SLAC: STATUS, RECENT PROGRESS, AND FUTURE PLANS*

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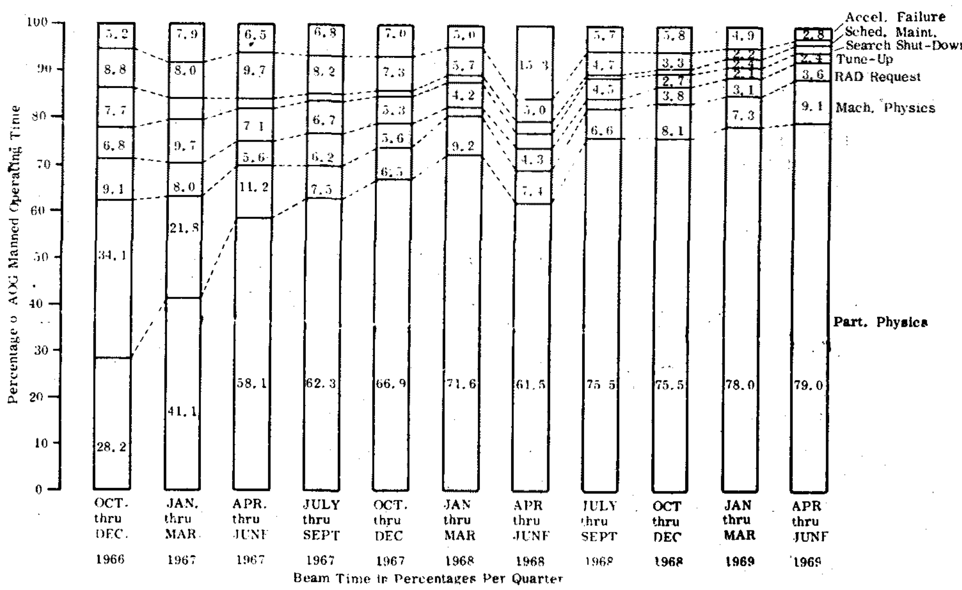
I. Operations Summary

Operating experience with the SLAC two-mile accelerator since the start of the physics program in November 1966 is shown in Table 1. An examination of this table indicates that: (a) the relative fraction of the operating time devoted to high energy physics has steadily grown while the fraction devoted to machine physics has decreased; and (b) the fraction of the operating time consumed by non-productive contingencies and functions such as accelerator failure, scheduled maintenance, tune-up, etc., has been steadily reduced during this period. Some of these

TABLE
ACCELERATOR OPERATIONS SUMMARY



* Work supported by U. S. Atomic Energy Commission.

improvements in operating efficiency are the result of accumulating experience and general machine improvements. A more recent source of improvement is the change from a two-week to a four-week operating cycle. Although the gaps between periods of operation have been adjusted so that the net operating time per quarter is approximately the same for the two cycles, the longer cycle has led to greater efficiency principally because the machine start-ups and shut-downs are one-half as numerous and the uninterrupted interval for physics is about twice as long as that available with the shorter cycle. It now appears that any further significant increase in the fraction of the opperating time available for high energy physics will be realized only with a substantial increase in the total number of operating hours per quarter. Such an increase in unlikely during the next year due to budgetary limitations.

Machine operating statistics for the past 8 quarters in terms of actual hours utilized for productive and nonproductive categories of work are shown in Table 2.

Table 2

Machine operations statistics

	FY 1968				FY 1969			
	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
A. Physics beam hours								
Machine Physics	130	82	74	142	68	121	105	130
Particle Physics	909	735	958	879	979	1.117	1.047	1.060
Total	1.039	817	1.032	1.021	1.047	1.238	1.152	1.190
Non-physics hours								
Scheduled Downtime	136	98	70	137	55	49	32	18
Unscheduled Downtime Due to Equipment Failure	163	134	107	230	105	104	84	46
All Other (Machine Tune-Up. etc.)	286	215	170	212	150	113	140	162
Total	585	447	347	579	313	266	256	226
Total manned hours	1.624	1.264	1.379	1.600	1.360	1.504	1.408	1.416
B. Experimental hours								
1. Machine Physics	164	104	103	194	153	106	124	259
2. Particle Physics	1.498	1.162	1.971	1.956	2.616	4.066	2.917	2.915
Total experimental hours	1.662	1.266	2.074	2.150	2.769	4.172	3.041	3.174

This table shows the steady gain in physics beam hours and the general decrease in non-physics hours during this period. It may also be observed in Table 2 that, because several experiments can be performed simultaneously during multi-beam operation, the total experimental hours have exceeded the total beam hours by an average factor of 2.8 during the past 4 quarters.

Electrical power usage during the most recently completed fiscal year (FY 69) is shown in Table 3.

Table 3

Electrical Power usage- FY 1969

Total Energy Consumed	221, 900 000 kW hrs.
Peak Demand During Year	51. 7*MW
Average Monthly Power Factor	0. 873
Average Monthly Load Factor	0 645
Energy Cost dollars	0. 0042 per kW hr.

* Components of Peak Demand:

Accelerator and Auxiliaries	26. 6 MW	(51 %)
Beam Switchyard	2. 6	(5 %)
Research Area	18. 6	(36 %)
Site Facilities	3. 9	(8 %)

During this year, the total energy consumption and the peak power demand both established new high level marks. The energy cost of 0.0042 doll. per kilowatthour is regarded as quite favorable. Power cost may rise somewhat in FY 1970 and beyond since a portion of the power now allocated by the Bureau of Reclamation may be retracted.

A summary of the SLAC manpower status as of June 1, 1969 is given in Table 4. The staffing level is expected to remain approximately constant during fiscal year 1970.

Table 4

SLAC manpower summary* (June 1, 1969)

	Professional		Non-Professional		Total	
	Number	%	Number	%	Number	%
Scientific	301	23	777	60	1078	83
Administrative	53	4	168	13	221	17
Total	354	27	945	73	1299	100

* Including graduate students, visiting scientists, and trainees.

II. Recent Beam Performance

A. **General**--An up-to-date summary of beam performance with electron and positron beams is given in Table 5. On April 27, 1969, a new high energy mark of 21.5 GeV was established for electrons. This energy corresponds to an average energy contribution of about 90 MeV per klystron station. Typically, experiments require beam energies in the range of 5 to 18 GeV but a few experiments have used beam energies above 20 GeV. The higher energies do not cause any great difficulties unless a high beam current is needed and another experiment requires an inter-laced beam of low energy and high current. In this case, the present focusing system is unable to optimize both beams and one of

Table 5

Electron and positron beam performance

	Positron	Electron
Beam Energy (max.)	13.5 GeV	21.5 GeV
Typical Energy Spectrum	1—2 %	0.2—2 %
Peak Current (max.)	1.2 mA[(1)]	55 mA[(1)]
Average Current (max.)	0 5 μA[(2)]	30 μA
Beam Power (max.)	7 kw[(2)]	500 kw
Repetition Rate	1—360 pps	1—360 pps
Pulse Length	0.05—1.6 μsec	0.05—1.6 μsec
No. of Simultaneous Beams (max.)	6	6
Typical Transverse Phase Space in Beam Switchyard	$0.3\,\pi\left(\frac{\text{MeV}}{c}\right)$(cm)	$0.05\,\pi\left(\frac{\text{MeV}}{c}\right)$(cm)

(1) Into 1% energy spectrum
(2) Based upon 140 kw maximum incident electron power on positron target.

the other must suffer or a compromise must be sought which is satisfactory but not ideal for either beam.

Most experiments require the maximum pulse length of 1.6 μsec and peak beam currents in the range of 500 μA to 40 ma. The maximum electron current level of 55 mA is limited by beam breakup and would be very difficult to obtain if simultaneons beams of different characteristics were being accelerated. Recent methods of increasing the beam breakup threshold will be discussed in II. D below.

B **Positron Techniques and Results**— Positrons may be obtained by bombarding either of two targets located at the one-third point (a the beginning of Sector 11) along the accelerator. The maximum posittron energy ($\sim$13.5 GeV) is thus approximately two-thirds of the maximum electron energy. The incident electrons are acclerated through the first third of the accelerator and arrive at the target with an energy of about 6 GeV and a maximum peak current of about 60 mA.

The two positron targets are: (a) an oscillating wand target which is used when inter-laced beam of positrons and electrons are wanted in the experimental area; and (b) a rotating wheel target which is used when positron beam only is desired. Characteristics and capabilities o these targets are given in Table 6.

Table 6

Positron targets in Sector 11

Oscillating Wand Target	
Typical Sweeping Rate	1-2 passes/sec
Typical No. of Pulses/Pass	5
Maximum Allowable Incident Electron Power	4 kW
Rotating Wheel Target	
Present Diameter	2"
RPM	200
Maximum PRR	360 pps
Maximum Allowable Incident Electron Power: Wheel Rotating	140 kW
Wheel Fixed	30 kW

The yield of positrons per incident electron on the target is given in Table 7. The most pertinent result for physics purposes is the yield

Table 7

Positron yields

Maximum Yield To Date	
at end Sector 11	6%
into BSY	4%
to experimenter, within 1 % spectrum	2%
Maximum Electron Current Incident On Target(1)	$\sim$60 mA
Typical Incident Electron Energy	6 GeV
Typical Positron Energy To Research Area	4-13.5 GeV

(1) Limited by beam breakup in first third of accelerator.

of $\sim 2\%$ within a 1% spectrum width to the experimental area. This positron current is typically within a transverse phase spase of $\sim 0.3\pi$ (MeV/c) (cm).

In the oscillating mode the wand target is limited to about 10—20 positron pulses per second (with the remainder of the possible 360 pulses per second being electrons if desired). On the other hand, the wheel target when used in the normal rotating mode provides only positron pulses and no electrons. An alternate scheme which has recently been proven feasible allows any desired combination of electron and positron pulses which do not add to more than 360 pulsus per second. In this scheme, the wheel target is operated in a stationery mode with the edge of the wheel slightly overlapping the beam axis. The beam aperture in the vicinity of the positron target is 19 mm in diameter and the beam is normally focused to ~ 2 mm in diameter at the target. When positron pulses are desired, the incident electron beam is allowed to impinge directly upon the target. On the other hand, when electron pulses are desired, the incident electron beam is deflected slightly by a pulsed magnet so that it misses the target but remains well within the beam aperture. The passing electron beam is then deflected by two other pulsed magnets to restore it to the beam axis and to aim it properly so that it can be accelerated through the rest of the accelerator. Since the power handling capability of the wheel target is limited to about 30 kW when it is operated in the stationary mode, the positron beam power available in the research area when using this scheme is ~ 1.5 kW, i. e., the average current is limited to ~ 0.1 μA. Using this method, inter-laced beams of various combinations of positron and electron pulses have been successfully accelerated.

C. Chopped Beam Results—Certain experiments desire increased separation of electron bunches beyond the normal 350 psec associated with the 2856 MHz accelerating frequency in order to carry out time-of-flight measurements. This is accomplished by means of a "beam knock-out" system which removes the unwanted bunches by means of rf chopping devices near the main injector. One chopper consists of deflecting plates on which a sinusoidal voltage at 39.667 MHz (the 72nd subharmonic of the 2856 MHz accelerating frequency) is impressed. When the voltage amplitude on the plates is sufficiently high, only one electron bunch at each voltage null is undeflected and subsequently accelerated through the machine; other bunches are deflected into the wall At lower voltage, several contiguous bunches survive and are accelerated. In either case, the separation of the accelerated bunch (or group of bunches) from the next accelerated bunch (or group of bunches) is 36 times the normal bunch separation, i. e., the time separation is 36×350 psec ≈ 12.5 nsec. The beam knockout system is controlled through the machine trigger and pattern systems so that it is possible to apply the system to one or more beams while other inter-laced beams are allowed to operate normally. A second chopper system can be operated at subharmonics of the first chopper, e. g.; at ~ 20, 10, and 6.6 MHz. When the two choppers are run simultaneously, bunch separation of 25, 50, or 75 nsec can be achieved. These separations can be doubled to 50, 100, and 150 nsec by using a steering dipole to produce a biasing deflection such that only those bunches occurring at a time corresponding to peak rf deflection of one polarity are transmitted.

When a very short injection pulse is used, the beam knockout system can be adjusted so as to allow acceleration of only single electron bunches during the period of each rf pulse. This type of operation is proving useful in the study of transient behaviour of the accelerator.

During beam knockout operation, the injected current can be increased so as to compensate partially for the current lost due to removal of the unwanted bunches. However, it is not possible to obtain as high a chopped beam current as with the normal unchopped beam because of beam breakup or injector limtations. The currents actually achievable are indicated in Table 8.

Table 8

Beam knockout: chopped beam capability

Chopper Frequency	Burst Spacing	Max. Average Pulse Current
40 MHz	12.5 nsec (single bunch)	~10 mA
40+20 MHz	25 nsec (single bunch)	~ 8 mA
40+20 MHz	25 nsec (several bunches)	~12 mA
40+10 MHz	50 nsec (single bunch)	~ 4 mA
40+6.6 MHz	75 nsec (single bunch)	~ 3 mA
6.6-20 MHz (continuously variable)	75-25 nsec (several bunches)	1-15 mA (gun limited)
40+10 MHz+50 nsec Gun Pulse	One bunch (~10 psec long)	$\sim 10^9$ electrons

The beam knockout system can also be used during positron acceleration.

D. Beam Breakup Threshold—As discussed above, the maximum current which can be accelerated through the machine is limited by beam breakup (BBU) phenomena. The electron bunches in the beam are initially displaced from the axis by rf noise components near the injector. Interaction of the beam with the accelerator structure results in the excitation of a transverse deflecting mode of the HEM_{11} type which causes continuing growth of the transverse mode and increasing displacement of the electron bunches in successive accelerator sections. Eventually, the beam displacement is so large that the beam strikes the accelerator walls and is lost. When the accelerator was first turned on in 1966, the maximum peak current achievable was $\sim$ 20 mA. Rearrangement and strengthening of the focusing system during the following 2 years resulted in step-wise increases in the BBU threshold to $\sim$ 25, $\sim$ 30, and $\sim$ 40 mA. More recently, a scheme called "dimpling" has been used to detune the transverse mode frequency by 2—4 MHz.

The dominant beam breakup mode, which occurs at a frequency of $\sim$ 4140 MHz, exists only in the first $\sim$20 cm of each tapered 10-foot accelerator section. Therefore only three cavities (Nos. 3, 4, and 5) of each section need to be de-tuned in order to reduce the coherent amplification along the accelerator. Since only a small fraction of each 10-foot section is de-tuned there is only a small decrease in the energy gain produced by the normal accelerating mode. The accelerator sections of Sector 1 were first de-tuned in this manner in August 1968 resulting in an increase in the BBU threshold to about 47 mA with negligible loss in beam energy. Subsequently, Sector 2 was de-tuned giving a further increase in BBU threshold to $\sim$ 55 mA. This brings the current capability of the accelerator above the original design goal of 50 mA. By the end of August 1969, it is planned have the "dimpling' of Sectors 3, 4, 5, and 6 completed.

Further details of the beam breakup phenomena and corrective measures are given in a separate report to this conference.[1]

E. Compensation for Beam Loading — Transient beam loading causes a decrease in beam energy during the pulse as the beam removes stored energy from the accelerator strcuture faster than it can be restored by the input power from the klystron source. This transient energy loading is shown in the two upper curves of Fig. 1 for beam currents ot 2 mA (light beam loading) and 40 mA (heavy beam loading). The standard method of compensating for transient beam loading is to delay the trigger to the klystrons of certain sectors so that the accelerator sections in these sectors are still filling when the beam is turned on. The rising field characteristic in these sections during the beam pulse then serves to compensate for the transient energy decrease due to beam loading. As the beam loading becomes heavier with increasing current, it is necessary to delay more klystrons in order to achieve reasonably good compensation. The compensation achieved using this technique for 40 mA beam loading is shown by the 3rd curve from the top in Fig. 1. In this example, the initial 5% beam loading transient has been reduced to $\sim$0.7%. The remaining energy spread occurs largely in a "gulch" which is about 0.6 μsec wide and which occurs about 0.6 μsec after beam turn-on. When operating with a narrow energy defining slit, "gulch" is manifested as a depression in the amplitude of the transmitted current pulse. The depression increases as the slit width is decreased. The energy gulch is caused by imperfect matching of the rising electric field characteristic from delayed accelerator filling with the falling field characteristic due to beam loading. A technique of filling the energy gulch which has recently proven feasible consists basically of adding an energy increment of the correct shape and amplitude at the proper time during the pulse. In practice, this scheme has utilized two adjacent klystrons which are independently adjustable in timing, pulse width, and phase. The first klystron contributes to the electron energy needed to fill the "gulch" whi e the second klystron cancels the effect of the first on the portion of the pulse following the gulch. The net result is a significant improvement in the flatness of the beam pulse passing through a narrow slit.

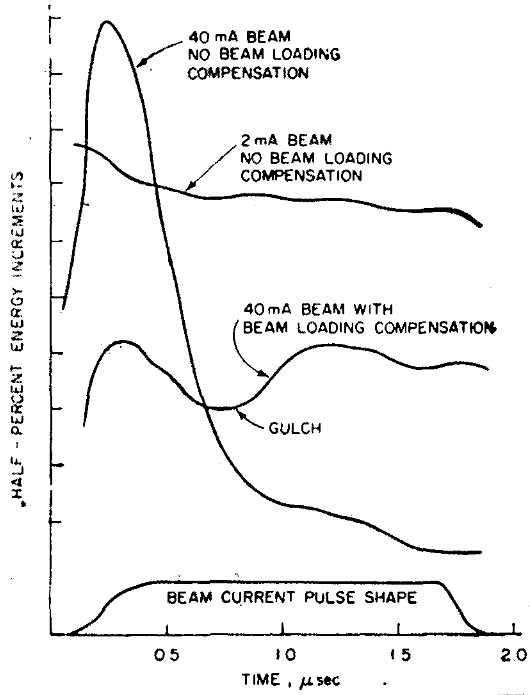


Fig. 1.—Mean electron energy vs time during pulse; beam energy 17 GeV.

III. Experience With Major Replacement Components

A. High Power Klystron Experience—Because the high power (20 MW) klystrons have a high initial cost, are used in large numbers (245) and have finite life, their operation and replacement constitutes a significant fraction of the total operations budget. For this reason, their performance and life are of great interest and concern to SLAC. Fortunately, these tubes have proven to be very reliable in operation and their lifetime has exceeded early estimates by a large factor.[2] Table 9 gives a summary of klystron usage and mean time between failure (MTBF) by quarter and cumulatively for the past 3 years. It may be noted that the number of failures has averaged about 20 per quarter over the most

Table 9

Klystron usage and mean time between failure

Dates	Per quarter				Cumulative			
	Operating Hours	Failures		MTBF	Operating Hours	Failures		MTBF
		Number	Mean Age			Number	Mean Age	
To 6/30/66					129,400	19	260	7,200
To 9/30/66	111,000	8	610	14,000	240,400	27	360	9,000
To 12/31/66	154,000	11	1,100	14,000	394,400	38	575	10,300
To 3/31/67	207,000	13	1,490	15,900	601,400	51	810	11,800
To 6/30/67	287,000	9	2,490	32,000	888,400	60	1,060	14,800
To 9/30/67	330,500	25	2,860	13,300	1,218,900	85	1,590	14,500
To 12/31/67	263,000	21	3,520	12,500	1,481,900	106	1,980	14,100
To 3/31/68	309,500	17	4,800	18,200	1,791,400	123	2,360	14,700
To 6/30/68	306,000	15	3,820	20,400	2,097,400	138	2,520	15,200
To 9/30/68	314,200	24	5,500	13,100	2,411,600	162	2,960	14,900
To 12/31/68	349,800	23	8,350	15,200	2,761,400	185	3,630	15,000
To 3/31/69	328,600	20	6,610	16,400	3,090,000	205	3,930	15,100
To 6/30/69	335,000	17	7,280	19,700	3,425,000	222	4,190	15,400

recent 8 quarters. The cumulative mean age at failure continues to increase each quarter, while the cumulative mean time between failure seems

time between failure seems to have settled out at a level of approximately 15,000 hours. Figure 2 shows the age

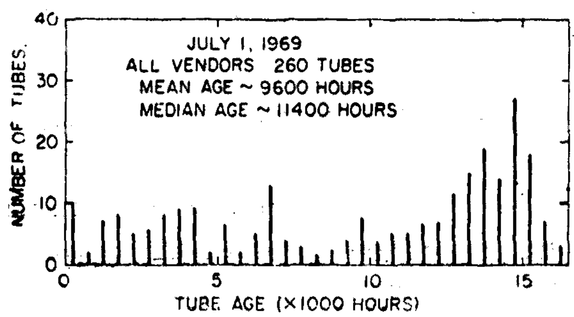


Fig. 2.—Operating klystrons age distribution in 500-hour increments.

to have settled out at a level of approximately 15,000 hours. Figure 2 shows the age distribution of all tubes now connected to the accelerator. The mean and median ages of all operating tubes (260) are now 9600 hours and 11,400 hours, respectively. The age distribution of all tubes that have failed (222) is shown in Fig. 3. The mean and median ages of the failed tubes are now 4140 hours and 3300 hours, respectively. The survival probability of all tubes used on the machine is shown in Fig. 4. Except for "infant" failure during the first 1000 hours

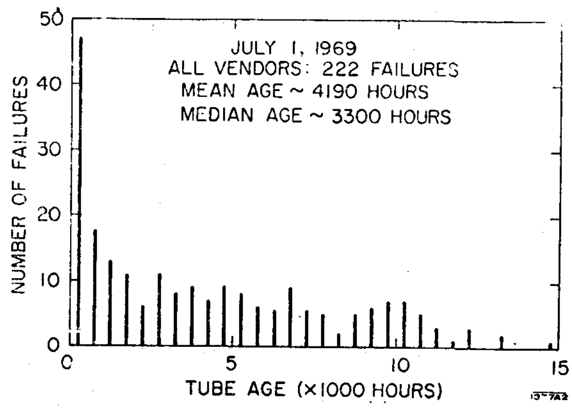


Fig. 3—Failed klystrons age distribution in 500-hour increments.

of operation, the failure probability is roughly constant (≈ 5% per 1000 hours of operation) up to 15,000 hours indicating that the failure mechanism exhibited thus far is purely random Figure 5 gives a summary

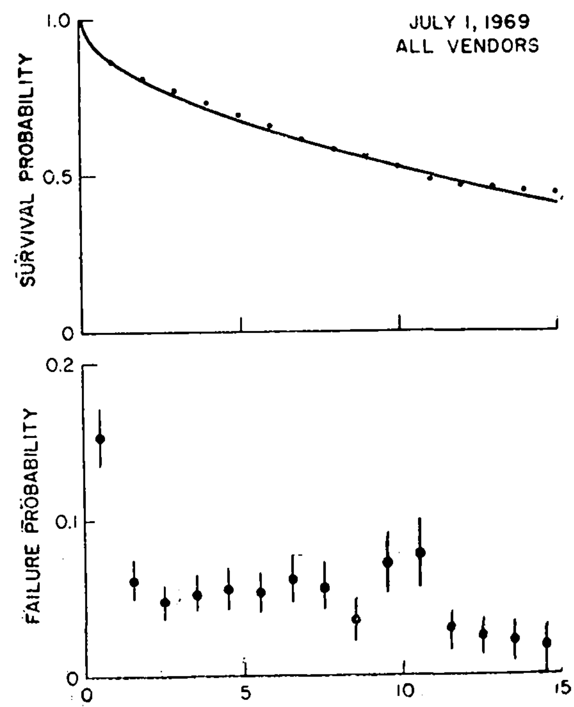


Fig. 4—Klystrons survival and failure probability.

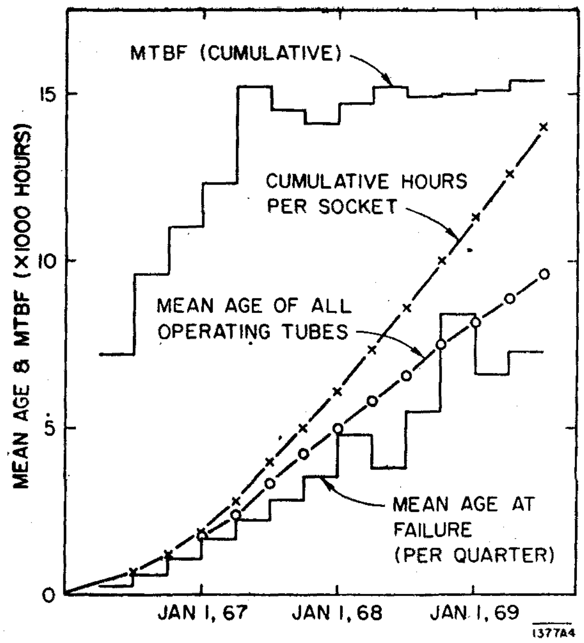


Fig. 5.—Summary of klystron statistics.

of the cumulative MTBF, the cumulative operating hours per socket, the mean age of all operating tubes, and the mean age at failure per quarter. Examination of the overall klystron failures since the beginning of operation in 1966 shows the causes of failure listed in Table 10.

Table 10

Percent of klystron failures from various causes

Failure	Percent of Total Failures
Output Window	40
Vacuum Deterioration	20
Over-Current*	20
High Voltage Seals	5
Low Emission	5
Miscellaneous	10

* Usually due to cathode-anode arcing.

B. **High Pover Modulator Experience**—There is one of these large units (rated at 64 MW peak and 74 kW average power) for each of the high power klystrons, or a total of 245. Up to July 1, 1969 the average cumulative operating time for the modulators is 14,500 hours.

Typically, during machine start-up about 93% of the modulators will start with no problems, 5% will have various electronic problems and 2% will have problems with the associated klystron. After the first 24 hours of a new operating cycle, about 1% of the modulators (~3) will still have problems. For the remainder of the cycle (~3 weeks) two or three of the modulators will typically be out of action at any given time. Failure experience with the principal modulator components during the past fiscal year (FY 69) is shown in Table 11.

Table 11

Failure experience with modulator components in FY 1969

Component	Number of Failures	Percent of Total	Comment
Pulse Capacitors	699	14.2	Higher quality replacement units are being purchased.
Charging Chokes	19	7.8	Failure due to internal corona which causes swelling and oil leakage. Units are repaired by rewinding.
Main Rectifiers	24	9.8	Failure generally due to dielectric breakdown of mounting card.
De-Q'ing SCR Assemblies	48	19.6	Failure usually associated with charging choke failure
Pulse Cable Assemblies	50	20.4	Major causes of failure are erosion of connector fingers and corona inside polyethylene dielectric.
Hydroden Thyratrons	274	112.0	Different life experience with tubes from two vendors (see Fig. 6).

Replacement of the large thyratron pulse switching device (1 per modulator) is the single most expensive factor in the operating costs of the modulators. Indeed, costs of thyratrons is roughly one-half of the cost of klystrons per operating hour. The average cost per thyratron hour during the entire operating period to date has been approximately 0.43. dol. There has been considerable disparity in the effective cost of tubes from the two principal manufacturers. Average lifetimes of the failing tubes from the two manufacturers are shown versus calendar year in Fig. 6. The lifetimes of tubes from manufacturers No. 1 and № 2 have tended to level out at ~ 3500 hours and 7000 hours, respectively.

IV. Experimental program Summary

In discussing the experimental program, it is convenient to divide experiments into two classes: (a) those using a bubble chamber as the principal instrument, and (b) those using various electronic devices (spectrometers, spark chambers, hodoscopes, counters, etc.) for measurement purposes. On this basis, the experimental experience at SLAC may be indicated as shown in Tables 12 and 13. Table 12 gives the number of electronic experimental hours by fiscal year and prorated as to whether the home institution of the experimental group was Stanford or "other universities." During the years shown, about 2/3 of the experimental hours have been assigned to Stanford and 1/3 to other universities. In

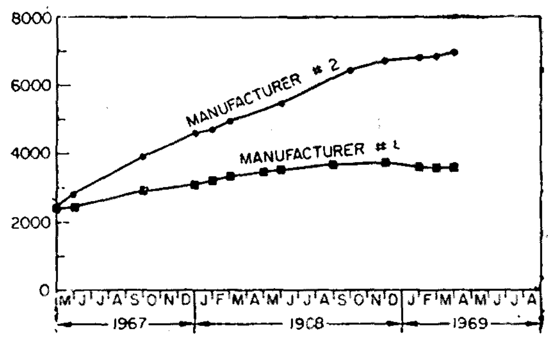


Fig. 6.—Average lifetimes of failed thyratrons.

Table 13, the number and percent of bubble chamber pictures assigned to Stanford, to other universities, and to collaborative experiments involving Stanford and one or more other institutions are shown for each fiscal

Table 12

Electronic experimental hours (pro-rated)

Fiscal Year	Total Hours	Stanford %	Other Universities %
1967	1138	57	43
1968	3451	72	28
1969	6012	62	38
Total	10601	65	35

Table 13

Bubble chamber pictures

Fiscal Year	Total Pictures Taken	Stanford %	Other Universities %	Collaboration %
1968	1,440,000	38	62	—
1969	4,961,000	26	58	16
Total	6,401,000	29	59	12

year since the beginning of the bubble chamber program at SLAC in FY 68. It is noted that the major fractions of pictures have gone to outside institutions.

The numbers of spark chamber events and bubble chamber events measured at SLAC during the last 6 quarters are shown in Table 14.

Table 14

Spark chamber and bubble chamber events measured at SLAC

	FY 1968		FY 1969			
	3rd Quar.	4th Quar.	1st Quar.	2nd Quar.	3rd Ouar.	4th Quar.
Spark Chamber Events	20,595	15,512	23,848	36,736	55,314	65,461
Bubble Chamber Events	36,002	35,419	36,665	26,649	26,050	25,445
Total	56,597	50,931	60,513	63,385	81,364	90,906

By the end of fiscal year 1969, the total number of electronic and bubble chamber experiments completed and the number in progress or scheduled are shown in Table 15.

Table 15

Experimental status

Type of Experiment	Number Completed	Number in Progress	Number Scheduled
Electronic	29	4	9
Bubble Chamber	15	3	4

V. Current Equipment Status

The major items of research equipment now in use at SLAC are listed in Table 16. Most of the experiments undertaken to date have employed one of these devices.

The inventory of experimental dc supplies available on July 1, 1969 is given in Table 17. SLAC is still deficient in power supplies and the sharing of these units among on-going experiments is often required. The corresponding number of experimental magnets (including dc dipoles, quadrupoles, sextupoles, septum and pulse magnets) on hand on July 1, 1969 is 73. These magnets are also in short supply.

The computers available on July 1, 1969 and their applications are listed in Table 18. It is clear that the use of computers in high energy. physics will continue to increase. During the last year the IBM 360/91

Table 16

Major items of research equipment

20 GeV Spectrometer
8 GeV Spectrometer
1.6 GeV Spectrometer
82 Inch Bubble Chamber
40 Inch Bubble Chamber
2 Meter Streamer Chambber
54 Inch Spark Chamber
Wire Spark Chamber Spectrometer (magnet aperture 100 cm×40 cm)
RF Separated Beam Facility
Back-Scattered Laser Beam Facility
Annihilation Beam Facility

computer has become a controlling factor in determinig the completion and publication of experimental results at SLAC. Several specific additions are now needed in the input-output equipment of this machine to

Table 17

Experimental dc power supply inventory (7/1/69)

Output Rating (kW)	Number of Units	Total DC Power (kw)
2— 20	17	85
100— 600	50	18,162
1000—6000	7*	20,380
Total	74	38,627

* 2 units at 1590 kW
2 units at 1500 kW (MG sets)
1 unit at 3400 kW
1 unit at 5000 kW
1 unit at 5800 kW

Table 18

Computers available at SLAC (7/1/69)

Computer Type	Approximate Cost*, dol.	Application
IBM 360/91	5,500,000	Central Use Facility
SDS 925	100,000	Beam Switchyard Control
SDS 9300	500,000	Online to Spectrometers
SDS 930	150,000	Support for Spectrometers
EMR 6020	130,000	Measuring Machines
PDP 8	30,000	Counter Experiments
PDP 9	50,000	Spiral Reader
IBM 1800	300,000	Wire Spark Chamber
PDP 9	90,000	Accelerator Control

* Including various peripheral devices.

take full advantage of its central processor and memory capability. Additional intermediate size computers are needed to process the data of the smaller on-line computers now employed with many electronic experiments so that the central computer will not become over-loaded with on-line activities. It appears that the trend is toward having a small on-line computer for each electronic experimental user. It is difficult to share these units because of the complexity and specialization of peripheral equipment needed for each specific experiment.

The measuring machines shown in Table 19 are now available at SLAC for measuring spark chamber and bubble chamber pictures.

Table 19

SLAC measuring machines for spark chamber and bubble chamber pictures

Number	Type	On-line	Associated Computer
6	General Purpose, Medium Quality	Yes.	EMR 6020
7	Special Purpose, Low Quality	No	—
1	Hummingbird (CRT-generated flying spot digitizer)	Yes	IBM 360/91
1	Spiral Reader	Yes	PDP 9

VI. Recent Improvements and Additions

A number of machine, research area, and general improvements and additions have recently been made at SLAC. Among the more significant are the following:

A. **Laser Beam Facility**—This facility became operational in the Fall of 1968. By large-angle scattering of laser light from the electron beam a photon beam is obtained which is monochromatic to $\sim\pm4\%$ (at 5 GeV photon energy). In addition, the beam retains the original polarization of the laser light which permits experiments to be carried out in a bubble chamber wherein the incoming polarization is correlated with the spin of the final-state particles. A yield measurement[3] with a 16 GeV incident electron beam, a Ruby laser output of 1 joule at 1.79 eV and a γ beam collimation half angle of 1.5×10^{-5} radians gave 800 back-scattered γ per 10^{11} electrons. One experiment has been completed and several others are underwary using this facility.

B. **Bubble Chambers**—Both the 40" and 82" chambers have been adapted to permit operation with deuterium in the chamber. The system design is also compatible with neon operation. A 35 mm camera system having a three film strip format has been built for use with the 82" chamber. The film is compatible with existing data analysing equipment.

A 2" rapid-cycle hydrogen bubble chamber has operated successfully at 60 expansions per second in a parasitic accelerator beam. A 4" chamber has also been run successfully up to 45 expansions/sec. These chambers are being considered for use as visaul targets.

C. **Control Room Expansion in Data Assembly Building**—This control room contains the instrumentation and control equipment for the Beam Switchyard. To improve the capability of handling multiple beams, a major rearrangement and expansion of the facilities in the control room was started in FY 1969 and will be completed around January 1970. A new dual console has been provided which allows separation of control and monitoring functions for multiple beams.

D. **Energy Absorbers**—An actuator capable of operation through many cycles without lubrication has been designed and is undergoing tests. This device is intended for use in high level radiation environments where lubricants tend to harden in relatively short periods.

The design of a new high power slit and a new tune-up dump utilizing a water-cooled volume filled with small aluminum spheres (1 cm dia.) as the energy absorber is in progress. This work is based upon the successful operation of a prototype beam dump[4] at a power level of 500 kW.

E. **Liquid Hydrogen Targets**—A target in which the liquid hydrogen density on the beam line can be maintained within $\pm1\%$ in the presence of high beam currents has been developed, fabricated, and used in physics experiments.

A helium refrigerator has been purchased and is being used in a system for condensing hydrogen in a target being used experimentally.

F. **Beam Position Monitors**—It is now possible to zero the beam position monitors located along the accelerator remotely from the Central Control Room without interference with the electron beam. This has greatly contributed to the ease and efficiency of accelerator operations.

G. **Central Control Room Computer**—A new PDP 9 computer was installed in the Central Control Room in January 1969. The first trial run occurred in March 1969. The initial use of this computer is to repla^e klystrons which "kick out'' or fail with stand-by units located along the accelerator. Another function is status and data logging of accelerator components and systems. As experience is gained, additional control functions will be assigned to the computer.

H. **Central Laboratory Aditton**—The construction of SLAC's remaining major building project within the original construction authorization was comleted in February 1969 and is now fully occupied. This building annex provides 30,000 ft^2 of additional space to house the offices and laboratories of the research staff.

VII. Future plans

It now appears that SLAC will have somewhat less financial support in FY 70 than in FY 69. Cost inflation will have a further adverse effect upon the planned programs. Present intent is to schedule approximately 600 shifts of operation and 4 million bubble chamber pictures in FY 70 which may be compared with the approximately 680 shifts and 5 million pictures achieved in FY 69. It is hoped that the increased efficiency arising from the 4-week cycle recently apopted (see Section I above) and the increasing effectiveness of multi-beam operations will compensate for the decrease in number of shifts so that the amount of experimental physics accomplished will not be significantly less than in FY 69. Changes in bubble chamber picture format which would reduce costs are under consideration; if these changes prove feasible it may be possible to increase the number of pictures above the presently planned level.

A. **High Power Klystrons**—Recently, SLAC and one of the outside vendors have succeeded in developing 30 MW klystrons which are completely inter-changeable with the present 20 MW tubes attached to he accelerator. The higher power tubes will operate at a voltage ot 265 kV compared to 245 kV for the lower power tubes. This higher voltage level is within the operating range of the existing modulators. Plans call for replacement of the present tubes as they fail with the new 30 MW tubes. It is anticipated that the total replacement will require 2-1/2 lo 3 years at the present failure rate . This process might be deliberatety retarded if the lifetime of the new tubes is significantly less than that of the present tubes. After complete replacement, the maximum energy of the accelerator should be 24 to 25 GeV.

B. **Pulsed Steering and Focusing**—As mentioned in Section II. A, multiple beam operation with beams of greatly differing energies and currents is difficult because the present steering systems are comprised of dc devices. In order to be able to optimize the transmission through the accelerator and the entrance conditions to the beam switchyard for each individual beam, pulsed steering and focusing devices have been developed and production units are now being fabricated.

The pulsed steering system will utilize the existing steering dipoles which are located at the end of each 333-foot sector but a new pulsed power supply is required for each dipole. These power supplies will be capable of pulsed outputs op to ± 9 A at repetition rates up to 360 pps.

For pulsed focusing, it will be necessary to supplement the existing dc quadrupole doublets located at the ends of the sectors with new laminated quadrupole doublets. One pulsed power supply will be provi-is favorable, ded for each doublet.

In early FY 1970, it ia planned to equip four selected sectors with pulsed steering and focusing.. If experience with these systems is favorable, additional units will be added along the accelerator.

C. **Off-Axis Injector**—An additional (off-axis) injector is being designed. It will be located adjacent to and will supplement the functions of the existing injector at the west end of the accelerator. The principal benefit will be an improvement in the operation of inter-laced beams of greatly different intensities. The new injector will also serve as a backup injector in case of failure of the main injector.

D. **Inereased Beam Power Capability in Beam Switchyard and Research Area**— All of the beam line components in the switchyard and research area are not capable of handling the 500 kW of average beam power which the accelerator can now produce . A program to increase the power handling capability of slits, collimators, vacuum chambers and beam dumps is now underway.

E. **Storage Ring**—The 2 GeV storage ring program is being discused in a separate report to this conference.[5] It is now planed to locate this ring in the research area instead of at the two-thirds point along the accelerator. Also, the ring will be designed for an energy of 2 GeV and a luminosity of 10^{32} $cm^{-2}sec^{-1}$ with capability of expansion to 3 Gev and a luminosity of 2×10^{32} $cm^{-2}sec^{-1}$ by future provision of additional power. These and other changes have resulted in a reduction of the estimated cost to 9.3 million dollars which is about one-half of the earlier cost estimate. The construction of this ring was not authorized for FY 70 bur there is a high degree of optimism regarding authorization in FY 71. In order to retain staff and momentum during the waiting research and development including fabrication of proto-type components from the operation budget during FY 70. If the storage ring construction is authorized in FY 71, it is hoped that the ring will be in operation late in the calendar year 1972.

F. Other programs which are under consideration for initiation in FY 70 are the following:

1. **Wire spark chamber**—A large wire spark chamber facility is being proposed to study the properties of meson resonances. The magnet size would permit study of the production and decay of mesons with mass up to ~ 3000 MeV produced at momenta between 5 and 20 GeV/c. If authorized, the time required to complete this system is estimated to be approximately 2 years.

Principal components of the facility are: (a) a 20 kG magnet with ~1% field uniformity, entrance aperture 3m×2m, 1-1/2 m length in beam direction; (b) wire spark chambers pulsed at rates up to 180/sec, size varying from 2 m to 1-1/2 m in front of the magnet to 5m×3m behind the magnet, magneto-strictive read-out; (c) Cerenkov counter window 9.2 m×4.3 m, Freon-12 gas, maximum operating pressure of 3 atm., 2300 Å to 5500 Å light collection range; and (d) computer SDS 9300 or IBM 260/44 class processor with 32 K words of memory.

2. **Superconducting coil for 40" bubble chamber**—Consideration is being given to the replacement of the existing 25 kG magnet coil of the 40" bubble chamber with a 70 kG superconducting coil. This modification would permit measurement of the width of resonances to an accuracy of ± 1—2 MeV for mass values up to 2 GeV and would also allow analysis of final states with two neutral particles. The proposed program would require approximately 2 years for completion but the chamber would be inoperative for only about 8 months.

3. **Spectrometer improvements**—Several improvements are being considered in the spectrometer complex which consists of 1.6, 8, and 20 GeV/c spectrometers plus related instrumentation and controls. These changes include: (a) improvement of fast electronics to permit an increase in the data rate which can be handled by the presently installed computer system (SDS 9300); (b) rearranging and increasing the power supply system to allow counter checkout to proceed parasitically on one spectrometer while another is actively engaged in physics experimentation; (c) improvement of control system of the spectrometer so that two different experiments can be performed simultaneously; and (d) rearrangement of counter hodoscopes.

G. **Superconducting accelerator**—A long range program to study the feasibility of converting the present 20 GeV two-mile accelerator to a 100 GeV superconducting machine is now underway. The status and goals of this program are being reported separately to this conference.[6] In addition to producing higher electron energies, the superconducting accelerator would have a duty cycle of 6%, which is two orders of magnitude higher than the duty cycle of the present machine. At reduced energies, the duty cycle could be even higher; at ≤25 GeV a duty cycle of 100% would be possible.

In the next two years it is expected that present work in this area will be expanded as follows: (a) several methods of fabricating solid niobium cavities including machining and forming techniques are being planned; (b) "sputtering" techniques of applying niobium onto suitable substrates will be further investigated; (c) technetium-plated cavities will be fabricated and tested to ascertain whether this material is feasible for superconducting accelerator purposes: (d) studies of the stability and characteristics of superconducting surfaces under a wide variety of environmental conditions will be conducted; (e) calculations and measurements of peak electric and magnetic fields in various cavity configurations will be made. These results will indicate whether the goal of 33 MeV/meter accelerating fields is practicable; (f) accelerator structures of both the standing wave and traveling wave with feedback will be tested; and (g) a 2 to 5 foot traveling wave structure with rf feedback will be tested and possibly used to accelerate an electron beam.

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ДИСКУССИЯ

Джелепов: В чем причина почему не удается на „СЛАК"е получить средний ток более 30 мкА?

Neal: This value if very near to the limit where beam blow-up begins. This value of average current corresponds to a peak current of 50 mA when the pulse repetition rate is 360 pps and the pulse length is 1. 6 μsec.