UNIVERSITY OF CALIFORNIA

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BEVATRON OPERATION AND DEVELOPMENT. XVI
November, December 1957, January 1958

Walter D. Hartsough and William W. Salsig

May 26, 1958

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Contents

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ABSTRACT

The study of interactions and decay of K mesons continued, using the 10-inch liquid hydrogen bubble chamber and emulsions. Four emulsion stacks were exposed for two internal groups and twenty-three stacks were exposed for seventeen groups from outside the Laboratory. Interactions of π^- mesons were observed with a 30-inch propane bubble chamber and with emulsions. Ten emulsion stacks were exposed to neutral-particle beams and one stack to the internal 6.2-Bev proton beam. The 30-inch propane bubble chamber and emulsions were used to study the interactions of antiprotons.

Eighteen target bombardments in the internal proton beam were made for the chemistry group.

Successful tests were completed of two static-electromagnetic velocity spectrometers for the separation of high-energy particles. One was of coaxial construction, the other of parallel-plate construction.

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EXPERIMENTAL FACILITIES

Gap-Mounted Targets

The gap-mounted targets that were available during this period are listed in Tables I and II.

Calibration of the Bevatron Beam-Induction Electrodes

To obtain an accurate measure of the charge in the circulating proton beam, using electric-induction electrodes, a harmonic analysis of photographically recorded beam-pulse configurations was recently made to determine calibration factors for the electrodes. This work has been reported separately.[1] The analysis yielded a calibration factor of 1.61. The previously used factor, based on the assumption that the induction-electrode signal was a series of half-wave sine-wave pulses, was 1.86. The beam-intensity values reported previously, therefore, should be increased by approximately 16%.

Regulation of the Bevatron Beam Amplitude

A circuit has been designed and operated successfully which allows beam-amplitude regulation. This work is reported separately.[2]

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[1] Harry G. Heard, Calibration of the Bevatron Beam-Induction Electrodes, UCRL-8092, Jan. 1958.

[2] Harry G. Heard, Regulation of the Bevatron Beam Amplitude, UCRL-8262 (in preparation).

Table I

Quadrant mounted targets

October 31, 1957 to January 2, 1958

Quadrant	Azimuthal Location (Ref: west straight section)	Radial Location		Target Material	Target Size a × b × c (in.)
		Outer-radius edge of target (in.)	Outer-radius edge of lip (in.)		
II	2°16'	601-13/16	602-1/16	Uranium	1 1/4 × 1/2 × 1/2
II	4°32'	599-9/16	599-13/16	Beryllium	6 1/2 × 3/4 × 1/2
II	14°00'	601-1/2	601-3/4	Beryllium	6 × 1/2 × 1/2
II	16°19'	605-1/6 to inner-radius edge (outer-radius target)	----	Copper	7/8 × 1 × 3/4
II	19°58'	601-1/8	601-5/16	Polyethylene	1 × 1/2 × 1
III	2°41'	601-1/8	----	Copper	
III	71°42'	599-5/8	600	Aluminum	4 × 1/2 × 1/2
III	72°43'	599-3/4	600-1/8	Copper	3 1/2 × 1/2 × 1/2
III	79°06'	596-5/16 to center of target	----	Polyethylene	1/8 diam × 1 high
III	85°15'	595-3/16	595-3/8	Tantalum	1/4 × 3 × 1/4

Beam ——→
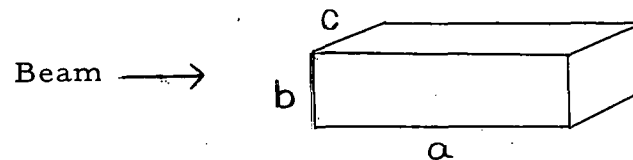
Table II

Quadrant-mounted targets
January 3, 1958 to end of Quarter

Quadrant	Azimuthal Location (Ref: west straight section)	Radial Location		Target Material	Target Size a × b × c (in.)
		Outer-radius edge of target (in.)	Outer-radius edge of lip (in.)		
II	3°12'	607 to inner radius edge (outer radius target)	----	Copper	3/8 × 3 × 1/4
II	6°20'	601-13/16	602-1/16	Beryllium	6 × 1/2 × 1/2
II	6°48'	600-5/16	600-9/16	Beryllium	6 × 1/2 × 1/2
II	14°00'	601-1/2	601-3/4	Beryllium	6 × 1/2 × 1/2
II	16°	605-1/16 to inner radius edge (outer-radius target)	----	Copper	7/8 × 1 × 3/4
II	19°58'	601-1/8	601-5/16	Polyethylene	1 × 1/2 × 1
III	2°41'	600-1/2	----	Copper	7/8 × 2 × 7/8
III	71°42'	599-5/8	600	Aluminum	4 × 1/2 × 1/2
III	72°29'	597-3/4	598-1/4	Copper	3 1/2 × 1/2 × 1/2
III	79°05'	598-7/8	599-3/8	Lead	4 × 1/2 × 3/4
III	85°15'	595-3/16	595-3/8	Tantalum	1/4 × 3 × 1/4

Beam ⟶   c   b   a
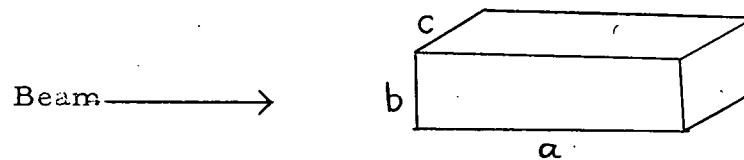
MAGNET POWER SUPPLY

Ignitron Performance

The ignitron fault record appears in Table III. A report of the comparative performance of the ignitrons on Tap 3 (16 kv) and Tap 5 (14 kv) is included in the section on operation.

Ignitron Failures
(Harold W. Vogel)

During the past few years, the magnet power-supply rectifier inverters have been the subject of considerable study and concern. The common causes of ignitron failure and of some of the conditions that are known to have affected the life and performance of the tubes are summarized as follows:

1. Approximately one tube per month fails because the anode vacuum seal becomes plated with a conducting film. Experience to date indicates that, although considerable effort has been expended in carefully rebuilding and outgassing the tubes,* this phenomenon is the most frequent cause of the failure of a rebuilt tube.

2. After any extended period of shutdown, it is necessary to repeat the high-voltage bake-in and outgassing of the ignitrons in order to minimize faults and therefore reduce the possibility of tube failures. During this procedure, the tube loading is gradually increased over an 8-hour period.

3. Vacuum leaks at the grid bushings have caused many tube failures. The original method of achieving a vacuumtight joint--a copper gasket--has been abandoned in favor of heliarc-welding the bushings to the ignitron tank. The weld is made on the inside of the tank. This change is now being made on all rebuilt tubes.

4. Fault rate vs ignitron operating temperature has been investigated. Below 45°C, the inversion fault rate increases rapidly; above 52°C, there is an increase in the arc-back rate. The ignitron barrel temperatures are now regulated at 50° ± 0.5°C.

5. Analysis of ignitron fault data indicated that, during inversion, the tube in question was unable to hold off forward voltage. The inner grid circuits are now being changed to provide a negative bias during the nonconducting period.

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*During the rebuilding process, the graphite parts of the tubes are vacuum-furnace outgassed at 1800°C for about 4 days. The reassembled tubes are then outgassed for a period of time at low voltage and high current. When the ignitrons are subsequently placed in service, the tube loading is gradually increased to full load during a 16-hour high-voltage bake-in period.

Table III

	5 to 6 pulses per minute						7 to 9 pulses per minute						10 to 17 pulses per minute					
	1500 to 6000 amp			6100 to 9000 amp			1500 to 6000 amp			6100 to 9000 amp			1500 to 6000 amp			6100 to 9000 amp		
Month	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F
1957																		
June	1144	...	1144	12799	23	550	1744	1	1744	36648	80	458	17929	9	1992	...	...	...
July	72	...	72	5012	11	456	1372	2	686	48854	70	6979	33027	35	945	106896	124	878
Aug.	2711	5	542	7463	14	533	536	1	536	81217	89	912	20918	5	4183	89439	53	1686
Sept.	959	2	479	5674	10	567	1035	3	351	22926	40	573	11644	18	647	98469	97	1015
Oct.	...	...	...	1335	5	267	1124	...	...	129138	114	3133	14070	4	3515	22967	25	918
Nov.	...	...	...	...	...	...	2419	4	605	117513	124	948	23379	4	5695	56409	50	1128
Dec.	...	...	...	359	...	...	...	...	...	4082	3	1360	11855	...	...	167868	175	1530
1958																		
Jan.	1842	0	1842	2423	2	1212	305	0	305	14974	12	1248	16435	4	4109	170844	106	1612

Totals

Month	Pulses	Faults		P/F
		Arc-backs	Arc-throughs	
1957				
June	70,264	6	117	562
July	195,233	29	247	707
Aug.	202,284	29	138	1211
Sept.	140,725	47	123	828
Oct.	168,634	80	68	1139
Nov.	199,720	67	115	1097
Dec.	184,164	41	137	1055
1958				
Jan.	206,823	31	93	1668

6. Inversion faults during Tap 3 operation were found to occur during forward voltage period, about $30°$ after crossing the zero-voltage point on the anode-to-cathode voltage wave. On Tap 5 operation, the phase to neutral voltage is reduced by 10%; the faults were found to occur immediately after extinction. At extinction, the inverse voltage rises to 7.5 kv in 100 microseconds; the current decreases at the rate of 4×10^6 amperes per second. A cushioning circuit is being installed on each tube on one ignitron unit (6 ignitrons), which will reduce the rate of rise of inverse voltage by a factor of two.

Motor Resistor Failures

On two occasions, this quarter, during normal dynamic braking operation, failures occurred in the banks of cast iron motor resistors that destroyed part of the resistors and some of the copper bus-bar connections. Upon examination of the first failure, it was apparent that it was necessary to rebuild all the resistor assemblies, as the contact surfaces between the cast iron resistors had deteriorated because of rust. (The resistor banks are used both for motor-starting resistors and for dynamic braking.)

In lieu of removing the resistor assemblies for disassembly, cleaning, and reassembly, it may be possible to eliminate the problem by welding together the contact surfaces. This solution is now under advisement.

Investigation of Motor Generator Shaft Stress

During the shutdown of September 18 - 22, 1957 the east motor generator set was realigned. Within two weeks thereafter, the generator was as badly misaligned in the opposite direction as it had been before the September realignment. In both cases, the shaft alignment was four to five times the maximum permissible misalignment originally allowed by the manufacturer.

This situation emphasized again the lack of realistic criteria by which to evaluate accumulating empirical observations of generator foundation behavior. More than two years ago, an optical-survey technique, developed to read magnet-sector elevations to a precision of ± 0.003 inch, was adapted for generator-shaft elevation surveys. Two years of data accumulation indicated that the generator foundation went through random vertical oscillations, with amplitude excursions four to five times the permissible misalignment. Attempts to realign the shaft often were ineffective, as indicated above, and would become prohibitive in Bevatron down time if conscientiously followed, as a week is required for each realignment.

The situation was reviewed and it was apparent that insufficient information on combined shaft stresses (resulting from electrical faults plus mechanical misalignment) was available to UCRL personnel for an intelligent assessment of the hazard. It also appeared that the electrical fault rate and the observed foundation movements must be more severe than original design had anticipated.

Although UCRL engineers, or engineering consultants from the campus, could resolve maximum stresses possible from misalignment bending combined with maximum torsional shock loads, these results must be correlated against shaft-material characteristics, which were not known because the steel is of proprietary manufacture. Accordingly, it was decided that a complete review should be requested of the manufacturer, including, in particular:

1. An analytical solution for shaft stresses whereby they may be evaluated from observed alignments.

2. An analysis of mechanical loads and hence of shaft stresses induced by the worst fault conditions known to occur in operation or to be theoretically possible.

3. A presentation of shaft bending stresses, shaft torsion stresses, and fatigue safety factors to allow rapid evaluation of the situation met in practice.

4. Information relating to the rate of propagation of fatigue cracks.

5. A review of the original Westinghouse alignment specifications; it would appear that a change in criteria could result in reduced shaft stresses.

6. Full mechanical properties of this shaft steel.

7. From the experience data and the associated analysis, an engineering evaluation and recommendation for future operation of the equipment to insure against a shaft fatigue failure from faults and (or) misalignments.

In parallel to this theoretical review, the UCRL engineering department intensified a program of observations of shaft torsional displacement to experimentally determine maximum load conditions. Measurements are made by use of gear-tooth magnetic pickups originally installed for speed-synchronizing the two generators. Additional equipment includes (a) a micrometer-positioned mount for pickup calibration (see Fig. 1); (b) holding voltmeters to retain the shaft-displacement signal until the next magnet pulse, or--in case of an electrical switching fault and hence intensified shaft stress--until the meter reading can be recorded and (c) a tape recorder which erases normal pulse information but allows manual removal of fault information. Thus, one can play back oscilloscope information of the detailed shaft-displacement history during the fault.

The manufacturer made a most excellent response, and in addition to supplying the information requested also defined shaft stresses for all alignment conditions observed to date, plus expected changes in bearing oil pressure for the alignment conditions observed. (During the factory engineer's visit to UCRL, an auxiliary discussion occurred on the possibility of monitoring alignment from bearing oil pressure. UCRL had done some preliminary work in this direction.)
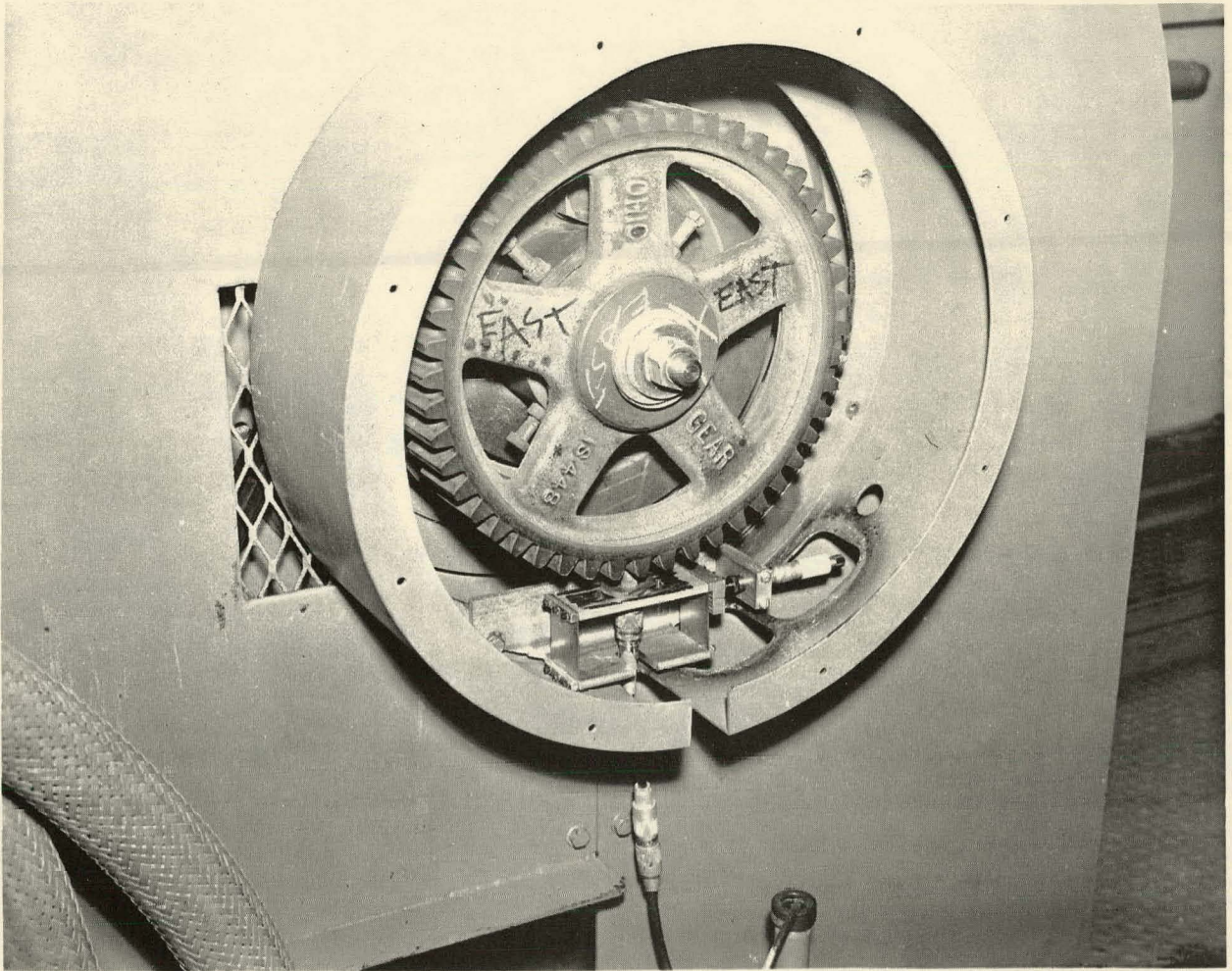
ZN-1942

Fig. 1. Gear-tooth magnetic pickup mounted on shaft of motor
generator set to monitor shaft torsional displacements.

Results to date of this review may be summarized as follows. The manufacturer supplied:

1. An analytical solution for shaft stresses due to misalignment which allows immediate translation of observed misalignment into shaft stress at three critical points.

2. An estimate of maximum torsional loads possible from the worst expected electrical fault conditions, which, when combined with maximum stresses from the worst observed misalignment, still indicates a comfortable 1.6 safety factor to the endurance limit of the shaft steel.

3. A revision of the maximum permissible misalignment criteria to permit misalignment stresses to 2000 psi (before size-effect and stress-concentration corrections). Such criteria include all alignment excursions observed to date. In addition, when alignment is again required, the coupling faces will be aligned parallel, rather than 0.002 inch open at the top, resulting in a slight improvement (200 psi less in stress).

4. An estimate that approximately 650,000 maximum-stress cycles would occur between initiation of a fatigue crack and complete shaft failure. The manufacturer's recommendation in the past was to inspect critical journals with "Magnaglo" technique every 100,000 cycles for the first 2,000,000 maximum-energy cycles. Other information available from the literature indicates that crack propagation rate from inception to failure is at least 100,000 cycles (above 1,000,000 cycle experience). Since cracks can occur from scratches due to inadvertent inclusion of dirt in the lubricating oil supply, and from incipient electrical arcing under oiling rings as well as from overstressing, it appears prudent to continue the "Magnaglo" inspections during scheduled Bevatron shutdowns (every 200,000 to 300,000 full-energy pulses). The hope here is that if --as is remotely possible--a crack should occur, it could be detected sufficiently early so that it could be removed by a minimum bearing-journal grinding operation (1/8 in. off 10 in. radius).

5. Complete mechanical properties of the shaft steel.

The UCRL experimental stress investigation has yielded the following information to date:

1. Calibration indicates the average generator-shaft end-to-end torsional displacement for full-energy inversion is 15 minutes to 16 minutes of arc.[3] Translated into stress, these observations are in reasonable agreement with original torsiograph measurements made at the time of generator acceptance,[4] and with the analytical estimate of full-energy

[3] Robert Acker, University of California Radiation Laboratory Engineering Note 4901-02 EE 528, Feb. 4, 1958.

[4] D. T. Scalise, University of California Radiation Laboratory Engineering Note 7302-04 M 17, Oct. 4, 1952.

transient stresses made in August, 1954.[5]

2. Many fractional energy electrical faults have been observed, giving torsional displacements to 24 minutes of arc (160% of normal full-energy-pulse shaft stress). One inversion arc-through at 7000 amp (84% full energy) has been observed with a resultant 29 minutes arc torsional displacement (190% of full-energy-pulse shaft stress), and one arc-back at 8000 amp (95% full energy) yielded the same order of stress. It is expected that an inappropriately timed arc-back at full energy will force the maximum shaft stress. One must keep in mind that the timing of the fault with respect to shaft resonance is probably of more importance than fault magnitude. This fact is emphasized by the excellent attenuation of shaft mechanical resonance that results from the 2- to 3-cycle step between rectification and inversion. Instead of the theoretically possible transient shock stress of three times the stress for steady-state load application, this possible transient has been reduced to a measured 0.8 of maximum steady-state load stress by allowing three quarters of a cycle of torsional swing in the shaft after removal of the original load, and before application of the reversed-direction load.

3. The highest shock stress measured to date came from an unexpected source: electrical failure in a pulse-control chassis caused a double pulse, and the conducted current rose to slightly more than 9000 amp before generator over-current protection operated. Normal shaft maximum torsional displacement rose to 38 minutes of arc (250% of shaft stress for full-energy pulse), and the calculated safety factor to steel yield point was 1.34 for this condition. It will be noted that this observation exceeds the manufacturer's estimate of maximum expected shock stress.

The empirical observations will continue until sufficient data are available to representatively assess peak stresses due to worst fault conditions.

OPERATION

Extension of the Operating Hours

On November 19, the Bevatron operating time was increased from 99 hours per week to 108 hours per week by staggering the work hours of the day shift personnel so that there is operating- and maintenance-crew coverage from 6:30 a.m. to 1:00 a.m. five days per week. Two days per week, when the Bevatron is shut down during the morning for maintenance, the day shift begins at 8:00 a.m. The period of "turn on" and "ignitron warmup" remains at 1-1/2 hours each morning; however, the "turn off" time is reduced from 1/2 hour to 1/4 hour six days per week.

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[5] D. T. Scalise, University of California Radiation Laboratory Engineering Note 7302-04 M 18, Aug. 2, 1954.

Resumption of Tap 3 Operation

During the 5-month period, June to November, 1957 (as reported in the preceding Quarterly Report), the magnet excitation voltage was 14 kv (Tap 5) as compared with a previous operating voltage of 16 kv (Tap 3). Operation at this reduced value of magnet voltage was expected to result in an improvement in ignitron performance and reliability. This improvement, however, has not been realized.

On November 11, pulsing on Tap 3 was resumed to obtain additional operating data to permit a better evaluation of Tap 3 vs Tap 5 operation. The power-supply performance on Tap 3 during this quarter can now be compared with a similar period of Tap 3 operation a year ago and with the recent period of Tap 5 operation. If the total number of magnet pulses per month is weighed (with variations in the scheduled operating hours taken into consideration), the pulse record shows that the average number of pulses per month is almost the same for each of the above three periods. Thus, the recent 10% increase in operating hours is reflected in an increase in total magnet pulses per month of about 10%. The number of pulses per fault, however--which is a measure of ignitron performance independent (for the most part) of the pulse schedule--indicates a retrogression in the magnet power-supply operating performance since last year. For example, an average of 1514 pulses per fault was recorded during the period November, December 1956, January 1957, compared with 1273 pulses per fault during this quarter and 1059 pulses per fault during Tap 5 operation last quarter.

As reported in the preceding quarterly, the number of rectification faults (arc-backs) remains higher than would be predicted from past performance. The reasons for the seemingly unpredictable fault behavior pattern remain unclear at this time.

The maximum recorded beam during this period, at high energy, was 7×10^{10} protons per pulse; the maximum injected beam was 300 microamperes.

A summary of the Bevatron operating schedule and performance record appears in Fig. 2.

RESEARCH

Table IV summarizes the research activity during this period. (The Alvarez Group took its 500,000th liquid hydrogen bubble chamber picture during this quarter.)

SHUTDOWNS

On November 1, the Bevatron tank was pumped down following a scheduled shutdown. From December 23, 1957 until January 4, 1958 the Bevatron was shut down for the Christmas holidays and for routine inspection, maintenance, and installation of new equipment. On January 11, a failure in the generator motor resistor bank caused the machine to be off for one day.

Bevatron operating schedule
November 1957—January 1958

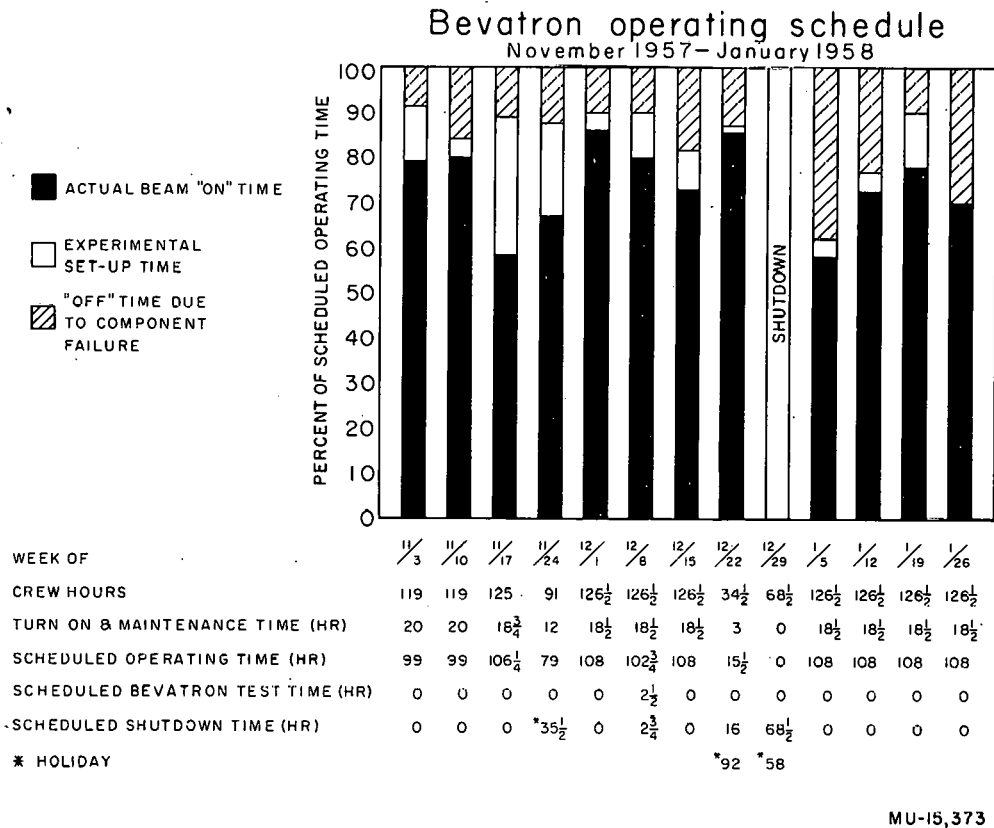|													
WEEK OF	$\frac{11}{3}$	$\frac{11}{10}$	$\frac{11}{17}$	$\frac{11}{24}$	$\frac{12}{1}$	$\frac{12}{8}$	$\frac{12}{15}$	$\frac{12}{22}$	$\frac{12}{29}$	$\frac{1}{5}$	$\frac{1}{12}$	$\frac{1}{19}$	$\frac{1}{26}$
CREW HOURS	119	119	125	91	$126\frac{1}{2}$	$126\frac{1}{2}$	$126\frac{1}{2}$	$34\frac{1}{2}$	$68\frac{1}{2}$	$126\frac{1}{2}$	$126\frac{1}{2}$	$126\frac{1}{2}$	$126\frac{1}{2}$
TURN ON & MAINTENANCE TIME (HR)	20	20	$18\frac{3}{4}$	12	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	3	0	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$
SCHEDULED OPERATING TIME (HR)	99	99	$106\frac{1}{4}$	79	108	$102\frac{3}{4}$	108	$15\frac{1}{2}$	0	108	108	108	108
SCHEDULED BEVATRON TEST TIME (HR)	0	0	0	0	0	$2\frac{1}{2}$	0	0	0	0	0	0	0
SCHEDULED SHUTDOWN TIME (HR)	0	0	0	*$35\frac{1}{2}$	0	$2\frac{3}{4}$	0	16	$68\frac{1}{2}$	0	0	0	0
* HOLIDAY								*92	*58				

MU-15,373

Fig. 2. Bevatron operating schedule. November, 1957 through January, 1958.

Table IV

Bevatron Experimental Research Program
November, December 1957, January 1958

INTERNAL GROUPS

Group

Experimenters	Experiments

ALVAREZ

Gow, Lyman — Interactions of negative particles in hydrogen using the 10-inch liquid hydrogen bubble chamber (927 Mev/c, 995 Mev/c, 1.05 Bev/c, 1.12 Bev/c, 1.24 Bev/c). Search for asymmetries in the production and decay of $\pi^- + p \rightarrow \Lambda + K$, $\Sigma + K$ and $K^- + p \rightarrow \lambda + \pi$, $\Sigma + \pi$. Also, search for $K^- + p \rightarrow \Xi^{-0} + K^{+0}$.

Blumberg, Gow — Test of the new 15-inch liquid hydrogen bubble chamber in a 1-Bev/c π^- beam.

Bradner — Search for magnetic monopoles using nuclear emulsions (four exposures).

Tripp, Ross, Horwitz, Murray — Setup and evaluation, using counters and emulsions, of a separated 300-Mev/c K^- beam preliminary to a future experiment using the new 15-inch liquid hydrogen bubble chamber. The coaxial static electromagnetic velocity spectrometer was used.

BARKAS

Heckman, Nickols — Study of the interactions of K^- mesons in emulsions using focused and separated 300-Mev/c K^- mesons. Two emulsion exposures (8.5×10^{13} p^+ and 3×10^{13} p^+).

HELMHOLZ-MOYER

Atkinson, Hess, Perez-Mendez, Wallace — Measurement of the attenuation mean free path of 5-Bev neutrons in various materials using counters. Good-geometry cross-section measurements.

LOFGREN

Horwitz, Murray — Test of a coaxial static-electromagnetic velocity spectrometer for separating high-energy particles, using counters and emulsions.

INTERNAL GROUPS

Group

Experimenters	Experiments

LOFGREN

S. Goldhaber, Horwitz, Murray — Emulsion exposure to 350-Mev/c K^+ mesons using the above coaxial beam separator. Search for 560-electron-mass particles. Observed K - H scattering events. Two emulsion stacks were exposed (1.7×10^{14} p^+ and 1.7×10^{14} p^+).

Cork, Lambertson, Wenzel, Zajec — Test of a parallel-plate static-electromagnetic spectrometer and measurement of the optical properties of 8-inch-aperture quadrupole magnet and the parallel-plate beam separator.

LOFGREN-SEGRE

S. Goldhaber, G. Goldhaber — Study of K^--meson interactions in emulsions. Emulsion exposure to a focused and separated 300-Mev/c K^- beam (6×10^{13} p^+).

MOYER

Patterson, Smith, Wallace — Radiation shielding study. Attenuation of neutrons in concrete and lead.

POWELL

Birge Group, Powell Group — π^--meson interactions in the 30-inch propane bubble chamber (5.5-Bev/c π^-)

$$\pi^- + p \to n^0 + \bar{n}^0 + N$$
$$\pi^- + p \to \Xi^- + K^+ + K^0$$
$$\pi^- + p \to \bar{p} + d$$

SEABORG

Alexander — Bombardments of Al, U foil
2.0 Bev 7.2×10^{13} p^+
6.2 Bev 6.1×10^{13} p^+
6.2 Bev 2×10^{13} p^+
6.2 Bev 1.4×10^{13} p^+
6.2 Bev 2.2×10^{14} p^+
6.2 Bev 6×10^{13} p^+

Altman — Bombardments of Bi, Al, Au foil
6.2 Bev 5×10^{12} p^+
6.2 Bev 1×10^{13} p^+
6.2 Bev 1×10^{13} p^+

INTERNAL GROUPS

Group

Experimenters	Experiments

SEABORG

Baltzinger — Bombardment of U, Al foil

6.2 Bev 5×10^{12} p$^+$

Currie
(Penn State Univ) — Bombardment of Sn, Al, U foil

6.2 Bev 4×10^{12} p$^+$

Bombardment of Pb, and Polyethylene targets

6.2 Bev 5×10^{12} p$^+$

Bombardment of Au, Al foil

6.2 Bev 4.8×10^{13} p$^+$

Bombardment of melamine, lucite, Au targets

6.2 Bev 7×10^{13} p$^+$

Ladenbauer — Bombardments of iodoform in cellulose acetate target.

1 Bev 2×10^{13} p$^+$

1 Bev 1×10^{13} p$^+$

4 Bev 2×10^{13} p$^+$

4 Bev 2×10^{13} p$^+$

SEGRÈ-POWELL

Segrè Group
Powell Group — Interactions of antiprotons in the 30-inch propane bubble chamber, using a focused and separated 740-Mev/c antiproton beam.

G. Goldhaber — Emulsion exposure to the separated and focused 740-Mev/c antiproton beam (2.4×10^{14} p$^+$).

EXTERNAL GROUPS

Group

Institution	Experiments

BLOCK

Duke University — Test of a helium bubble chamber in a 1-Bev/c π^- beam.

BRUIN

University of
Amsterdam, Holland — Emulsion exposure to focused 5.5-Bev/c π^- mesons

BUGG, KING

University of
Tennessee — Emulsion exposure to the internal 6.2-Bev proton beam (4×10^6 p$^+$)

EXTERNAL GROUPS

Group

Institution	Experiments
CAMERINI, FRY	
University of Wisconsin	Search for Ξ^- produced by 1.12-Bev/c K^- mesons in emulsions (2×10^{13} p^+).
	Emulsions exposed to a neutral particle beam. Interactions of θ_2. Three stacks (9×10^{13} p^+, 6×10^{13} p^+, 3×10^{13} p^+).
LEVI-SETTI	
Enrico Fermi Institute, Chicago	Emulsions exposed to a neutral particle beam. Lifetime of θ_2. Two stacks (3.5×10^{13} p^+, 7.5×10^{13} p^+).
NIER	
University of Minnesota	Analysis of copper targets for tritium. Targets were bombarded by 6.2-Bev protons.
PEVSNER, ANDERSON	
Johns Hopkins University	Emulsion exposures to a neutral particle beam. Three stacks (3.5×10^{13} p^+, 3.5×10^{13} p^+, 7.5×10^{13} p^+).
ROEDERER	
Argentine Atomic Energy Commission	Emulsions exposed in a neutral particle beam. Behavior and interactions of θ_2 in a magnetic field. Two stacks (9.9×10^{13} p^+ each).

Emulsions were exposed to a focused 4.5-Bev/c π^- beam by the following groups:

BUGG, KING	
University of Tennessee	Two stacks (4.6×10^{13} p^+ each).
FRY, SCHNEPS, SWAMI	
Tufts College	Two stacks (4.6×10^{13} p^+ each).
SORENSON	
University of Oslo, Sweden	One stack (4.6×10^{13} p^+).

EXTERNAL GROUPS

Group

Institution   Experiments

Emulsions were exposed to analyzed and separated 300-Mev/c K$^-$ mesons by the following groups:

CECCARELLI

      Padova, Italy 6×10^{13} p$^+$

CRUSSARD

      Ecole Polytechnique, 6×10^{13} p$^+$
      Paris

GOTTSTEIN

      Max Planck Institute, 6×10^{13} p$^+$
      Göttingen

      University of 6×10^{13} p$^+$
      Rome

DANYSZ

      Poland 5×10^{13} p$^+$, 6×10^{13} p$^+$

LEVI-SETTI, SLATER, TELEGDI

      Enrico Fermi 1×10^{14} p$^+$
      Institute, Chicago

PEVSNER, ANDERSON

      Johns Hopkins 6×10^{13} p$^+$, 9×10^{13} p$^+$, 1.4×10^{14} p$^+$,
      University, Rochester 2.3×10^{14} p$^+$
      University

POWELL

      Bristol, England 1.2×10^{14} p$^+$

BURHOP

      London, England 1.2×10^{14} p$^+$

OCCHIALINI

      Milan, Italy 1.2×10^{14} p$^+$

ROBERTS, SCHLEIN

      Northwestern 9×10^{13} p$^+$
      University

EXTERNAL GROUPS

Group

Institution	Experiments

SEEMAN, SHAPIRO

Naval Research Laboratory, Washington, D. C. $9 \times 10^{13} \, p^{+}$

SCHNEPS

Tufts College $9 \times 10^{13} \, p^{+}$

VITALE

Catania, Italy $1.4 \times 10^{14} \, p^{+}$

WHITE

UCRL Livermore $6 \times 10^{13} \, p^{+}, \; 5 \times 10^{13} \, p^{+}$

ZORN

Brookhaven National Laboratory $1 \times 10^{14} \, p^{+}, \; 9 \times 10^{13} \, p^{+}, \; 6 \times 10^{13} \, p^{+}, \; 6 \times 10^{13} \, p^{+}.$

Emulsion exposures to separated and focused 740-Mev/c antiprotons were made by the following groups:

FRYE

Los Alamos $1.5 \times 10^{14} \, p^{+}$

KAPLON

Rochester University $2.4 \times 10^{14} \, p^{+}$

PROWSE

University of Bristol, England $2.3 \times 10^{14} \, p^{+}$

WILKINSON

Oxford University, England $2.4 \times 10^{14} \, p^{+}$

YAGODA

National Institute of Health, Maryland $5 \times 10^{12} \, p^{+}$

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