BEVATRON OPERATION AND DEVELOPMENT. 55. JULY -SEPTEMBER 1967.

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Publication Date
1968-01-31

UCRL-17932
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University of California

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July through September 1967

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UCRL-17932
UC-28 Particle Accel. and
High Volt. Mach.
TID-4500 (51st Ed.)

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

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*Preceding Quarterly Reports: UCRL-17931, UCRL-17543.

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Lawrence Radiation Laboratory
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ABSTRACT

The beam was off 5.8% of the scheduled operating time because of equipment failure and 5.8% of the time for experimental setup, tuning, and routine checks. The beam was on for 88.4% of the scheduled operating time. During this quarter, the Bevatron accelerated 2.05×10^{18} protons.

The maximum operating beam intensity was raised to 4×10^{12} protons per pulse.

Construction on the new External Proton Beam Hall and new two-channel beam facility continued. An experiment was set up at the second focus in channel I, and preliminary tests were made on the new beam transport system to that area.

Tests continued on the resonant extraction system for the external proton beam.

A generator field pole connection on one of the main motor generator sets failed on September 24. The Bevatron was shut down for about 2 weeks to rebraze all the field pole connections on both motor generator sets.

I. MACHINE OPERATION AND EXPERIMENTAL PROGRAM

The Bevatron operation record is shown in Fig. 1. The beam was off 5.8% of the scheduled operating time because of equipment failure and 5.8% of the time for experimental setup, tuning, and routine checks. The beam was on for 88.4% of the scheduled operating time. During this quarter, the Bevatron accelerated 2.05×10^{18} protons.

When we resumed operation in June 1967, the maximum allowed operating intensity was raised from 3×10^{12} to 4×10^{12} protons per pulse. The maximum that we achieved, however, during the first 2 months of operation, was 3.5×10^{12} protons per pulse, and we generally operated between 2.5 to 3×10^{12} protons per pulse. In the middle of July the operations crews were encouraged to try to increase the beam intensity to the new maximum allowed operating level. On August 4 the crew reached an operating intensity of 4×10^{12} protons per pulse and were able to operate at this intensity level whenever the experiments could use the full beam.

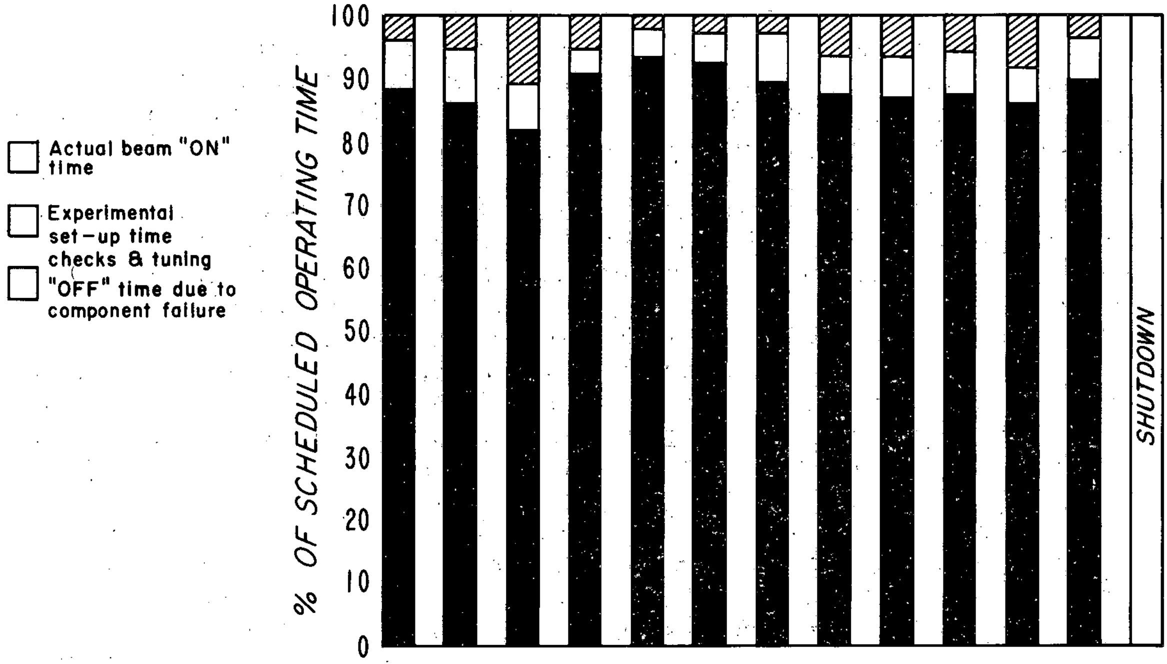
Construction continued through this quarter on the new External Proton Beam (EPB) Hall. Excavations were made for the utility tunnels during July. The tunnels were formed and poured during August and September. The layout is shown in Fig. 2. The new curved-bridge crane was installed in the new EPB Hall (see Fig. 3). Final testing of this crane was under way at the end of the quarter, and final acceptance is hoped for at an early date, so the crane can be used for the installation of the EPB shielding in the backstop area.

The Lofgren Group Experiment 67 was set up at the second focus in EPB channel I. A temporary backstop was installed between the second and third focus to allow running beam for tune-up and operation of this experiment. It also permited checking the operation of the EPB channel up to the second focus (F 2). (See Fig. 2.)

There were two basic modes of magnet pulsing this quarter. The first mode was a 300-msec flat-top at 6.1 BeV. In this mode the 25-inch bubble chamber and the University of Washington—U. C. San Diego Group (Williams, Masek; Expt. 50) ran on alternate magnet pulses. The 25-inch Bubble Chamber Group received a 300-μsec beam spill just after the start of flat-top and a second 300-μsec spill just before the end of flat-top. On the alternate pulse the University of Washington Group received a 150-msec spill during the flat-top. (See Fig. 4.) The University of Washington (Davis) Group (Expt. 54) was set up downstream from the University of Washington—U. C. San Diego (Expt. 50) secondary beam-channel target and detectors.

The second mode of magnet pulsing was a 900-msec flat-top at 5.3 BeV. The Moyer Group received a 600- to 800-msec spill during this period (Fig. 4b). The Lofgren Group in the EPB shared internal beam simultaneously with the California Institute of Technology Group and the Moyer Group.

The University of Washington—U. C. San Diego Group completed their experiment on September 9. A summary of the experimental program for this quarter is shown in Table I.



Week of	7/2	7/9	7/16	7/23	7/30	8/6	8/13	8/20	8/27	9/3	9/10	9/17	9/24
Crew hours	144	168	168	168	168	168	168	168	168	144	168	168	168
Turn on & maintenance time (h)	11	13	11	12	11	8	10	10	10	25	10	12	0
Scheduled operating time (h)	119	136	133	136	134	136	122	130	157	110	137	138	0
Scheduled Bevatron test time (h)	14	19	24	20	23	24	36	28	1	9	21	18	0
Scheduled shutdown time (h)	0	0	0	0	0	0	0	0	0	0	0	0	168
Holiday	24	0	0	0	0	0	0	0	0	24	0	0	0

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Fig. 1. Bevatron operation record.

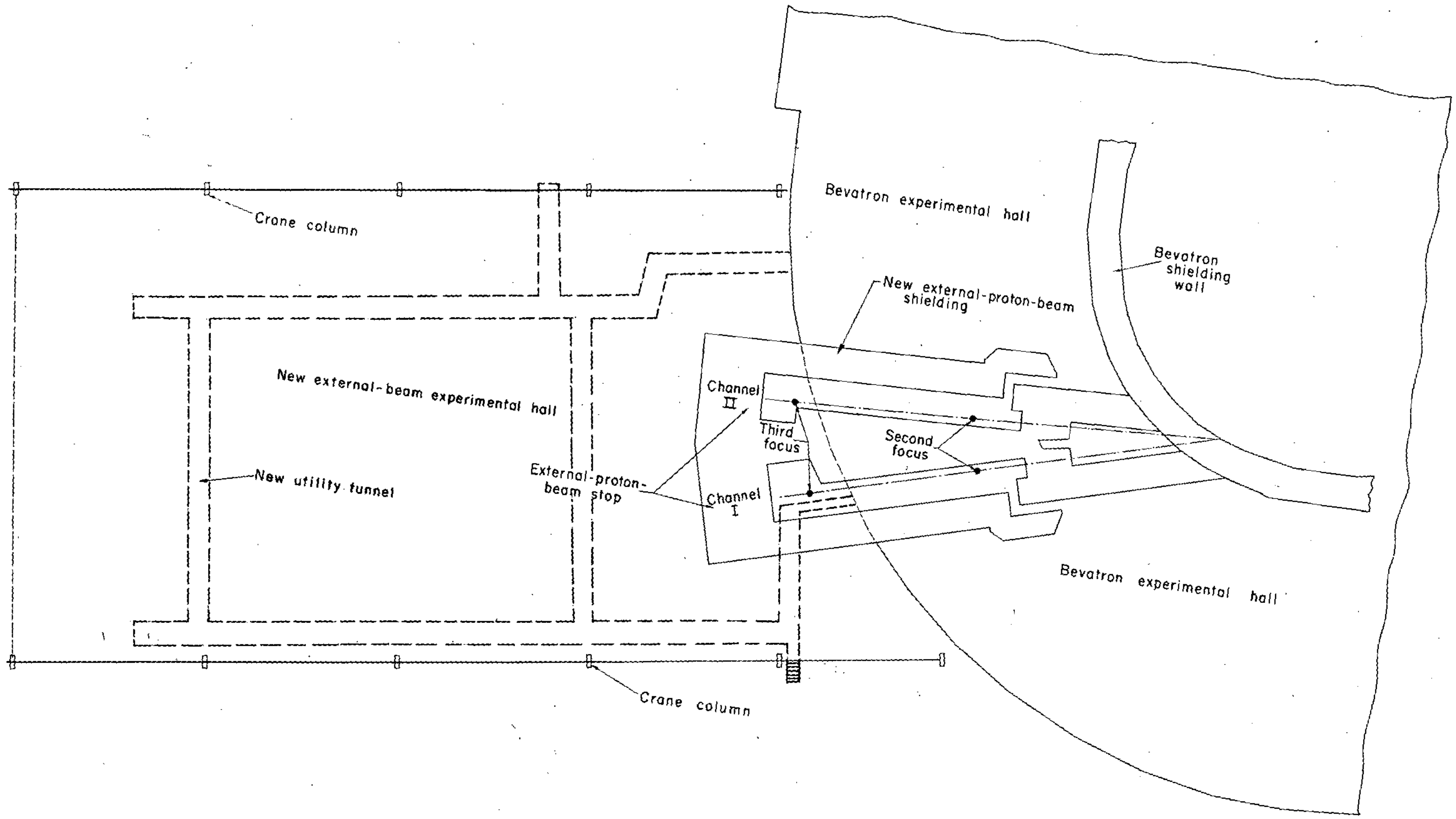

Fig. 2. Utility tunnel layout in new EPB hall.

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Fig. 3. New curved-bridge crane installed at north end of craneway of new EPB hall.

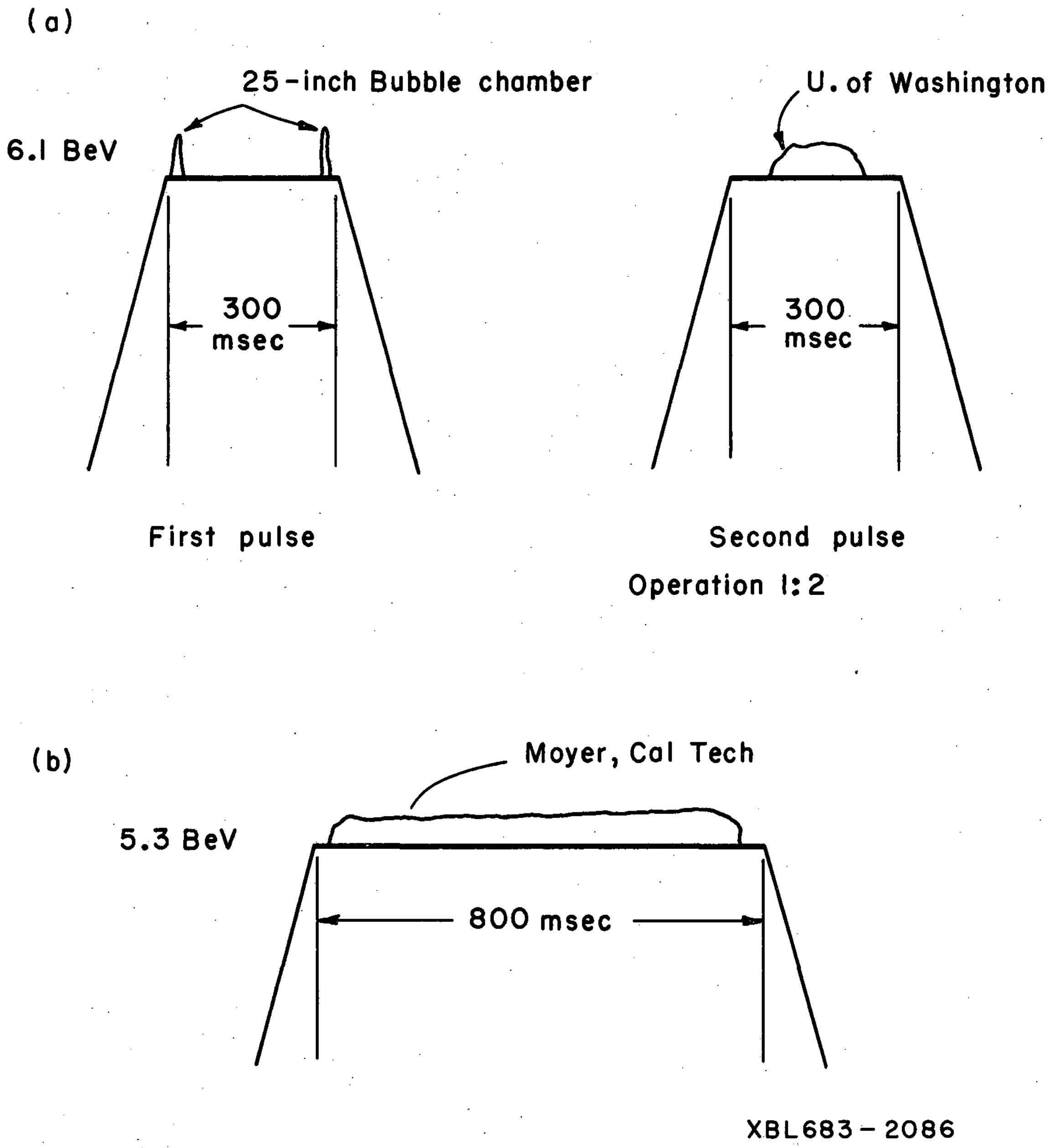

Fig. 4. Bevatron magnet pulsing modes.

Table I. Summary of Bevatron experimental research program, July through September 1967.

Groups	Dates: Run	Dates: Start	Dates: End	Experiment	Beam Time: This quarter (July-Sept.) 12-Hour periods	Beam Time: This quarter (July-Sept.) Hours	Beam Time: From start of run through September 1967 12-hour periods	Beam Time: From start of run through September 1967 Hours	Pulse schedule	Primary or secondary experiment
Internal Groups										
Alvarez (Murray)	39	8/5/65	In progress	K_1^0-K_2^0 interference, using the 25-in. bubble chamber	18	131	235	2435	1:1	P
Moyer-Helmholz (Parker)	47A	5/19/66	In progress	Neutral decay rate	34	393	125	1359	1:1	P
				$K_L^0 \to 2\pi^0$	0	5	66	833	1:1	S
Lofgren	67	8/28/67	In progress	Ke_2 branching ratio	2	28	2	28	1:1	P
		6/7/67		0.5-BeV/c separated K^+ beam	3	51	7	113	1:1	S
Trilling-Goldhaber	75	7/25/67	8/28/67	K^-p reactions in 250-MeV/c separated K^- beam, using 25-in. bubble chamber	43	479	43	479	1:2	P
Poskanzer	P-24			Search for n^x-neutron multiplets. Nuclear chemistry exposed to Bevatron internal beam	0	2		2	1:1	P
External Groups										
U. of Washington	50	3/16/66	9/9/67	Magnetic moment of Ξ^- cascade	0	2	114	1278	1:1	S
U. C. San Diego		5/20/66	9/9/67		5	49	40	430	1:1	P
		9/10/66	9/9/67		70	776	109	1204	1:2	P
Calif. Inst. of Technology (Tollestrup)	80	8/31/67	In progress	Leptonic decay, $K \to \pi^{\pm}, e^+, \nu$.	0	6	0	6	1:1	P
		8/11/67		Determination of $\Delta S/\Delta Q$ in 2- to 3-BeV/c π^- beam	10	133	10	133	1:1	S
U. of Washington (Davis)	P-12	7/21/66	In progress	Spark chamber tests for Run No. 54	0	3	20	248	1:1	S
					0	6	38	432	1:2	S

II. SHUTDOWN

A five-day shutdown was scheduled to start on September 25 for routine maintenance on the main motor generator sets and to relocate an underground 12-kV power line in the EPB Hall construction area. The shutdown started a day early when a generator field pole connection on the east main Bevatron generator failed. The details of the generator repair work are given in Section IV of this report.

There was a short vacuum shutdown to install a new scintillator on the septum and aperture of the resonant extraction magnet. During the original installation of the extraction magnet, a 0.30-in. -thick alumina scintillator had been installed on the septum and across the aperture of the extraction magnet. The alumina did not scintillate well at the beam densities available during extraction studies. A more sensitive scintillator was needed. A zinc sulfide scintillator on 0.003-in. aluminum foil was made. When it was taken into the Bevatron vacuum system to be installed on the magnet, the zinc sulfide came off the aluminum foil. A new zinc sulfide scintillator had to be made, and was installed two days later during a second short vacuum shutdown.

The external proton beam plunging magnets were inspected for wear and radiation damage, and were found in good condition. The graphite septum of the electrostatic inflector had a crack at the output end. A new septum was installed.

The high-voltage column between the Cockcroft-Walton high-voltage supply and the linac was overhauled and nine new insulators installed.

A new water-cooled graphite block was installed as a beam stop between the ion gun and the linac. This replaced an old swing cup that could be placed in the beam. These devices are part of the safety interlock system which stops the beam from the ion source before it goes into the linac.

The remainder of the shutdown work was devoted to routine maintenance of the Bevatron and associated equipment.

III. BEVATRON DEVELOPMENT AND STUDIES

The machine study periods this quarter were devoted almost exclusively to the problems of resonant extraction of the proton beam. A major part of the time was spent in getting diagnostic equipment built and made operational. Measurements were made of radial and vertical beam dimensions. The radial ν value was measured as a function of radius. Initial tests were made of the radial growth of the beam, using a perturbation of $\Delta\nu$ equal to -0.02. A gold foil irradiated at the first septum has indicated that all the beam grows to a 5-in. amplitude and has a jump per three turns of about 0.75 in. These results are in satisfactory agreement with the calculations. Tests will continue on resonant extraction.

IV. MAGNET POWER SUPPLY

Robert Frias

A. Failure of a Generator Field Pole Connection

At 0120, 24 September 1967, the field of the east generator was relayed off the line, with an indication of a ground on the field excitation power supply. In attempting to locate the problem, we found by visual inspection that the electrical connection between poles No. 3 and No. 4 had parted and that there was a splattering of copper over the adjacent area. An insulation test of the field to ground was taken; it read 500 000 ohms. A megger test was made on the field on the west machines, and showed 80 megohms. Figures 5 and 6 show the broken brazed connections and their location on the generator rotor.

The poles had been installed only 3 months prior to this failure, and carried 1 year's warranty by the Westinghouse Electric Corporation. Westinghouse engineers were called immediately and an investigation of the cause of failure was begun.

The field electrical connections on both machines were cleaned, visually inspected, and "Zyglo" checked. The results of these inspections showed, in addition to the original trouble, cracks in the welds between poles 5 and 6 and between 7 and 8, on the east machine. Cracks were detected on the west machine between poles 3 and 4, 5 and 6, and 7 and 8.

x Rays were taken of numerous connections, and showed a high porosity in most of the brazed joints. The electrical connections (all) were cut open on both machines; this revealed that the brazed connections were poorly bonded. The electrical connections were then cleaned and fitted in preparation for rebrazing. The burned and smoked areas were cleaned and the damaged areas eventually attained an insulation level of more than 200 megohms.

A previously scheduled shutdown for the week of September 25 through 29 to tighten the keys of the generator field poles was started and completed. Preparations were made by Westinghouse to have brazing materials, equipment, and welder here for the week of October 1. A brazing specialist arrived October 1 from the Westinghouse Electric Corporation factory, East Pittsburgh, Pennsylvania, to assist in the brazing technique.

The entire week, October 1 through 7, was utilized in experimenting with different types of brazing materials and methods of brazing. All samples were tested by noting how much strength was required to part the connection. Difficulty was encountered in obtaining a high-quality bond due to the requirements set forth by the Westinghouse factory on the maximum temperature of 250°C at the field coil insulation.

On October 7, after careful consideration of the accumulated data, it was decided to proceed with a technique of brazing on the generators using "Easy Flo" alloy. The connections were made on the west machine and considered to be satisfactory. All brazing was completed by the evening of October 9. The machines were then started and the magnet was pulsed until 0800, 16 October, when they were shut down for normal scheduled maintenance. At this time, all field electrical connections were "Zyglo" inspected and no

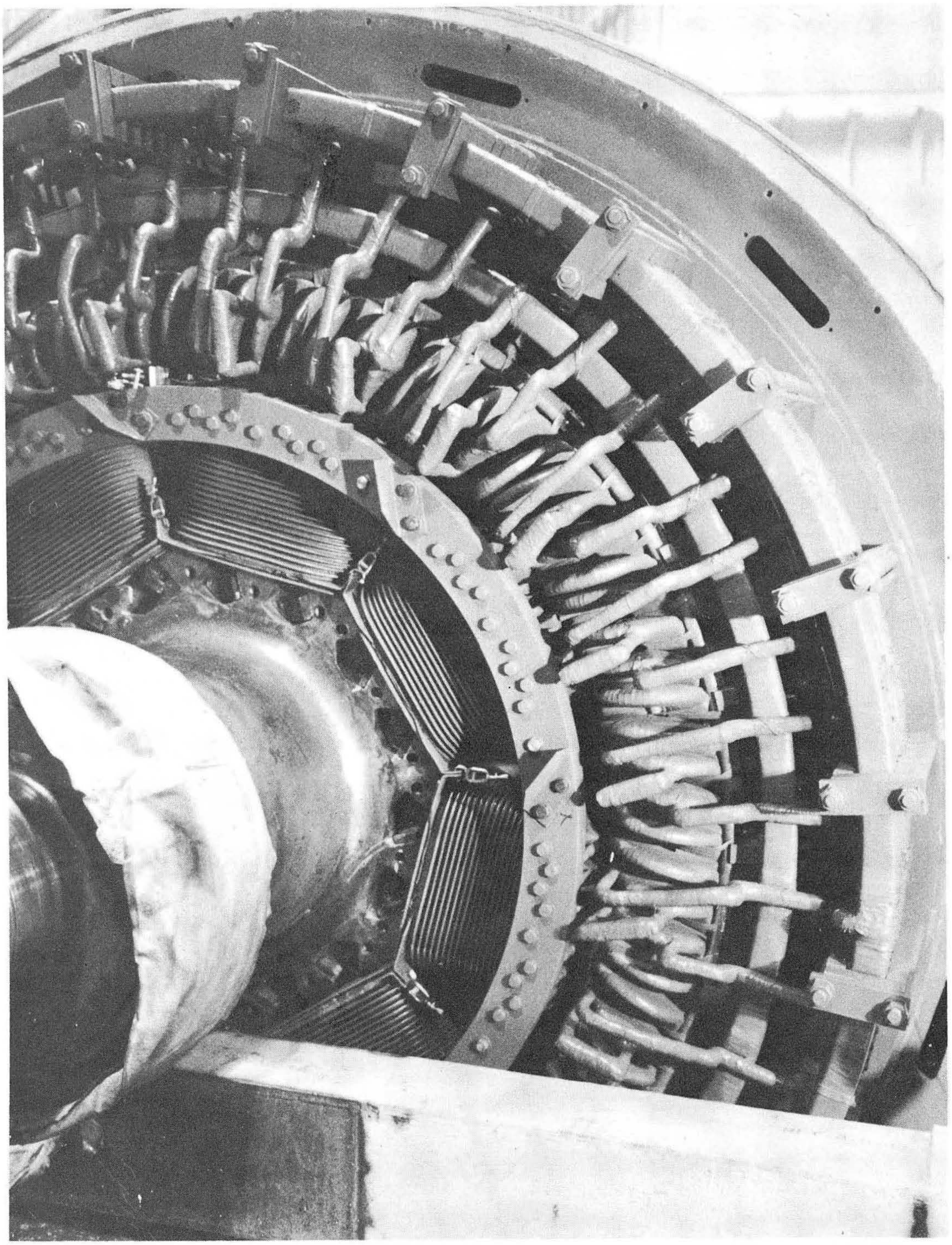

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Fig. 5. The location of the brazed coil connection on the 46-MVA generator. The connectors are pointed out by the battery clips.

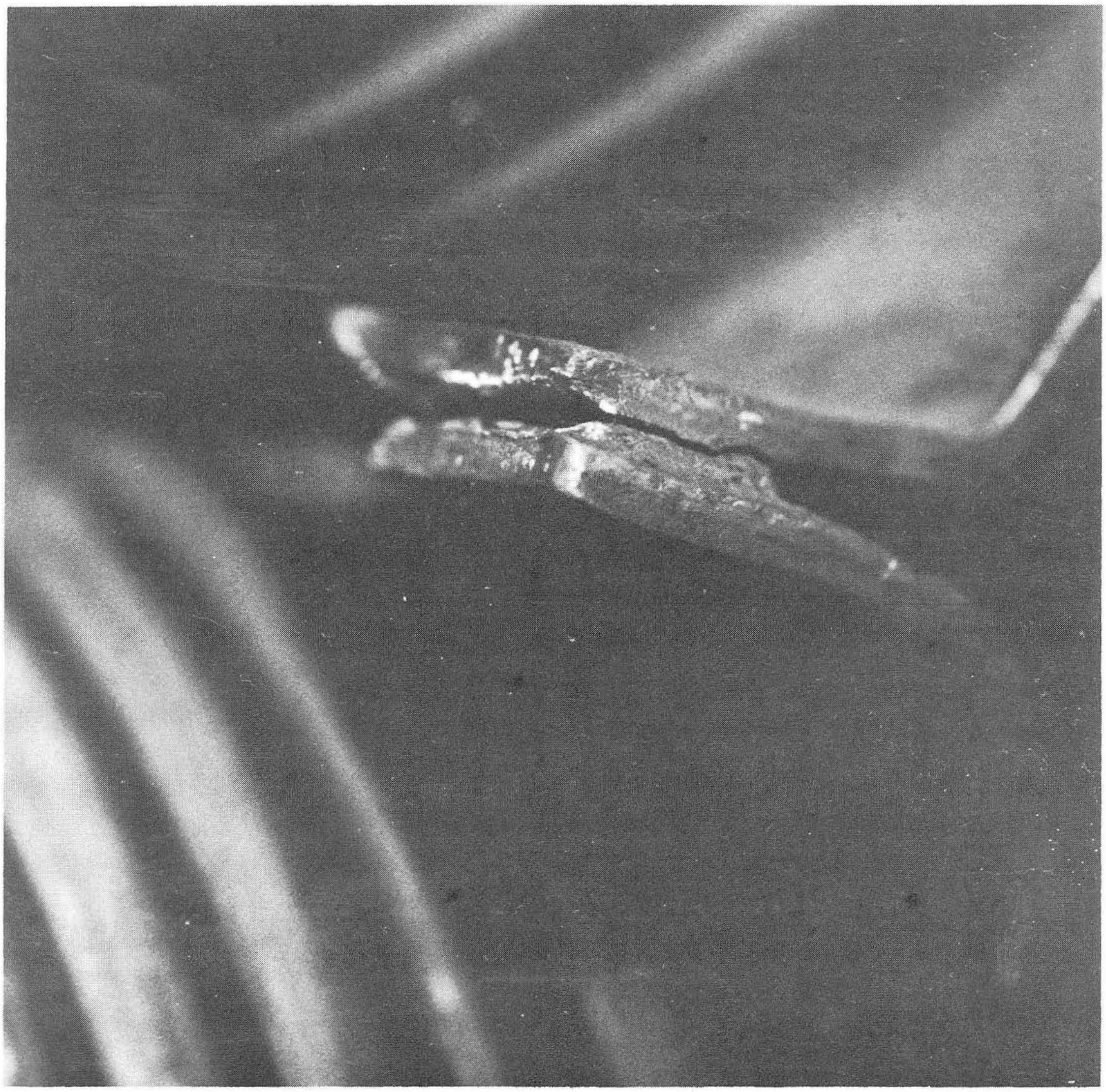

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Fig. 6. The break in the pole connection.

faults were found. Voltage drop tests of all connections were made, and considered essentially the same as those made before running. These tests will be continued on a weekly basis until it is assured that the problem has been completely solved.

B. Stability of the Flat-Top Current Slope

Until now, rates of current rise during flat-top have not been critically controlled. Generally, a 50-amp (±5 amp) rise during an 800-msec flat-top has been acceptable tolerance. Developments in resonant extraction of the Bevatron's external beam have called for an increase in pulse-to-pulse stability. Flat-top current slopes of less than 1A for a period of 0.8 sec are now required.

A block diagram of the main control systems in the Bevatron magnet power supply is shown in Fig. 7. The sketch shows three closed-loop systems:

(a) the generator field regulator for ac voltage regulation,
(b) the dI/dt regulator for dc voltage control,
(c) the Kramer regulators for machine speed range control.

Since each of these three loops affects the operational range of the others, it was necessary to establish the proper sequence of adjusting the reference to these regulators. Generally, the following technique is used.

(i) The magnet pulser is set to provide the requested pulse rate and flat-top length. (The Bevatron flat-top period is provided by inverting one power supply while the other is still rectifying.)

(ii) The field regulator is adjusted to insure that each machine provides exactly half of the load. The load is determined by system losses, which, under normal, full-power operation, is 3 MW per machine. With load sharing, repeatable speed-voltage conditions can lead to optimum pulse-to pulse symmetry.

(iii) If variations in speed range exist even though the load is balanced, the Kramer system is adjusted.

(iv) Once the system is stabilized at the required load, the current slope during flat-top is set by adjusting the open-loop firing angle of the grid-controlled ignitrons.

(v) The dI/dt slope control is then switched "on" and the system regulates for a constant B-dot value during the flat-top. This closed-loop control is provided by changing the firing angle of the inverting ignitrons.

An analysis of the B—dot loop output shows that with slopes of from one to two A the pulse-to-pulse repeatability is good. When the tolerance required is less than 1 A, small drifts are still encountered. Development is still under way to reduce these instabilities.

During this development period the setup time required to run the "zero B—dot" mode has been reduced from as long as 1 hour to approximately 2 min.

C. Magnet Pulsing Record

This record is shown in Table II.

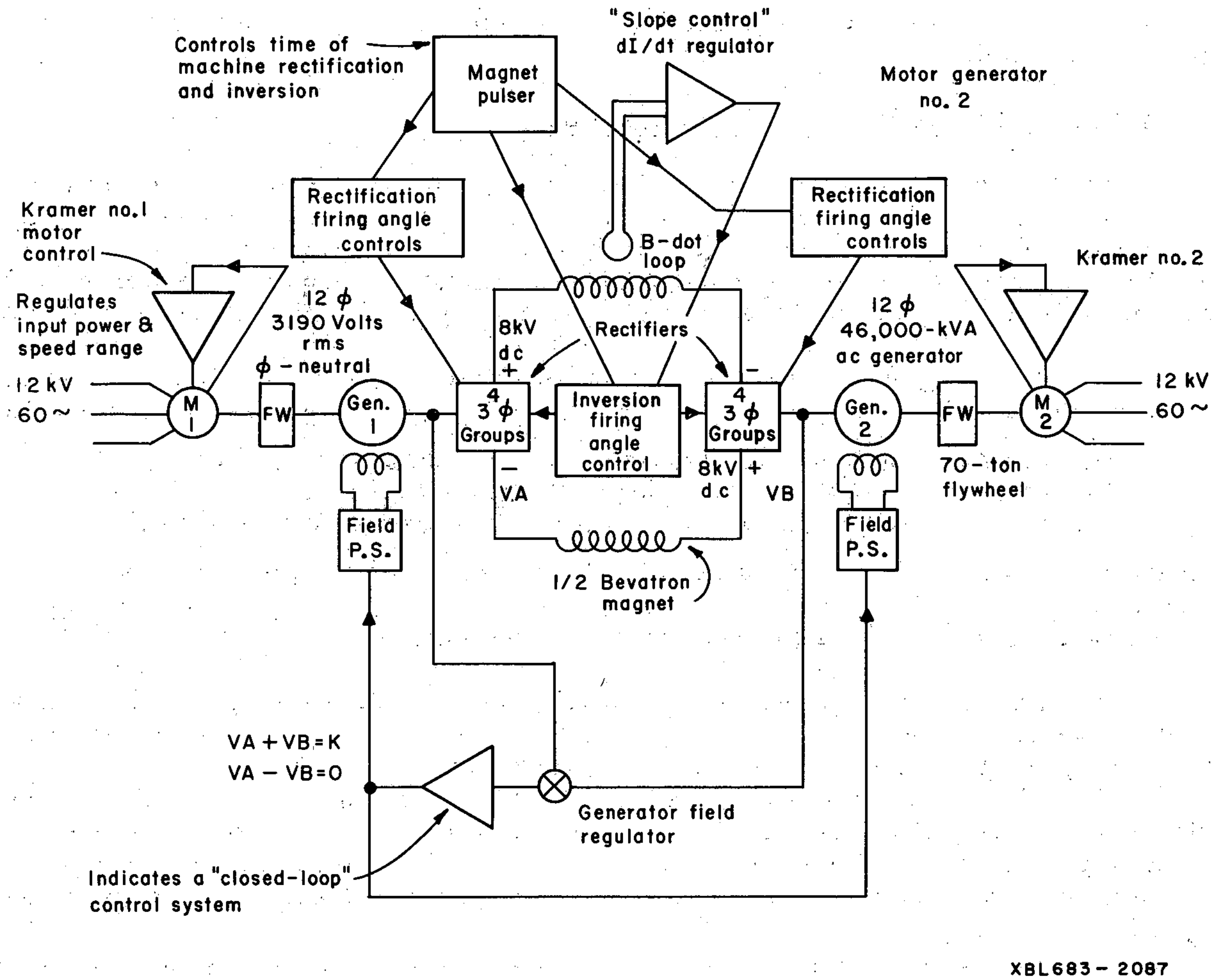

Fig. 7. Bevatron power supply control systems.

Table II. Bevatron motor generator set monthly fault report.

1967	4 to 6 pulses/min								7 to 8.7 pulses/min								9.3 to 17 pulses/min								Total				
	1.5 to 6.9 kA				7.0 to 9 kA				1.5 to 6.9 kA				7.0 to 9 kA				1.5 to 6.9 kA				7.0 to 9 kA								
	Pulses	Faults		P/F	Pulses	Faults		P/F	Pulses	Faults		P/F	Pulses	Faults		P/F	Pulses	Faults		P/F	Pulses	Faults		P/F	Total	Arc backs	Arc through	P/F	Ignitrons replaced
		14	26			14	26			14	26			14	26			14	26			14	26			14	26		
Jan.																													No pulsing; pole replacement
Feb.																													
Mar.																													
April																													
May	1,202	0	7	171																						0	7	172	Over-speed test
June	1,660	0	0	∞					130,221	1	10	11,838	48,831	3	5	6,104	117,334	1	2	39,111	9,662	1	1	4,831	307,708	6	18	12,821	
July													11,281	0	0	∞	92,033	3	8	836	243,712	5	17	11,079	347,026	8	25	10,515	
Aug.													3,942	0	0	∞	141,360	3	17	7,068	245,219	4	12	15,300	390,521	7	29	10,847	
Sept.									7,182	1	0	7,182	15,998	1	0	15,998		8	6	11,940	77,123	6	2	9,641	267,551	16	8	11,147	
Oct.																													
Nov.																													
Dec.																													

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