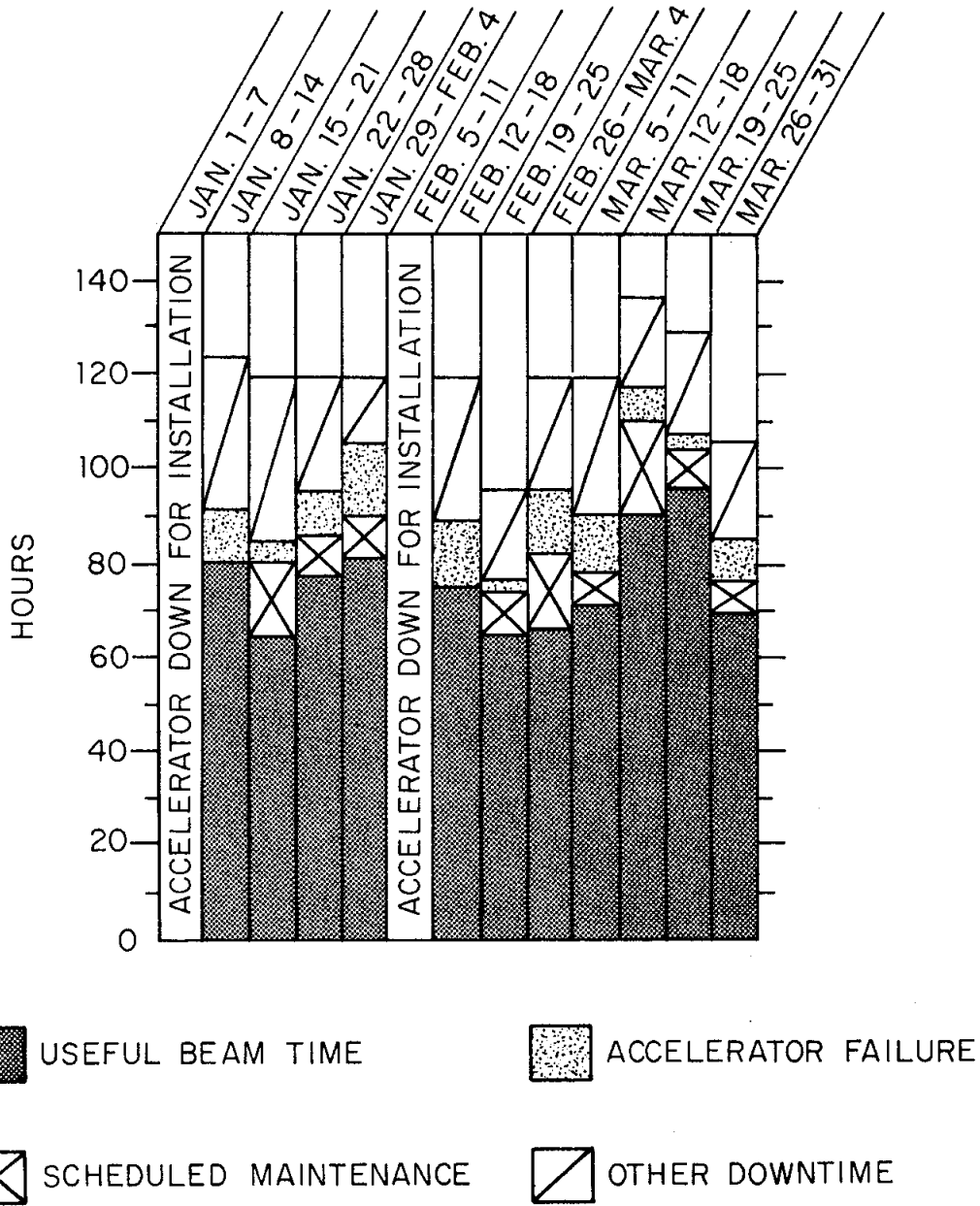
11. Operating Statistics, First Quarter

During the report period, there were 164 shifts of manned operation. This does not include the two weeks that the machine was down for equipment installation. The accelerator operated for 15 shifts per week (from 0800 hours Monday to 0800 hours Saturday) until early March, at which time an extra shift was added from 0800 to 1600 on Saturday. To accommodate the experimenter, it was necessary several times to run past the scheduled weekend shutoff time. The number of hours of manned operation for the period totaled 1315.

To determine the operating efficiency of the accelerator, it became customary to break down the operating hours into several categories. This will be useful, as time goes on, in analyzing the operation to determine where efforts must be made to increase efficiency (efficiency here means the percent of useful beam hours as a function of the total operating hours). Figure 8 shows the breakdown of the operating hours during the first quarter. The various categories, as depicted on this graph are defined in SLAC 73, as mentioned above.

12. Operating Statistics, Second Quarter

There was a total of 192 shifts of manned operation during this reporting quarter. This does not include the week of June 28 which was scheduled down-time for equipment installation. The accelerator was manned 16 shifts a week, from 8:00 am Monday until 4:00 pm Saturday. The total number of manned hours for the quarter was 1536.



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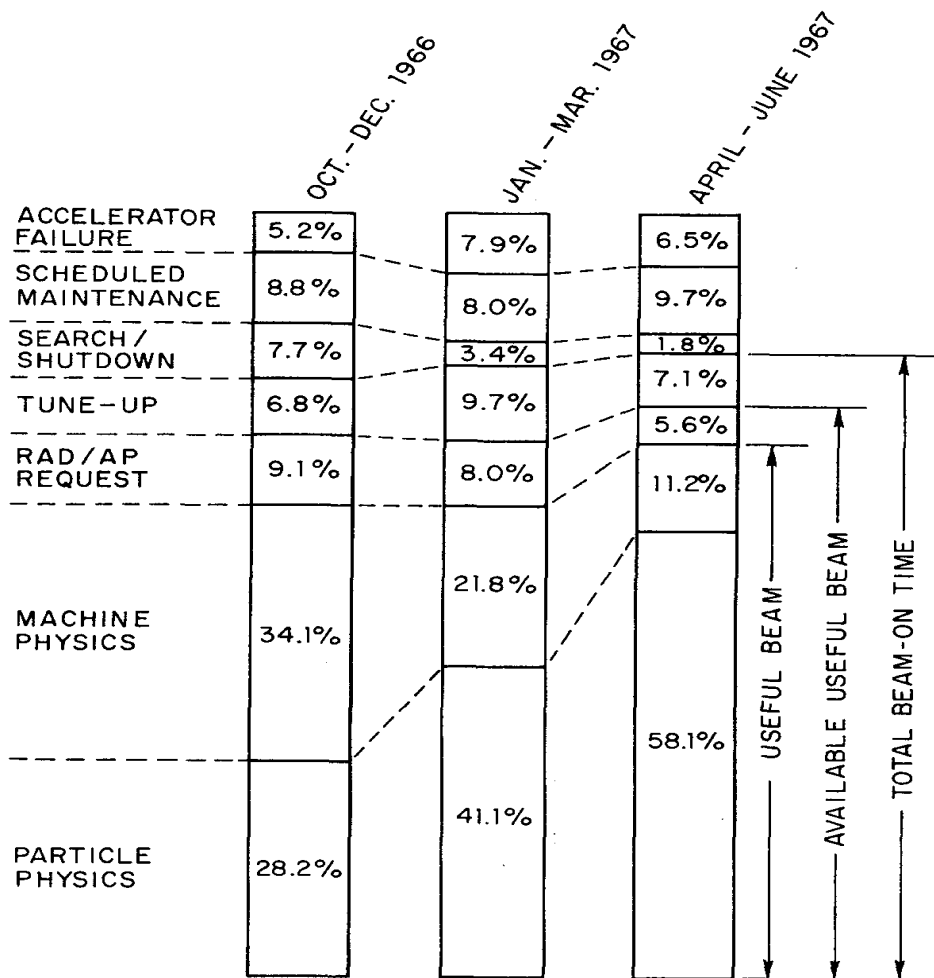
FIG. 8- WEEKLY OPERATING STATISTICS, FIRST QUARTER

It has been the practice to break down the operating time into several categories. Most of these are described in SLAC-73 as previously mentioned. Specifically discussed here are the following:

1. "Search/Shut-down"--the time spent searching the housing before turn-on, and the time required at the end of the week to secure the accelerator.
2. "Scheduled Maintenance"--in general a 12-hour period on Monday.
3. "Accelerator Failure"--time lost from delivering beam to the experimenter because of accelerator failure or operator error.
4. "Tune-up"--the time elapsed between first beam turn-on and the attainment of a beam of the characteristics required by the experimenter. The time required to change parameters for an experimenter or between successive experiments is also included in tune-up, as is the time required to up-grade a beam that has deteriorated with time.
5. "RAD/AP Request"--the time a beam of the desired parameters is available but is off because it has been requested by the experimenter or the BSY operator.
6. "Delivered Beam"--is beam-on time when the beam has been determined to have the required characteristics and is under the control of the DAB operators or the experimenters.

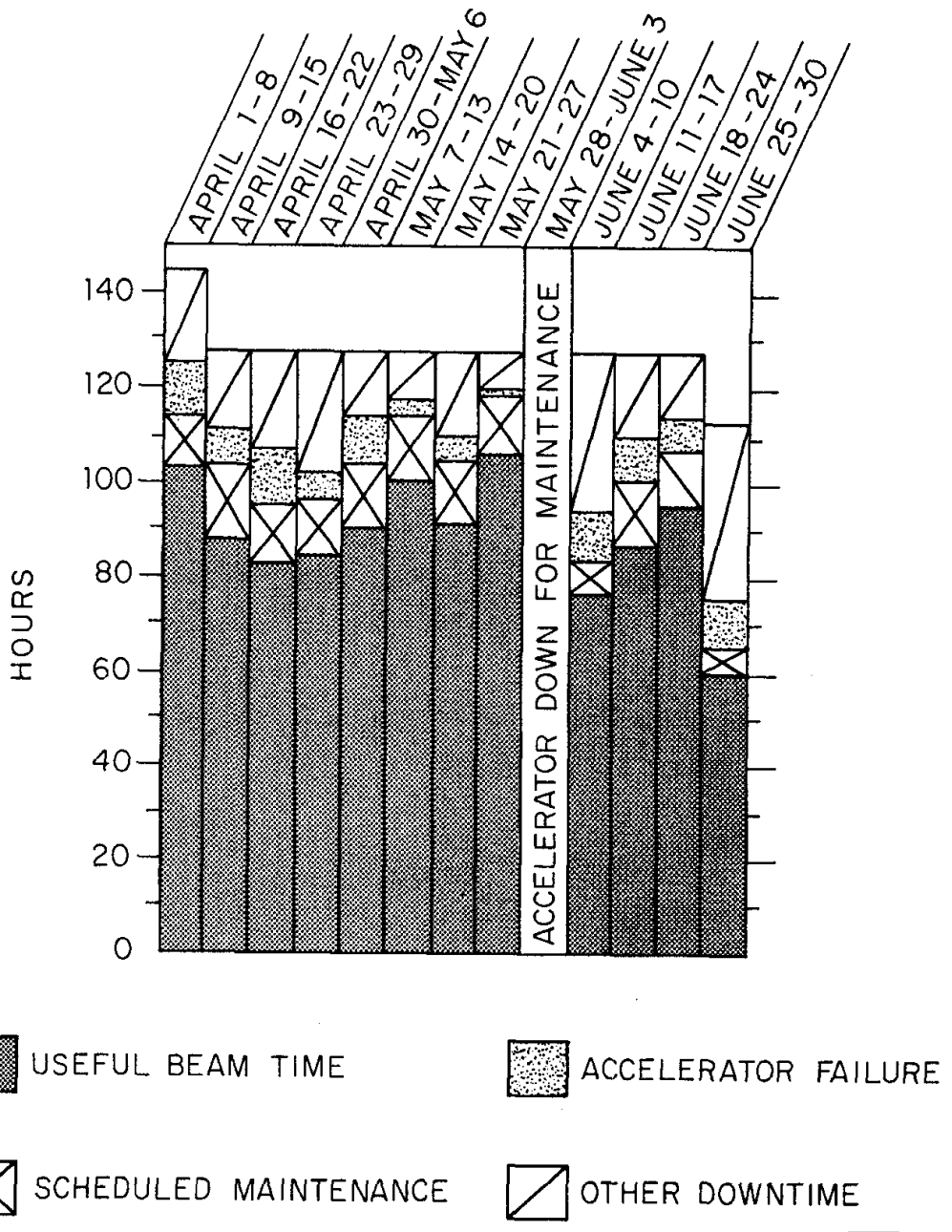
A bar graph showing these times (as a percentage of the total manned hours) for the report quarter and for the preceding two quarters is presented in Fig. 9. As might be hopefully expected, it can be seen that the delivered beam time has shown a steady increase from the initial turn-on in September 1966. There has been an improvement in all categories except scheduled maintenance where the increase is largely due to the addition of four hours of hot maintenance each week--the hot maintenance period being set aside for maintenance while the equipment is in operation at the injector and first few sectors of the machine. The figure of 9.7% is close to the 9.4% calculated for 12 hours per week of maintenance.

An examination of the week-by-week operation as shown in Fig. 10 is not as encouraging, with a strong fall-off of delivered beam hours shown during the month of June. This deterioration can be explained at least in part. There was an unfortunate rash of problems encountered during the week of June 4, following the week of shut-down, and largely due to work done on the accelerator and associated electrical equipment. A good portion of the downtime during the last week of June can be attributed to problems associated with initial turn-on and tune-up of the positron wand. It is to be hoped that this is just a relatively minor perturbation in the otherwise rather steady improvement.



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FIG. 9- MACHINE TIME AS PERCENTAGE OF TOTAL MANNED HOURS



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FIG. 10- WEEKLY OPERATING STATISTICS, SECOND QUARTER

There was a total of 1066 hours of delivered beam for both particle and machine physics. Counting multiple beams, it can be said that there was a total of 1604 hours of delivered beam for an enhancement factor (e.f.) of almost exactly 1.5. Equivalent figures for the previous quarter are 540 and 780 hours respectively for an enhancement factor of 1.44. The larger e.f. attained during the latter quarter is not necessarily a good thing. For example, if two experiments are sharing beam time and each is taking 180 pps of beam, continuous running would give an e.f. of 2.0. However, if each experiment could double its data taking rate by running alone at 360 pps, the experiments could run consecutively, each for half as long a period for an e.f. of 1.0, yet with no experimental gain from running multiple beams. And, in fact, the accelerator may well have run better under single beam conditions, particularly if the two required beams are quite different in energy and/or current. However, multiple beam operation is quite beneficial when one (or more) of the simultaneous experiments does not require the full pulse rate capability of the machine.

13. Search/Shutdown, First Quarter

The significant improvement in this figure comes about largely as a result of the improvement in the reliability of the Personnel Protection System. It was necessary formerly, at the conclusion of the housing search, to make a complete check of the tone loop system. Since this system was rewired, late in the last quarter, this check has no longer been required; search time has accordingly been diminished significantly.

One housing search is required each week; this, plus the 30-40 minutes required for shutdown of the machine on Saturday, sets a minimum figure of about 2.5% for this category.

14. Scheduled Maintenance, First Quarter

Unless it becomes feasible to shorten the housing open period on Mondays, no improvement will be possible here. At present, the 12 hours of scheduled maintenance per week limits the figure to close to 9%. (The lower figure of 8% obtained this quarter reflects the fact that there were no scheduled maintenance shifts in the week following each of the two non-operation weeks.) The 12 hours of scheduled maintenance each week include the 8 hours of housing open, plus an average of 4 hours of hot maintenance. Hot maintenance is preventive maintenance that requires a modulator/klystron station to be operating--though not accelerating beam--and cannot be done during the scheduled housing open period. Hot maintenance goes on almost continuously during operation in all sectors except at the injector end of the accelerator, where the

loss of even one station will have a large effect on the beam. Therefore, four hours a week have been set aside to perform hot maintenance in the injector area and Sector 1. In general, no useful beam is possible during this period.

The scheduled hot maintenance period has, until recently, been a full eight-hour shift--either Tuesday or Thursday--every two weeks. It is not scheduled to follow the housing open period on Mondays. The new system should both reduce tune-up time, and accelerator failure time, as the trouble shooting necessary after a shutdown period can be done in parallel with the hot maintenance work.

15. Accelerator Failure, First Quarter

This is a category where it is hoped that the useful beam figure can be improved; it should be possible to cut and keep the downtime caused by accelerator failure to a fairly low value. Failures in many areas actually do not appear in this category; loss of a klystron or a sector can usually be compensated for by the addition of another klystron or sector, or by dropping the beam energy. In those cases when loss of the equipment terminates beam operations, it has often been possible to design redundancy into the circuit. For example there are two master oscillators, three master trigger generators, etc., where switchover to the standby unit is automatic. In other cases the standby unit can be brought into service rapidly. As experience is gained, it should be possible to determine those areas where standby provisions must be added, or procedures set up to insure rapid recovery after a failure.

B. SYSTEM AND COMPONENT PERFORMANCE

During these two quarters, as discussed in the last quarterly report, the contributions of the Accelerator Physics Department to the operation of the accelerator could again 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

Pulsing of the injector for multiple beams with the use of all available pulse height and width channels became commonplace during the first quarter. The overall system worked very well and the injector was routinely run unmanned. However, the flexibility of the gun modulator was being taxed to its limit and installation of the new gun modulator should considerably improve the multiple beam capability of the injector.

During the second quarter, multiple beam pulsing requirements of experimenters exceeded the capability of the two height channel capacity of the gun modulator, and it was agreed to attempt installation of a third channel on the present modulator. This was accomplished by using some of the circuitry designed for the new gun modulator and revision of existing Manson circuitry. The modification was successful but efforts on this work delayed progress on the new modulator. The overall injector system continued to operate with very little trouble. Only intermittent glitches and drifts in the gun grid pulse were still being observed and had not yet been entirely eliminated.

2. Drive System

a. Master Oscillators

At the beginning of the first quarter, machine operation was hampered for several shifts by beam instability, which was traced to the generation of spurious outputs in the master oscillators. These units were cleaned and re-tuned, using a high-sensitivity spectrum analyzer which was not available at the time the Master Oscillators

were purchased. With this equipment, it was possible to reduce the power of spurious sideband signals to more than 60 dB below the fundamental. No further trouble was reported.

b. Low Frequency Transmission on the Main Drive Line

The diplexers installed at the Injector and the End Stations were used successfully in transmitting 39.7 MHz signals along the Main Drive Line during the first quarter. The signals were used in conjunction with the Beam Knockout System to make time-of-flight measurements.

c. Main and Subdrive Lines

During the second quarter, the main drive line transfer switch in the injector area apparently developed an arc and created a high VSWR which subsequently caused an arc in the output cavity in one of the main booster amplifier klystrons. A spare switch was installed but during installation and testing of the new klystron, the switch was accidentally activated in the presence of rf power and the contacts in the spare switch were damaged. Replacement parts for both switches were on hand and accelerator operation was not delayed. A long term solution to the short life of the switch has not yet been found. Several possibilities are being explored. During the repair of the transfer switch, the dummy water load for the standby main booster was suspected of having a water leak or other damage. Consequently, it was re-assembled with new water seals and re-installed. Subsequently, rf tests indicated that it again met the original specifications. A delay in obtaining a necessary meter relay prevented the use of the main booster automatic switch. The relays are expected early next quarter and will be installed as soon as convenient.

With the exception of the transfer switches, the main and sub-drive line systems have had trouble-free operation. The use of the diplexers at the injector and end stations has been extended to successfully transmit 15- μ sec pulses in the frequency range 10-20 MHz on the main drive line.

d. Main Booster Amplifiers

As mentioned above, main booster klystron No. 1 failed during the second quarter, and after replacement, the new klystron developed an arc in the output cavity thereby puncturing the vacuum seal and letting the tube up to air. The manufacturer is recommending that a fast arc detector be installed. The two amplifiers had operated without problems during the first quarter.

e. Varactor Frequency Multipliers

The first quarter of operation showed no increase in failures. Three spares were adequate to keep the machine in operation. During the second quarter the input power levels to the multipliers were re-examined. The main booster output power was adjusted to make these levels coincide as closely as possible with the levels used for the original varactor tune-up. By this process, it was hoped that longer time between readjustments and more stable operation will be achieved. All routine problems are now being handled by the Maintenance Department.

f. Positron Phase Shifters

The fast phase-shifters in the Sub-Booster IØA Units in Sectors 1 through 10 have continued to perform satisfactorily during both quarters, both for positron beam operation and for production of multiple beams of very different energies. Experience with operation of the Positron Source in Sector 11 showed that the phase shifters should be reset to give a phase delay of 165° instead of 180° . This was done.

g. Sub-Booster Modulators

The failure rate remained at about 10 failures per month during the first quarter, but decreased to about five during the second quarter. The switch tubes averaged about 4 failures per month and the precision power supplies and fuses about 3 failures per month during the first quarter. Records have shown a decrease in total failure rate from 30 in January to 18 in March. Of the total of 15 reported failures during the second quarter, six were for filament supply fuses, one for pulse length, two for switch tubes, and six for miscellaneous causes. Otherwise operation was very satisfactory.

3. Phasing System

The reliability of the system continued to improve slowly. Although thirty trouble reports were written during the first quarter, only eleven of these were traced directly to Phasing System faults. Only six trouble reports were written in the second quarter and just two were directly attributable to Phasing System faults. Breakdown is as follows for the two quarters:

Type of Fault	Number Reported During Quarter	Remarks
Thermionic Diode unbalance	3	All diodes are rebalanced weekly.
Isolator, Phase-Shifter, Attenuator Unit	2	Brakes failed to release.
Servo Amplifier	1	Component failure
Spurious trigger signals reaching the Gated Voltmeter	6	The only systematic fault discovered during the quarter. Trouble eliminated by improving shield grounding on coaxial video cables.
Programmer Wiring	1	Connector tabs loose.
Sector Wiring	4	---
Absence of CW Reference signal from Drive System	2	---
Programmer Inoperative	1	Low battery supply voltage in sector.
Klystron Phase Jitter	1	---
Undetermined	15	Systems functioned normally when trouble reports were investigated.

Progress on system improvements is described in the Equipment Development Section of this Status Report.

4. Beam Position Monitors

a. In-Line Beam Position Monitors

The monitoring system continued to operate satisfactorily during both quarters. During the first quarter, a test system was installed in Sector 28 which enabled the Central Control Room (CCR) operator to use the Steering Control switches to balance the diodes in the Beam Position Monitor Detector Panel. Balancing the diodes at a particular beam current level eliminates zero errors from the beam position displays in the CCR, making it easier to steer the beam to the accelerator axis. The test system was approved.

b. Beam Switchyard Beam Position Monitors

The monitors continued to operate satisfactorily. Some additional calibration work was done in the first quarter. Conversion factors for determining beam current and position from video pulse voltages were accurately measured and the information was given to the Research Area Department.

5. Beam Analyzing Stations

The two stations operated satisfactorily during both quarters. No changes were made.

6. Beam Break-Up Experiments

a. Measurement of Spurious Outputs from High-Power Klystrons

During the first quarter, several klystrons in the Test Laboratory were examined for spurious outputs in the frequency range 4000 to 4500 MHz. In each case, the klystron under test was connected to a 40 dB coupler and a dummy load. The coupler output was passed through a six-foot length of WR 187 waveguide (cut-off frequency 3100 MHz) and suitable low-pass filters to remove the 2856 MHz fundamental and its harmonics. The filtered signal was detected with a superheterodyne receiver having a minimum discernible signal level (MDS) of -85 dBm. With a combined coupler and filter insertion loss of 50 dB, this meant that a klystron output of -35 dBm at 4000 to 4500 MHz could be detected. No such signals were observed. The results are not considered conclusive because the performance of the coupler with higher order modes in the main guide is not known, and the dummy load almost certainly did not simulate the load conditions around 4000 MHz experienced by a klystron on the accelerator.

It is planned to build a special narrow-band coupler, centered at 4140 MHz, and to install it on the machine, immediately above a klystron output.

b. Measurement of the Klystron Input Signal Level Required to Induce BBU

Continuous wave power at the known BBU frequencies, viz., 4140 and 4428 MHz was coupled into the inputs of the klystrons in Sector 1. The beam was accelerated in Sectors 1 through 4 to 2.2 GeV and then allowed to drift through the rest of the machine. Beam current was increased to a level at which natural break-up began at the end of Sector 19. The level of the CW signal was then raised until there was a discernible increase in beam break-up. It was found that this signal level varied randomly from klystron to klystron in the range of 50 mW to 500 W. The power level appeared to depend only upon the particular klystron, and there was no correlation with position on the machine.

c. Measurement of the Klystron Output Signal Level Required to Induce BBU

Selected klystrons in Sectors 1 through 4 were disconnected one at a time from the machine and a CW signal at 4140 MHz was fed into the waveguide port leading to the accelerator sections. With the same beam conditions as described in the preceding paragraph, the power to produce a discernible increase in BBU was measured. In this case there was a clearly defined relationship between klystron position and the power required to stimulate BBU. As shown in Fig. 11, the experimental points agree quite well with the computed rate of growth of noise-induced BBU signals along the machine.

d. Second Quarter Experiments

During this quarter, the installation of the 40-foot quadrupoles in Sector 1 through 6 was completed. Thus, the entire rebuilt accelerator focusing system consisting of singlets every 40-feet in the first six sectors and strong doublets at the end of each sector from there on could be put into operation. Under these conditions, the corresponding betatron wavelengths are approximately 150 and 400 meters, respectively.

The resulting beam break-up threshold for a pulse length of 1.6 μ sec was approximately 42 milliamps, still somewhat short of the 50-milliamp current originally specified but more than twice as large as the current obtained when the machine was first turned on. This improvement is entirely due to the new focusing system.

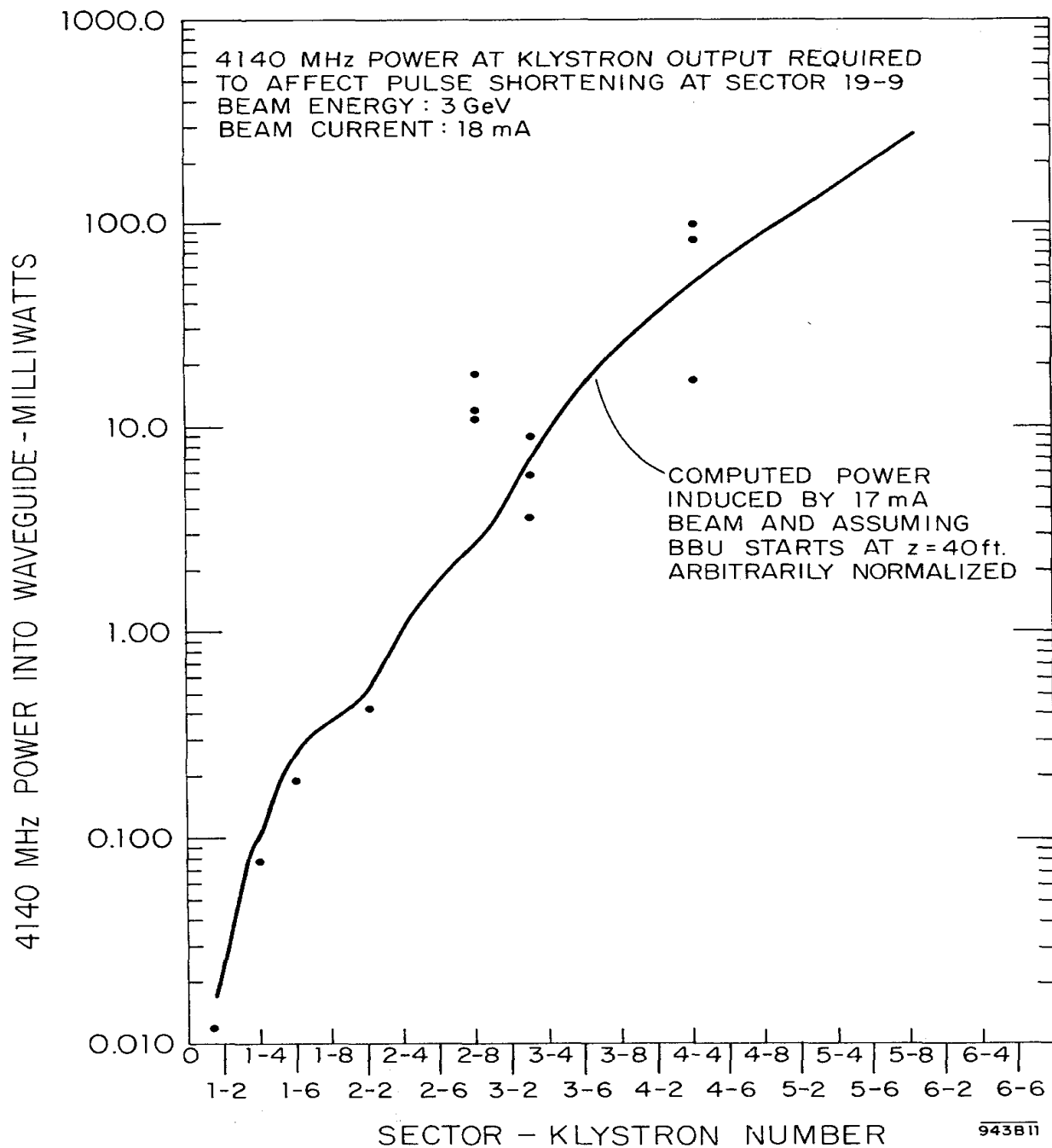


FIG. 11- MEASUREMENT OF KLYSTRON OUTPUT SIGNAL LEVEL RELATIVE TO BBU

7. Klystrons

During the first quarter, a total of 228,000 operating hours was accumulated on high power klystrons, and 303,000 hours were accumulated in the second quarter. The total number of failures in the gallery was 28 in the first quarter and 26 in the second, giving a cumulative total of 130 failures since the beginning of operation of the machine. There were approximately 130 spare klystron tubes, including 12 available for immediate installation as of the end of June.

Driver amplifier klystrons accumulated 39,000 hours in the gallery and nearly 3,000 hours in the test laboratory during the first quarter, and 60,000 hours and 3,000 hours, respectively, in the second. There was one failure during the first quarter, and three tubes that had been removed the prior quarter were tested and found to have failed. Five tubes failed in the gallery and three in the test laboratory in the second quarter.

Main booster klystrons accumulated approximately 3,000 hours without a failure in the first quarter, and one failed during the second period.

No major problems were encountered in vacuum system maintenance.

a. High Power Klystron Operations

The following table gives a 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 12/31/65	-	27,000	-	-	10	297
To 3/31/66	11,000	38,000	13	252	23	272
To 6/30/66	118,000	156,000	16	234	39	256
To 9/30/66	127,000	283,000	15	594	54*	350
To 12/31/66	176,000	459,000	23*	1070	76*	575
To 3/31/67	228,000	687,000	28	1670	104	860
To 6/30/67	303,000	990,000	26	2166	130	1130

* A tube which was thought to have failed in the first quarter of FY'67 was returned by the vendor, at no cost, in operating condition.

b. First Quarter Operation

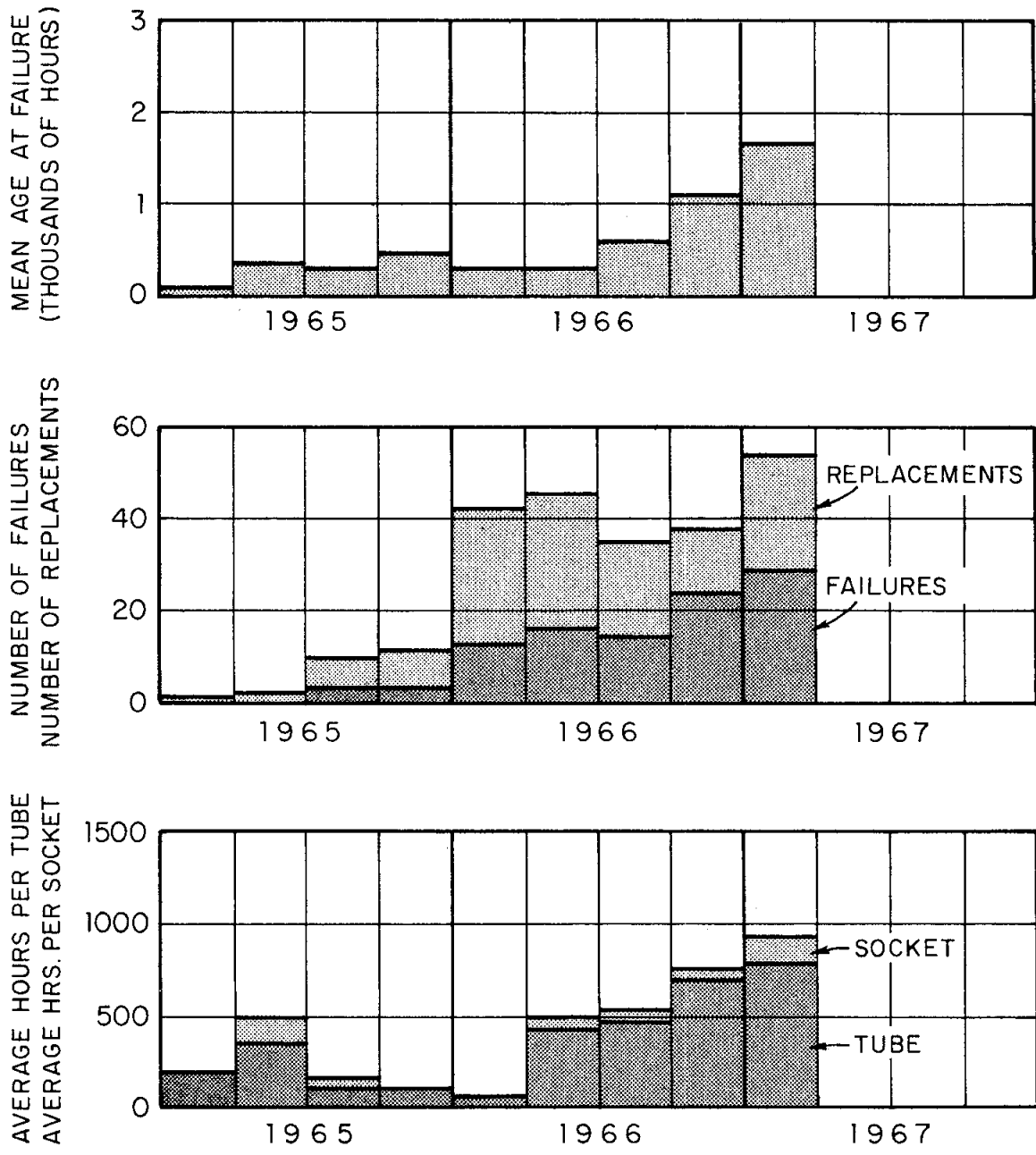
Of the 28 failures in the first quarter, 15 were Sperry tubes and one an Eimac tube procured on a special six tube contract. An analysis of the cause of failure for RCA, Litton and SLAC tubes for that quarter and since the beginning of operation follows:

Table II - Analysis of Causes of Failure by Vendor

Cause of Failure	Litton		RCA		SLAC	
	Quarter	Total	Quarter	Total	Quarter	Total
Temperature Limited	-	1	-	-	1	1
High μk	3	4	-	-	-	-
Faulting	-	2	-	2	-	2
Window	-	2	3	14	-	-
Vacuum	1	2	3	9	1	5
Shorted Filament	-	-	-	-	-	1
High Voltage Seal	-	-	-	2	-	-
Total	4	11	6	27	2	9

In many cases it is difficult to determine whether the failure is caused by a loss of vacuum in the tube resulting in faulting, or whether the faulting and arcing in the gun region is caused by other problems. Hence, no great accuracy can be claimed for the choice of one or the other reason for failure. It is significant, however, that the majority of RCA failures are caused by window problems, and that the single largest cause of Litton failures appears to be high microperveance. The mechanism for this high microperveance is not understood, but is probably similar to the "burning" which was observed on a few SLAC tubes approximately one year ago. Basically, we believe the mechanism is associated with magnetron action in the cathode region. A very small amount of emission from the outside of the focus electrode support can result in bombardment of the same cathode support at some voltages because of the stray magnetic field in that area. This results in enhanced temperature and enhanced emission. The phenomena is usually accompanied by apparent breakup of the backswing voltage and excessive heating of the anode.

As seen from Table I, the average tube life at failure was 2166 hours, the average life at failure for all tubes since the beginning of operation is 1130 hours. The variation in klystron operation since the first turn-on of the machine is shown in Fig. 12. The age distribution of tubes installed in the gallery is given in Fig. 13



943A12

FIG. 12- KLYSTRON QUARTERLY OPERATING EXPERIENCE - ALL HIGH POWER KLYSTRON VENDORS, THROUGH FIRST QUARTER

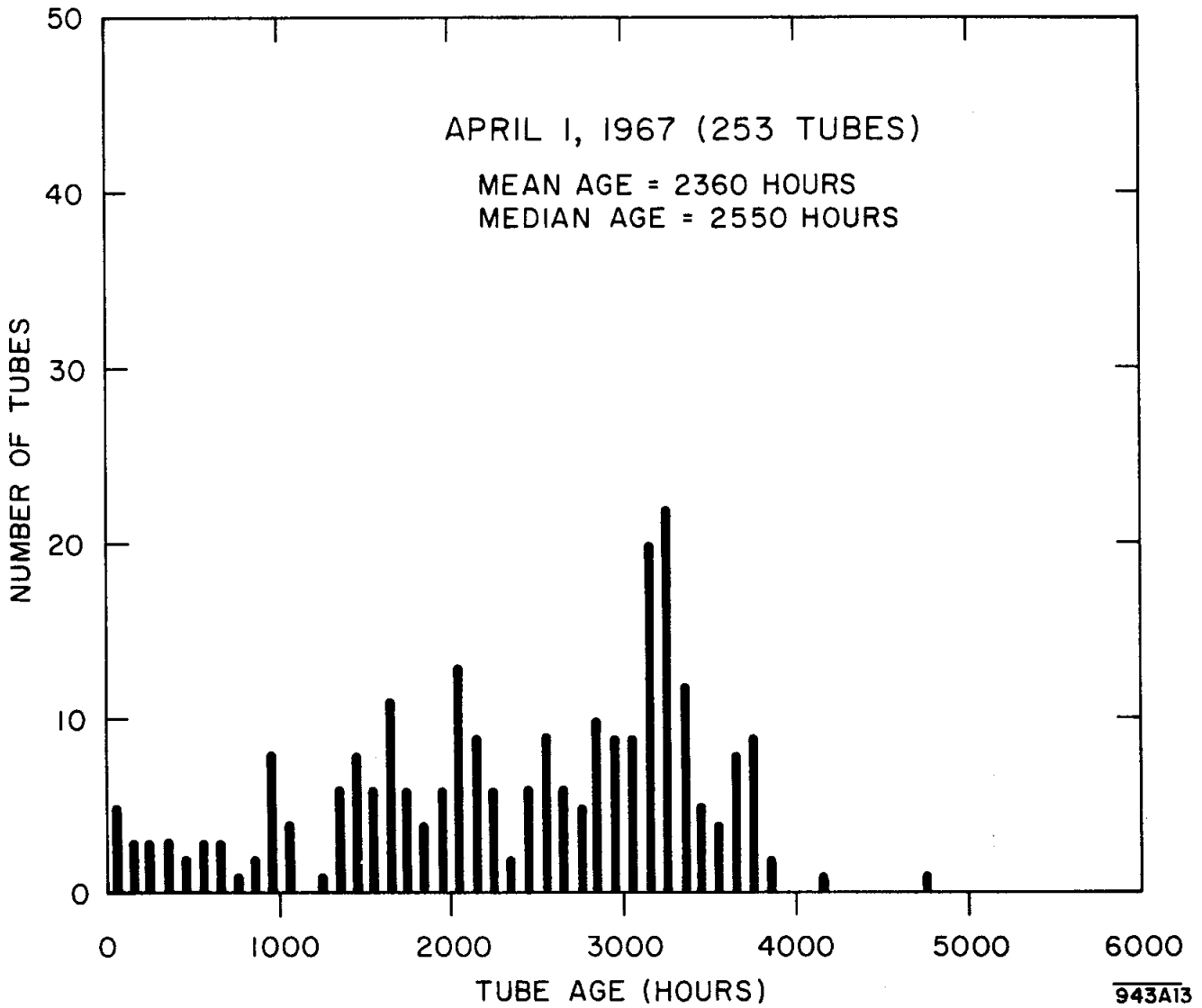


FIG. 13- KLYSTRON AGE DISTRIBUTION (ALL VENDORS)
 IN 100-HOUR INCREMENTS, FIRST QUARTER

943A13

which shows a mean age of 2360, a median age of 2550 hours. It is interesting to note that since the last quarter of 1966, the median age has increased by 730 hours, whereas the average operating hours per socket was 930 hours. We also have approximately 80 tubes with a life in excess of 3000 hours, so that the klystron mean-time-to-failure (MTTF) of 3000 to 4000 hours predicted last quarter is probably realistic and may even be low. The mean number of operating hours between failures for the quarter was approximately 8000 hours, up from 7500 hours for the last quarter which again gives us reasonable assurance that the predicted MTTF is realistic.

c. Second Quarter Operation

Sixteen of the 26 failures in the second quarter were experienced on Sperry tubes at an average age at failure of approximately 2050 hours. Window problems continued to account for the majority of RCA failures, and for between 30 to 50% of the failures of either Litton or SLAC tubes. Litton tubes still experienced "burning," resulting in high microperveance. Considerable time is being spent both by Litton and SLAC personnel to understand the problem better and, hopefully, to achieve corrective measures in the near future. As shown by Table I, the average tube age at failures is still increasing in spite of the fact that we are still experiencing a number of early failures. One of the RCA window failures was undoubtedly caused by malfunction of the vacuum protective circuit in the positron source area.

Figure 14 gives the operational statistics of all tubes installed in the machine since the first turn-on. It is significant that the total number of tube removals from the gallery remains substantially equal to twice the number of tube failures. The number of operating hours per socket and per tube is still increasing as well as the average life at failure and average age of tubes installed. Figure 15 shows the age distribution of tubes installed in the gallery with a mean age of 3360 hours and a median age of 3575 hours. One tube has exceeded 6000 hours of operation.

Figure 16 gives a plot on probability paper of the failure experience combined for RCA, Litton and SLAC tubes. It indicates a probable MTTF of between 5000 and 6000 hours at the present operating levels. During the last two quarters, half of the sockets were operated at $100 V_{ref}$ (215 ± 5 kV), the other half at $110 V_{ref}$ (235 ± 5 kV). At present, there appears to be no significant difference between the number of failures at the two operating levels. With the evidence at hand, no difference in failure rate or MTTF can be detected between sectors running at the two stated operating levels. The predicted MTTF on probability paper may be

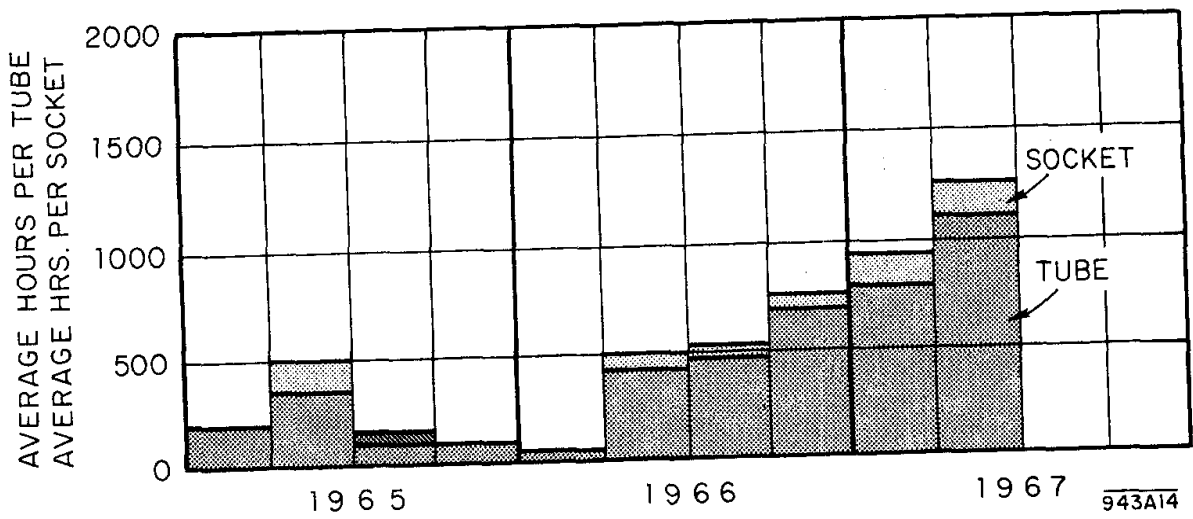
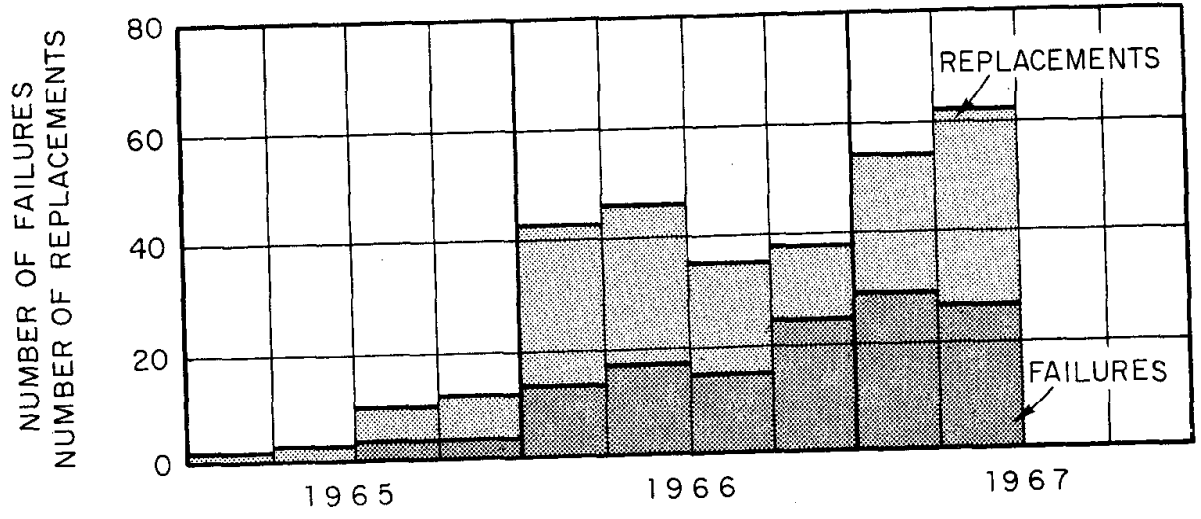
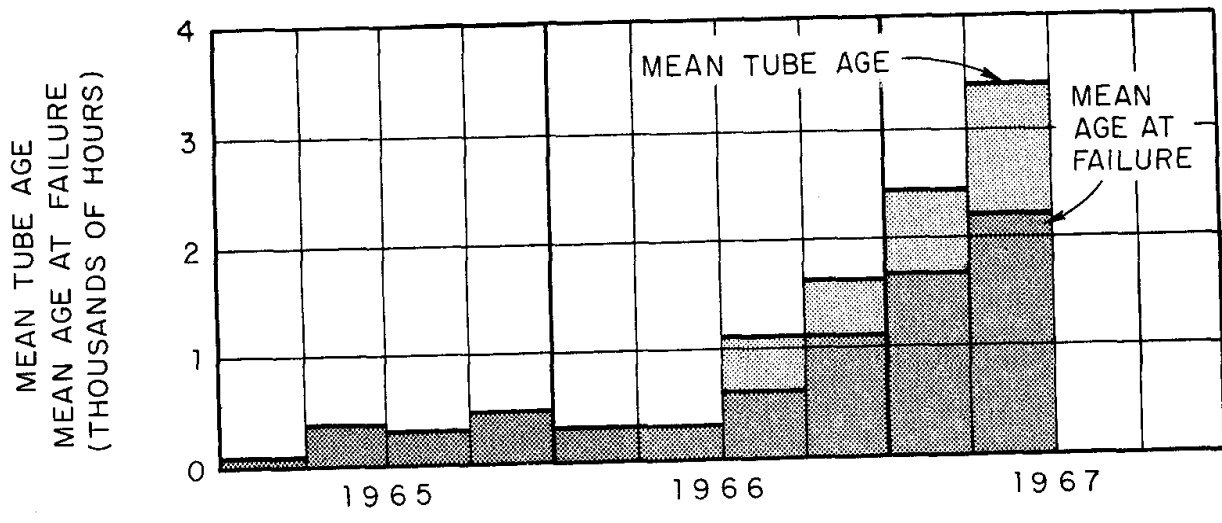


FIG. 14- KLYSTRON QUARTERLY OPERATING EXPERIENCE - ALL HIGH POWER KLYSTRON VENDORS, THROUGH SECOND QUARTER

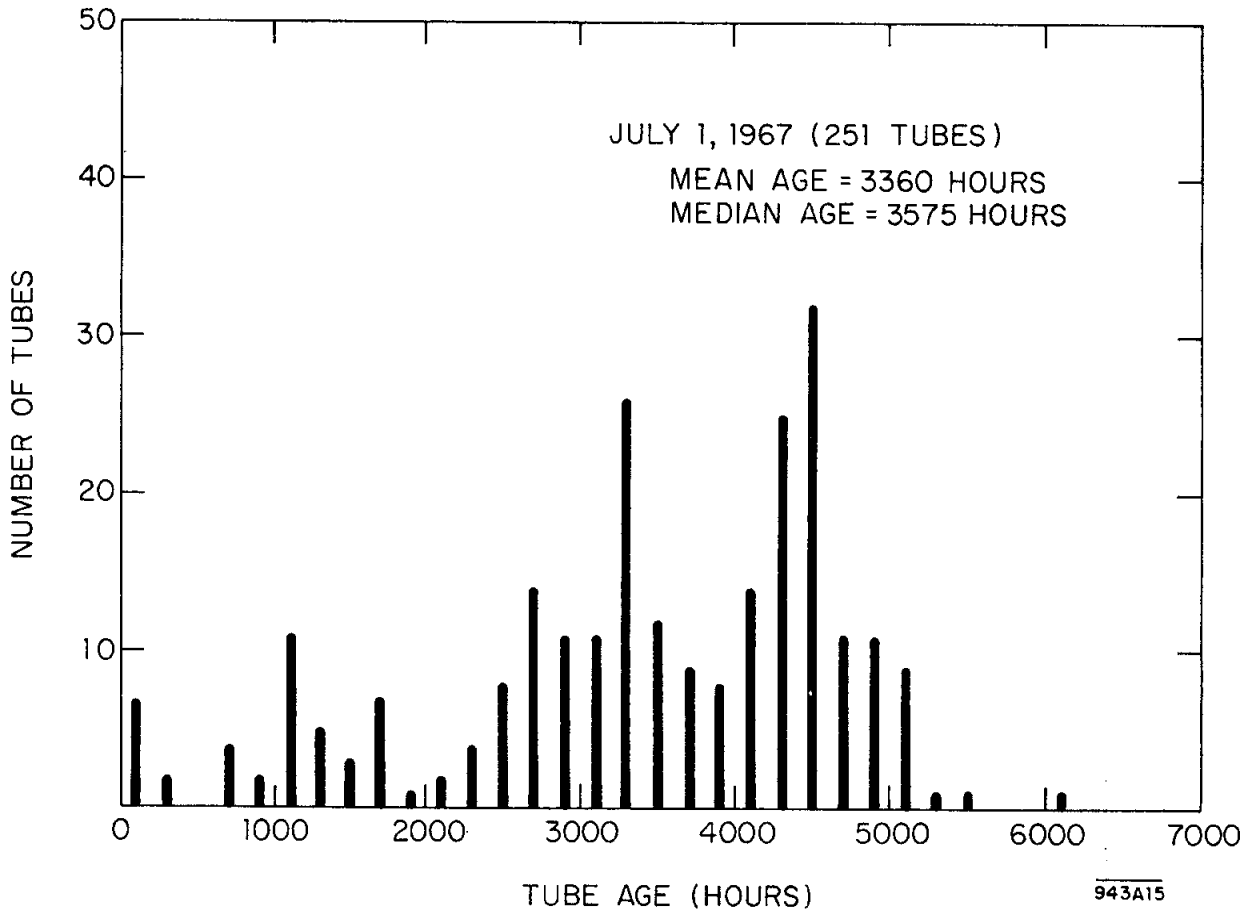


FIG. 15- KLYSTRON AGE DISTRIBUTION (ALL VENDORS)
 IN 200-HOUR INCREMENTS, SECOND QUARTER

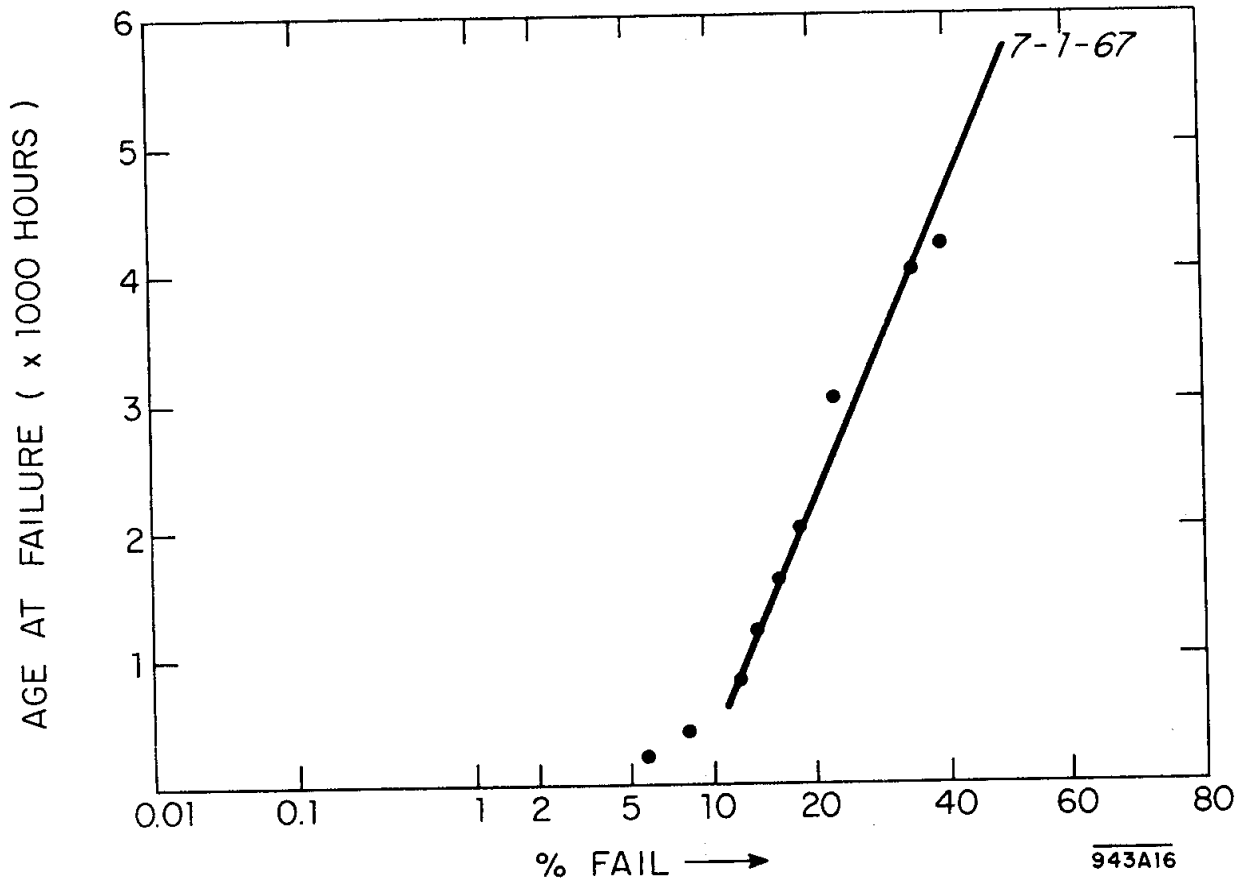


FIG. 16- COMBINED KLYSTRON FAILURE EXPERIENCE FOR RCA,
LITTON AND SLAC TUBES

optimistic since only 12 tubes passed the 5000 hour mark, and it is not known whether a sudden rash of failures may occur during 5000 and 6000 hours.

d. High Power Klystron Maintenance, First Quarter

During the first quarter, 54 klystrons were replaced in the gallery, and in addition to the tubes removed because of failures or suspected tube failures, nine were removed because of pulse tank transformer problems, 10 because of oil leaks, and two because of water leaks. In addition, klystrons were removed from 8 stations to allow the beam break-up experiments to continue.

The number of trouble reports checked increased drastically since the previous quarter; from 310 to 723. Based on the number of operating hours we had last quarter, one failure report for every 570 klystron operating hours, this quarter we had one for every 310 klystron operating hours. We believe that the additional attention required by several stations reflects the fact that the tubes are aging, and we also believe that the comparatively few failures observed were a direct function of the attention given to the trouble reports.

In addition to the trouble reports, approximately 400 stations received preventative maintenance checks which were almost 20% below our goal. Approximately 10% of the stations checked indicated klystron problems, some of which could be solved without removing the tube. Actually, the percentage of tubes found out of specifications during preventative maintenance was not significantly different from that of the previous quarter.

The tube handling was improved by the acquisition of a new fork-lift truck with a much better control of the low speeds necessary to pick up tubes safely. In addition, the lift has 50% more lifting capacity than the old one, and appears to be much more stable in handling. One of the Hov-Air stands has been modified to make the height adjustable, which again simplifies the tube installation and removal from the gallery. This Hov-Air can be towed by the new fork-lift. Thus the overall efficiency of the klystron handling operation appears to have increased considerably.

e. High Power Klystron Maintenance, Second Quarter

Approximately 60 klystrons were replaced in the gallery during the second quarter. Approximately half of these were because of suspected tube failures, a quarter for oil leaks between the tube and pulse transformer tank, and the remainder for miscellaneous reasons.

The number of trouble reports checked in the gallery decreased to approximately 1 per 550 operating hours. The total number of preventive maintenance checks increased, but we were not able to average the 500 hours of operation between preventive maintenance. One of the main purposes of the preventive maintenance is to insure that tubes are not operated temperature-limited. To help analyze the variations, a careful temperature-limited check is now a standard part of the tube runup procedure.

f. Driver Amplifier Klystrons, First Quarter

During the first quarter there were approximately 39,000 hours of driver amplifier klystron operation in the gallery and 3000 hours in the test lab for a total of 42,000 hours. Since the beginning of operation, the total cumulative hours of operation was 93,000 hours in the test lab and 166,000 hours in the gallery. One tube was removed from the gallery during the quarter and was found to have failed. In addition, three tubes which had been removed during the previous quarter were also found to have failed. To date, none of these tubes apparently have failed from lack of emission. Figure 17 gives the history of the quarterly operating experience for the Eimac driver amplifier klystrons used to date. The operating life to failure of the driver amplifier klystrons appeared to be increasing as expected. With almost 260,000 hours of operation and 38 failures, one would expect a mean time between failure of almost 7000 hours. Figure 17 gives the history of tube failures and Fig. 18 the tube age distribution. The latter figure indicates the median age of tubes now in use was 3900 hours; the mean age was 4730 hours.

From a maintenance standpoint, the majority of the problems were solved by continuing work on the modulators by the electronics crew which had apparently overcome the beam pulse flatness problems. As a result, the phase shift during the pulse was within specifications.

g. Driver Amplifier Klystrons, Second Quarter

During the second quarter, the running time meters indicated approximately 60,000 hours of operation for the driver amplifier klystrons. However, a correction was needed on this number because of a modification in modulator operation introduced during the second quarter. On the weekends, the high voltage was maintained on the switch tubes, but removed from the klystron by turning off the trigger. However, the high voltage running time meter continued to count. Accordingly, the real operating time of the driver amplifier klystron in the gallery was probably close to 45,000 hours. Steps were taken to modify the running time meter circuit so the real operating time would again be counted.

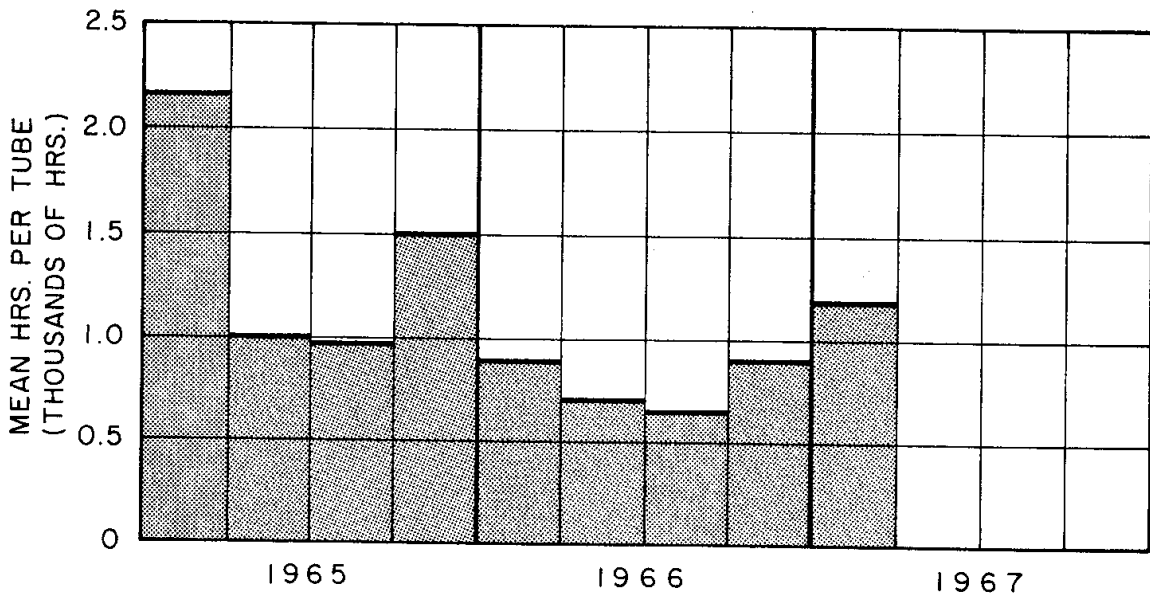
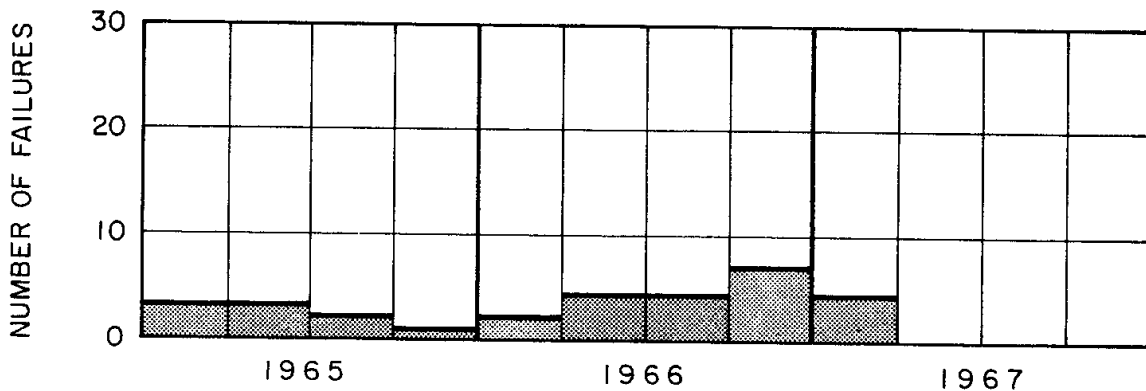
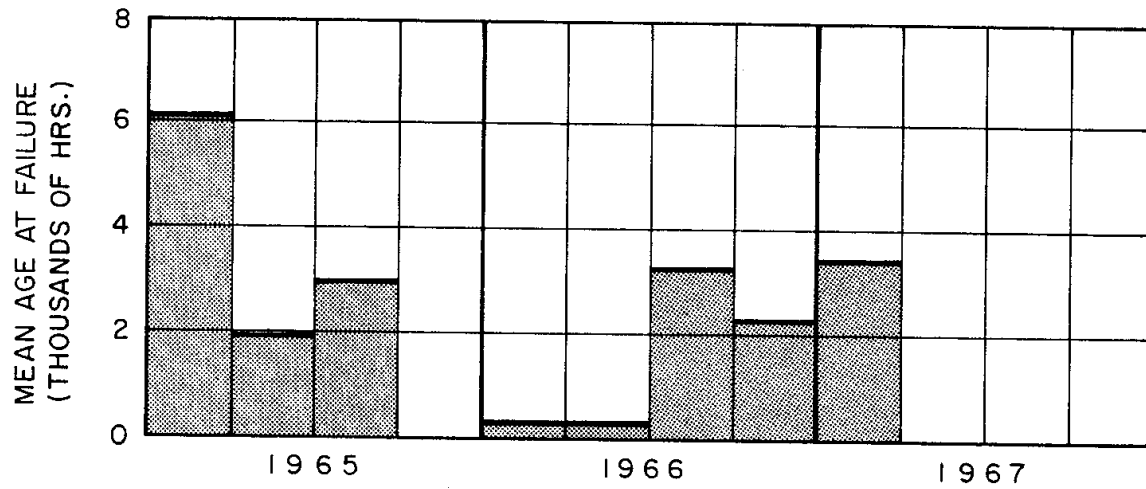


FIG. 17- DRIVER AMPLIFIER KLYSTRON QUARTERLY OPERATING EXPERIENCE THROUGH FIRST QUARTER

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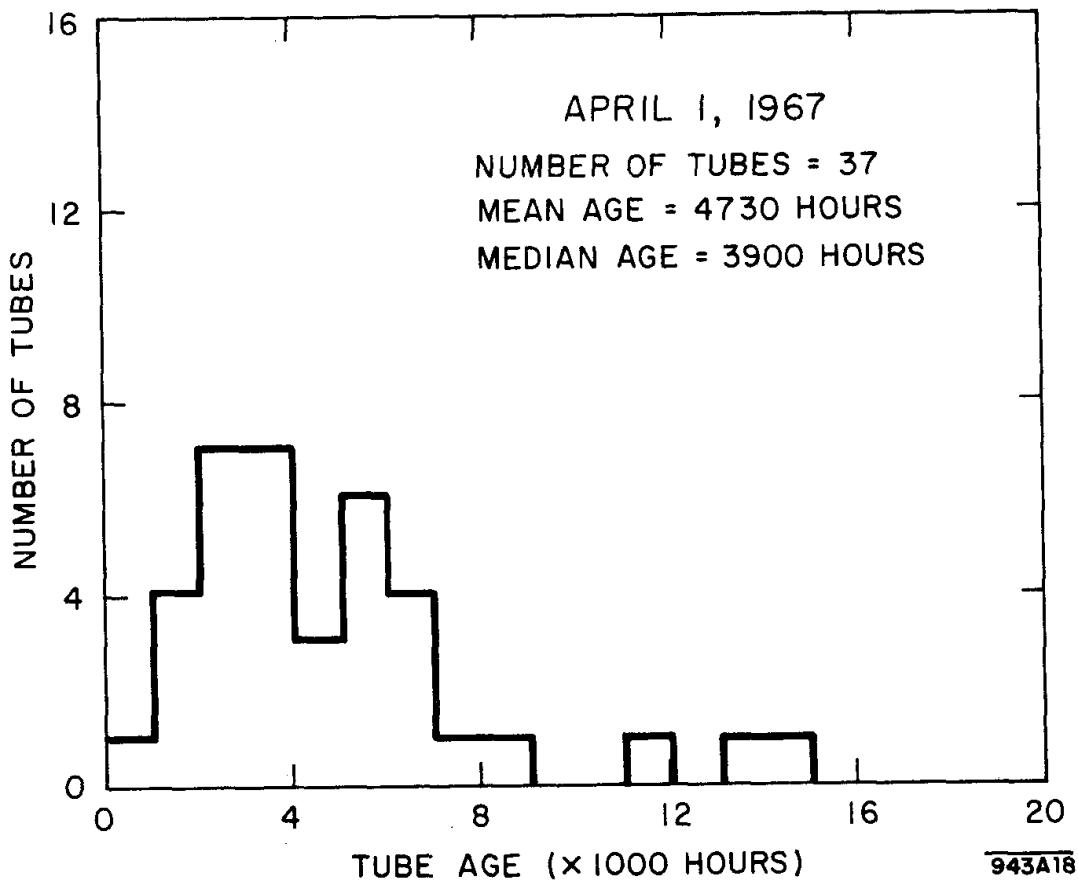


FIG. 18- DRIVER AMPLIFIER KLYSTRON AGE DISTRIBUTION,
 FIRST QUARTER

Four Eimac driver amplifier klystrons failed in the gallery because of a pulse droop that resulted in a large phase shift across the pulse. The average age at failure was 4200 hours. A Litton driver amplifier klystron failed shortly after installation for reasons which were not clear, but which resulted in low emission. In addition, three Eimac driver amplifiers failed in the test laboratory at an average age of 13,125 hours. Figure 19 shows the driver amplifier operating history including hours per-tube per-quarter, number of failures, and mean age at failure. Figure 20 shows the tube age distribution of the tubes in the gallery.

h. Main Booster Klystron, First Quarter

There were no major problems during the first quarter in operation of the main booster klystrons. However, one of the tubes could not be driven to full saturation because of erosion in the input cavity gap reported in the previous QSR, SLAC Report No. 73, page 38. To improve the stability of this amplifier, the output of the master oscillator was increased allowing both main boosters to be operated at saturation.

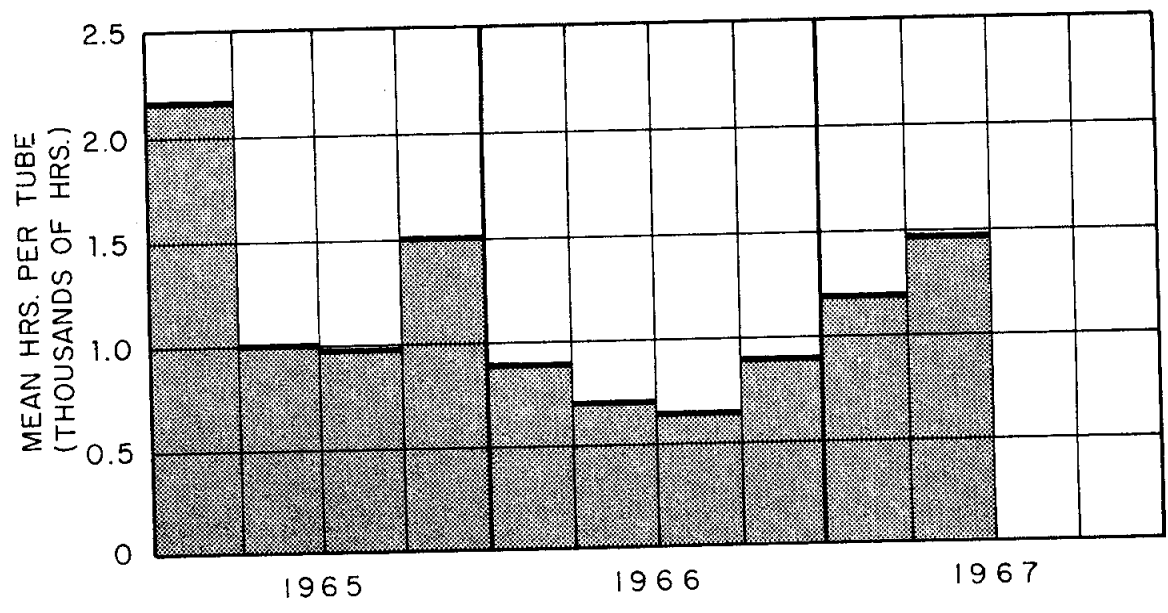
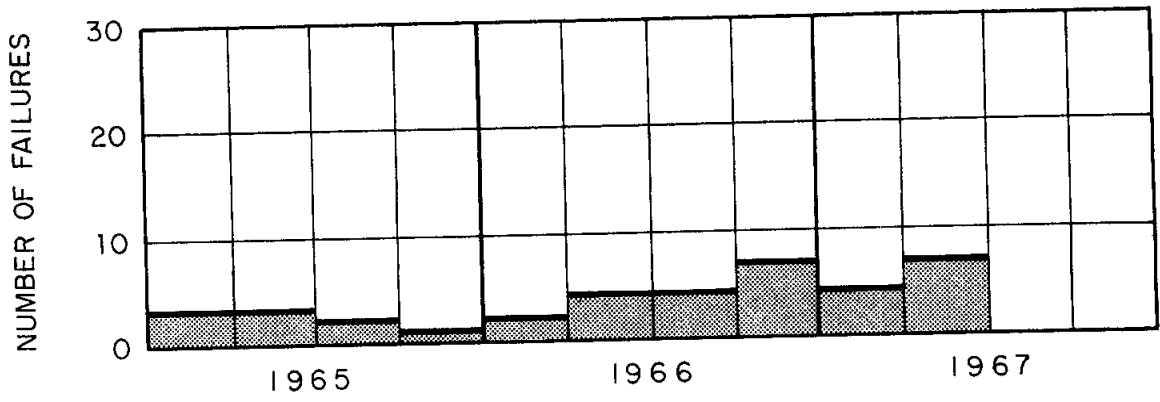
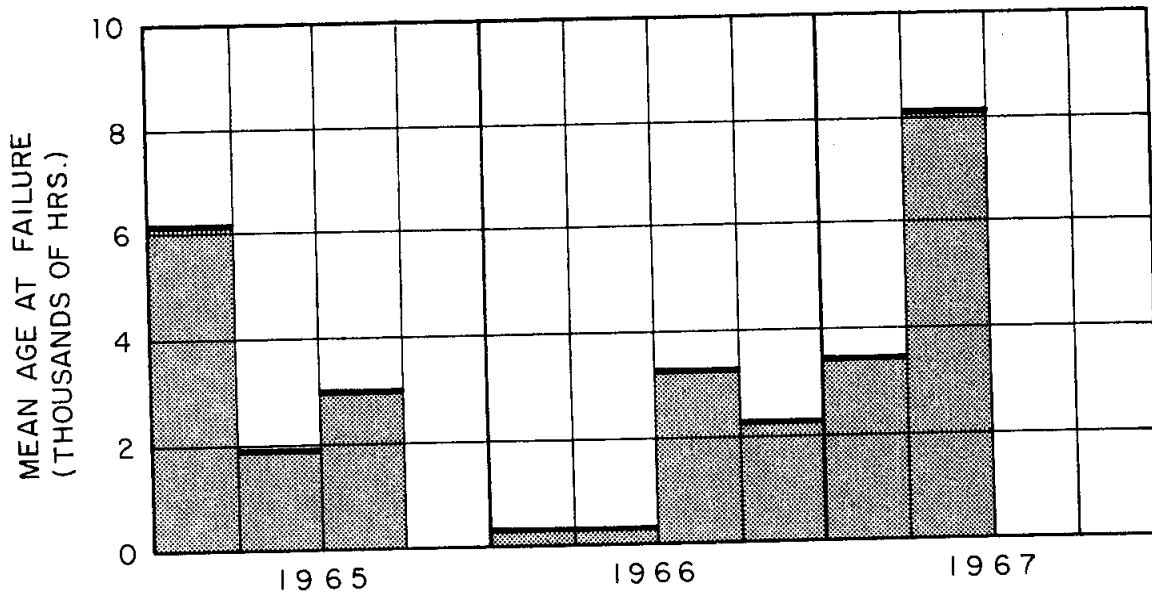
There appears to be a daily body current drift which is small, but constant; high at mid-day, low at midnight. A more stable operation should be realized after the installation, by Electronics, of dc supplies for the filament power and regulated supplies for the focusing coils.

i. Main Booster Klystron, Second Quarter

Main booster klystron operation increased somewhat during the second quarter. We experienced one failure after very few hours of operation. The failure appeared to be caused by arcing in the output cavity which resulted in a leak in the heliarc joint between the tube body and the output window. The initial cause of the arcing was not fully determined, but additional interlocking (arc detector) was ordered for installation for further protection of the main boosters.

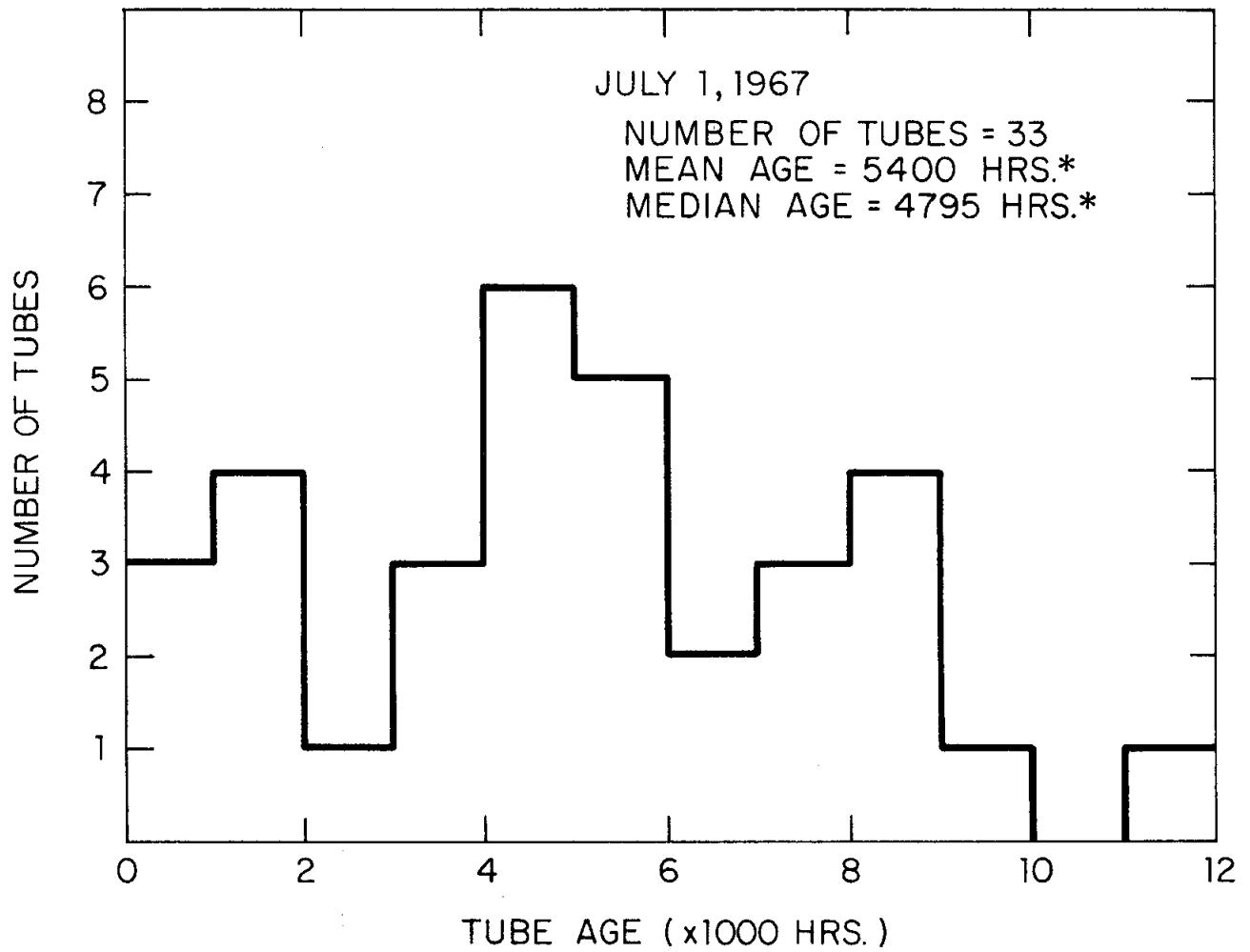
Improvement of the dc power supplies to the main boosters was continued, including an addition of dc filament supply to the number 1 station. This change resulted in a reduction of approximately 75% in output ripple from the main booster. Regulated focusing power supplies will also be supplied to improve further the power output stability.

All components were procured and assembly was well along for a complete spare main booster klystron and carriage assembly. The use of such a spare will allow us to replace a failed tube more rapidly than is possible at present. The present carrier focusing coil assembly will also be modified to allow easier installation.



943A19

FIG. 19- DRIVER AMPLIFIER KLYSTRON QUARTERLY OPERATING EXPERIENCE THROUGH SECOND QUARTER



* THE ACTUAL HOURS ARE PROBABLY BETWEEN 400-500 HOURS
 LESS THAN INDICATED.

943A20

FIG. 20- DRIVER AMPLIFIER KLYSTRON AGE DISTRIBUTION, SECOND QUARTER

In addition, the air cooling used on penultimate and output cavities will be filtered to prevent the deposition of dust in these cavities.

8. Vacuum System, First Quarter

There were no real vacuum problems throughout the first quarter. In general, the base pressure of the accelerator vacuum system continued to improve slightly. The average value of ion pump pressure with no rf on is about 8×10^{-9} torr. Pressures at the klystron windows average about 3×10^{-8} torr with no rf on. With rf on, these pressures are about a factor or two higher.

Drift section letups continued throughout the first quarter on a once-a-week basis to allow ME & F to make quadrupole modifications.

Fabrication of 25 additional thermocouple gauge assemblies were completed and readied for installation on the main 8-inch sector manifolds.

Leak checking and letups for modifications in the positron source continued throughout the quarter.

Sectors 1 and 2 were letup for installation of quadrupole magnets between each 40-foot girder.

Liquid nitrogen usage has continued at an approximate rate of one 600-liter tank per week.

9. Vacuum System, Second Quarter

No major changes occurred in the operation of the vacuum system. The pressure at the ion pumps averaged close to 1.5×10^{-8} torr under full rf operating conditions. Weekly letups of various sectors continued for modifications and improvements of the accelerator pipe including the installation of quadrupoles and work on the positron source.

An additional roughing system consisting of a 50 CFM mechanical pump and a 12-pound cryosorption pump has been tested and shows an overall speed approximately equal to that of the 100% cryosorption systems.

10. Test Laboratory, First Quarter

There were no major maintenance problems during the first quarter, no major component failures and only four sub-booster modulator switch tube failures.

Because of the interest in obtaining higher power from some of our tubes, one test stand was run up to 300 kV at 360 pps. The promising results obtained indicated the need for reliable modulator operation at over 250 kV and one of the stands was being modified. In principle, it will operate one of our tubes with a

perveance of 2 at 300 kV, 360 pps. At the end of the quarter, we had reliably obtained 275 kV, 360 pps and 300 kV at 180 pps. Additional modifications were being made to obtain reliable operation.

11. Test Laboratory, Second Quarter

The klystron testing program continued with five major areas: SLAC tube processing and testing, incoming vendor tube testing, gallery return testing, final test of tubes on pulse transformer tanks for the gallery, and shelf life testing.

A large amount of time was spent in trying to help one of our vendors resolve his problems. Specifically, a vendor engineer spent several weeks at SLAC trying to understand the difference between the behavior of their tubes in our modulator and in their modulator with respect to the "burning" problem. At the end of the quarter, no complete solution had been reached.

Test stand maintenance offered no major problems and the maintenance crew spent considerable time modifying test stand #03 for reliable operation up to 300 kV at 360 pps. This modulator will be used as a vehicle for testing the 40-MW klystrons proposed by SLAC, but will also be a useful vehicle for tests of thyratrons and other modulator components at the higher power levels.

One of the continuing test lab activities is a routine check of permanent magnets when they come back from the gallery. So far, little or no change in magnetic field has been observed. In addition, we have determined the modifications necessary so that magnets initially supplied with Sperry tubes can be utilized with SLAC tubes. Several such magnets will be modified during the next quarter.

12. Modulators

a. Main Modulator

These units continued to operate satisfactorily the first quarter in spite of weaknesses in the main rectifiers and pulse capacitors. Generally, 97% of the modulators are available for operations at any given time. Some of the same problems existed in the second quarter also and oil leaks were experienced in the main rectifier transformers.

b. Main Rectifiers

Three main rectifiers burned out during the first period as compared with five during the previous quarter. The problem was improved somewhat by removal of side panels on all rectifiers which in the past had sometimes resulted in arc-overs from card to card due to dirt and moisture collecting on their surfaces. Also, in case of fire, the damage would be reduced because the amount of combustible material was minimized. As a back-up measure, orders were placed with three companies for small quantities of improved rectifiers for evaluation.

Four main rectifiers burned out during the second period. The damage was generally confined to three cards out of a total of 60 in each rectifier. In each case the cards were replaced and the rectifiers were put back in service.

The damage was minimized because the fire alarm circuits functioned in each case. They removed power, stopped fans and turned in an alarm.

As a backup measure, we received and installed 10 rectifiers from Westinghouse, and 9 from International Rectifier Corporation. These rectifiers operated satisfactorily.

c. Pulse Capacitors

The pulse capacitor situation improved somewhat during the first quarter. Ninety-two capacitors were removed from service in January because of internal defects, 125 in February, and only 25 in March. The high failure rates early in the quarter are not really realistic because many of them had actually deteriorated during the previous quarter and were not replaced until this quarter because we did not have sufficient replacements at that time. Deliveries from the supplier improved both in quality and quantity so that by the end of the quarter we had sufficient spares. However, in order to provide a back-up source, we drew up new specifications for small quantities of improved capacitors to be purchased from each of several manufacturers.

Pulse capacitor failure, however, continued to be our main problem during the second quarter. Twenty-six capacitors failed in April, 38 in May and 52 in June. The primary manufacturer is continuing to provide us with sufficient spares.

As a back-up measure, we ordered small quantities of capacitors from several sources. At the end of the quarter, orders were placed with four companies.

d. Switch Tubes

New contracts for a new set of main switch tubes were signed and by the end of the first quarter new tubes began arriving.

Thirty-five large, single tubes, or pairs of smaller tubes, failed on the accelerator during the first quarter for a total of 48 since May, 1966. The average life among the failed tubes is about 2600 hours. This number is continuing to increase. The average number of high voltage hours on the tubes still operating on the accelerator was about 2100 at the end of the quarter.

Both vendors continued to deliver tubes at a satisfactory rate the second quarter. In fact, our predictions of failure rates were pessimistic so we had more than enough spares at the end of the period.

The failure rate, however, increased from 10 to 20 per month during the second quarter. The total number of failures since June 1966 stood at 99 by the end of the quarter. The average life among the failed tubes was 2646 hours and increasing with time. The average life among the tubes still operating on the accelerator was 3064 hours at the end of the quarter.

A problem that cropped up during the second quarter was large grid voltage spikes that seem to appear with age on some of our thyratrons. Some tubes would develop voltage spikes of as much as 80 kV on their grids and these were causing failures in the 500 PF ceramic capacitors in the de-spiking networks.

We tried various schemes to arrest the spikes, or isolate them from the triggering circuitry, so that we might squeeze more life out of the thyratrons. We found that by connecting three thyrite disks in series between grid and ground, the spikes were attenuated to about 1/3 of their original amplitude without appreciably affecting the trigger pulse. This circuit was installed on thirty old tubes on the machine as a test.

e. De-Q'ing SCR Assemblies

The manufacturer of these assemblies reworked some of them during the second quarter by the addition of RC transient suppression capacitors across the SCR's. Unfortunately some of the resistors were too small in power dissipation and were mounted too close to the gate transformer. The resistors burned up and also burned the gate transformers.

We installed larger resistors on the other side of the heat sink on a fiberglass board. Unfortunately a few of the capacitors shorted causing increased current in the resistors and overheating to the point where the fiberglass board caught fire.

After several fires started in this manner, and after studying the failure data, we decided the RC circuits were not doing much good so we disconnected them to prevent future fires.

f. Modifications

The modification of the M-K package and modulator interlock chain which interrupts the trigger to the modulator instead of the main contactor (as mentioned in the previous SLAC QSR) was made on most stations during the first period. It has shown itself to be a very desirable modification both from the standpoint of minimizing erosion of the contactor contacts and wear and tear on the modulator. The modification was completed during the second quarter. This modification has resulted in less wear and tear on the modulator contactor contacts.

The shunt trip coil modification of the main HV circuit breaker (also mentioned in the previous report) was installed in many modulators. This modification proved very desirable because without it we set the circuit breaker magnetic trips on sensitive so that they would always trip out for any HV fault in the modulators. This was done to save the main rectifiers in case the main contactor fails to open due to eroded contacts welding together or to a malfunction in the relays feeding it. Unfortunately switch tube faults would trip the circuit breakers under these conditions and with the large number of modulators on the line and only a few operations people available to reset them it was difficult, at times, to keep all of them on the line, even though switch tube faults are very infrequent for any given modulator. The modification was completed in all modulators during the second quarter and resulted in less circuit breaker tripping and smoother accelerator operation.

A third modification that was run into most of the modulators was a fire alarm circuit. This system utilizes several short runs of twisted steel wire strategically located throughout the modulator. The twisted wires are separated with plastic insulation which melts at a predetermined temperature, thus closing the circuit. The circuit is arranged so that, in the event of a fire, the high voltage is turned off, fans are stopped, and an alarm is turned into the Stanford Fire House, and to the Central Control Room. The installation was completed in all modulators during the second quarter. It proved so sensitive that many false alarms were turned in and steps had to be taken to reduce sensitivity. This modification has resulted in less wear of the modulator contactor contacts.

13. Research Area Instrumentation

a. Beam Instrumentation

Installation of off-line instrumentation for experimental beams No. 2 and No. 7 comprised most of the activity during the first quarter of the year. The basic instrumentation for the Central Beam, up to the second focus, was started during the first quarter. All of the instrumentation for these beams was completed during the second quarter.

b. Beam Current Monitoring

Preliminary design was completed and a prototype built for a shielded amplifier assembly for the Central Beam toroid. After tests in the lab, it was decided to test the amplifier/toroid assembly under operating conditions in End Station B. These tests were still in progress at the end of the second quarter, but indicated that a sensitivity of 10 μ A peak current can be achieved. This is approximately 10-20 times the present sensitivity of the BSY system. Design was started on a system for a general improvement of sensitivity for all BSY toroids, with a final objective of 2-10 μ A peak.

Cable equalization for all cables in the BSY Current Monitoring System was begun. Problems with the computer program used for equalizing network design prevented completion of this job, but some cables have been equalized. Work was continuing to improve the program.

A toroid charge-per-pulse monitor was completed and installed in the DAB. This unit will also be used for precise calibration of the BSY current monitoring system.

c. High-Power, High-Z Slits and Collimators

The slit/collimator control system (including Computer Control) debugging was completed and the system is fully operational.

Using in-line calibration data obtained with the electron beam and current monitors, the laser beam, and optical alignment procedures, the High-Power and High-Z Slits and the Collimators were realigned during the two quarters.

d. Beam Dump

The highest average power deposited by the electron beam was 240 kW into the A-Beam Dump. The window and dump performed successfully.

e. Radiolytic Gas Evolution

Further measurements of the rate of evolution of free hydrogen in the gas space on top of the dump water system surge tank were taken. Approximately 90% of the energy entering the dump is directly dissipated in the water; the remaining 10% is deposited in the copper plates, and a very small part is lost from the system due to radiation.

Hydrogen evolution was measured for electron energies of 10.0, 12.0, and 16.3 GeV, pulses of 6×10^6 to 5.4×10^7 g-rads, and average power into the dump ranging from 20 to 170 kW. The average rate of evolution was 0.3 liters H_2 /(MW sec). This corresponds to $G(H_2)_{av} = 0.14$ molecules H_2 /100 eV.

Two systems were considered for safe disposal of the hydrogen: 1. A catalytic recombination system, and 2. A dilution-chemical, removal-holding-venting system. The first system was adopted.

Preliminary testing of a catalyst for recombining the hydrogen with oxygen was successfully completed. Temporary recombiner systems were installed and are operating at the A-Slit, A-Beam Dump, and Beam Dump East surge tanks. Hydrogen and oxygen sensing equipment was evaluated and tested. The tests were completed and two reliable and reproducible systems were found.

Design of the final recombiner systems was completed and production of the first recombiner (to be installed in the A-Beam Dump radioactive water loop) started in May.

14. Research Area Electronic Systems

a. Machine Protection Interlock System

Design and packaging of the Interlock Selectors were completed, and production of the A-Beam selector was started. Logic design for the main interlock logic was essentially complete by the end of the second quarter.

The existing interlock system was converted to independent operation; i. e., each interlock turns off only the beam causing the trouble. Changes in certain signal processing devices were also being made as required by the new interlock system. These include the Temperature Detector Chassis, Ion Chamber Integrating Detectors, and the like.

b. Spectrum Instrumentation

Tests on the video spectrum analyzer in the BSY indicate that most of the cable pick-up noise is generated at the spectrum analyzer itself. New shielding was designed and was being installed.

A preliminary design was made for a new current integrator for the spectrum monitor (tune-up monitor). The present sensitivity is a $10\text{-}\mu\text{A}$ average current. The new circuit will provide about ten times that sensitivity. In addition, thin ion chambers instead of secondary emission foils were proposed, and these should provide another factor of ten in sensitivity. The ion chambers were designed.

Design of the spectrum drift indicator was started. This sub-system of the spectrum analyzer will allow slow drifts in spectrum and transmitted current to be monitored.

15. End Stations Personnel Protection System

The Emergency Stop System was installed and checked out. Stop controls were provided in all critical areas of the Research Yard.

The illuminated End Station warning signs were procured. The audible alarm, a buzzer, associated with these signs was not loud enough to give sufficient warning. An ordinary automobile horn was tried because this "sound" had not been used previously at SLAC, at least in these areas. The automobile horn would not operate over extended periods of time, however, because of heating. As a result, a special, heavy-duty ac horn was purchased at the end of the second quarter and was being tested. Two of these horns should cover an End Station easily.

16. Research Area Experimental Activity and Support

The search for new particles experiment using the first two sections of the muon beam in End Station B ran during the first quarter and was completed in early March. Work was completed on the beam and detector system for the study of the μ -p inelastic scattering experiment which began in March and continued to the end of the second quarter.

The development and checkout of the quasi-monochromatic γ beam in the central outlet of the B-beam was in operation during both quarters. Operating experience led to much developmental change on the geometry of this beam. Installation and modification work on this beam was also performed to prepare for the study of photoproduction of boson pairs.

The neutral particle experiment, one part of a three-part proposal, was run in the K_0 beam in End Station B, during both quarters.

Construction of the charged particle beam planned for use with the 82-inch bubble chamber was nearly completed by the end of the second quarter and initial checkout runs with the beam were scheduled to start by the end of June.

In End Station A, the first quarter was devoted to, successively, the checkout with the beam of the 8-GeV spectrometer, the 20-GeV spectrometer, the two-meter streamer chamber, the 1.6-GeV spectrometer, and various pieces of beam line equipment. Following the checkout, beam time was devoted to secondary particle production survey with the 20-GeV spectrometer and to experiments on electron-proton elastic scattering, a survey experiment on photon-meson production processes at backward center-of-mass angles, and a study of photoproduction of forward angles using the 20-GeV spectrometer. Experience during the running of

these experiments led to many changes to beam line components within the End Station, in the shielding and beam line components downstream of the End Station; and to arrangement of components in Beam Dump East. These changes provided for a steady increase of allowable beam power in the second quarter, and by the end of the period, powers of up to 70 kW were being maintained through the Station and into the dump. Further increases in power were expected to be dependent on other changes to the beam line.

II. ACCELERATOR AND RESEARCH AREA
EQUIPMENT DEVELOPMENT

A. ACCELERATOR PHYSICS

During the first quarter, because many of the accelerator systems were being completed a large number of summary papers was presented at the U. S. National Particle Accelerator Conference hold in Washington, D. C., March 1 to 3, 1967.

Those papers pertinent to this section are listed below:

Z. D. Farkas, C. J. Kruse, G. A. Loew, R. A. McConnell,
"Design and Performance of the SLAC RF Drive System"

W. B. Herrmannsfeldt, M. Anderson, D. Connell, B. Hooley,
J. G. Niforopulos, R. J. O'Keefe, E. J. Seppi, J. M. Voss,
H. A. Weidner and J. K. Witthaus,
"Precision Alignment of a Large Beam Transport System"

E. V. Farinholt, Z. D. Farkas, H. A. Hogg,
"Microwave Beam Position Monitors at SLAC"

G. A. Loew,
"Electron Linac Instabilities"

R. H. Miller, J. Berk, T. O. McKinney,
"The Electron Gun for the Stanford Two-Mile Accelerator"

R. F. Koontz,
"Multiple Beam Pulse Capability of the SLAC Injector"

These papers have been printed in "IEEE Transactions on Nuclear Science," June 1967, Volume NS-14, Number 3, together with other papers contributed from SLAC to the conference.

1. Injection

a. Electron Gun

During the first quarter, beam profile and phase-space measurements were completed on a Model 1-3 gun. This gun was made by the Mark III gun laboratory for SLAC, and, from the point of view of beam optics, it can be considered a typical Mark III gun. Phase-space measurements were made on a 4.4 micro-micro perveance beam ($42 \mu\text{A}$ at 45 kV). Ninety percent of the beam current from a space-charge limited cathode could be found within a phase-space area of less than 21 milliradian-cm. The beam from a temperature-limited cathode measured less than 16.3 milliradian-cm.

A focused image of the grid structure in the first anode hole was obtained in the beam analyzer. The gun was then returned to the Mark III gun lab and the grid structure was removed. The cathode was recoated and converted during the second quarter, and the beam measurements were repeated as discussed below.

A high voltage isolation power transformer was fabricated and tested. This completed the instrumentation of the gun lab test modulator Model 3-1. This modulator now allows operation of either a bombarder or an indirectly heated cathode with an injection voltage up to 100 with adequate room on the 100 kV deck for test instrumentation. A vacuum manifold with a window for observation of an operating cathode in a SLAC gun was also completed the first quarter.

Production of spare gun parts continued with priority given to cathodes, filaments and vacuum envelopes.

The gun testing facility was improved during the second quarter. A vacuum chamber, containing a beam collector with a 7052 glass window to permit cathode temperature measurements on an operating gun, was constructed. A solenoid coil outside the vacuum chamber can be energized and its armature, inside the vacuum chamber, removes the Faraday cup from the beam path so that a direct view of the cathode becomes possible.

Beam optics data were taken on the latest version of the SLAC gun (4-2A) with the electron beam analyzer. The gun was also tested at 80 kV dc for 3 hours. The tests were performed with a thoriated tungsten cathode.

The SLAC computer program for gun design is being translated from BALGOL to PL/1 for the IBM 360-75 computer.

The main injector was let down to nitrogen for maintenance on February 12; the gun vacuum was kept better than 1×10^{-8} torr during that time. A subsequent test after work was completed, showed that emission has suffered, perhaps from exposure to some contamination introduced into the accelerator vacuum system. However, a test 4 weeks later showed the gun to be back to its usual emission characteristic. By July 1, the gun had operated for 8300 hours.

Beam optics tests were continuing on the gun for the Mark III accelerator and the prototype superconducting accelerator. The gun grid was removed, the cathode recoated and converted. Then this gun was placed on the beam analyzer to record the effect of the grid mesh removal. This test was still in progress at the end of the quarter.

Construction was started on a gun emission test apparatus to be located in the accelerator housing by the standby gun. Periodic checks on the standby gun may then be made without taking separate instruments and supplies down the accelerator housing ladder to perform this necessary test.

b. New Gun Modulator

The cabinet for the new gun modulator was procured and delivered during the first quarter. The two critical chassis are the bias switching chassis and the pulse amplifier chassis. These were constructed and undergoing testing and modifications in order to meet specifications. All low level transistor logic, sensing, and pulse generation circuitry were completed and on hand. It was anticipated the system should be completed the second quarter and installed on the machine in early fall. However, personnel vacations and other work slowed down the progress on this activity during the second quarter. The services of three job shop assemblers were available for approximately one month, and they were used to construct two gun filament controllers, the modified control panel, a spare ac regulator chassis and the relay logic chassis. The control logic network for automatic turn-on of the modulator was designed, but awaited technician time for assembly. Because of numerous multiple beam requirements, the height and width channel capacity of the modulator was increased from three channels each to six channels each.

c. Transformer Development

In constructing the high power pulser during the first quarter, much research was done on transmission-line type transformers. In the course of this work, a new coaxial cable-type transmission line transformer capable of transferring pulses with rise times as short as 2 nsec across a high voltage gap of up to 100 kV was developed. This would allow the gun to be pulsed from ground level rather than having all of the electronics on high voltage decks. The transformer will be studied further for other possible uses.

d. Beam Knockout System (BKO)

The 40 MHz subharmonic resonant BKO system was tested and was being used by experimenters. In general, the system worked well and had enough power to produce single bunches of electrons. However, the phase stability was somewhat inadequate and efforts were being made to measure and possibly correct the effects of slow phase drifts which required frequent readjustments of the system.

Components for remote phase control of the 40 MHz, single bunch, system arrived during the second quarter. In the meantime, phase control from CCR was obtained by means of a temporary set-up. Phase stability measurements on the system narrowed down the drift problem to the modulator-transmission-line-resonator system. The drift seemed to have been caused by temperature changes in the components which in turn are due almost exclusively to changes in the repetition rate. A new trigger system was designed and installed by the Instrumentation and Control group to provide a standby trigger to the modulator 25 μ sec late, when the prompt trigger is off. Thus the duty cycle of the modulator is held constant and the temperature and phase are stabilized.

Also during this second period, the 10-20 MHz Beam Knockout System modulator was completed and installed by the Modulator Group. A resonator designed to operate at 10 MHz was constructed and installed in the tunnel, and the system was put into operation. A full system test was performed from injector to end station and the resulting chopped beam consisting of a train of 3 to 5 electron bunches appeared to meet specifications.

e. Second Generation Guns and Modulator Systems

Much new work has been done in the electro-optical field in producing very fast rise time, high power laser pulses. Combining such systems with a photoelectric cathode could conceivably produce a very fast gun with a much wider variety of possible pulse configurations than the conventional hard tube pulsed triode gun. Preliminary studies of the feasibility of such a system were underway during the first quarter.

Some preliminary information was assembled on photocathodes during the second quarter. From this information it appears that the present state of the art on photocathodes makes them quite compatible with our gun requirements. The first object is to develop a photocathode gun with satisfactory optics. Illumination and modulation schemes will be developed later.

f. Sector 27 Video Instrumentation

In order to improve monitoring of the injector beam, an instrumentation package consisting of three special toroids was being constructed during the second quarter

for installation in the Sector 27 drift section. These toroids have the following properties:

(a) Single turn toroid:

This toroid has an upper frequency band limit of approximately 1 GHz and will be used to observe the fine structure of the beam when the Beam Knockout systems are in operation.

(b) High quality accelerator toroid:

This is a standard accelerator toroid terminated in a high quality 50 ohm match in the housing and brought directly to CCR on a 1/2-inch Prodelin cable. It will faithfully reproduce the beam pulse envelope with an intrinsic rise time limit of less than 20 nanoseconds. It will be sensitive down to approximately 1 milliamp of peak beam current.

(c) High sensitivity accelerator toroid:

This is also a separate standard accelerator toroid but it is terminated into a higher resistance to increase the sensitivity.

A low noise wide band amplifier with four tubes is mounted directly on the toroid and provides 40 dB of amplification. The output is transmitted directly to CCR by means of a Prodelin cable. The rise time of this system is about 0.5 μ sec and it can display a beam of less than 1 μ amp peak.

The entire system will be installed in the accelerator housing during the next quarter.

2. Drive System

a. Main and Sub-Drive Lines

The 3 dB hybrid at the end of the Main Drive Line which divides the 476 MHz power between the two end stations was modified by the external addition of resonant coupling and isolation elements, so that it also acts as a matched power divider in the frequency range 0 to 50 MHz. The overall attenuation from the Main Booster

to each end station is as follows:

<u>Frequency</u>	<u>Attenuation to End Station A or B</u>
10 MHz	11.0 dB
20 MHz	13.5 dB
30 MHz	15.0 dB
40 MHz	18.0 dB
476 MHz	36.0 dB

The 30 sub-drive lines continued to operate without troubles. The sub-drive line transfer switch located in the injector area was inadvertently switched under power and damaged during the first quarter. Cleaning, replacement of damaged contacts, and selective plating restored the switch to operating condition. A spare unit is now on hand.

b. Positron Phase Shifters

Three booster amplifiers for the Positron Pattern Signal were added in Sectors 1 through 10 in the first quarter. These amplifiers now assure correct operation of the phase-switching system at the maximum rate of 360 pps.

c. Sub-Booster Klystrons

The Eimac contract was completed during the second quarter. The new contract with Litton Industries did not progress as planned during the first quarter. Difficulties were encountered in the areas of gain, power output and stability which were still present during the second quarter, but their magnitude had been reduced. The predicted production and delivery schedule was not entirely met.

d. Drive System Control Unit

By the end of the first quarter, the master oscillator rack modifications had been completed and tested. No further work was indicated in this rack assembly.

e. Fast Phase Shifters

Fast phase shifters were added to the Sub-Booster IØA Units in Sectors 11 through 30 during the second quarter. The phase shifters, employing a ferrite switching circulator, are of the same design as used in Sectors 1 through 10. When a trigger pattern is made available to these phase shifters, they can be used for electron beam deceleration in the latter part of the machine. This mode of operation may make it easier to steer and focus multiple beams having widely different final energies.

f. Experimental Studies of the Accelerator Sections

Measurements of the Q of the Beam Break-Up mode have been performed on a six-cavity constant-gradient sub-assembly by feeding it from the back end through a C-band wall coupler preceded by a C-band slotted line.

Two different values, Q_x and Q_y , were obtained as shown below:

$$Q_x = 3500 \text{ at } f = 4139.6 \text{ MHz.}$$

$$Q_y = 8300 \text{ at } f = 4140.7 \text{ MHz.}$$

Q_x was obtained from VSWR data with the C-band coupler in the plane of the constant-gradient input coupler, Q_y , with the C-band coupler turned 90° .

Measurements were also performed in the first few cavities in order to understand the variation of coupler mode polarization with frequency. Figure 21 is a plot of axial electric field amplitude as a function of azimuthal angle for different frequencies.

3. Phasing System

a. Isolator, Phase-Shifter, Attenuator (IØA) Units

One spare standard IØA unit was modified during the first quarter, by changing the phase-shifter motor and adding a readout potentiometer, to make a spare Sub-Booster IØA unit.

The eight IØA units in Sector 27 were modified to permit the phase shifters to be controlled individually from the CCR for vernier adjustments of beam energy. Control is effected by means of a small stepping motor which can be coupled to the phase-shifter by energizing an electromagnetic clutch. Operation of the automatic phasing system in this Sector is unaltered. Control and relay panels in the CCR and the instrumentation and control alcove were being built. Control wiring will be completed next quarter.

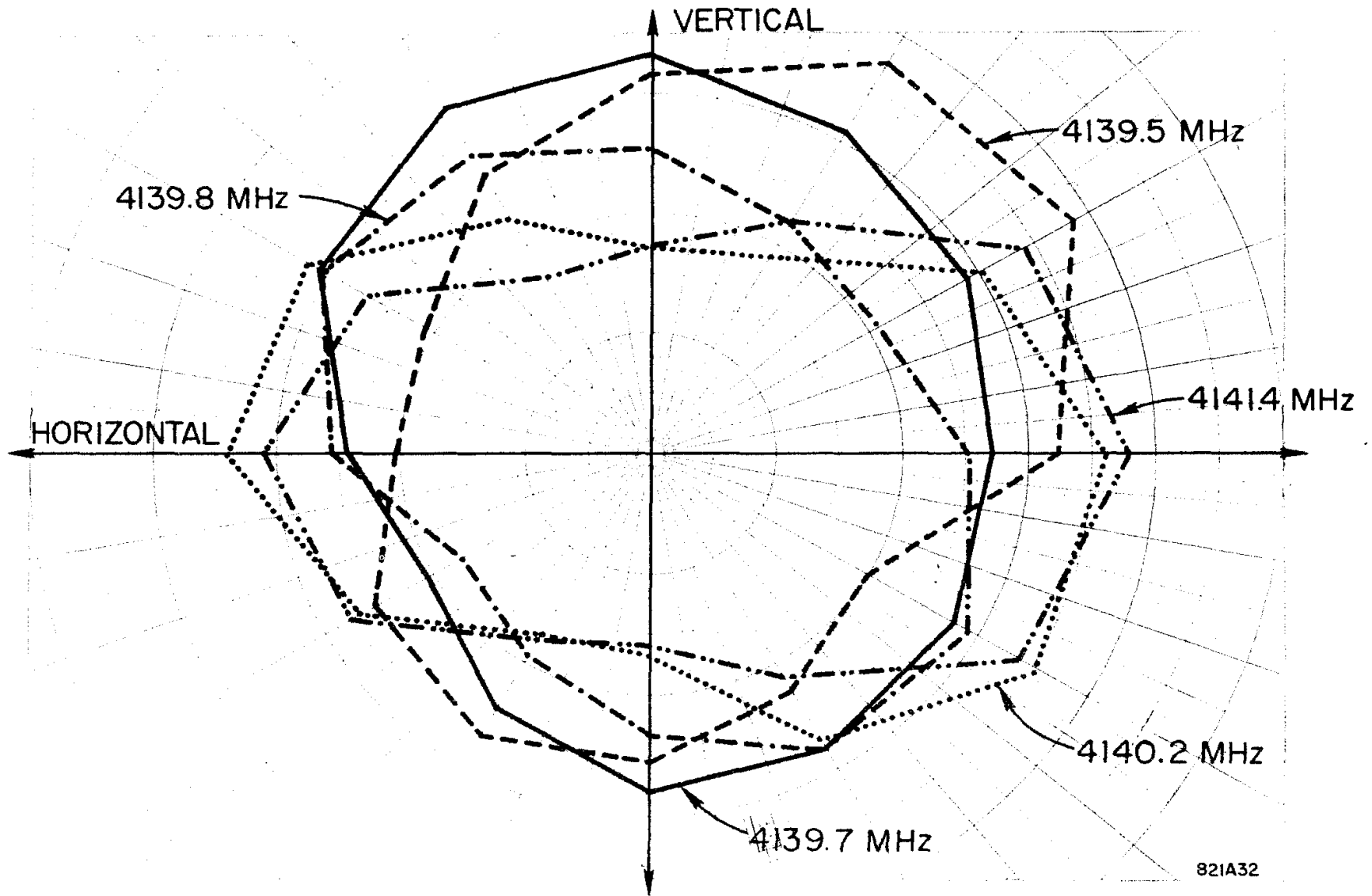


FIG. 21- AXIAL ELECTRIC FIELD AMPLITUDE AS A FUNCTION OF AZIMUTHAL ANGLE IN FIRST ACCELERATOR SECTION CAVITIES AS A FUNCTION OF FREQUENCY. (DATA TAKEN AT 1/4-INCH RADIUS WITH METAL BEAD USING FREQUENCY PERTURBATION METHOD.)

The control relay panel for the special IØA units in Sector 27 was installed in the instrumentation and control alcove during the second quarter. Wiring was almost complete. The system will be put into operation during the next quarter.

b. rf Detector Panels

No more switched attenuators had been fitted by the end of the first quarter, although the two modified rf Detector Panels continued to operate very satisfactorily. The reason is that high power latching ferrite circulators, which were just coming onto the market, offer a better solution to the problem of reducing the range of power applied to the thermionic diodes. These can be used to form fast-acting, phase-compensated attenuators which can be switched in the time interval between accelerate and standby pulses. Use of a fast-switching attenuator will ensure that the diodes are always protected from the high power klystron pulses. This should increase diode life and permit the minimum beam current for phasing to be reduced by a factor of 3, as well as eliminating the diode unbalance problem. A latching circulator was ordered.

The evaluation of a fast-acting, phase compensated attenuator continued during the second quarter. A high power latching ferrite circulator was procured and tested for phase stability and switching speed. It was found that the differential phase shift between the two alternative paths through the circulator changed by less than 3° as the temperature was increased from 80° to 140° F. A special driver circuit which provided the required switching pattern was designed and built.

This circuit switched the circulator to the low attenuation path during a period which bracketed the "accelerate" pulse on the first time slot, returning the circulator to the high attenuation path at all other times. The rf switching time was found to be about $10 \mu\text{sec}$.

The feasibility and cost of building an integrated stripline package containing the circulator, attenuator and phase compensator were being studied.

c. Programmings and Electronics Units

Some phasing troubles during the first quarter were traced to the appearance of false triggers at gated voltmeter inputs, when the klystrons were running at 360 pps. The spurious inputs were eliminated by the addition of local grounds on the outer conductors of the coaxial trigger cables.

A beam detector circuit was designed. This will monitor the beam-induced signal video output from one thermionic diode. The circuit will inhibit phasing if the beam-induced signal in the first time-slot drops below the level corresponding to a

1 mA beam, or if the beam pulse repetition rate is a submultiple of 60 pps. The circuit will permit the phasing program to continue as soon as the minimum beam conditions are re-established.

The rf Detector Panel differential video output was to be amplified by a $\times 10$ amplifier mounted on the same printed circuit card as the beam detector. The amplifier output will be transmitted to CCR.

During the second quarter, the switching logic of all Programmers was modified to permit stepping through the phasing program without setting klystrons to standby. A previous modification with this intention was not successful because Programmer relay timing permitted an instantaneous contact closure which was sufficient to pull in the "set-to-standby" relay in the MTMSCL panel.

A printed circuit prototype of the beam detector circuit mentioned above was constructed and tested. This circuit is intended to stop klystrons being misphased by operation of the automatic phasing system when the beam current or beam pulse repetition rate is too low. The printed circuit board also contains amplifiers which will be used in transmitting phasing signals to CCR. Some further work is required before the design is finalized.

4. Beam Position Monitors

a. In-Line Beam Position Monitors

The Beam Position Monitor Detector Panel and Steering Power Supply Control Units in Sector 28 were temporarily replaced in the first quarter by units which were modified as follows: (i) the diode balancing potentiometers in the Detector Panel were motor driven, (ii) a switching system was added such that the CCR control which disconnects the rf position signals in the Detector Panel also switches drive signals from the Steering Control motors to the Balancing Potentiometer motors. This modification enabled diode balancing at a particular current to be done from CCR. Standard equipment was reinstalled after tests were completed.

It was decided during the second quarter that the Controllers for the Steering Power Supplies would be replaced with redesigned units at the same time as the remote balancing system for the Beam Position Monitor thermionic diodes was installed. Redesign was in progress.

b. End-Station Beam Position Monitor

The copper tube adjacent to the beam position sensor was coated with Kanthal during the first quarter to damp the spurious resonance which was observed when

the monitor was installed in End Station A. At present there are no plans for further beam tests on the monitor.

5. General Microwave Investigations

a. Klystron Filters

Work continued during the first quarter on 3 types of filters, designed to be placed at the outputs of the high power klystrons to suppress signals at the two frequencies known to predominantly stimulate beam break-up, viz. 4140 and 4428 MHz. The first type of filter has four cylindrical resonant cavities, iris-coupled to the broad walls of modified S-Band waveguide. Design work on this filter was completed. It has relatively narrow stop bands covering the two frequencies of interest (about 16 MHz at 40 dB rejection). The filter length, which is about 14 inches, cannot be reduced because of inter-cavity coupling. A vacuum prototype was constructed and was tested during the second quarter.

The second type of filter employs quarter-wave resonant stubs in waveguide WR 187, loading a piece of WR 229 waveguide which propagates the fundamental 2856 MHz power from the klystron. This filter has slightly better stop-band widths than the iris-coupled cavity filter, and can be made about 6 inches long. A vacuum prototype will be constructed and tested.

As a third approach, a corrugated-ridge-waveguide filter was being investigated. Preliminary tests indicate that such a filter can easily have a stop-bandwidth of 500 to 1000 MHz, with a rejection greater than 60 dB. However, internal waveguide dimensions are much reduced, and it is feared that breakdown at 2856 MHz will be a problem.

A vacuum prototype of the quarter-wave resonant stub filter was built and tested at low power during the second quarter. It has two stop-bands, each approximately 25 MHz wide at 40 dB rejection, centered at 4140 MHz and 4428 MHz. Center frequency and higher order mode rejection are greater than 60 dB. The VSWR at 2856 MHz is less than 1.1:1. If high power tests are successful, a minimum of four filters will be built and installed in the output waveguides of the klystrons in the injector and the beginning of Sector 1.

It was found that the resonant stub filter was both cheaper to make and superior in performance to the cylindrical, resonant cavity, iris-coupled filter, so work on the latter was discontinued.

A vacuum prototype corrugated-ridge waveguide filter was also completed. Attenuation of the TE_{20} mode was too low for the filter to be effective.

Work is continuing on a low priority basis.

b. Klystron Coupler

A directional coupler which has a 20 dB coupling ratio at 4140 MHz, but which has a secondary arm cut-off frequency of 3 GHz was designed and cold-tested during the second quarter. A model which can be operated at high power and in high vacuum will be built and used to make sensitive measurements of spurious outputs from klystrons at the main BBU frequency.

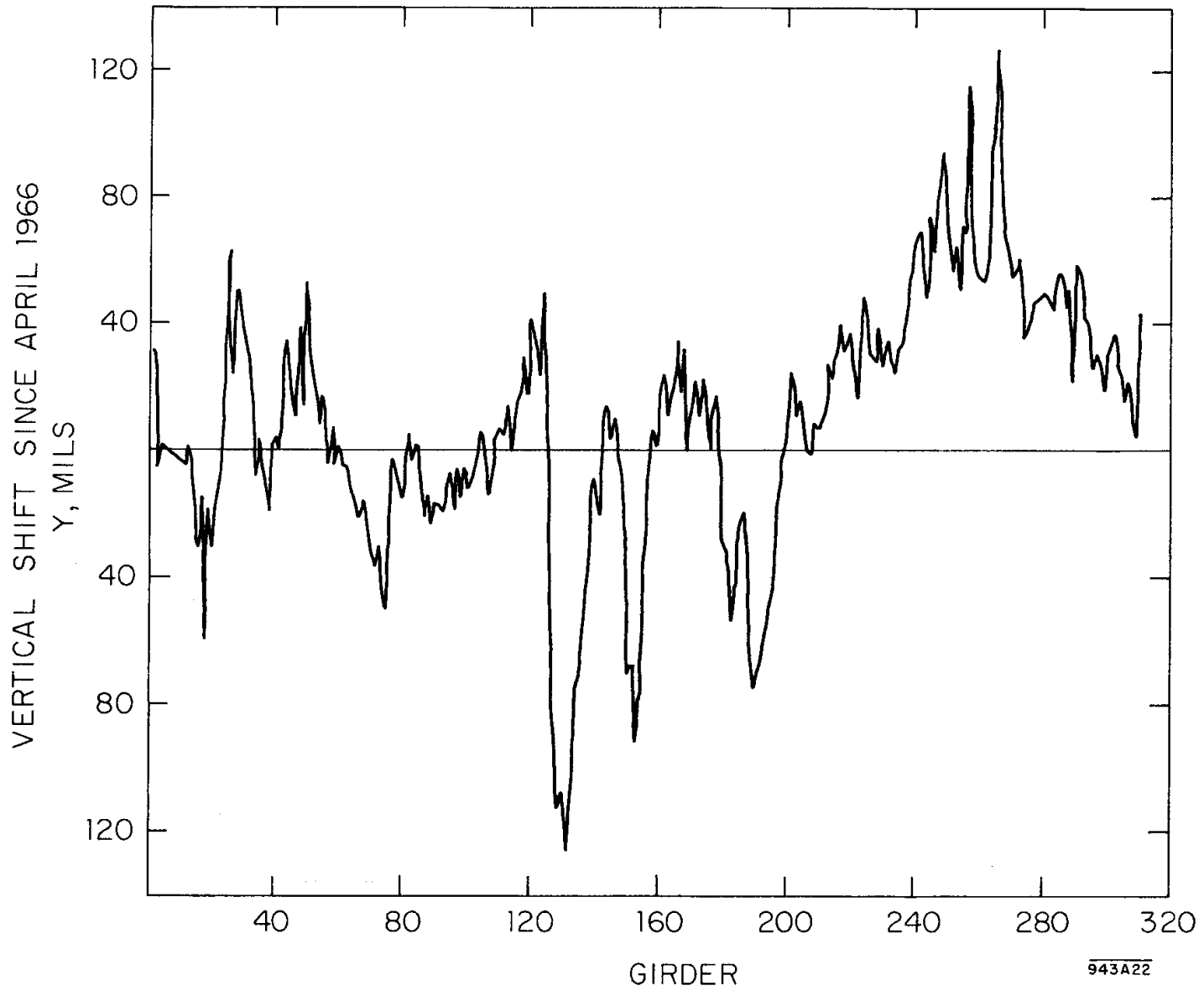
c. Design Studies in Connection with Beam Break-Up

A constant-gradient input subassembly was modified during the first quarter such that the endplate hole was enlarged from $2a = .752$ to 1.300-inches and the thickness increased from .763 to 1.500 inches. At C-band it was found that the maximum longitudinal electric field before and after the modification remained the same, but filling the hole with absorption material decreased this field by about 20% at 4140 MHz and by about 30% at 4153 MHz. In addition, two eight-cavity structures with two different disk hole sizes (1.2 and 1.115-inch diameter) were completed, together with the associated input and output couplers and the transition piece between the sections. C-band bead measurements are in progress on the composite structure.

6. Optical Alignment System

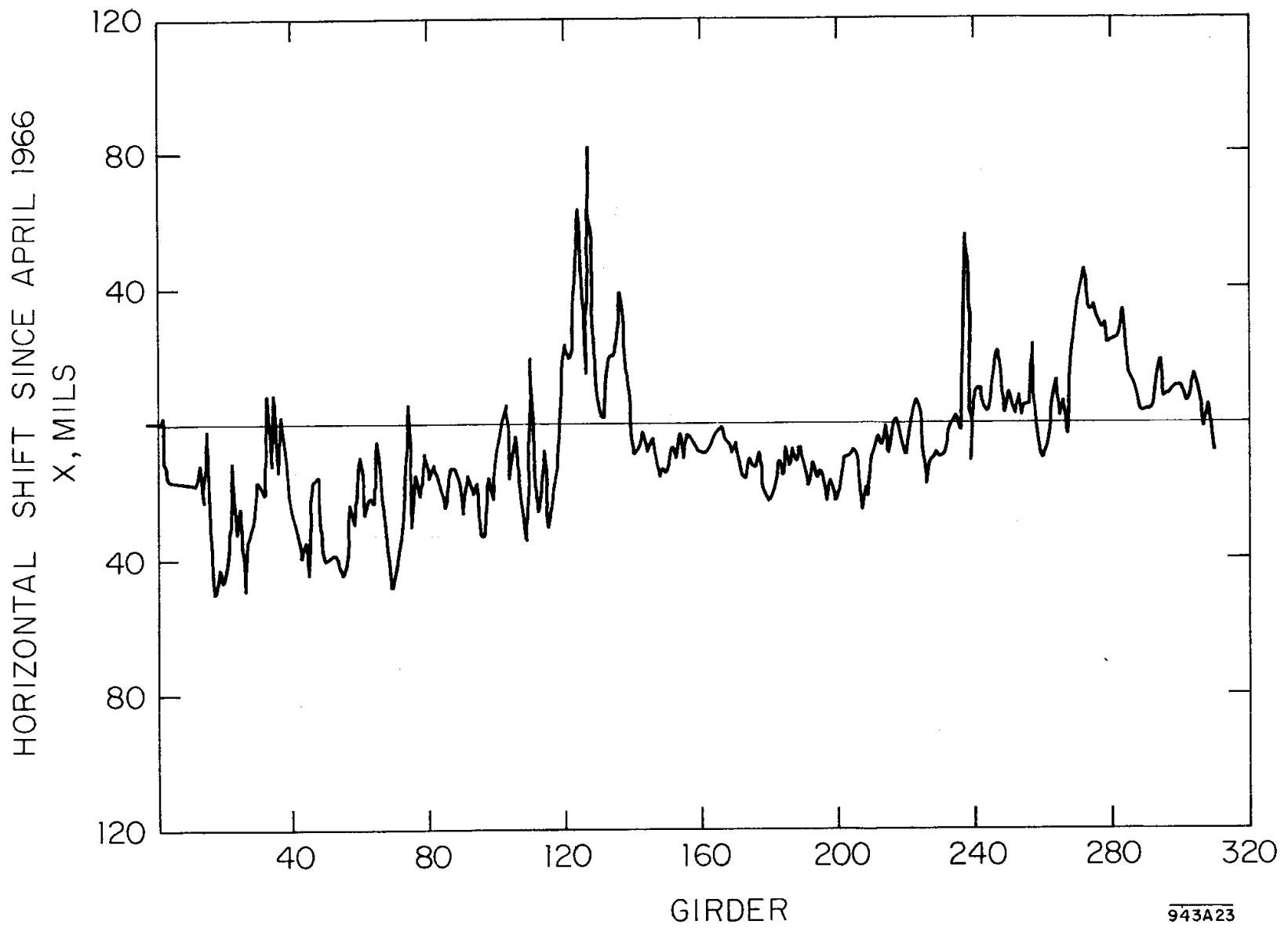
a. Realignment

The third complete realignment of the accelerator was accomplished during the first quarter and the fourth during the second. The maximum total excursion from April 1966 to the end of the first quarter was ± 3.0 mm vertical and ± 2.0 mm horizontal. The complete results showing total accumulated displacements from April 1966 to the end of June 1967, are given in Figs. 22 and 23. A report entitled "Precision Alignment Using a System of Large Rectangular Fresnel Lenses" was prepared and submitted to "Applied Optics." The authors are M. J. Lee, J. J. Spranza, K. R. Trigger and W. B. Herrmannsfeldt.



943A22

FIG. 22- TOTAL ACCUMULATED VERTICAL DISPLACEMENT



943A23

FIG. 23- TOTAL ACCUMULATED HORIZONTAL DISPLACEMENT

b. Alignment Computer Program

The alignment bookkeeping program was revised during the second quarter and translated into PL/1 for the new SLAC IBM system 360 model 75.

c. Modifications to the Alignment System

The shaft encoders and counters in the alignment room were overhauled during the second quarter by using components of more recent design. It is expected that this work will improve the speed and reliability of the alignment work. In the laser end, a new laser and laser mount were installed. The new laser mount permits quick adjustments and yields better stability. The new laser is a dc excited model which should have improved life-time over the old rf excited model.

d. Light Pipe Application

The unique facility provided by the two-mile evacuated light pipe has never been used for any other application except for the alignment system. It was suggested by several geophysicists that the alignment system could serve as a strainmeter for measurements of earth crust movements. Preliminary studies along these lines continued during the first quarter report period with the result that a proposal was being prepared during the second quarter for support to make an optical interferometer with a 6-km light path. This interferometer could be used to make precision strain measurements over a very long distance.

7. Theoretical and Special Studies

a. Beam Break-Up Studies

Analytical work on the SLAC beam break-up phenomenon, as described in the status report for the last quarter of 1966 and as reported at the Los Alamos Linac Conference, was continued during both quarters. Attempts were being made to correlate various new experimental data with computer results. A review paper on beam break-up already listed in the introduction, was also presented at the 1967 U. S. National Particle Accelerator Conference. Further theoretical work will be published during the next quarter.

A study of steady-state beam break-up in superconducting linacs has also been published. ("Preliminary Estimate of Beam Blowup for a Superconducting Electron Linac," R. H. Helm, SLAC TN-67-6/HEPL TN-67-3, March 1967.)

b. Beam Switchyard

Several special beam setups for the switchyard were added to the beam catalogue during the first quarter. The most important of these defines special conditions for creating a good photon beam. The techniques used on the A-beam side were also extended for the first time to the B-beam. A well-focused beam on the target on the B-side was required and the appropriate magnet settings were added to the beam catalogue. The experimental results agree well with the predictions which, at least in the case of the B-beam calculation, resulted in a better, more stable, spot.

8. Magnetic Measurements

During the first quarter, the Magnetic Measurements group accomplished the following:

a. They completed measurements on the 20-GeV Spectrometer magnets. These included dipoles B-201, B-202 and B-204 and sextupoles S-202 and S-203.

b. The rapid magnet mapper was used to make a preliminary analysis of the 2-meter streamer chamber magnet and the analysis of that data indicated several engineering problems in the mechanical and electronic systems that required solution. These were being modified with further small design changes. The mapping of the streamer chamber magnet with the 5.8-megawatt power supply was scheduled for the second quarter.

c. Preparations were in the final stages for measurement of the 40-inch hydrogen bubble chamber magnet and the mechanical positioning device was tested with the electronic logic.

d. Preparations were also in an advanced state for the measurement of the 54-inch spark chamber magnet.

e. Miscellaneous measurements were made during the quarter on several magnets in End-Station B.

f. Studies on the run-up rate dependence of $\int Bdl$ and B of laminated and solid-core bending magnets were made in the Data Assembly Building using B-300 and the prototype 0.1° pulsed magnet. In addition, more measurements of $\int Bdl$ for various run-up rates were made on B-100 in the DAB.

During the second quarter, the Magnetic Measurements group accomplished the following:

a. They measured and reduced data on almost all of the magnets for the C-beam.

b. Preparations were almost completed for mapping the streamer chamber magnet at 2500 amperes. Measurements are to begin in the next quarter.

c. Mapping of the spark chamber magnet was scheduled to commence upon completion of the streamer chamber mapping.

d. Several measurements were made on experimental magnets in the end station area.

e. The model beam dump magnet to be used in the K-beam was excited and measured.

f. Studies of run-up rate dependence of $\int Bdl$ and B of laminated and solid-core bending magnets were completed and the results will be published at the Second International Conference on Magnet Technology, to be held at Oxford, England, July 11-14, 1967.

B. KLYSTRON STUDIES

Work was continued on the main amplifier klystrons both at Stanford and vendors' plants during the first quarter. The majority of the vendors' work during both quarters concerned improving yield and tube life and solving some of the problems that affect life. At Stanford, we tested an experimental tube up to 300 kV with a power output in excess of 42 MW, and were working on the development of a tube capable of reliable operation at 300 kV. Driver amplifier development work progressed considerably the second quarter and some acceptable tubes were delivered.

1. Klystron Procurement

a. Sperry Subcontract

During the first quarter, the Sperry subcontract was terminated by mutual agreement between Sperry and SLAC. There will be no further deliveries of Sperry tubes.

b. RCA Subcontract

The total deliveries from RCA were small during the first quarter. Their manufacturing troubles were not completely solved. One of the problem areas was still the window, although a new procedure by which the load side of the window is coated after the window is brazed on the tube improved the yield. RCA was continuing on an extensive program of window investigation with the collaboration of their laboratories in Princeton where tests were being carried on with other coatings such as boron nitride and titanium dioxide.

At the end of the first quarter, a series of cathode problems (no emission and temperature limited emission) had developed at RCA and resulted in low manufacturing yield. The problems were under investigation.

The product improvement program initiated earlier (see QSR, SLAC 73, page 52) was continuing, but progress was slow. Various structural design changes were made, but the elimination of the output waveguide tuners had not been accomplished.

During the second quarter a modification to the contract was negotiated with RCA. As a result, the RCA tubes are now covered by an extended warranty. The modification was similar to that previously negotiated with Litton, and insures that all tube failures will be replaced by RCA in exchange for hourly payments to the vendor. The warranty extends through June 30, 1970.

The main additional development work at RCA was directed towards a new collector design to ease the reworkability of the tube. Some tubes were built with the new design. The temperature-limited cathode problems mentioned above were resolved by a change in base metal and a more thorough spectrographic analysis of the base metal.

RCA was continuing work on window problems. At the end of the quarter, they seemed to have solved the immediate processing difficulties through realistic quality control which eliminates questionable windows during tube processing. Obviously, the method is expensive and other design approaches were being investigated to improve window yield.

In addition to the window problems at RCA, there also appeared to be more window failures at SLAC from RCA tubes than from other vendors. Out of 5 RCA failures during the quarter, there were 4 window failures. Two of those were early failures, and one was probably caused by interlock malfunction. The other 2 occurred after approximately 3000 and 4000 hours of operation, respectively. One of these two windows had been salvaged approximately 2000 hours earlier by removing a metal deposit which had gathered near the edge of the window opposite the window transition. A similar metal deposit accumulated after that and apparently caused the failure; the other window had pretty well disappeared when the tube was removed. RCA was continuing work to understand the mechanism of failures with the aim to improve window life.

In addition, RCA performed some tests on tube operation at higher powers. They took one of our standard tubes in a permanent magnet and were able to operate it at 270 kV at a reduced duty cycle (60 pps), with a power output of 27.6 MW and an efficiency of 33%.

c. Litton Subcontract

Deliveries of Litton high-power klystrons were slow during the first quarter mostly due to a series of cathode problems associated with sparking and gassing. It was determined that tubes faulting in the Litton modulators will also fault in the SLAC modulators.

Another problem area was the high second harmonic output still being observed on several Litton klystrons. The majority of the tubes showing excessive second harmonic could be corrected by dimpling the outside of the output waveguide, which appeared to have a resonance at the second harmonic, between the waveguide

transformer and the output window. If this dimpling process did not decrease the second harmonic output sufficiently, Litton added a low pass filter in the output waveguide between the window and the output flange.

Litton tubes evidenced a phenomenon which we call "burning," which appeared on a number of the tubes delivered the second quarter as well as on some of the tubes already installed in the gallery. The "burning" phenomenon appeared to be a critical function of modulator pulse shape, and as of this writing, had not been observed in test at Litton. A similar phenomenon was observed on a few SLAC tubes over a year ago, but only when the tubes were operated in permanent magnets.

The "burning" manifests itself by radical increases in tube perveance which is accompanied or preceded by breakup of the inverse beam voltage. It was believed to be caused by emission from the cathode support area which at certain voltages causes additional heating of the cathode support by magnetron action in the stray field of the permanent magnet. It is conceivable that this action increases the cathode support temperature to the point where sufficient emission during the main portion of the pulse results in pulse heating of the anode shell. The shell can then in turn emit and cause the pulse breakup observed on the inverse beam voltage.

At present, the above explanation of the phenomenon does not account for all the observed problems, and Litton had not yet found a reliable solution to the "burning" problem by the end of the second quarter. This problem is obviously extremely serious for Litton, because it caused rejection of 3 tubes during acceptance tests at SLAC, and accounted for a reasonably high percentage of Litton failures.

Other minor problems were observed during the acceptance tests. These were, in general, of a mechanical nature, and could be corrected by Litton personnel prior to completion of acceptance tests at SLAC.

d. SLAC Klystron Development

Stanford also experienced a rash of cathode problems and/or gassy tubes during the first quarter. Several tubes required excessive heater power and even then still tended to be temperature limited. It was since discovered that in some cases at least, a modified focusing electrode was probably responsible for the problems. The reason for the extreme gassiness in most cases was not clear, and a careful review of all manufacturing techniques was initiated. Some joints which are susceptible to virtual leaks were being eliminated and heater coating techniques were being reviewed and modified.

Several beam testers were built and tested to confirm the validity of the eventual magnet field reversal tests which we intend to pursue with beam testers. Although the power output is acceptable (80 to 90 kW in electromagnet at 26 kV), there were still some problems which must be resolved concerning the perveance stability as a function of heater power before the tubes are really good vehicles for magnetic field testing.

Several high power experimental tubes were tested, including one with a shortened output gap and tuners in the output waveguide. There was rf pulse breakup in the output of this tube which came from breakdown in the tuners (as evidenced upon physical examination when the tube was dismantled). The gain was not as high as desirable, but otherwise the tube performed extremely well as evidenced by the performance curves (see Fig. 24). We measured between 28 and 29 MW at 250 kV repeatedly, and approximately 42.5 MW at 300 kV. The tube efficiency appears to be higher than any of the previous tubes built, and it is suspected that the improvement in efficiency was caused by a decrease in output gap length, and resulting improvement in beam coupling coefficient. The decrease in efficiency at 300 kV was not understood. This same tube in a specially shunted permanent magnet produced 27.8 MW at 250 kV, and 34.2 MW at 270 kV, with an efficiency in excess of 42%. The efficiency decreased rapidly at voltages in excess of 270 kV.

The fabrication problems with SLAC tubes during the second quarter were mostly limited to occasional gassy tubes which do not process easily to full beam voltage. In the middle of the quarter, a change was introduced in the cathode activation schedule during tube bake. Tests revealed that the cathode had not been run sufficiently hot to complete conversion while on the bake station. Cathodes converted with the new bake schedule appeared to remain active even down to 200 W heater power, whereas with the old bake schedule, temperature-limited indications began at 250 W.

We still observed wide variations in tube power output which are not understood. Measured peak power in electromagnet varied from 22 to 29.4 MW at 250 kV, with an average of 27.5 MW and a median of 26.9 MW.

The work on beam testers, particularly with respect to field reversal, was temporarily discontinued because of other pressures on magnetic field measurements and magnet modifications. We found it possible to modify some of the General Electric magnets originally procured for operation with Sperry tubes for use with SLAC tubes. Experimentally, we obtained in excess of 25 MW in a few tubes

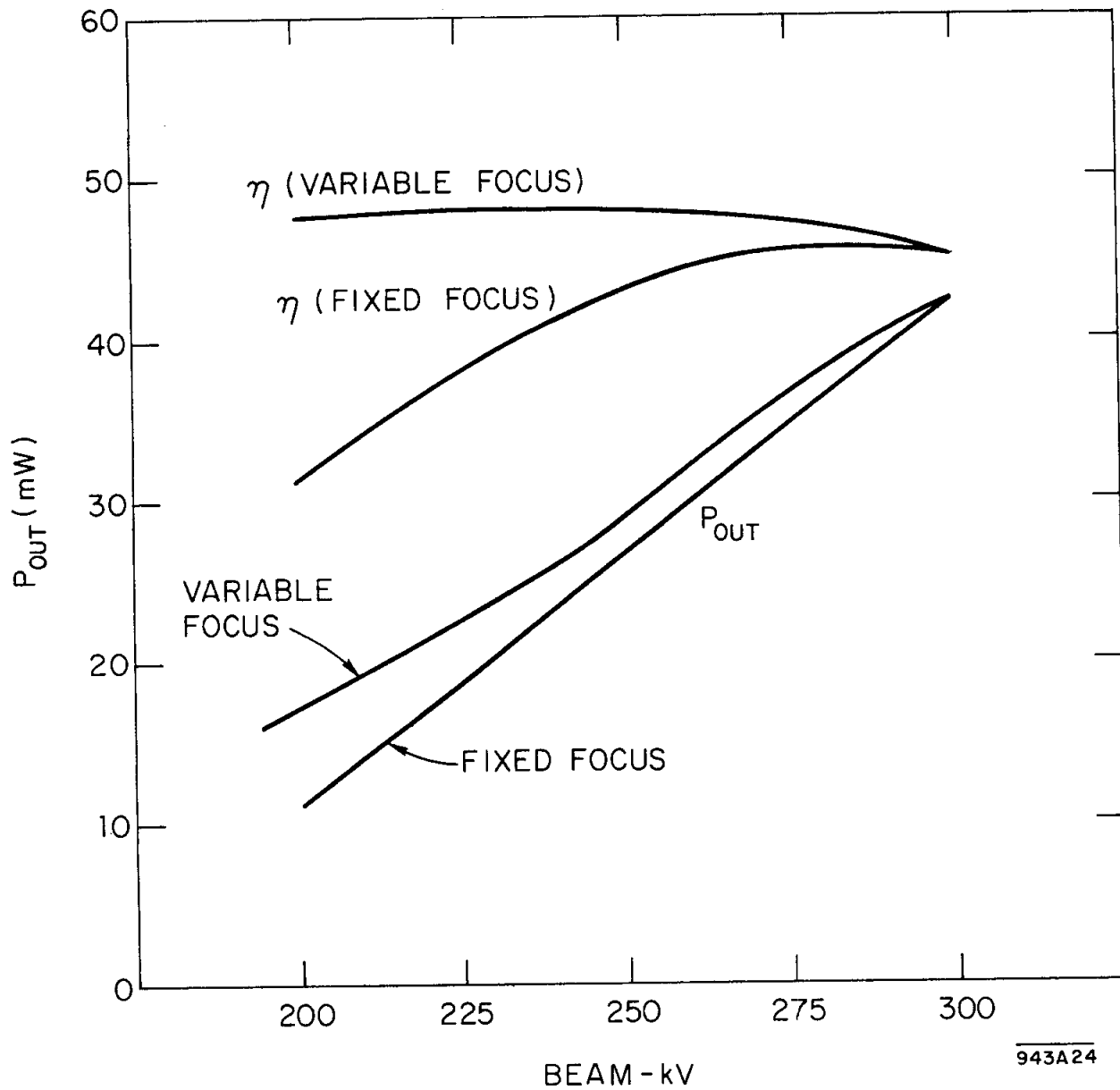


FIG. 24- EXPERIMENTAL KLYSTRON PERFORMANCE IN ELECTROMAGNET

tested on the first modified magnet. We expect to modify a half dozen more magnets to increase the total number of spares available for the gallery once the present complement of Sperry and experimental Eimac and Litton tubes have failed. At that time, we would only have 106 Litton magnets available, 104 RCA magnets available and 54 SLAC magnets available. Considering the average turn-around time of installation, tests and the expected number of tube removals, we will need more than 10% spares available. Hence, the necessity for increasing the number of magnets which can be operated with SLAC tubes.

A great deal of planning has gone into the design of a tube for operation at 300 kV with a potential power output of approximately 40 MW. Some modifications were introduced in experimental tubes to determine the possibilities of maintaining maximum efficiency up to 300 kV. Two long tubes were built and tested during the second quarter. Their total drift distance is approximately equal to that which we expect to be near optimum at 300 kV operation. Both tubes behaved well in electromagnets, with an efficiency of between 44 and 45% at 250 kV, and approximately 41 and 41.5% at 300 kV. It appeared that the change in length should be adequate for 300 kV operation. However, the final tests of the 300 kV modulator had not been completed.

2. High Power Klystron Windows

a. Window Failures

Two SLAC klystron windows failed in tube-test during the first quarter. Both were thermal failures apparently caused by excessive resistance loss in the coating layer. One of the failures was a carry-over from the earlier quarter, not discovered until the klystron was being prepared for rework. Only one window failure was observed among the 19 tubes processed the first quarter. Despite this failure, tube-test window temperature data indicated a significant overall improvement of window performance in comparison with the two previous quarters. The improvement seems to have followed adoption of a revised vacuum bake program in tube processing.

The highest window mortality in service on the accelerator continued to occur on RCA klystrons. It may be that some of the failures were caused by foreign material which had fallen onto the window surface. Some of the remaining RCA window problems appeared to be associated with a phenomenon unique to their window design. Deposits of metal build up gradually in certain portions of the ceramic-metal boundary, and eventually render the window inoperable. The cause

of this problem had not been determined, but is believed to be traceable to the particular window design and possibly to the configuration of magnetic fields at the window. Fortunately, this particular mechanism does not always cause permanent ceramic damage and can often be corrected by cleaning away the accumulated metal deposits.

One SLAC window failure was discovered on a klystron removed from the gallery after 4180 hours of operation during the second quarter. It was a clear case of thermal failure and was on a tube which had gone through several bake cycles without change of window. It is not known how long the tube had been operated with a cracked window.

b. Resonant Ring Tests

Routine pretesting of klystron windows in the first quarter continued with 100% acceptance of the SLAC and Mark III windows coated and tested during the quarter. These results were apparently attributable to resumption of the exclusive use of coatings sputtered in an atmosphere of pure argon along with strict adherence to a maximum coating thickness limitation of 130 Å. The present coating procedure appears to have attained a degree of reliability that would justify discontinuation of pretesting all klystron windows. However, an extended acceptance test program was being initiated to evaluate the serviceability of present SLAC windows for the projected 300 kV SLAC klystron.

The bulk of experimental ring testing was devoted to evaluation of alternative window coating materials. Specimen coatings tested were evaporated by electron beam bombardment from amorphous boron nitride and crystalline titanium dioxide (rutile). Both coatings were successful in suppressing secondary emission on the basis of visual observations during ring test. Thermal stabilities of the coatings were evaluated in double window tests, with each of the specimen windows mounted alongside a window with the standard titanium coating. The double window tests indicated the comparatively high stability of the boron nitride coating. The operating temperature of the BN-coated window following exposure to vacuum bake was substantially lower than that of its companion window, while the window coated from rutile did not differ significantly from its standard titanium-coated companion. Further evaluation of the boron nitride coating is obviously indicated and will be performed by means of the resistance versus temperature-measuring technique.

Other resonant ring tests included completion of double window tests of the stability of the Litton evaporated coating and measurements of variations of window

operating characteristics (ring gain, window temperature) related to small dimensional variations in the window geometry. Further tests of grooved windows as an alternative means of suppressing multipactor are pending completion of brazed-in grooved window specimens.

The majority of the test time during the second quarter was used in pretesting SLAC klystron windows. However, the test level was doubled to 86 MW peak and 80 kW average, as part of the initial tests of windows in preparation for a 40 MW tube. Because of the higher energy levels, a lead shield had to be installed around the ring.

Tests of special windows and coating materials were limited during the quarter because of the inability of obtaining additional windows coated with boron nitride. A sample reacted violently in the coating apparatus and delayed the production of additional coated windows until the end of the second quarter. Additional tests were performed on a grooved window which appeared promising. By putting the grooves on the tube side of the window, it is possible that the resistive loss problem of the coated window exposed to vacuum bake could be eliminated.

c. Window Coating Activity

Apart from the evaporated coatings of boron nitride and titanium dioxide, window coating work during the first quarter was confined to routine application of coatings on tube windows. Further experimental evaluation of increased oxygen content in the coating was postponed pending completion of the improved resistance versus temperature measuring equipment.

The resistance measuring device, and its vacuum station and rf induction furnace accessories were nearly completed and will soon be ready for use. The measurement fixture will not only provide accurate window coating resistance data during exposure to vacuum bake conditions, but will also provide resistance data taken during application of the coating. The latter data along with crystal monitor information should serve to describe more precisely the constituency as well as the thickness of the coating. Other coating investigations including calibration of coating thickness indicated by crystal resonance shift should also be facilitated.

3. Driver Amplifier Klystrons

a. Litton Subcontract

Some progress was being made at Litton during the first quarter towards meeting the specifications of the driver amplifier klystron. They built four tubes during the quarter, but the total number of test vehicles exceeded four because of many reworks.

None could have been used at SLAC because of spurious oscillations on the output pulse over a wide range of drive levels.

In addition to possible magnet problems (transverse fields and/or non-optimized axial fields), the following problems were disclosed by Litton investigations as possible causes of oscillations:

- (1) Cavities were not tuned to optimum frequency.
- (2) Input and output coupling loops were not optimized.
- (3) Multipactoring on output window.

Most of the problems had been solved by improved design of the tube and magnet. By the end of the first quarter, the spurious oscillations had been reduced but not entirely eliminated. It is suspected that the remaining oscillations are the result of electron feedback and that this feedback can be eliminated by modification of the magnetic field.

During the second quarter, however, very few tubes had been delivered. The main problem was caused by spurious signals. In addition, it was believed that the magnet might have excessive transverse field. The initial tests on 2 tubes undergoing acceptance tests, indicated that they were free from spurious signals. However, the tubes had to be hand tailored at the factory to achieve acceptability. It was believed that the majority of the problems were caused by returning electrons. The problem had been at least partially eliminated by changes in collector geometry. Adjustments in tube body length were also made to bring the output cavity in the region of higher magnetic field, and except for the necessity of individual adjustments on the tubes and magnets, the vendor should be able to supply us with an adequate number of tubes.

b. Eimac Subcontract

During the second quarter, Eimac delivered and we accepted all tubes outstanding against the contract.

4. Related Klystron Studies

Some experimental work was done during the first quarter in an attempt to determine the possibility of improvements of conditions which might lead to beam breakup. Because of the difficulty of obtaining sufficient filtering, no significant data had been obtained in our attempt to measure the klystron output in the region from 4000 to 4500 Mc.

A review of the literature was initiated to determine the possibility of noise generation in the injection gun of the accelerator. Several points were apparent and were discussed with the Injection Group:

- (1) The noise input is greatly increased from non-convergent to convergent type gun (like our injection gun).
- (2) The intercepting grid will contribute additional noise power in direct ratio to the amount of current intercepted.
- (3) The location of the gun with respect to the first noise standing wave minima should be considered in the design of a minimum noise injector.

There appeared to be a good possibility of substantial reduction in the noise of the present gun.

We also started an experimental program to discover the noise from ion pumps and gauges. The results were not complete, but the indications are that both the 50 and 600 Liter/sec. pumps used in the accelerator end of the machine are good sources of noise in the 4000 to 4500 MHz region.

5. Vacuum Studies

We continued a thorough investigation of the behavior of ion pumps during the second quarter. This work was begun as an attempt to determine the amount of microwave noise measured in pumps, but appears to be profitable in obtaining a good understanding of the pumping mechanisms in the various types of either titanium sublimation or sputter pumps. Original results were encouraging and additional measuring equipment was procured. As expected, the noise has a broad spectrum, but there appears to be some high localized peaks which are not yet understood.

The design work was also completed on a system which could determine whether the waveguide valve or the three-inch valve leaks in case of partial loss of vacuum when a klystron is being replaced. However, no decision was made to procure the equipment which appears necessary to resolve the problem of which valve leaks.

C. MECHANICAL ENGINEERING AND FABRICATION

1. Positron Source

The wand positron source was installed during the last quarter of 1966 and was adjusted and operated during the first half of 1967. Timing checks indicated that the wand target could be made to swing through the beam sufficiently fast to interrupt only 7 beam pulses. To reduce deceleration forces, the wand was slowed down so that it interrupted 9 beam pulses.

A short circuit developed in the edge-cooled solenoid coils (Coil 0) just upstream of the positron source. The short was found to be from coil to coil, and limited operation to 2000 amps instead of the design value of 4000 amps. The shorted coils were removed and replacement coils installed. It was feared that a similar shorting problem could recur and a redesign of the coils, using hollow conductor, was initiated.

Difficulties were encountered in developing a reliable wheel positron source and drive system. A stationary positron source called the "slug" was therefore designed, built, and installed to produce positrons until the wheel positron source system was completed. Two "slug" type targets were built and one was tested for power handling capability in the central beam of the Beam Switchyard. The slug target withstood 120 kW of incident beam power but began to show signs of failure at 140 kW. On the basis of the central beam test results, operation of the slug target at the positron source was limited to 70 kW incident beam power. The de-rating was thought desirable since the test in the central beam was a short-term test (minutes) while the target at the positron source was to operate many hundreds of hours. In addition, failure of a target at the positron source could contaminate the accelerator vacuum system to such an extent that a prolonged shutdown would be necessary to make the accelerator operational again.

Both the wand target installed at the positron source and the wheel target being fabricated were laminated targets with cooling water flowing between the target plates. Thin windows separated water from vacuum on the beam line. Window failure could result in a major vacuum problem in the accelerator.

The positron yields from the slug target and from the laminated wand target were found to be comparable. A solid copper type target was felt to be safer than a laminated target so that redesign of both wheel and wand targets to solid copper types was initiated.

Tests of the positron wheel target drive system in the shop led to failure of a water-to-vacuum bellows and a redesign was initiated to eliminate the water-to-vacuum bellows. A pantograph system was designed incorporating a single air-to-vacuum bellows. The drive system yielded a nearly circular beam path on the wheel target. The beam path diameter was 5 inches and the deviation from a circle was .070 inch. The new drive system is currently under construction.

2. Accelerator Maintenance

Maintenance and repair of mechanical components of the accelerator were minimal during the first half of 1967. Repairs consisted of the replacement of a fast valve because it would not seal; the repair of three minor water leaks at solder joints; the changing of springs in thin valves as described in previous Quarterly Report, SLAC Report 73. This work continued with 60 of the springs being replaced. A laser alignment target actuator spring was also replaced.

Maintenance activity included the remelting of 50 indium seats on thin valves. This is a procedure carried out after every ten valve closings. The accelerator sections were re-aligned on 40 girders to correct for the change in the girder deflection. The change in girder deflection was caused by the gradually rising temperature in the accelerator housing. The accelerator realignment activity will continue until the accelerator sections on all 240 girders have been aligned. Future accelerator re-alignment because of the ambient temperature change will not be necessary as the accelerator housing is now very nearly at equilibrium temperature. Accelerator alignment will be spot-checked periodically to check for changes in alignment due to seismic effects and differential settling between the accelerator housing and the klystron gallery.

3. Beam Break-up

The conversion of quadrupole triplets to quadrupole doublets at each drift section was completed. The drift sections in sectors 18 through 29 were converted during the report period.

The installation of quadrupole A's at 40-foot intervals in sectors 1 through 6 was completed. This activity consisted of replacing the drift tube and bellows assemblies between each of the girders of the six sectors and installing a quadrupole at each location.

D. INSTRUMENTATION AND CONTROL

The major activities during the first quarter were (1) installation of new quadrupoles and supplies for suppression of beam break-up; (2) completion of instrumentation for operation of the positron wand target; (3) a number of modifications of interlocks, beam monitoring signals and CCR console arrangement; and (4) design and preliminary test of modifications of the phasing, video and beam monitoring systems.

A survey was made of the feasibility of operating the accelerator and the switchyard and research area beam handling equipment from a single control room. Cost estimates were prepared for (1) operating the Data Assembly Building (DAB) from the CCR; (2) operating the accelerator from DAB; and (3) moving the CCR completely to DAB. Each possibility was shown to be mechanically feasible; but sufficient operational gains could not be established for any of them. It was therefore decided to discontinue the study.

1. Beam Guidance and Monitoring

a. New Quadrupoles

Supplementary quadrupoles were installed in Sectors 1-6 during the first quarter, and larger quadrupole supplies are used from Sector 15 on. The I & C work involved installation and relocation of the proper power supplies and connections to the quadrupole configurations.

Remote control circuits for the additional power supplies in Sectors 1 to 6 were installed in April and May. Remote controls were also installed to permit operation from CCR of the new quadrupoles in Sectors 1-6, and eighteen power supplies and controllers to provide stronger quadrupole focusing in the latter half of the accelerator were installed and checked out during the second quarter.

Twenty-five power supplies capable of delivering 15A have been procured and eight have already been installed in the gallery, together with new controllers for remote adjustment.

The increased quadrupole strength made available has increased the beam breakup current limit, as discussed in Section II, 5-c, above.

b. Pulsed Steering Power Supply

A power supply was developed in the first quarter to provide positive and negative current pulses of up to 15A magnitude to the horizontal steering magnet to separate the positrons from any electrons that may be present in the beam downstream from the wand positron source.

The power supply was installed in Sector 11 and will be field-checked during the first wand source operation.

c. Beam Monitoring

A diode mixer was installed during the first quarter for combining the linear Q signals from three switchyard locations, I_3 , I_{10} , and I_{30} . Similarly, a mixer amplifier was designed and installed for the In Q, X, Y signals for P_2 , P_{10} , and P_{30} . The beam displays in the CCR have thus been extended well into the switchyard.

Tests were completed on a system to permit CCR control of the zeroing system for the beam position monitor through the steering controls in the operator's console. The tests were considered successful and modification can commence when time permits.

2. Trigger System

a. Pattern Generator

A counter/frequency-divider with six independent channels and an associated patch panel were installed during the first quarter. The counter/frequency-divider channels can be interconnected with one another and with the pattern selector by means of patch cords.

Operated as a frequency divider, each channel can produce essentially any desired submultiple of 360 pps or of any 60 pps phase. Thus, it is now possible to produce interlaced beams that are different submultiples of 60 pps and that are synchronous with either the same or different sequence-generator phases.

Operated as counter-delays, the channels can be interconnected for timing events such as wand target start, bubble chamber start and quiet period (no electron beam) that must occur during the relatively long pulse period that is required when using the positron wand target.

The pattern selector was modified by the addition of interlock relays that can be controlled from multiple remote points to turn each beam off (independently of the operators at the CCR) or on according to permissible conditions of personnel and machine safety, and experiment readiness. The selector has also been provided with remote control from the operation console in the CCR so that it can choose between two repetition rates on each beam line (such as a low frequency for tune-up and a high-frequency for experiment), or to turn the beam off.

The supply voltage of the pattern generator line drivers was increased from 8 to 12 volts to eliminate marginal gate thresholds in the injector trigger generator and in a number of sector trigger generators.

A 30-channel auxiliary buffer/driver was installed for driving positron phase shifters, for transmitting a start pulse to the wand target in Sector 11, and for future needs.

b. Trigger Generators

Two "local" trigger generators were installed during the second quarter, with one in the CCR and one in the DAB. These trigger generators provide separate pre-trigger and main trigger pulses, some ungated and some gated, at a number of separately buffered outputs. In the CCR this has eliminated serious trigger problems that had resulted from different users of the pre-trigger and/or main trigger pulse sharing a common source. The unit in the DAB was installed only recently, but is expected to alleviate similar problems there.

3. Central Control

The panels on the operations-control console were rearranged during the first quarter in accordance with the approved "one man" operating policy. They had originally been spread out so that they would be easily accessible for initial checkout. Minor modifications and panel rearrangements were carried out to make operation more convenient as need became apparent.

The Primary Water Cooling Panel audible alarm system was modified so that the bell rings for each new alarm. High voltage coax connectors on the CCR oscilloscopes were changed with the expectation of reducing the chances of arcing when the connectors are disengaged under load. The connectors still arc, however, and an improved connector is required.

Part of the system for counting klystrons was placed into operation. It is now possible to keep track of the number of "rf OK" klystrons operating in the "Accelerator" mode in each of three groups of sectors. The three groups may, but need not, overlap.

Design was completed and construction started on the new battery charger installation in the second quarter. A temporary circuit was installed to give an audible warning when the CCR battery charger fails. A more elaborate system will be installed later. A standby charger and a 24-48V-dc-to-dc connector will be installed in the CCR basement. Charger operation will be monitored at the CCR console.

Running time meters were installed in the CCR to record elapsed time for five functions: Sector 30 secure, all sectors secure, injector tone receiver reset, one or more variable voltage substations on, and entry permitted.

4. Control Systems and Data Handling

a. Video System

Remotely operated switches will be added to the video signal repeaters in each sector so that each of the two video cables may be connected to one of a number of signals in any sector. Most of these signals will originate in the phasing system. The design for this switching was started in the second quarter. This is a modification of the existing video repeaters in each sector to allow remote control from the Central Control Room. The operator will be able to select for transmission to CCR any one of several video signals available in the sector. Remote gain switching and reverse transmission features will be incorporated.

The two test video systems in Sectors 1 and 2 have been operating successfully for several months. The printed circuit card and schematics were being prepared so that this project could be started during the second quarter. No down time is anticipated.

To provide greater flexibility for video signal transmission between the DAB and the CCR, an independent system will also be installed. Design was completed during the second quarter and equipment was being fabricated for the selection, transmission and display of any two of 25 (max) video signals from the DAB. The system will have an alpha-numeric readout in the CCR showing the name of the selected signals. Design was started on a nixie tube readout system for easy identification of profile monitors displayed on CCR TVs. System design was started on the upgraded communication system for accelerator-research area intercommunication. The installation will allow two-way, hands-free communication between selected points. Orders have been placed for two wireless (FM) microphones.

b. Monitoring System

Work proceeded slowly upon equipment for the exchange of monitoring signals between the DAB and the CCR during the second quarter. Circuits were connected to the DAB to indicate changes in klystron count for up to three beams. A temporary arrangement was made in the CCR to facilitate monitoring the transmitted beam pulses delivered to the two end stations. Beam pulses belonging to the six different time slots can be made to appear on six different traces. Pulses belonging to End Station B are displaced to the right. This system was installed to replace certain spectrum monitor signals for the DAB which are missing so far. The CCR-DAB video cable system was rearranged to improve performance and convenience.

5. Phasing System

The number of intermittent and non-traceable phasing system troubles was drastically reduced during the first quarter by the addition of a new grounding strap on the programmer end of one of the trigger cables. Apparently a high level pulse was getting into the Phasing System trigger line from Klystron 5 and causing false and mis-timed triggering. Since the new ground strap was installed no reports of troubles have been received of the type previously attributed to this fault.

Although it is possible to phase all sectors simultaneously once a beam is established through the entire machine, this is seldom done because loss of the beam would cause probable mis-phasing of all those klystrons being phased during the loss. As a consequence the machine is most often phased two or three sectors at a time, with one operator watching to be sure the beam does not disappear during the phasing operation, and the other operator keeping track of the sectors being phased so he can restart them if it does disappear. To accelerate the phasing operation a "Beam Presence Detector" is being designed for installation in each sector Phasing Electronics Unit. This detector will immediately stop phasing on loss of beam. Phasing would be resumed automatically on restoration of the beam.

The phasing programmers have all been modified so that it is possible to phase a single klystron in a sector with only a minor disturbance to the other klystrons. This minor transient, unfortunately, exists long enough to set each klystron to standby just after leaving it. A small additional circuit change, which will eliminate the transient and permit phasing of a single klystron with no effect on any other klystron, has been tested. Parts have been ordered for installation of this change coincident with the video system installation.

6. Positron Source Electronics

A water-cooled copper slug was installed in Sector 11 during the first quarter to serve as a source for positrons until the wheel will go in. This device operates with the wheel controls and interlocks. It has been used several times successfully.

A pulsed power supply for the horizontal steering dipole in the rf deflector was installed and checked out. Pattern signal connections were completed.

The "wand driver and positron interlock" chassis was developed to provide the electrical pulses to drive the wand through the beam aperture, and to interlock the beam through the 50- μ sec permissive pulse system. This provides that a permissive pulse is sent to the injector only when the wand is either completely out of the beam aperture

for electron beams, or when the wand is in the exact beam center-line for positron beams. The chassis was installed and checked out in the gallery in the first quarter.

A 50- μ sec permissive pulse "And Gate" chassis was installed in the CCR to interlock positron beams generated either with the wand or the wheel.

By the end of the second quarter, instrumentation had been provided for a number of positron targets. The "wand" target is designed to pass rapidly across the accelerator aperture at a rate of 1 or 2 passes per second. Between each pair of passes, a normal electron beam may be operated. Operation with the moving wand commenced during the second quarter; it was found that additional delay compensation had to be added to the wand driver to equalize the time required for the up and down strokes.

Prior positron operation used either the wand fixed at the center of the accelerator aperture and operated at 10 pps, at reduced intensity, or the "slug", a fixed target designed for continuous operation at moderate intensity. Control circuits were completed for the "wheel" target, a moving target designed for continuous operation at high intensity. It was anticipated that the wheel would be installed during the third calendar quarter.

The pulsed steering supply used to separate positrons and electrons was checked out and its operation was found satisfactory. It is used in conjunction with an rf deflector, 20 feet downstream of the positron source. One polarity of pulse is required for positrons, the opposite polarity is required for electrons.

It was found that additional special steering was required to get electrons through the solenoids at the positron source during interlaced positron-electron beam operation. Temporary dc supplies were added; three additional pulsed supplies will be built to perform this function properly.

7. Personnel and Machine Protection Systems

a. Personnel Protection System

The "EMERGENCY STOP" circuit described in the QSR for the last quarter of 1966 was in service during the first quarter of 1967, with four stop buttons located in the experimental area and three pre-production ion chambers mounted on the End Stations' shielding. The complete system requires installation of additional cable between the DAB and the End Stations.

The prototype "fail-safe" ion chamber was built and the production models were ordered. The entire circuit should be operational in July.

The personnel protection tone loop was modified during the second quarter to provide for safe beam operation into BAS II, while work is being done in the BSY housing. This mode of operation requires that beam stoppers be inserted in Drift Sections 20-9, 21-9 and 28-9. Full interlocking requires testing that the Beam Switchyard is ready for beam before restoring normal operation. This was accomplished by splitting the "Housing Secure" tone loop system in two: one portion for Injector through Sector 29, and the other for Sector 30 and the DAB. In the BAS II mode of operation, only the former need be complete in order to run rf. The latter loop must be complete to allow transfer to normal operation in the BSY; both loops must be complete to run rf in the accelerator.

b. Machine Protection System

The installation of the additional water temperature sensors in the cooling water loops along the accelerator was completed during the first quarter and included connections to the VV substations involved.

A key-operated disabling switch was installed in the machine-protection long ion chamber (PLIC) interlock system, so that certain beam break-up experiments can be performed more conveniently. These experiments sometimes produce very large PLIC pulses, corresponding to very large local beam power loss, and thus must be performed at very low repetition rate.

PLIC linearity was verified over a range of 1000:1. This was checked during the owl shift on February 21. The results are indicated in Fig. 25. The beam energy was measured at the Tune-Up Dump, and then the beam was mis-steered upward at the end of Sector 5, using about 10 A steering current. The peak beam power is the product of the current indicated at Sector 5 by the linear Q monitor, and the Tune-Up Dump energy, corrected for beam loading losses. The PLIC pulse height was read on a Tektronix oscilloscope. The solid line on the graph has unity slope, corresponding to a linear function. The lowest point was taken at 0.118 MW peak beam power, giving a PLIC pulse of 15 mV. The topmost point was at 156 MW, 16 V. The lowest point is subject to considerable error, since it corresponds to less than half the minimum specified linear Q signal, and since the PLIC pulse appeared to be appreciably shorter than in the other cases.

The temporary 50- μ sec generator in the CCR, used when operating in the BAS II mode, was replaced by a SLAC-designed unit.

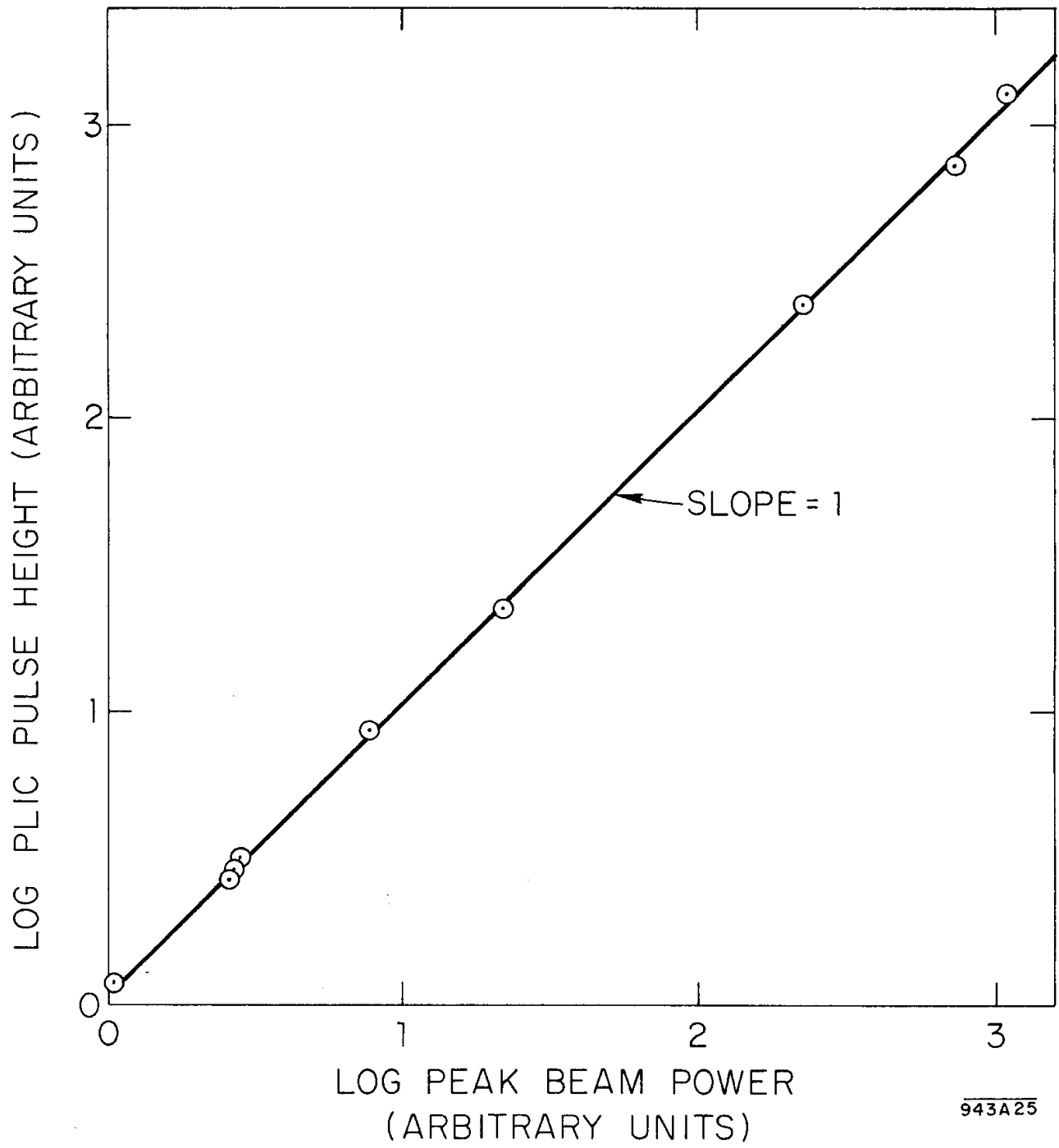


FIG. 25- LOG PLIC PULSE HEIGHT VS LOG BEAM POWER LOSS

The BAS mode of operation allows operation of a beam to the analyzing station at Sector 20 while the Switchyard and End Stations are open for maintenance and construction. The transfer from BAS to BSY mode is interlocked to prevent changing while the accelerator is on. The change-over procedure is too slow, and the interlocks were redesigned during the second quarter.

The PLIC circuit was modified during the second quarter so that the discriminator setting is normally fixed at a level suitable for 360 pps operation. A key switch was provided so that a higher discriminator level, suitable for 60 pps operation, can be selected if necessary. Another key switch, installed in the previous quarter, can disable the PLIC beam shut-off function altogether.

A temporary circuit was provided to operate the PLIC positron gate for certain positron experiments for which no positron pattern is turned on. The positron gate prevents beam shut-off due to PLIC pulses originating near the positron source. Several other minor modifications were made to the PLIC system to improve reliability and maintainability.

E. ELECTRONICS ENGINEERING

1. Magnet Power Supplies

The 1590-kW power supplies and the 567-kW power supplies for Group A were put into operation during the first quarter of the year. The utilities and load were connected to the 3.4 -MW power supply for the 40-inch Bubble Chamber and checkout of the unit began during the first quarter. While the supply was operating at 4000 A, one of its transformers began overheating. Investigation revealed that both transformers were defective in design and they were removed and sent back to the manufacturer. It was also found that the cabinet-cooling for the units was insufficient, causing higher transformer power loss than was specified. The problems were solved and the power supply was put into operation during the second quarter.

The vendor continued work on the 400-kW power supplies during both quarters and they were approximately 90% complete by the end of June. The Positron Source power supplies were put into operation during the first quarter.

A circuit was designed and built for regulating current from a motor-generator set into a research area magnet. The regulator was completed and installed during the second quarter and performed satisfactorily, with variations in current less than + .03%.

2. Beam Knockout Modulators

The 39.9-MHz beam knockout modulator unit construction, testing and installation were completed during the first quarter and the unit continued to run satisfactorily through the second quarter.

The second unit, one that is tunable from 10 to 20 MHz, was designed and constructed during the first quarter and was tested and installed during the second.

3. Trigger Systems and Related Components

The trigger system was improved by several changes in the Pattern Generator. Pattern Generator problems were experienced, however, during the second quarter, because of randomly missing pulses. It was found that random bursts of noise appearing on the leading edge of one phase of the Pattern Generator input from the sequence generator were resetting the flip-flops in the count-down scaler before they reached the desired count. The problem was solved by installing Schmitt trigger circuits in each of the six Pattern Generator input lines.

During the first quarter, a counter/frequency divider was added which provides pulse trains at sub-multiples of 360 pps for interlaced beams in the machine. A pattern selector was also added so that each beam could be turned on or off remotely.

A 30-channel auxiliary buffer/driver was installed with several channels driving positron phase shifters while another channel pulses the wand target for the Positron Source in Sector 11.

The main trigger line was pressurized over its entire length with 5 psi of dehydrated air during the first quarter to protect it from humidity effects. Another trigger problem that was also solved concerned the pulse-to-pulse jitter of 20 to 40 μ secs. It was found to be caused by insufficient drive to the Master Trigger Generator shaper circuit. After the drive was increased, the jitter was reduced to 1 μ sec.

The design of a program selector for the CCR and two klystron trigger generators for Sectors 27 and 28 was completed and fabrication was started on all three units during the second quarter.

By the end of the second quarter, the design of a modification to the Injector Trigger Generator to provide a beam knockout standby pulse was essentially completed. The standby pulse will keep the beam knockout modulator operating at a constant rate to reduce phase drifting.

4. Liquid Hydrogen Target Controls

During the first quarter three target control systems were completed. The first system which controls the Annihilation Beam LH_2 target was installed in Hut B. It is being used as a target for the Positron Beam.

The second target installed was the A beam target. The target controls are located in the Counting House while the target is located in End Station A. It was operational and was being used by Group A.

The third target control system, the Mu beam target, was completed during the first quarter, but since the target was not installed the control system has not had operational tests.

5. Magnet Current Interlock

A device to interlock the B-Beam bending magnet current and the dump magnet current for the Annihilation Beam was completed in the first quarter and installed in the End Station B interlock chain.

6. Hydrogen Recombiner

Electronic controls were designed for the first hydrogen recombiner system.

They are as follows: 1. Heater Control and Temperature Indicator, 2. Remote Heater Control and Temperature Indicator, 3. O₂ Indicator Control, 4. O₂ Remote Status, 5. Local H₂ Sensing Amplifier Chassis.

F. COUNTING ELECTRONICS

1. End Station Charge Monitors

The End Station A unit described in the previous QSR, SLAC Report 73, was modified in the first quarter to permit operation of the accumulator at 360 pps regardless of the beam rate. Display buffers were added to permit visual display of the charge per beam pulse. Work on the End Station B charge monitors described in the same report continued; two units were completed and ready for checkout.

Work continued during the second quarter to eliminate noise problems on the End Station A monitor. Coherent pickup in the Counting Room possibly associated with 115V, ac line transients due to SCR-regulated magnet supplies, continued to limit the noise averaging capability of the instrument. A special, asynchronous ac power supply was being used for the amplifier section in an effort to reduce these effects.

Maintenance problems during the second quarter were primarily associated with Nixie displays and cable connectors.

Delivery of two End Station B units was made in May and June. One of these units requires a special interface to work with a video preamplifier, used on the low-level positron beam. A prototype circuit was installed and operating. The second unit operates with a standard toroid and, because of a long input cable run without additional copper pipe shielding (as used in End Station A unit), severe pickup problems were being experienced.

2. 100 MHz Counter (Scaler) Readout System

The first unit and cables were delivered to Group B in February and the unit worked successfully. Two digital data scanners and associated cables were built during the second quarter. A junction box was built to expand the capability of the scanner to 40 channels. This 40-channel system was delivered to Group D.

3. Time-of-Flight System

Development of circuits continued during the first quarter. A second 40 MHz mixer of opposite phase was added in order to identify which phase of the knockout signal was associated with each event, thus allowing for asymmetries in the knockout system.

The system dynamic range was extended by some redesign of circuits. The combined errors, in the electronics alone, for an amplitude change of 2:1 and a

phase change of 180° in the IF, such that both 40 MHz channels were used, were shown to be less than 100 psec.

The system was installed and tested in the End Station A, 20 GeV spectrometer in April. The resolution obtained was only about 0.6 nsec, using a scintillator and tube supplied by Experimental Group C. The pulse shapes from the phototube were very irregular, and no means was provided to correct for time displacements due to the finite spatial distribution of particles traversing the scintillator. The system was removed to the laboratory for further study of problems surrounding the detector.

4. Equipment Pool

Work continued in evaluation and maintenance of scalers and logic modules, during the first quarter. Evaluation and testing of new equipment was also being performed for specific research groups.

Requests for proposal were submitted for the supply of 150 high-speed logic modules and 50 bins. All equipment was specified to conform to AEC NIM standards. A SLAC specification was written for this procurement covering the following items: dual discriminator, dual two-fold, dual three-fold majority, four-fold majority, fan-out, and module bin.

Contracts were let for the supply of new (150-200 MHz) logic modules and bins during the second quarter. The new equipment was all specified to AEC NIM standards. Deliveries were anticipated in June but were not completed.

A gating problem in the TSI M71 Counters (Scalers) was discovered on some units. Counting Electronics tested and repaired all counters which were made available. They also tested new integrated circuit scalers for Group F, and were planning to build a special test box to facilitate such testing in the future. A test box was also designed and built to facilitate checkout and maintenance of the HP recorder.

III. PHYSICS RESEARCH EQUIPMENT DEVELOPMENT

A. SUPERCONDUCTING MAGNET DEVELOPMENT

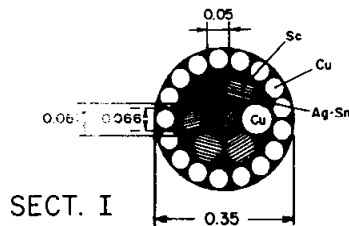
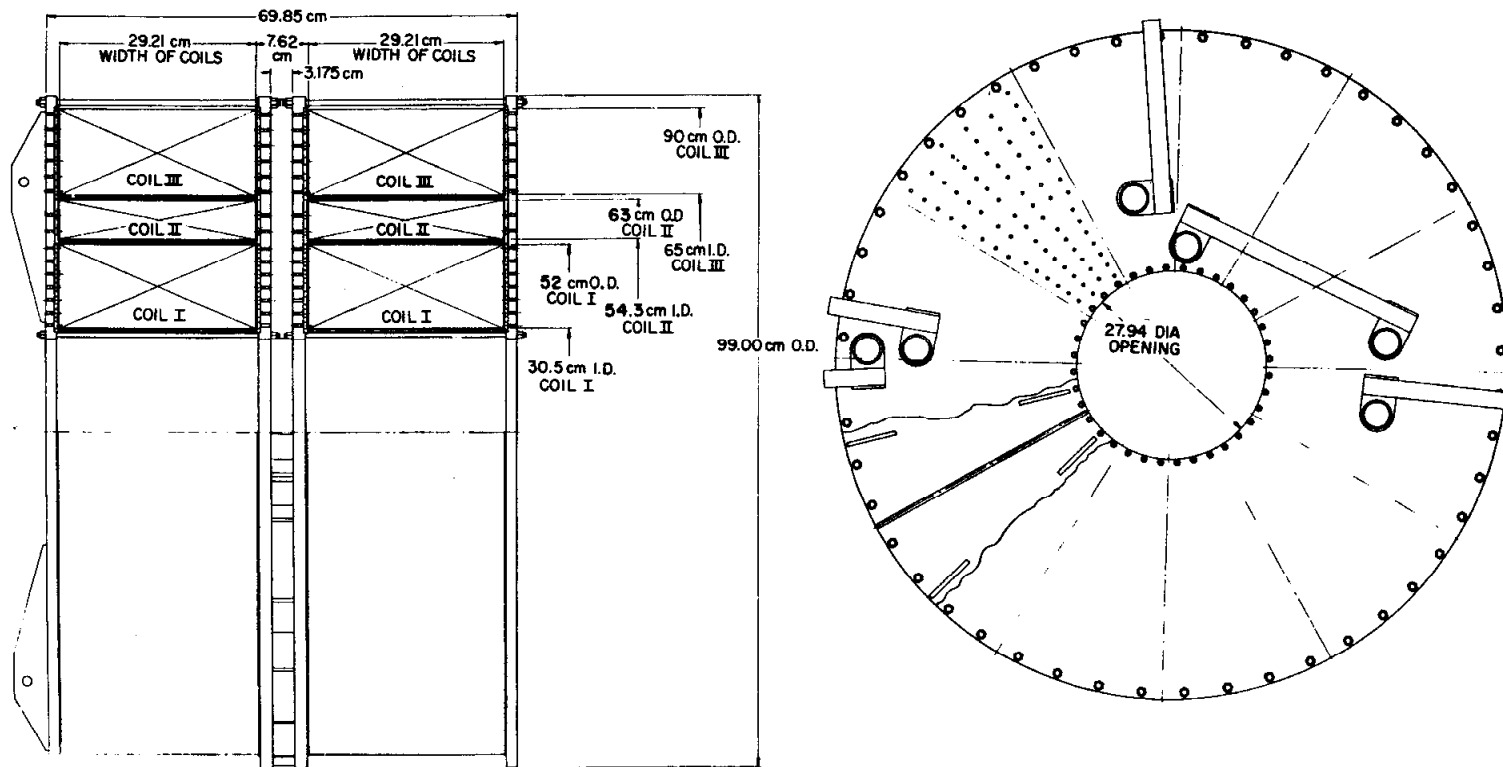
After final preparations for the 12-inch SLAC, split-coil magnet were undertaken, such as development of proper interturn insulation, completion of the impregnation and insulation machine, and completion of the coil-winding machine, the coil winding began. A few short-sample and cage tests were carried out at MIT, National Magnet Laboratory to determine the current-carrying capacity of the superconducting cables for fields up to 93 kG. Four coil sections were wound by April 1967, and the first tests at SLAC began on April 14. Various difficulties in transferring liquid helium prevented full operation of the magnet at that time. The second attempt, on May 5, to cool down the magnet also had to be interrupted because of a gasket rupture.

The first successful run was performed June 14-18. Approximately 710 liters of helium were required to cool down the magnet from 78° K to 4.2° K and to fill the storage dewar. The magnet was energized from two power supplies which delivered 510 and 525 amps, and which yielded a central field of 43.2 kG. The expected currents were about 600 amps, but at the 525-amp level excessive helium evolution was observed and the test was interrupted. The coil was energized to full current in a time of less than 20 minutes. The helium gas, prior to the excessive boil-off, was collected in containers for reliquefaction.

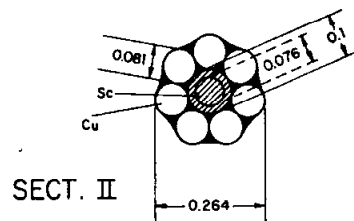
The total stored field energy at 43.2 kG was 1.2 megajoules. Figure 26 illustrates the conductor geometries. The intermediate coil consists of a cable having one superconductor with a diameter of 0.076 cm. From recent tests on small coils it has been found that a single large superconductor is more unstable than a number of smaller superconductors connected in parallel. No current-sharing in the single superconductor is observed, and thus the current has to be increased or decreased at a much slower rate than that used in the above test.

Publications

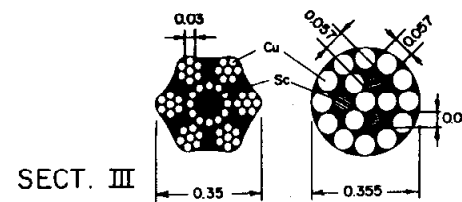
1. "Magnetic Slit" (SLAC-PUB-294)--to be published in Review of Scientific Instruments.
2. "Materials in Electromagnets and Their Properties" (SLAC-PUB-320)--Invited paper presented at the Second International Conference on Magnet Technology, Oxford, England, July 1967.
3. "Superconducting Magnets for High Energy Physics Applications" (SLAC-PUB-274)--presented at the International Cryogenic Engineering Conference, Kyoto, Japan, April 1967.



SECT. I
 CABLE FOR COIL I
 30 LAYERS WITH 70 TURNS/LAYER
 ≈ 2070 TURNS/SECT.
 $J_{av} = 3.3 \times 10^3 \text{ Acm}^{-2}$



SECT. II
 CABLE FOR COIL II
 14 LAYERS WITH 88 TURNS/LAYER
 ≈ 1200 TURNS/SECT.
 $J_{av} = 3.5 \times 10^3 \text{ Acm}^{-2}$



SECT. III
 CABLE FOR COIL III
 32 LAYERS WITH 66 TURNS/LAYER
 ≈ 2126/2100 TURNS
 $J_{av} = 3.4 \times 10^3 \text{ Acm}^{-2}$

507-15-C

FIG. 26- COIL GEOMETRY FOR THE SLAC 12-INCH SUPERCONDUCTING MAGNET

B. SPECTROMETER PROGRAM

All three spectrometers--the 8 GeV, 20 GeV, and 1.6 GeV, in that order --were completed and had their optical properties measured during the first quarter.

The 8-GeV spectrometer proved to be close to design except in one matter--the required quadrupole strengths for proper focussing, which were about 2% different from design. Momentum calibration was better than 1/2% and the solid angle of acceptance was essentially to design.

The 20-GeV optical properties were close to design, but owing to the complexity of the system, some of the aberrations had not been corrected. It is believed that the asymmetry of the first bending magnet was the cause.

All of the power supplies were controlled successfully by the computer for the optics test phase. Magnet water-flow and temperature interlocks performed satisfactorily. Additional tests are described below.

1. 1.6 GeV Spectrometer

During the first quarter, the spectrometer was erected and successfully powered. Its optics were tested using a floating wire and the accelerator beam and the tests proved very satisfactory. The first order properties were precisely as predicted. The θ and momentum focal planes were found to be in coincidence without any adjustments being made. The momentum focal plane was at 90° to the beam direction. The high precision predicted in the p and θ planes was achieved over 70% of the aperture. Beyond the 70% region the resolution deteriorated because of fringe-field effects.

Experiments performed using the 1.6 GeV spectrometer during the second quarter are reported elsewhere.

2. 8 GeV Spectrometer

The 8 GeV Spectrometer was checked out during the first quarter and its optical parameters were measured using the beam. The measurements were performed by varying x_0 , θ , and ϕ by B1, B11, and B111, and varying δ_0 by changing the spectrometer momentum.

Because of the lack of precision in the setting of B1 in order to vary x_0 , there was a coupling between x_0 and θ_0 . This limited the precision, for $x_0 \neq 0$, in θ to 0.15 mrad, or 0.6 cm in x at the θ focal plane. To get around this difficulty, the θ dispersion was also measured by rotating the spectrometer and leaving the electron beam undeflected. The results agreed within 0.5%. The results of the measurements are shown on Table II. The quoted errors were extracted from differences between different measurements plus reading errors on the screens of 1 mm. It must be acknowledged that there might have been hidden systematic errors.

There were differences between the design parameters and the measured ones. Though these differences are understood to some extent, no attempt will be made to explain them here.

Table III

Parameter*	Calculation	Measured
(x/x_0)	0. m rad	0.1 ± 0.05 m rad
θ dispersion (x/θ_0)	4.24 "	4.405 ± 0.01 "
(θ/x_0)	- 0.236 "	$-0.22 \pm 0.2^{**}$ "
(θ/θ_0)	4.74 "	5.02 ± 0.05 "
(y/δ_0)	- 2.955 "	-2.92 ± 0.1 "
(ϕ/ϕ_0)	- 1.056 "	-1.12 ± 0.01 "
Tilt of focal plane	13.7°	$14.2^\circ \pm 0.6^\circ$
Coupling terms (x/ϕ_0)	0. cm	0.03 ± 0.003 cm
(y/θ_0)	0. "	$\sim 0.$ "
(y/x_0)	0. "	$\sim 0.$ "

* All distances are measured in centimeters and all angles in milliradians.

** The high error in (θ/x_0) comes from the uncertainty in setting B1, which mainly sets x_0 , but may introduce a small θ_0 .

3. 20 GeV Spectrometer

The 20 GeV hodoscope and particle discriminator were readied and installed in the 20 GeV spectrometer early in the first quarter and the beam was used to checkout the unit. In the second period, the spectrometer was used for secondary particle production survey.

4. Time-of-Flight System

The time-of-flight system for the 1.6 GeV spectrometer was completed during the second quarter. The modulation plates in the gun of the accelerator were improved to run at the higher voltages necessary because of the lower frequencies involved. The high-power transmitter to drive the modulation plates was completed in the first quarter. Its frequency is variable from 8 to 20 MHz, and the frequency can be changed over this range in a few minutes.

A time-marking signal derived from the modulation plates of the order of 25 volts was arranged to be sent the full length of the accelerator to the Counting House. This signal was being used as a time reference in time-of-flight electronics.

A toroid with a rise time of approximately 1/2 nsec was installed in the BSY before the energy analyzers to monitor the modulation in the electron beam. A high-quality cable from the toroid to the Counting House was also installed. This will be especially useful when using photon beams in End Station A to monitor the modulation of the beam.

5. Hydrogen Target

The high-power hydrogen target for End Station A was completed and tested during the first quarter and was installed and in use during the second. A variety of target cells was made together with two different scattering chambers. The target can be used as easily with deuterium as hydrogen, and has been tested at high power levels.

C. STREAMER CHAMBER PROGRAM

1. Two-Meter Chamber

The chamber was installed in the two-meter magnet in its final configuration during the first quarter. The magnet had been completed during the same period and operated at low power (2500 amps). Successful tests were made of the chamber using a photon beam during the second quarter. Large trigger backgrounds were obtained initially and the collimator system had to be modified. Additional work was underway to reduce the background triggers still further. Figure 27 is a photograph from the test runs.

2. 5.8 Megawatt Power Supply

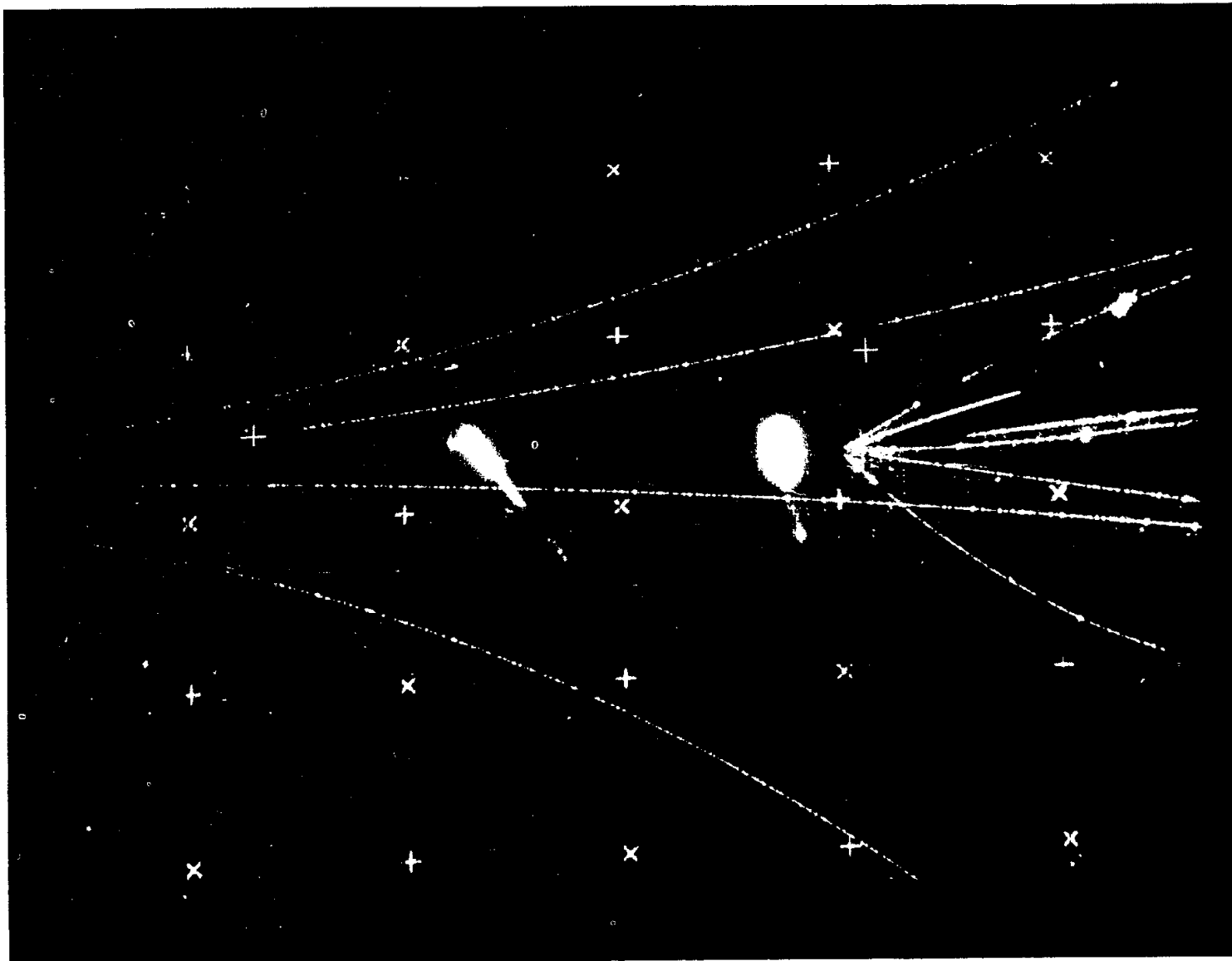
A fire occurred in the power supply before its tests and acceptance during the first quarter. It was caused by the breaking of an oil cooling line. The power supply was rebuilt and underwent preliminary tests during the first quarter and was then operated into the two-meter magnet during the second.

D. COLLIDING-BEAM STORAGE RING WORK

1. rf Cavity

The design considerations for the Colliding-Beam Storage Ring indicated the following requirements for the rf cavities:

- (1) The operating frequency is to be 50 MHz.
- (2) The cavity must develop a peak voltage of 200 kV.
- (3) The cavity must be included in a 2-meter-long straight section of the storage ring.



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FIG. 27- STREAMER CHAMBER TEST RUN PHOTO

Originally, a cavity design was considered in which vacuum windows separated various regions of the cavity. The use of windows allows most of the cavity to be outside the main vacuum system, thus simplifying the design of rf couplers and tuners. However, the high dielectric losses, because of the large voltages in the region where the windows must be situated, lead to large thermal stresses in the ceramics and make this approach less desirable. Since the vacuum system of the rest of the ring will be constructed out of aluminum and the problem of transition from aluminum to stainless steel has been solved by the use of stainless-steel-to-aluminum flange sets,¹ it appeared feasible to use an all-vacuum cavity constructed from aluminum. Outside connections from the cavity would be by means of aluminum flanges which can be welded to the cavity. Input loops, tuners, etc., would utilize stainless steel flanges which would mate with the aluminum flanges on the cavity.

An experimental cavity design is shown in Fig. 28. The cavity consists of two quarter-wave, capacitively-loaded coaxial cavities with a common high-voltage gap. The over-all length is 57-1/2 inches. The outer and inner diameters are 37 inches and 10 inches, respectively, and the gap spacing is 6 inches. A cavity was constructed to this design, utilizing 6061-T6 aluminum with all joints fusion-welded with an inert-gas-shielded tungsten-arc (TIG) process. The welds were all made to ultra-high-vacuum quality with care taken to eliminate voids and subsurface defects. The cavity can withstand a vacuum bakeout of 250^o C. The outer wall thickness is 1/2 inch and the reinforced end plates are 5/8-inch thick. The counterflow heat exchanger on the center conductor is designed conservatively to handle over 20-kW dissipated power.

A coaxial input window, originally designed for a high-power klystron and supplied by Eimac, is used. The coupling loop is water cooled. Frequency tuning is achieved by means of a water-cooled paddle, which may be moved into or out of the cavity by lateral motion of a vacuum bellows, with negator springs added to compensate for atmospheric pressure on the bellows. Two glass viewports were incorporated to allow observation of the cavity interior during high voltage testing. The surfaces in the region of high voltages all have extremely smooth finishes.

Figure 29 is a view of the completed cavity. The measured Q of the cavity is 13,500 with a shunt resistance R at the edge of the gap of 1.24 megohms and at the center of the gap of 1.12 megohms. The shunt impedance was measured by two

¹QSR, SLAC Report 73.

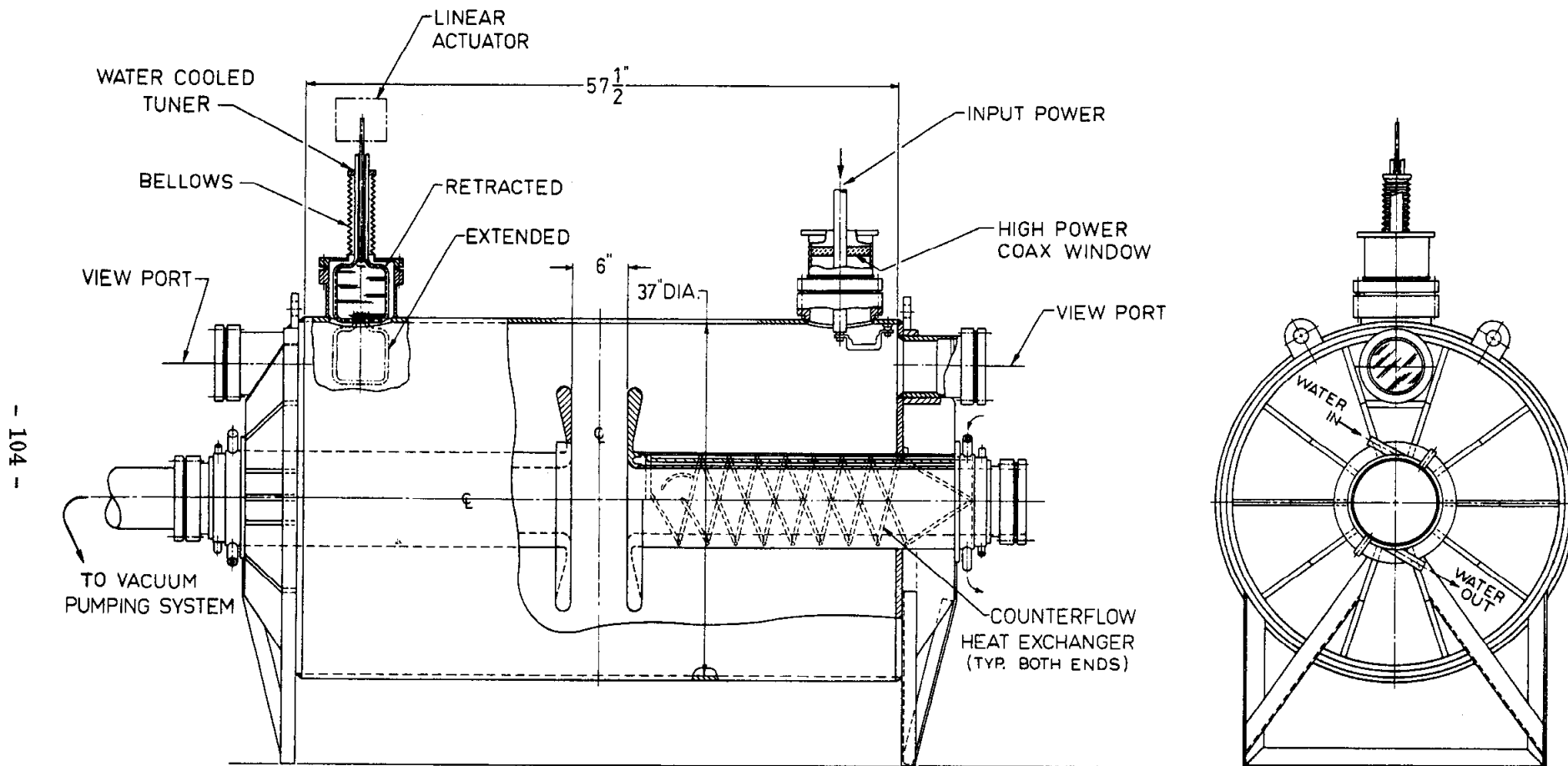
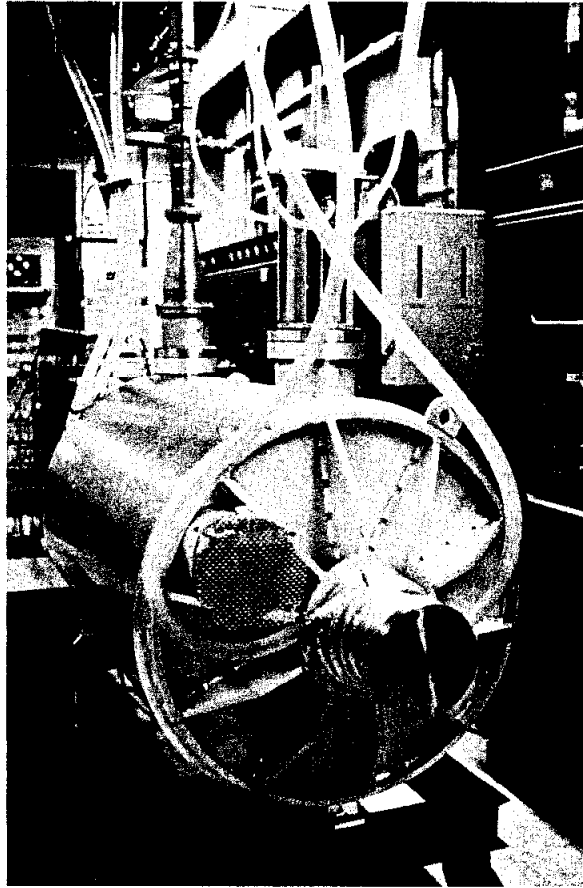


FIG. 28- EXPERIMENTAL RF VACUUM CAVITY DESIGN

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FIG. 29- COMPLETED RF EXPERIMENTAL CAVITY

methods: one which yielded R/Q, and the other which measured R directly. Both methods agreed within 5%. The cavity is subject to multipactor discharge at a few hundred milliwatts, but this can be easily switched through by setting the oscillator frequency and switching through to a higher power level than the multipactor level.

The cavity was run up to 46 kW continuous power with no indication of voltage breakdown. This power corresponds to over 300 kV across the high voltage gap. Because of the heating of the baffles, the cavity was lowered in frequency by about 200 kc at thermal equilibrium at the 32-kW level. Calorimetric measurements at 20 kW indicated 30 watts dissipated in the input loop and 150 watts dissipated in the tuner. At 32-kW input, the outer wall temperature stabilized at 144^oF. Consequently, some cooling of the outer wall may be desirable, though not necessary. Cooling would improve personnel safety and reduce the shift in frequency due to thermal expansion.

Soft x-ray emission from the region of the gap was detected by external survey meters at power levels above 10 kW, necessitating shielding during laboratory use.

During the experiments on the cavity, the frequency of the source was automatically adjusted to the frequency of the cavity by means of an automatic frequency control loop which compared the forward and reflected signals to the cavity and produced a voltage proportional to the phase difference between these signals. This voltage tunes the exciter. However, the ultimate intent is to have a constant frequency and tune the cavity itself. This is discussed in more detail below.

The tuner on this experimental cavity provides 30 kHz of tuning. This amount of tuning is sufficient for the 3-GeV, 2-amp mode of operation, but is insufficient for the lower energy, high-current modes of operation. A tuner which will give the required 2 MHz of tuning has been designed and will be installed in this cavity. The tuner will tune capacitively near the high-voltage, capacitive-loading baffles.

The cavity is equipped with a 500 liter/sec, Ultek evapor-ion pump, and it pumps down to a pressure of 4×10^{-9} with no rf present. With 20 kW rf coupled into the cavity and thermal equilibrium established, the pressure is 1.6×10^{-6} torr. After a planned bakeout at a temperature of 250^o C, it is expected that pressures in the region of 10^{-9} will be maintained with high rf-power input.

A model cavity of one-quarter scale at 200 MHz was constructed from copper with soldered joints. All higher-order modes with field in the beam region were mapped, up to a frequency whose wavelength is comparable to the bunch length at 3 GeV (28 cm).

None of the higher-order modes were close to a harmonic of the ring frequency. A mapping of the full-sized cavity is planned.

Two systems for automatically tuning the cavity were developed. The first system employs two square-law detectors which sample the input line currents. The detectors are located $\lambda/8$ and $3\lambda/8$ away from the cavity reference plane. The difference voltage output from the two detectors is a discriminator characteristic, as shown in Fig. 30, and can be used to control the cavity tuner.

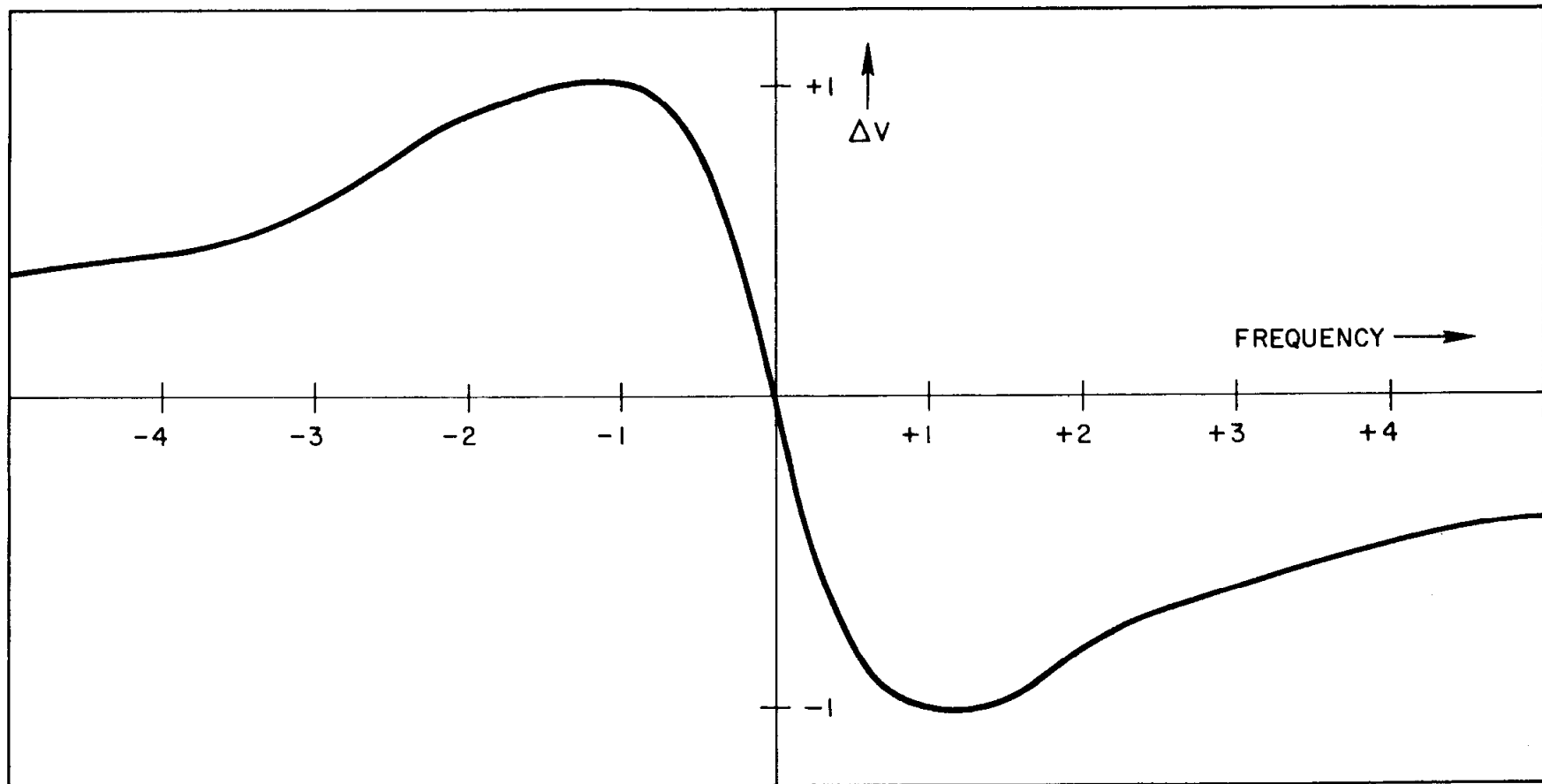
The disadvantages of this system are that it has a limited dynamic range, and the accuracy with which the tuner can be controlled depends on the detectors maintaining a square-law characteristic over a wide range of input power levels. Furthermore, the location of the detectors is critical, and for large amounts of detuning, the control voltage becomes very small.

A second system was developed which avoids the difficulties mentioned above. Two directional couplers are placed at arbitrary locations in the input line. One coupler responds to forward power and the other to reverse power. The phase angle of the reflection coefficient can be measured by making a phase comparison between the two couplers. This measurement can be made conveniently with the newly developed Hewlett-Packard Vector Voltmeter, which produces a voltage as a function of detuning and having the shape shown in Fig. 31. This function is more suitable for control of the tuner than that of Fig. 30, since it does not fall off for large values of detuning. In addition, the vector voltmeter has a dynamic range of 80 dB, and the location of the couplers is not critical.

A system for automatically controlling the cavity coupling was also developed. It is similar to the first of the two tuning systems described above except that the two square-law detectors are located $\lambda/4$ and $\lambda/2$ away from the cavity reference plane. The difference voltage output from the two detectors is zero for unity coupling, and reverses polarity for over and undercoupled conditions. Thus the output can be used to control the coupling circuit.

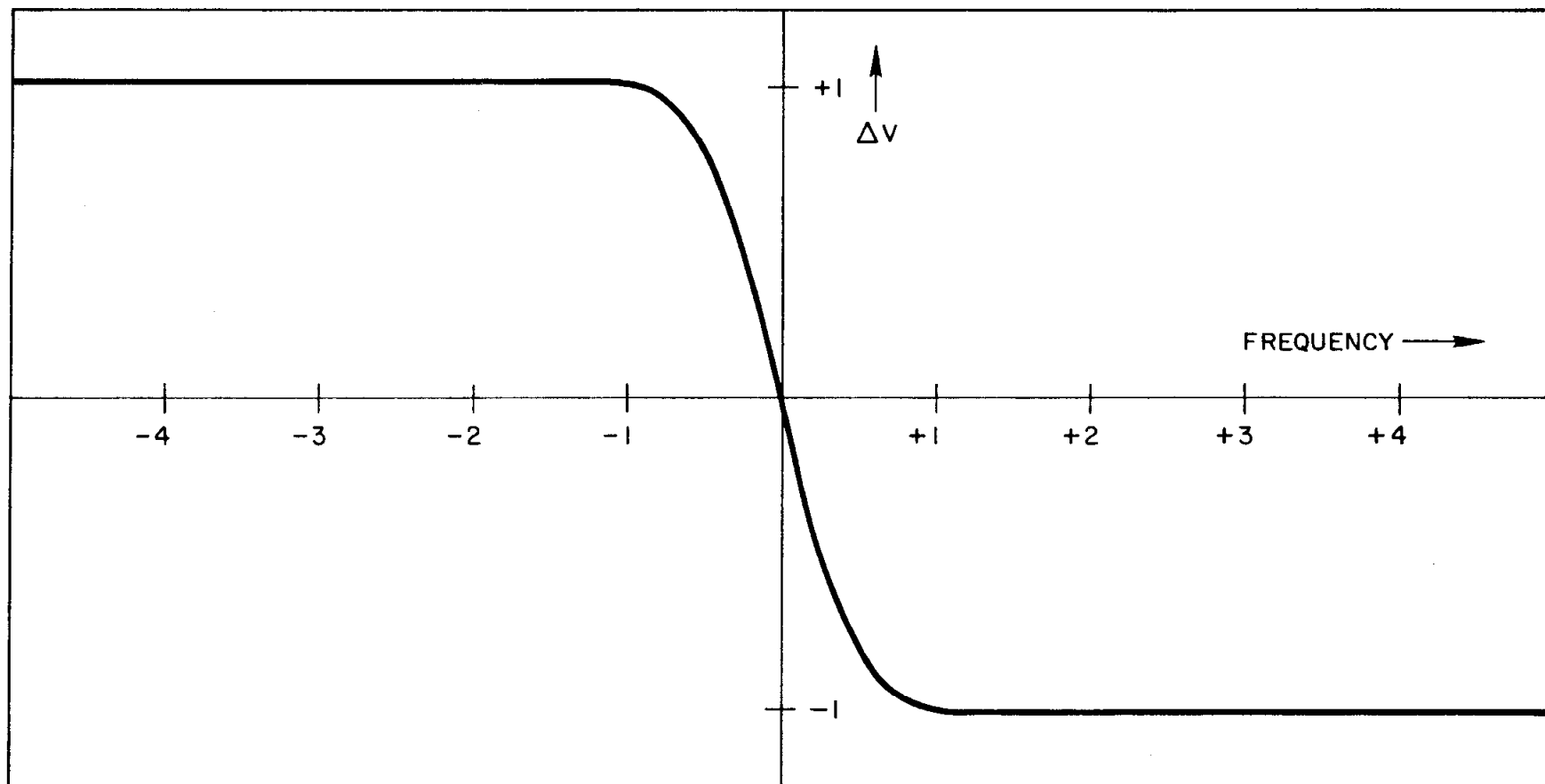
A system was developed also to maintain constant gap voltage. In this case a detector senses the fields within the cavity, and the output of the detector is compared to a reference voltage. Any deviation between the detected voltage and the reference can be used to control the rf drive to the cavity, thus maintaining constant gap voltage.

All the control systems described above generate dc output voltages. Circuitry from the two-mile accelerator automatic phasing system was modified to convert these dc signals to two-phase, 30-cycle square-wave signals capable of driving small motors which, in turn, drive tuners, couplers, etc.



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FIG. 30- ΔV VS FREQUENCY WITH DETECTORS AT $\lambda/8$ AND $3\lambda/8$



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FIG. 31- ΔV VS FREQUENCY FROM VECTOR VOLTMETER OUTPUT

2. Conventional Facilities

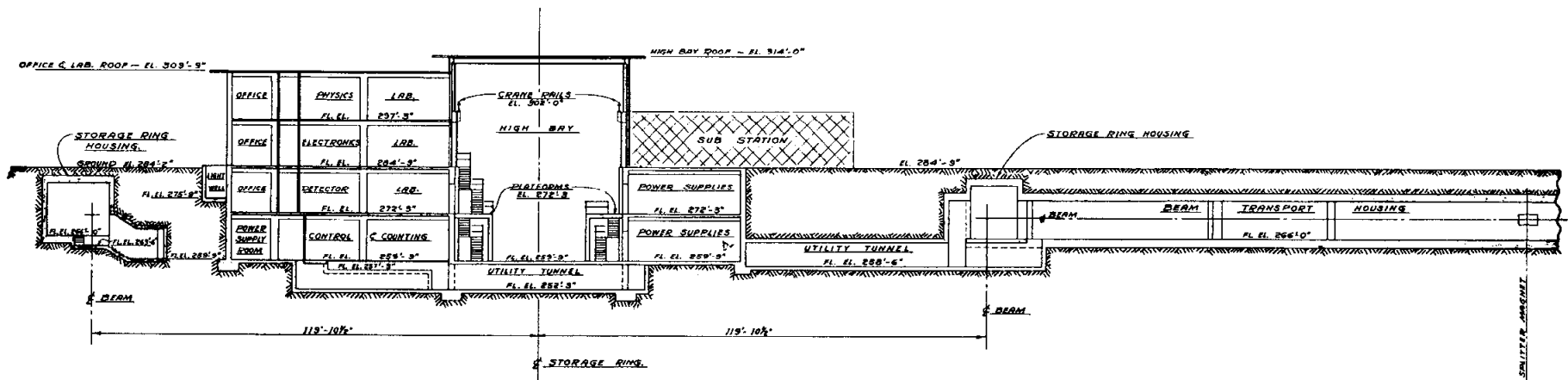
The only work done on the storage ring conventional facilities the first two quarters was completion of a revised cost estimate based on the new building layouts. These layouts were changed to conform to the latest storage ring, magnet-lattice and beam-transport system.

Rotation of the ring made it more feasible to locate the office and laboratory wing inside the storage ring adjacent to the high bay, providing better access to the control room and experimental areas. The ring housing will be located underground to provide better shielding. The new layouts are shown in Figs. 32 and 33.

3. Experimental Equipment

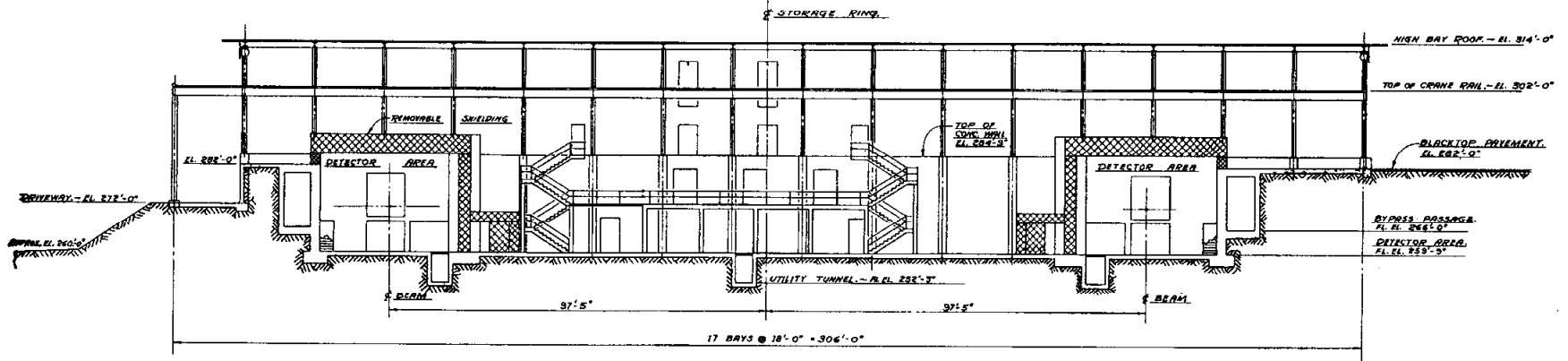
A gas Cerenkov counter to be used as a beam-position monitor for low-intensity electron and positron beams was fabricated and tested. The counter uses mirrors and four photomultiplier tubes to sense the position of the beam axis. Tests indicate that the position accuracy of this monitor is approximately $\pm 1/2$ mm.

A large-aperture magnet using a hollow aluminum conductor for its coils was designed, built, and tested. This magnet has a gap of 16 inches, a pole width of 40 inches, and a pole length of 48 inches. The peak field is 20 kilogauss, and measurements made with a long coil showed that the integral of the field over the length of the magnet was constant to within $\pm 1\%$ throughout the aperture.



SEC. A-A

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SEC. B-B

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FIG. 33- ELEVATION OF PROPOSED STORAGE RING FACILITY

E. COLLIDING BEAM VACUUM STUDIES

Tests on the 10-foot-long, stainless-steel, cryo-pumped model of the vacuum chamber were completed and testing was terminated. Preliminary steps were initiated for the design, fabrication, and assembly of a 10-foot-long, half-scale, cross-section extruded aluminum test model. Vacuum chamber components were tested and evaluated for engineering-design studies. Design studies were pursued and preliminary layout drawings were produced. Electron desorption studies were continued.

1. Chamber Design

The thermal heat flux on the chamber wall and the resulting radiation-induced gas desorption and pressure distribution were calculated. Based on these calculations, the reduced reflection of synchrotron radiation, and the high thermal conductivity of aluminum, it was decided to use aluminum for the vacuum chamber instead of the previously proposed stainless steel. The calculations also justified the substitution of sputter-ion vacuum pumps alone, in lieu of a combined system of ion and cryo pumping. The present calculations show that the peak heat fluxes will be 150 watts/cm in the cavities and 275 watts/cm at the beam scrapers in the transitions at the ends of the bending magnet sections.

Large-scale study drawings were made with special attention to the vacuum chamber transition region between bending magnets and the quadrupoles which contain the pump ports, high-voltage and other feed-throughs. A decision was made to install the ion pumps horizontally. Provisions were made to incorporate removable access flanges to support a water-cooled beam scraper that protects the bellows expansion joints.

Tests and calculations have shown that the ring bake-out can be accomplished by bolting strip heaters to the side of the vacuum chamber. Adequate contact will be insured by installing crumpled aluminum foil between the heaters and the chamber. Tests also indicated that glass-fiber felt is a satisfactory thermal insulation for this application.

Problems of fabrication and procurement of large extruded aluminum sections were studied and discussed with various suppliers.

2. Test Model

Several aluminum "bridge" extrusions were procured and evaluated for leak tightness and bridge weld soundness. The tests showed that the bridge extrusions were not completely reliable and it was decided to design on the basis of mandrel extrusions.

Two, 15-foot-long, half-sized, die-and-mandrel extruded sections were procured and subjected to preliminary measurements. These sections will be used to fabricate a model for testing under ultra-high vacuum.

In the course of preparing to fabricate a test model, it was necessary to study and improve the in-house aluminum welding techniques for reliable vacuum-tight joints. A systematic study determined that minute contaminants due to handling and storage were largely responsible for porosity. Chemical and mechanical cleaning techniques were studied. At present, the results indicate that chemical cleaning, high-speed wire brushing, and hand scraping will result in satisfactory welds. Effects of preheating were also studied.

Dies and jigs for drawing aluminum ports were built and tested. These drawn ports will facilitate welding and help minimize virtual leaks.

3. Aluminum-to-Stainless-Steel Transitions

Several methods for making aluminum-to-stainless-steel transitions were investigated and tested. The cost of commercially produced transitions of acceptable reliability seems to be prohibitive. Cups formed from roll-bonded stainless steel and aluminum were machined and tested. Some of these cups were found to be defective, and there was mechanical separation of the aluminum from the stainless steel. At the present time it appears that flanging is the most reliable method for making the necessary transitions. A detailed report on aluminum-to-stainless-steel transitions will be published in the near future.

4. Stainless-Steel-to-Aluminum Flange Sets

An 8-inch O.D. flange set with an aluminum gasket was fabricated from a modified LRL, Livermore, design. The flange set was subjected to various bake-out and mechanical shock cycles. The flange was further modified in order to test for the limits of its performance. These tests were not completely satisfactory because of random marks due to surface lapping. This was corrected by reverting to the original method of lathe-turning the faces. The tests were being continued.

5. Bellows Expansion Joints

A study was made of the comparative merits of the use of aluminum versus stainless-steel bellows. Several methods of manufacturing were reviewed, and the use of aluminum bellows was rejected. A newly developed type of non-welded nesting bellows was also investigated.

6. Clearing Field Electrode Feed-throughs

A commercial high-voltage alumina insulator for possible use for the clearing field electrode feed-throughs was subjected to a life test. The insulator withstood 55 kV after exposure to 30 kV for 6500 hours in a normal ambient environment. Discoloration due to dust and other airborne contaminants did not cause breakdown but did add to the corona noise at 55 kV.

7. Stable Inert Gas Pumps

Equipment and materials for a stable inert gas pump were procured. The pump will be assembled and tested in order to evaluate the possibility of using such pumps on the storage ring.

8. Aluminum Out-Gassing Measurements

Preliminary measurements were made on the out-gassing from stock 1100 and 6061 aluminum sheets and found to be $\sim 10^{-13}$ torr-liter/sec-cm² after baking for 24 to 72 hours. Subsequent to the original measurements of total out-gassing, the apparatus has been equipped with a residual gas analyzer.

9. Electron Desorption Studies

The desorption of gases from an aluminum sample under electron bombardment was subject to intensive study. A quadrupole mass spectrometer permits measurements of the individual gases produced or desorbed during bombardment. The principal gases which are in evidence are H₂, CO, and CH₄. Gas production rates and electron desorption efficiencies were measured with respect to the following parameters:

- (a) Electron energy from 0 to 15 kV.
- (b) Sample temperature from 77° K to 500° K.
- (c) Electron flux density from 1.0 to 2000 $\mu\text{A}/\text{cm}^2$.
- (d) Electron dose from 2×10^{18} to 5.6×10^{20} electrons/cm².
- (e) Gas density and exposure time between bombardments.

The results are summarized below:

a. Energy Dependence. The threshold energy for electron desorption occurs near 20 eV. The interaction cross sections reach maxima between 200 and 400 eV. Above these energies the electron desorption rate falls off until the energy exceeds previous bombarding energies at which point the desorption rate increases sharply. It appears that the more penetrating electrons can activate the removal of subsurface gases. Thus the concentration of these subsurface gases determines the nature of the high-energy electron desorption response. By bombarding with higher-energy electrons (up to 15 keV) to doses $>10^{19}$ e/cm², it was possible to reduce the bulk gas effects and get a true measure of the cross section variation with energy. These cross sections for surface desorption were also measured by adsorption and desorption of carbon monoxide containing the stable 18 O isotope.

b. Temperature Dependence. After high temperature baking or long-time high-energy electron bombardment, the low-energy desorption rates do not show any temperature dependence over the range from 77° to 500° K.

c. Electron Flux Dependence. The electron desorption rate was found to vary linearly with the electron flux density over the range from 1.0 to 2000 μ A/cm².

d. Dose and Time Dependence. Initial electron desorption rates at 300 V for the unbaked surface were

$$\begin{aligned} \text{H}_2 &\sim 3 \times 10^{-3} \text{ molecule/electron} \\ \text{CO} &\sim 1 \times 10^{-3} \text{ molecule/electron} \\ \text{CH}_4 &\sim 2 \times 10^{-4} \text{ molecule/electron} . \end{aligned}$$

After extended high- and low-energy bombardment, the gas production rates have been reduced to

$$\begin{aligned} \text{H}_2 &\sim 2.9 \times 10^{-7} \text{ molecule/electron} \\ \text{CO} &\sim 2.8 \times 10^{-7} \text{ molecule/electron} \\ \text{CH}_4 &\sim 1.2 \times 10^{-8} \text{ molecule/electron} . \end{aligned}$$

There is some evidence that the methane produced is not desorbed directly but is the product of a hydrogen-carbon reaction occurring in the system. For all test runs, the desorption rates decay in accordance with

$$\eta = \eta_1 t^{*\alpha} ,$$

where η = desorption rate, molecules/electron
 t^* = dimensionless time = actual time t /initial time t_1
 η_1 = initial desorption rate at $t = t_1$
 α = decay slope.

For almost all test runs, there is a short-time decay for time less than 10 to 20 minutes, and a long-time decay for all times thereafter. The values of α vary from 0.3 to 1.0. No correlation with other parameters had yet been established.

e. Repopulation. In the absence of bombardment, gases re-adsorb on the surface and the electron desorption rates increase slowly until saturation at rates 10^3 to 10^4 higher. Average sticking probabilities vary between 10^{-2} and 10^{-4} . Current efforts are directed toward understanding the re-adsorption process in detail for carbon monoxide and hydrogen.

A third-generation apparatus was being assembled which should further extend our understanding of photo and electronic desorption processes. The new device will have the following features. It will permit bombardment by either soft x-rays ($\lambda = 0.71\text{\AA}$) or low-energy electrons. It will allow foil samples to be thermally flash-desorbed to remove both surface and bulk gases. A quadrupole mass spectrometer will be mounted to receive neutrals and ions directly from the sample surface without intermediate wall collisions.