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BEVATRON OPERATION AND DEVELOPMENT. 59 JULY - SEPTEMBER 1968

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January 17, 1969

LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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BEVATRON OPERATION AND DEVELOPMENT. 59

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Berkeley, California

April 16, 1969

ABSTRACT

The Bevatron was "on" for experimenters 84% of the scheduled operating time, and a total of 1.9×10^{18} protons was accelerated this quarter.

A total of 14 experiments operated; two experiments were completed. A new technique of flattopping the Bevatron magnet was tested and placed in operation. This new technique has provided a desired reduction in cyclic stress on the motor generator sets and has provided flattops of up to 1 second duration at 5.3 GeV and 2.5 seconds at 3.7 GeV.

* Preceding Quarterly Reports, UCRL-18482, UCRL-18259

I. MACHINE OPERATION AND EXPERIMENTAL PROGRAM

The Bevatron operation record is shown in Fig. 1. The beam was "on" for 84% of the scheduled operating time. It was "off" 8% of the scheduled operating time because of equipment failure and 8% of the time for experimental setup, tuning, and routine checks. During this quarter, the Bevatron accelerated 1.9×10^{18} protons.

During September, beam was provided to as many as 10 experiments simultaneously. Seven of these experiments were in the data-taking stage. Fourteen experiments were operated and integrated a total of 403 12-hour periods of operation. Two primary experiments were completed. Experiment #83, a collaborative effort of Lawrence Radiation Laboratory Group A (Abolins-Smith) and the University of California at Davis (Lander), was completed on September 25, 1968. This experiment was set up at the third focus of the external proton beam (EPB) Channel II. Experiment #86, a collaborative effort of two Lawrence Radiation Laboratory groups--Moyer-Helmholz (Kenney) and Group A (Pripstein), was completed on September 16, 1968. This experiment was set up in a secondary beam from an internal target near the north straight section of the Bevatron. The 25-inch hydrogen bubble chamber was forced to suspend operations on July 3, 1968, because of a short-circuit to ground in the magnet windings. They resumed operation early in September, but suspended operation again on September 24, 1968, because of a failure in the third and fourth stages of the hydrogen compressor. The group expects to resume operation early in October.

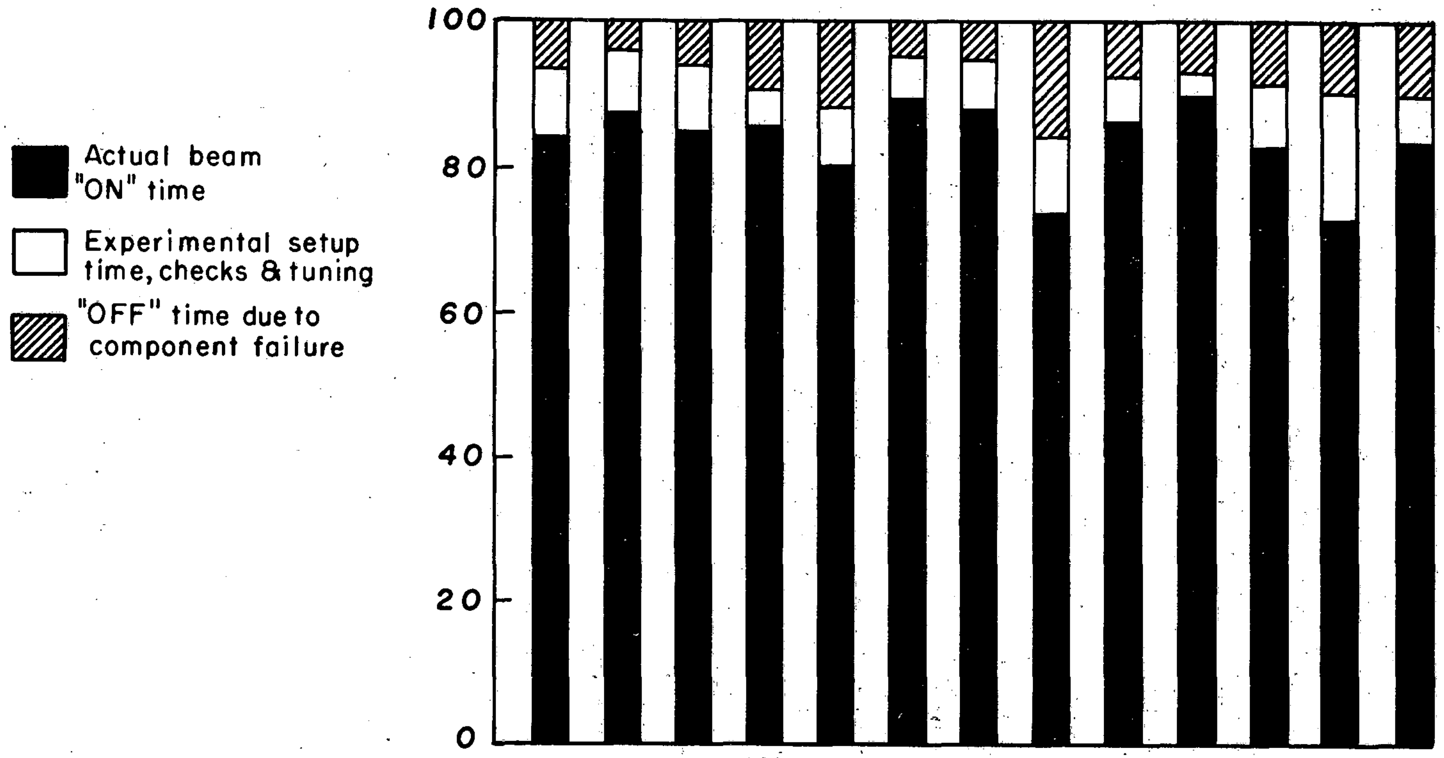
A summary of the experimental program for this quarter is shown in Table I.

A new technique[1] of flattopping the Bevatron magnet was given an operational test, starting on July 22. The tests proved quite satisfactory and the new mode became the standard operating mode. This mode provided a desired reduction in cyclic stress on the motor generator rotors, and has allowed flattop pulse lengths heretofore not possible. At an energy of 3.67 GeV, we were able to operate with a 2.5-sec flattop and with long beam spills of more than 2 sec: at 5.3 GeV with a 1-sec flattop. The method used to provide this new flattop is described in Section IV of this report.

II. SHUTDOWN

The machine was shut down over July 4, 1968, in observance of Independence Day. The Bevatron was again shut down on Labor Day, September 3, 1968, and remained down that week for routine maintenance, inspection of the main motor generators, and equipment modification.

The only significant change to equipment during this shutdown was to the south plunging magnet in the Bevatron. This magnet is the second in the external proton beam extraction system. The junction between the magnet and the plunge system was modified to place the minimum plunged position at a 2-inch-smaller radius than previously. This change was required for the resonant extraction studies.



Week of		6/30	7/7	7/14	7/21	7/28	8/4	8/11	8/18	8/25	9/1	9/8	9/15	9/22
Crew hours		144	168	168	168	168	168	168	168	168	144	168	168	168
Turn on & maintenance time	(h)	14	10	12	10	10	10	10	10	10	6	0	10	10
Scheduled operating time	(h)	130	158	156	158	158	158	158	158	158	68	168	158	158
Scheduled Bevatron test time		9	17	14	0	0	0	6	14	18	0	0	8	6
Scheduled shutdown time		0	0	0	0	0	0	0	0	0	70	0		0
Holiday		24	0	0	0	0	0	0	0	0	24	0		0

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Fig. 1. Bevatron operating schedule.

Table I. Summary of Bevatron experimental research program, July through September 1968.

Groups	Experiment location	Dates: Run	Dates: Start	Dates: End	Experiment	Beam Time: This quarter (July - September): 12-Hour periods	Beam Time: This quarter (July - September): Hours	Beam Time: Start of run through September 1968: 12-Hour periods	Beam Time: Start of run through September 1968: Hours	Pulse schedule	Primary or secondary experiment
Internal Groups											
Powell-Birge (Kalmus)	EPB 25-in. BC	72	2/21/68	In progress	π^+p interactions	25	242	95	1027	1:1	P
Powell-Birge (Ely-Kalmus)	EPB 25-in. BC	73	6/8/68	In progress	K^-p and K^-d reactions	14	132	34	346	1:1	P
Segrè-Chamberlain (Wiegand)	EPB XI F2	81	7/17/68	In progress	K-mesic x rays	37	395	37	395	1:1	P
Group A (Abolins—Smith) U. C.—Davis (Pellet)	EPB XII F3	83	6/14/68	In progress	$pp \rightarrow d + x$	64	701	68	749	1:1	P
Moyer-Helmholz (Kenney) Group A (Pripstein)	Internal north area straight section	86	8/14/67	In progress	Branching ratios for the neutral and charged decay modes of the η	59	612	101	1093	1:1	P
Segrè-Chamberlain (Chamberlain) U. Michigan (Longo)	EPB XI F3	91	7/20/68	In progress	Polarization in $np \rightarrow pn$ charge-exchange scattering, 1-6 GeV.	13	150	13	150	1:1	P
Nuclear Chemistry (Hyde-Poskanzer)	EPB XI F2	104	9/21/66	In progress	Production of light fragments from p-nucleon collisions	7	69	108	1323	1:1	P
Miller (Miller)	Internal north area straight section	P-32 (95)	5/31/68	7/20/68	$K^0{}_{\mu 3}$ charge-asymmetry tests for future Exp. #95.	4	49	4-1/2	72	1:1	S
External Groups											
U. Hawaii (Cence) Moyer-Helmholz (Perez-Mendez)	Internal west area straight section	P-31 (60)	8/27/68	In progress	Counter and spark-chamber tests for Exp. #60 to be set up at EPB XI F3	6	70	6	70	1:1	S
U. Washington (Williams)	EPB XII F3	70	5/3/68	In progress	Σ^+ magnetic moment	50	537	71	740	1:1	P
U. C.—San Diego (Piccioni)	EPB XI F3	71A	3/15/68	In progress	K regeneration amplitudes 1-1.5-GeV/c separated $K^\pm$ beam	49	524	74	801	1:1	P
U. C.—San Diego (Masek)	EPB XI F3	79	3/27/68	In progress	$K^0{}_2(e_3)$ charge asymmetry	62	672	82	931	1:1	P
U. Michigan (Jones)	Internal north area straight section	94	7/23/68	In progress	Neutron cross sections for p,d, and various metal targets	50	544	50	544	1:1	P

Table I

III. BEVATRON DEVELOPMENT AND STUDIES

The major effort during machine development periods this quarter was devoted to the new flattop pulsing mode.

A number of short periods were devoted to injection studies, beam sharing, extraction efficiency, and beam-spill studies.

IV. BEVATRON MOTOR GENERATOR

Major modifications were made during this period in order to develop a flattop pulsing technique which does not cause large speed excursions of the generator.

It has been noted in previous reports that the speed change during flattop pulsing and the resultant cyclic centrifugal loading on the generator rotor probably caused the fatigue damage in the old generator poles which eventually resulted in replacement of the poles. As some cracks have subsequently appeared in the new poles, even under greatly reduced speed-range conditions, it was deemed necessary to make a change in the pulse system in order to further reduce cyclic loads on the rotors and to provide the long flattops required by the experimental program.

Power Supply Reconnection

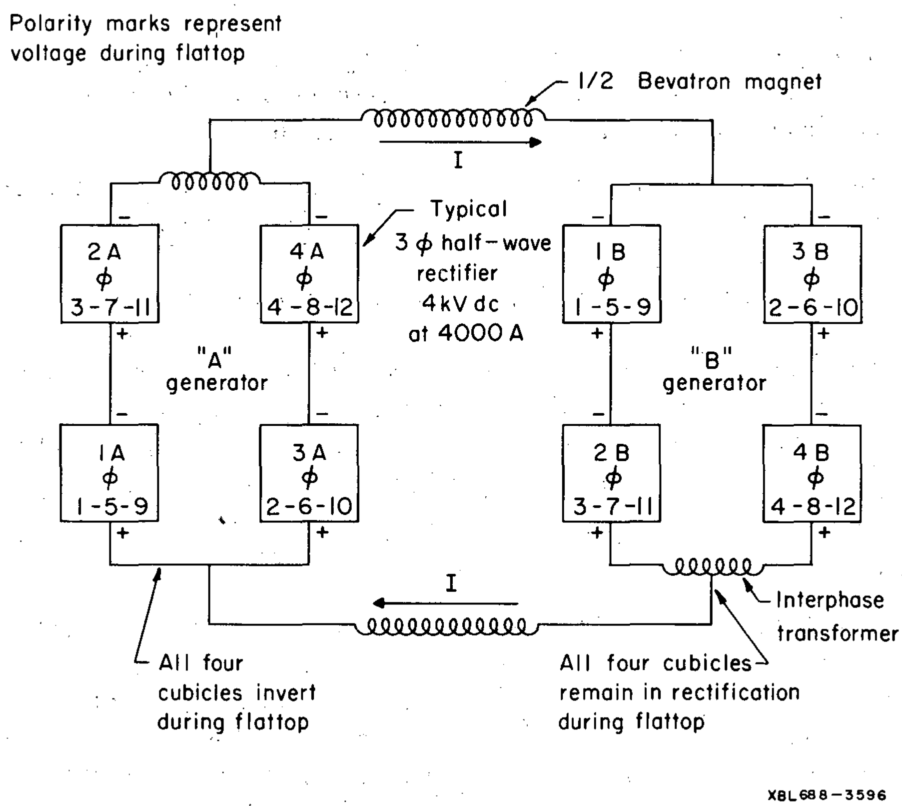
A new interconnection of the existing high voltage rectifier cubicles that eliminates energy exchange between the two Bevatron generators makes it possible to have long flat-top pulses with small speed changes. The old and new connections are shown in Fig. 2.

In the old flattop pulsing mode one generator, and the associated rectifier cubicles, were always in full rectification from "magnet on" to "end of flattop." In the new mode, in which a grouping of four rectifier cubicles includes excitation from both generators, each generator is half in rectification and half in inversion during the flattop period. Therefore, the only change in speed during a flattop period is a result of system losses, not energy exchange between machines.

Prior to this reconnection the typical change in speed during a 6400-A (5.3 GeV) 1-sec flattop was 117 rpm. The speed range is now 44 rpm for the same Bevatron pulse. This modification should insure that the speed range never exceeds the range of the Bevatron's original 8333-A peak pulse. This original non-flattop mode was pulsed for about 10 years without noticeable pole damage.

Step Change-Over for Shaft Mechanical Damping

The new mode of operation also made it possible to provide a necessary step change-over period when the rectifiers are switched from rectification to inversion. The step-change period is required to dampen shaft oscillations excited by the sudden changes in shaft torque.



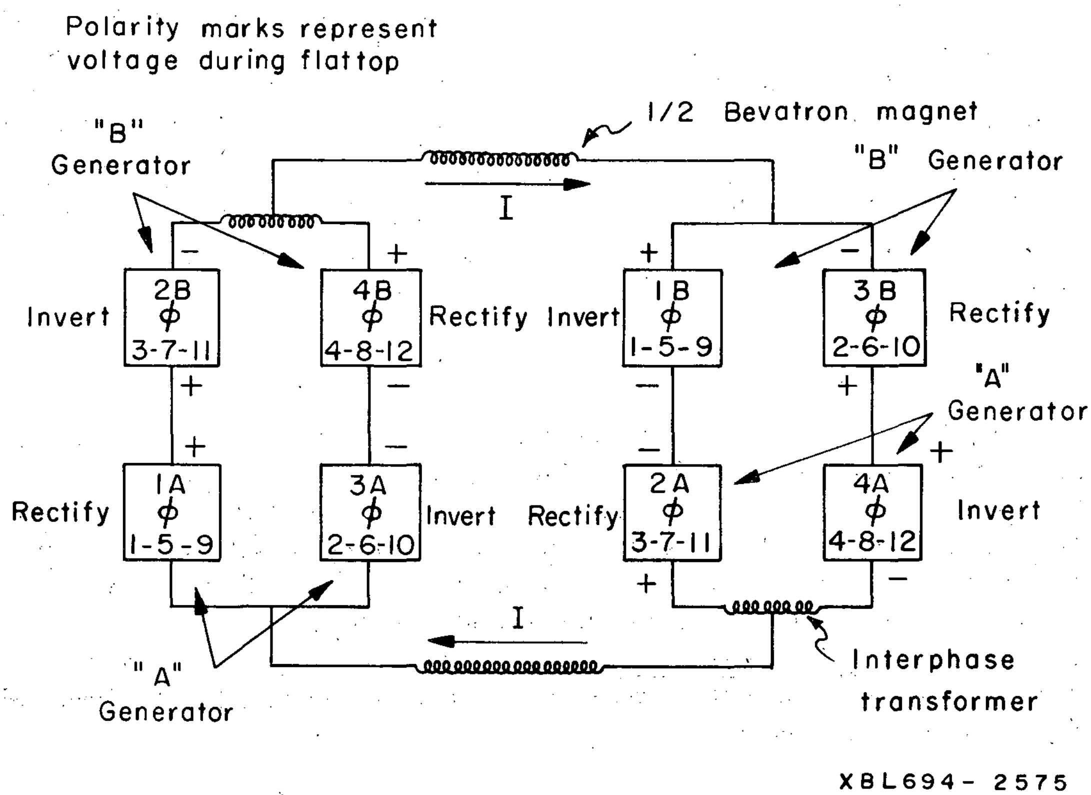


Fig. 2. Old (above) and new (below) power supply connections.

Some pulse modes that were tested in developing the new system did not allow for this feature and were therefore considered undesirable from the standpoint of possible pole failure due to cyclic stress initiated by shaft oscillation.

Figure 3 shows the step transition into and out of the flattop mode, and also points out the cubicle programming now necessary for flattop operation.

Synchronization of the Motor Generator Sets

A prerequisite of pulsing with the new connection was synchronization of the two MG sets. Synchronization would insure that each half of the power supply would function as four three-phase half-wave rectifiers with a 12-phase ripple regardless of the fact that the excitations were coming from two generators instead of only one.

Various control schemes were tried before an acceptable synchronization was developed.

Figure 4 shows the two closed-loop control systems that were added for synchronization. Synchronization error is less than 5 electrical degrees displacement for most pulsing modes. Since the two 46 000-kVa generators have eight field poles, the maximum mechanical displacement is of the order of 1 deg. The phase loop can control 3 MW of differential power between the two motors. Frequency response of this loop is approximately 5 Hz.

The current-balance loop was added when it was found that the currents flowing in the parallel paths of the rectifier cubicles had a tendency to shift to one branch or the other at random times. This unbalance caused a loss of synchronization and an increased rate of ignitron faults. The current-balance loop insures balanced dc loading.

The phase loop and current-balance loop actuators are low-power devices, approximately 150 mW for the phase loop and 30 W for the current-balance loop. The Kramer system and inverter peaker systems were existing and operational prior to these recent changes.

Additional Benefits from the New Connection

The new Bevatron pulsing configuration has made it possible to simplify and improve operating characteristics in the following areas:

<u>Current Jitters.</u> Pulse-to-pulse current variation at the start of flattop has been reduced from a minimum of 15 A to less than 3 A. This was made possible by the repeatability of pulse-to-pulse machine speed. It is now possible to program the same amount of conduction cycles during the full rectification period of each pulse.

<u>Simplified Magnet Grounding Parameters.</u> Only one machine ground is now needed no matter in what pulse mode the Bevatron is operated. The ground is still switched to the magnet ground for injection.

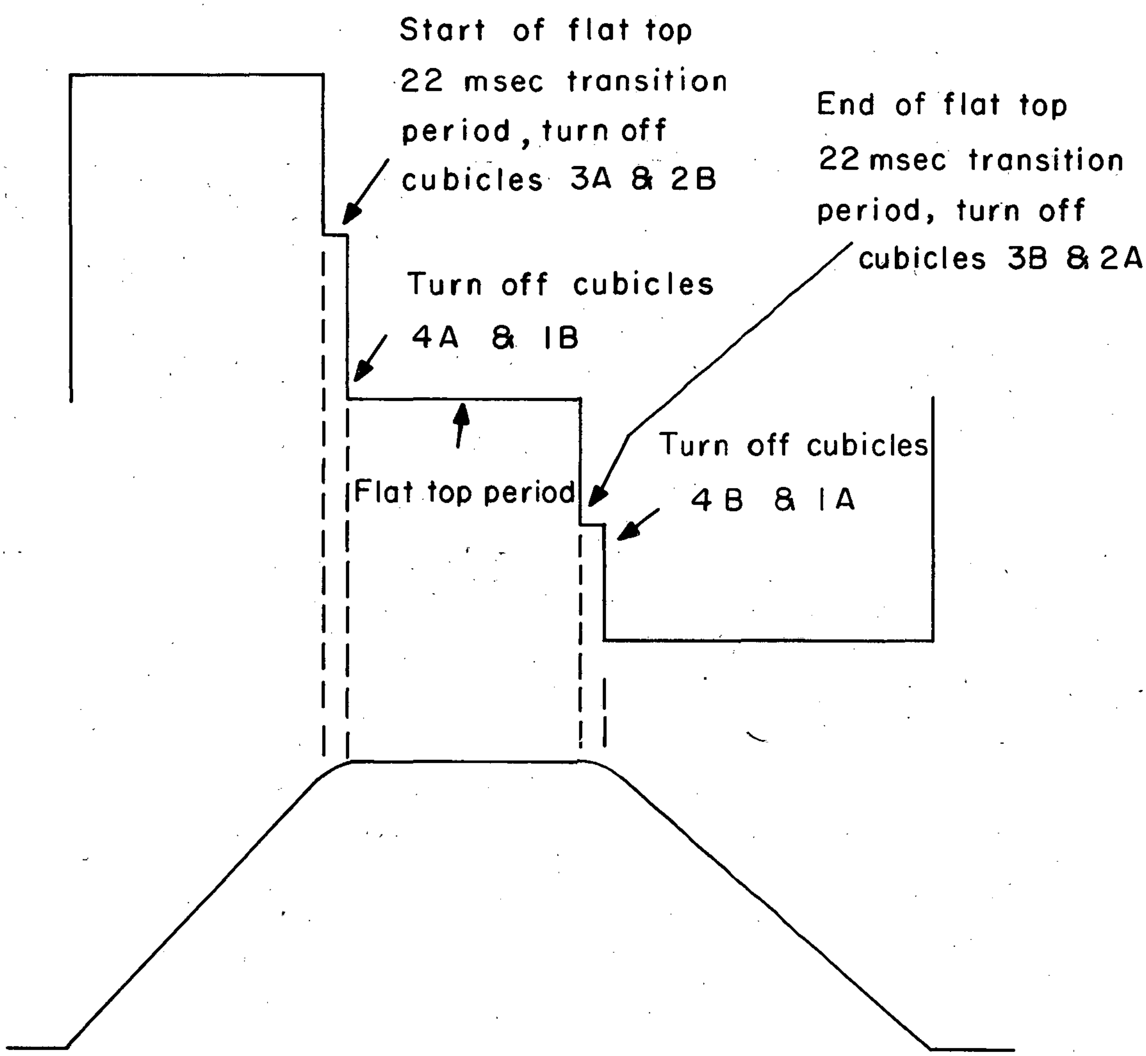


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Fig. 3. Bevatron magnet idealized voltage and current waveform. Flattop pulse cubicle turn-off sequence.

3A
2B
22 msec
4A
1B
flattop period
3B
2A
22 msec
4B
1A

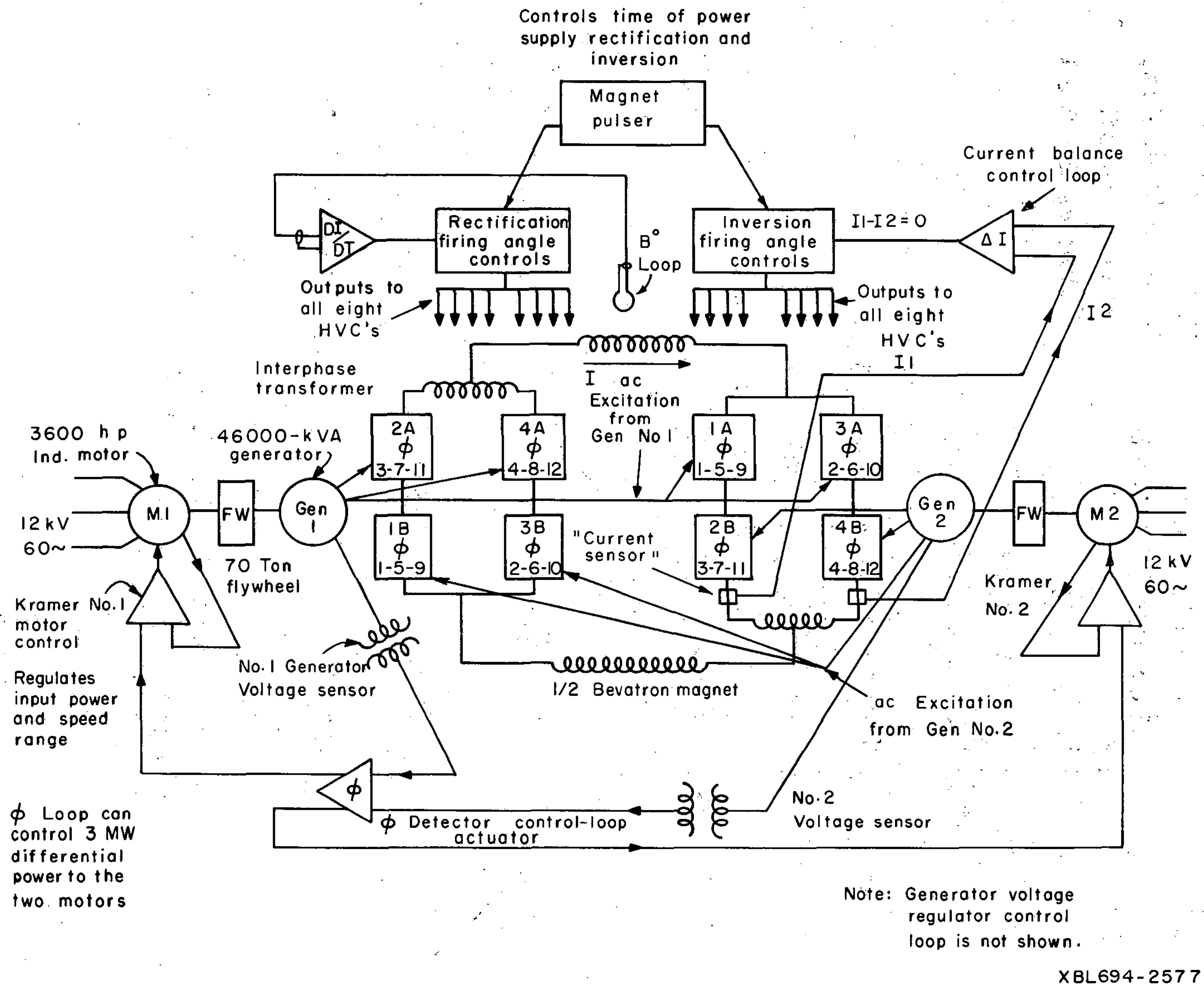

Fig. 4. New Bevatron power supply control system.

Longer Low-Current Flattop Periods. In the old mode overspeed limitations restricted the low-current flattop lengths. This was due to the fact that the inverting machine was taking power from the rectifying machine throughout the flattop period. Now only motor power demand or available pulse time as a function of repetition rate limits the length of the flattop period. Low-current flattops of from 2 to 5 sec are now realizable at a possible reduction of maximum repetition rate.

Evaluation of Early Operational Performances and Plans for Additional Pulsing Modes. All of the steps outlined in this report have improved operational stability. The most important fact is that no new pole-lamination cracks have developed nor have the old cracks propagated since this change was made. The 6400-A 1-sec flattop has been continually run since the change-over.

After a week or two, the operating group mastered the synchronization technique, and usually the machines are synchronized one or two pulses after the normal operating current is reached.

The mezzanine mode has not been operated since the change. However, no difficulty is expected once additional control changes are completed. The mezzanine mode and a projected "back-porch" mode will, in fact, be much easier to control because of the power balance between the two machines. These modes should be operational and available for experimenters' use during the next quarter.

The magnet pulsing record is shown in Table II.

REFERENCE

1. Kenneth C. Crebbin and Robert Frias, Bevatron Operation and Development. 58, UCRL-18482, January 17, 1969.

Table II. Bevatron motor generator set monthly fault report.

4 to 6 pulses/min

1968	1.5 to 6.9 kA Pulses	Faults AB	Faults AT	P/F	7.0 to 9 kA Pulses	Faults AB	Faults AT	P/F
Jan.	–	–	–	–	200	–	–	–
Feb.	–	–	–	–	1 625	–	–	–
March	1 834	0	–	–	–	–	–	–
April	1 689	–	–	∞	180	–	–	∞
May	1 594	–	–	∞	308	–	–	∞
June	873	1	1	436	175	–	–	∞
July								
Aug.								
Sept.	1 711	–	–	∞	207	–	–	∞
Oct.								
Nov.								
Dec.								

7 to 8.7 pulses/min

1968	1.5 to 6.9 kA Pulses	Faults AB	Faults AT	P/F	7.0 to 9 kA Pulses	Faults AB	Faults AT	P/F
Jan.	4 956	–	–	–	9 182	1	1	4 591
Feb.	–	–	–	–	25 816	2	8	2 582
March	687	–	–	–	15 065	1	7	1 883
April	203	–	–	∞	960	1	1	480
May	–	–	–	–	976	–	–	–
June	410	–	–	∞	–	–	–	–
July								
Aug.	10 819	1	7	1 352	2 515	1	3	628
Sept.	42 050	1	0	42 050	434	–	–	∞
Oct.								
Nov.								
Dec.								

9.3 to 17 pulses/min

1968	1.5 to 6.9 kA Pulses	Faults AB	Faults AT	P/F	7.0 to 9 kA Pulses	Faults AB	Faults AT	P/F
Jan.	414 210	9	27	11 506	4 289	1	2	1 430
Feb.	195 627	6	9	13 042	55 162	2	10	4 596
March	293 760	46	7	5 543	88 108	14	13	3 263
April	198 047	9	11	9 902	183 230	10	36	3 983
May	95 108	3	6	10 568	106 720	13	27	2 668
June	303 899	16	29	6 753	114 209	10	27	3 087
July	425 825	20	50	6 083	3 474			
Aug.	409 847	27	34	6 718				
Sept.	284 739	5	7	23 728	1 386	–	–	∞
Oct.								
Nov.								
Dec.								

Total

1968	Pulses	Arc-backs (AB)	Arc-through (AT)	P/F	Ignitrons replaced
Jan.	432 837	11	30	10 557	0
Feb.	278 230	10	27	7 520	1
March	399 454	61	27	4 539	2
April	384 309	20	48	5 652	2
May	204 706	16	33	4 178	1
June	419 566	27	57	4 995	1
July	429 299	20	50	6 133	0
Aug.	423 181	29	44	5 797	0
Sept.	330 527	6	7	25 425	1
Oct.					
Nov.					
Dec.					

Table II

STAFF

Edward J. Lofgren	Bevatron Group Leader
W. A. Wenzel	Alternate Group Leader
Walter D. Hartsough	In charge of Bevatron operations
Kenneth C. Crebbin Fred H. G. Lothrop Wendell Olson	Operation Supervisors
William Everette	Radiation Control
G. Stanley Boyle Frank W. Correll Robert G. Gisser Ashton H. Brown Joseph F. Smith	Operating Crew Supervisors
Richard L. Anderson Robert W. Brokloff Gary M. Byer Donald N. Cowles Charles H. Hitchen Robert M. Miller Harvey K. Syversrud Marsh M. Tekawa John E. Tommaney Stanley T. Watts	Bevatron Operators
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Marion Jones	In charge of Electrical Coordination Group
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Harold Vogel Robert Frias	In charge of Motor Generator Group

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