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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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ABSTRACT

The beam was on for experimenters 81.9% of the scheduled operating time. During this period the Bevatron accelerated 1.9×10^{18} protons. We provided beam for 12 primary experiments and completed three primary experiments.

The external beam transport magnets have been placed under computer control. This, coupled with new Bevatron main magnet pulsing modes, has greatly increased the flexibility of machine operation and the ability to satisfy simultaneously the needs of a number of experiments.

The extraction efficiency, for short beam pulses as required by the bubble chamber, has been doubled by going to an outer-radius target.

I. MACHINE OPERATION AND EXPERIMENTAL PROGRAM

A. Physics Research

The Bevatron operation record is shown in Fig. 1. The beam was on for 81.9% of the scheduled operating time. The beam was off 8.9% of the scheduled operating time because of equipment failure and 9.2% of the time for experimental setup, tuning, and routine checks. During this quarter the Bevatron accelerated 1.9×10^{18} protons.

During the period covered by this report, we provided beam for twelve primary experiments and three secondary experiments. Three primary experiments were completed this quarter: (a) Experiment 79, being done by the University of California–San Diego Masek Group, was completed on March 17, 1969. This experiment was done in the external proton beam channel I at the third focus. The experiment was a study of K^0e3 charge asymmetry. (b) Experiment 91 was completed on February 24, 1969. This experiment was a collaborative effort of the LRL Segrè-Chamberlain group and the University of Michigan (Longo) group. This experiment, a study of polarization in the $np \rightarrow pn$ charge-exchange scattering, was done at the third focus of channel I in the external proton beam facility. (c) Experiment 97 was completed on March 24. 1969. This experiment was a collaborative effort of two LRL groups: Group A (Pripstein) and the Moyer-Helmholz group (Kenney). This experiment, a study of differential and total cross sections for $\pi^- p \rightarrow n\eta$, was done in a secondary π^- beam from an internal target near the north straight section of the Bevatron.

During this quarter, we provided 106 12-hour periods of Bevatron operation for high

*Preceding Quarterly Reports: UCRL-18890, UCRL-18864 energy physics. We integrated 267 12-hour periods of data taking, 222 periods of tuning by primary experimenters, and 14 12-hour periods for secondary experiments, for a total of 503 12-hour periods of experimental physics.

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

B. Bevatron Operation Modes

1. Control of External Proton Beam Transport Magnets

A computer-based digital-structured data-acquisition and control system has been developed for the purposes of on-line programmed control of external proton beam (EPB) transport magnets.

The control algorithm accommodates all modes of Bevatron operation by separating the operating cycle of the accelerator into several zones. This technique allows independent processing of Bevatron field values within each zone and the introduction of zone-related time-variable functions in each of the controlled magnet currents.

With expansion of the EPB facilities the operator-controlled beam transport system has become sufficiently complex to warrant consolidation from the former "several-knob-per-magnet" technique to a single multiplexed knob, applicable to any magnet in any one of the several zones.

The digital system has been in operation full time, controlling 18 magnets, since January 27, and will be extended to the remaining unpulsed magnets in the system during the month of May.

The hardware capability has been based upon a total capacity requirement of 64. This provides control capability of 64 magnets of either pulsed or dc operation and 64 channels of analog data monitoring. All data transfers are on a direct memory-access basis to a PDP-8 12-bit 4096-word digital processor.

The data-sampling rate is adjusted to conform to the firing period of the three-phase SCR-type power supplies, i.e., approximately 3 milliseconds.

The digital transmission device is a parallel-data dc-line twisted pair per bit type, providing excellent noise immunity. Digital-to-analog conversion is done at remote locations, as close as practicable to the power supplies under control. There are presently four widely separated areas in which power supplies are located, and each area has a single transmitter-receiver combination.

The Bevatron field value at each 3-msec period is obtained by monitoring the B-dot windings in the magnet gap with a voltage-to-frequency converter and accumulating counts at approximately a 2-MHz rate in a digital up-down scaler. This scaler then contains the instantaneous value of the integral of B-dot (quantized to 500 nsec).

During the initial period of operation, an all-out program of interpreting operator needs and desires and converting them into hardware and software has been in progress. This has resulted in continuously increasing the flexibility of the controller and evolving a more useful data-display and diagnostic capability.

A "perturbation" mode has been included, together with a series of software time delays and gates. This provides the capability of stepping or offsetting magnets for operator-determined time periods to accommodate special extraction techniques and switching of beam paths in EPB channels.

Work has begun on a program aimed at controlling pulsing modes of the Bevatron guide field which should result in faster setup and eventual substitution of smoother progression for the quantized pulse rate of the Bevatron.

2. Bevatron Main Magnet Pulsing Modes

The new method of providing Bevatron main magnet flattop modes has been described in a previous quarterly report.[1] The new flexibility in control of the EPB transport magnets was described above. These two improvements provided a major gain in operating flexibility at the Bevatron. It is now possible to provide beam in the EPB system at several different energies on the same magnet pulse. For example, Experiment 93, being done by the Palevsky group from Brookhaven National Laboratory, required protons at a lower energy than the rest of the experiments. In addition the experimenters needed an rf-off type of spill, which required that their beam spill be after all the other beam spills. If the rf-off type of spill were given first the beam would have to be recaptured and bunched by the rf, with resultant beam losses. To satisfy the needs of both groups of experiments, we provided beam spills for the bubble chamber and other counter experiments on flattop at 4.8 GeV. We provided a 3-GeV rf-off spill for the BNL group on a flat portion of magnetic field generated during the decreasing portion of Bevatron field. This flat region (we call it a back porch) is shown in Fig. 2a.

A second dual-flat-portion mode of magnet pulsing was used this quarter to provide a higher-energy proton beam for the bubble chamber operation than was need for the counter experiments. We normally provide the bubble chamber with a short beam spill at the beginning of flattop and a second beam spill at the end of flattop. Beam is spilled for the counter experiments between the two bubble chamber beam spills. Because of power requirements, the higher the energy of beam the shorter the flattop portion we can provide. Because of the K yield, the bubble chamber needed 5.3-GeV protons. The counter experiments were satisfied with 4.8-GeV protons and wanted the maximum possible length of beam spill. We therefore operated a flattop at 5.3 GeV for the bubble chamber and a back porch at 4.8 GeV for the counter experiments (Fig. 2b). The counter experiments had a shorter beam spill at 4.8 GeV than they normally would have with a 4.8-GeV flattop, but it was longer than they would have had if we had operated them between the two bubble chamber pulses at 5.3 GeV.

3. Outer-Radius Targetry and Extraction of RBE Pulses.

A new and more efficient mode of producing and extracting short beam spills from the Bevatron has been successfully tested and placed in operation this January. The scheme employs the RBE (rapid beam ejector, a fast pulsed magnet), the conventional two-magnet extraction system, but with the inner-radius energy-loss target replaced by an energy-loss target outboard of the circulating proton beam. The significant advantages of this new mode are two: The extraction efficiency for short beam pulses (200 to 500 usec pulse duration for bubble chamber operation) is increased from less than 10% to about 40% for typical operation compatible with long-beam-spill uses; and the flexibility of operating both long- and short-spill experiments on the same Bevatron pulse is greatly improved.

When an inner-radius target is used for RBE operation, as was previously the case, a lip is required to damp betatron oscillations. Beam from such an inner-radius target sweeps across the aperture of the first extraction magnet (M1) and only a fraction of the beam is transmitted. Therefore the extraction efficiency when such a target is used is low. The improvement in extraction efficiency for RBE pulses using outer-radius targetry comes about because a lip is not required. In this case the RBE spill does not sweep the aperture of M1. A large fraction of the beam that hits the target, therefore, can be made to fall within the aperture of the first extraction magnet (M1) and is efficiently extracted.

Another factor that had influenced RBE extraction efficiency when an inner-radius target was used was target radius. Extraction efficiency had been critically dependent on target radius, dropping rapidly as the energy-loss target and the extraction magnets moved radially inward. This factor severely influenced the efficiency of compatible operation within long-spill users. The present outer-radius target mode allows a large degree of independence of RBE-spill users and long-spill users. The long beam spill counter experiments frequently require variations in beam intensity. The internal target experiments and EPB experiments simultaneously share the long beam spill. Variations in intensity to these experiments are achieved by adjusting the relative radial positions of the targets. With a separate target for the RBE spills, these adjustments can now be made with little effect on the RBE spill to the bubble chamber.

In order to achieve good extraction efficiency for both the short and long beam pulses on the same Bevatron pulse using this system, magnet-current programming had to be provided for extraction magnets M1 and M2 such that the current could be different in the magnets during the short spills from what it is during the long spill. Provision for this current programming was made during the shutdown early in January. In March this current programming was provided by the "perturbation" mode in the computer programming described in IB1 of this report.

4. <u>Bevatron Experimenters' Meeting</u>

On January 18, 1969, a Bevatron Experimenters' Meeting was held. A total of 108 persons attended, 73 from LRL and 35 from outside institutions. Three papers were presented on theoretical and experimental high energy physics. Present Bevatron operations and the current high energy experimental physics program were discussed. Future Bevatron developments were taken up, and two papers on advanced accelerator studies were presented.

II. SHUTDOWN

The shutdown that started on December 20, 1968, ended on January 12, 1969. The first week of January, after the Christmas holidays, was spent on routine inspection and maintenance of the Bevatron, the motor generator sets, and other related equipment. Extensive modifications were made to the backstop region of Channel II in the external proton beam facility, as required by the two new experiments being set up in that area.

During the week of February 10 most of the Bevatron operations periods were devoted to machine development and studies. This was part of the slowdown in the high energy physics program because of budgetary problems.

III. BEVATRON DEVELOPMENT AND STUDIES

A number of projects continued through this quarter directed toward general improvement and upgrading of Bevatron operation. Testing and updating the features of the new computer control of the external beam transport magnets continued. Some time was devoted to main motor generator tests to upgrade their pulsing control and flexibility. Study continued on extraction efficiency and on beam tracking for the new "back porch" mode of operation. The major effort of the Bevatron development program was again devoted to the resonant-extraction studies and to high-beam studies.

IV. BEVATRON MOTOR GENERATOR

A. Pulsing Modes

The new method of flattop pulsing has simplified the development of mezzanine and back porch constant-current regions during a Bevatron pulse. It is now possible to initiate as many "flat" current regions as found compatible with both beam distribution techniques and maximum power limits. Combinations of mezzanine, flattop, and back porch periods have been operated in order to distribute a variety of beam energies during a single pulse. Figure 3 shows magnet voltage and current waveforms of recent pulsing modes.

B. Tap #5 Operation

The continued effort to reduce ignitron faults to a minimum has prompted tests of Bevatron operation at reduced magnet voltage excitation. Tap #5 operation is 2000 volts less than the 16-kV excitation of Tap #3. No significant beam loss was attributed to the longer current rise time of the Tap #5 excitation. Tap #5 has been used exclusively during this quarter.

C. Tap #5 Pulsing Graphs

The graphs in Figs. 4 through 7 represent full-load pulsing curves at Tap #5 excitation. Full load is defined as rated +10% or 3 megawatts per M. G. set. If a pulsing mode other than full load is requested, various limitations prevail which make the selection of operational points more critical. Limiting parameters would include repetition-rate time limits and machine speed range limits.

The new power supply connection allows magnet pulsing without regard to machine speed except at 8000 -A current levels. The maximum speed range change per Bevatron pulse has been set at 70 rpm. This value is approached only when high-current long flattops are operated.

A line denoting the intersection of full-power pulsing curves and curves representing maximum flattop length as a function of repetition rate is shown on the flattop graph. This is the only exception to the full-load criterion, and is added because of the interest in long low-current flattop modes that do not approach full power demands.

D. Magnet Pulsing Record

The magnet pulsing record is shown in Table II.

Table I. Summary of Bevatron Experimental Research Program - January through March 1969.

			Dates			Beam Time					
						This quarter January - March		Start of run through March 1969			
Groups	Experiment location	Run	Start	End	Experiment	12-Hour periods	Hours	12-Hour periods	Hours	Pulse Schedule	Primary or secondary experiment
Internal Groups											
Powell-Birge (Kalmus)	EPB 25" BC	72	2/21/68	In progress	π^+p interactions	31	314	126	1341	1:1	P
Powell-Birge (Ely-Kalmus)	EPB 25" BC	73	6/8/68	In progress	K^-p and K^-d reactions	0	0	87	899	1:1	P
Trilling/Goldhaber (Kadyk)	EPB 25" BC	76	10/30/68	In progress	Λp Scattering	24	270	34	374	1:1	P
Powell-Birge (Gidal)	EPB 25" BC	87	11/26/68	In progress	π^+p Interactions	0	0	32	345	1:1	P
Segrè-Chamberlain (Chamberlain) U. Michigan (Longo)	EPB XI F3	91	7/20/68	2/24/69	Polarization in $np \rightarrow pn$ charge exchange scattering. 1-6GeV	52	531	108	1166	1:1	P
Moyer-Helmholz (Kenney) Group A (Pripstein)	Internal north area straight section	97	11/1/68	3/24/69	$\pi^-p \rightarrow \eta n$ differential cross sections	66	691	90	962	1:1	P
Nuclear Chemistry (Hyde-Poskanzer)	EPB XI F2	104	9/21/66	In progress	Production of light fragments from p-nucleon collisions	56	617	247	2823	1:1	P
Miller (Miller)	Internal west area straight section	P-32 (95)	5/31/68	In progress	$K^0\mu3$ Charge-asymmetry tests for future Exp. #95	6	76	15	210	1:1	S
LRL-Lofgren (Wenzel)	Internal west area straight section	P-33	10/11/68	In progress	Preliminary counter checks for future Exp. #82	9-1/4	103	10	126	1:1	S
Group A (Flatté)	Internal north area straight	P-37	11/27/68	12/14/68	Scintillation counter tests for future experiment at SLAC	0	0	1-1/4	11	1:1	S
External Groups											
U. Hawaii (Cence) LRL-Moyer-Helmholz (Perez-Mendez)	EPB XIF3	60	8/27/68	In progress	Ke_4 Decays	19	257	19	257	1:1	P
U.C. San Diego (Masek)	EPB XI F3	79	3/27/68	3/17/69	$K^0_2(c_3)$ charge asymmetry	87	904	256	2738	1:1	P
UCLA (Nefkens) LRL (Crowe)	Internal west area straight section	88	12/5/68	In progress	$\pi^-p \rightarrow n\gamma$ Differential cross sections	52	561	53	568	1:1	P
BNL (Palevsky)	EPB XIIF3	93	2/4/69	In progress	p-d Elastic and inelastic scattering	31	367	31	367	1:1	P
U. of Michigan (Jones)	Internal north area straight section	94	7/23/68	In progress	Neutron cross sections for p, d, and various metal targets	26	345	139	1594	1:1	P
U. of Arizona (Jenkins)	EPB X1F2	106	1/16/69	In progress	$K^\pm$-Nucleon cross sections	91	948	91	948	1:1	P
UCLA (Schlein) CIT (Gomez) NAL (Malamud)	EPB 25" BC	112	2/16/69	In progress	Study of $k\pi$ system	1	13	1	13	1:1	P
Space Science Laboratory (Smith)	Internal west area straight section	P-30	10/1/68	In progress	Counter tests for balloon experiment	6	69	12 1/2	143	1:1	S

Table II. Bevatron Motor Generator Set Monthly Fault Report.

1969	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 AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Faults AB	Faults AT	P/F	Pulses	Arc-backs (AB)	Arc-through (AT)	P/F	Ignitrons replaced
Jan.	3 979	-	1	3 979	-	-	-	-	3 307	-	-	-	-	-	-	-	241 713	7	15	10 987	5 144	3	5	643	254 786	10	21	8 219	1
Feb.	661	-	-	-	-	-	-	-	1 740	-	-	-	21 868	2	1	7 289	280 881	5	8	20 063	18 290	2	1	18 290	323 440	9	10	17 023	1
March	-	-	-	-	-	-	-	-	120 914	-	-	30 228	4 212	8	1	4 212	247 406	1	5	24 741	1 738	1	2	579	374 270	10	8	20 793	0
April																													
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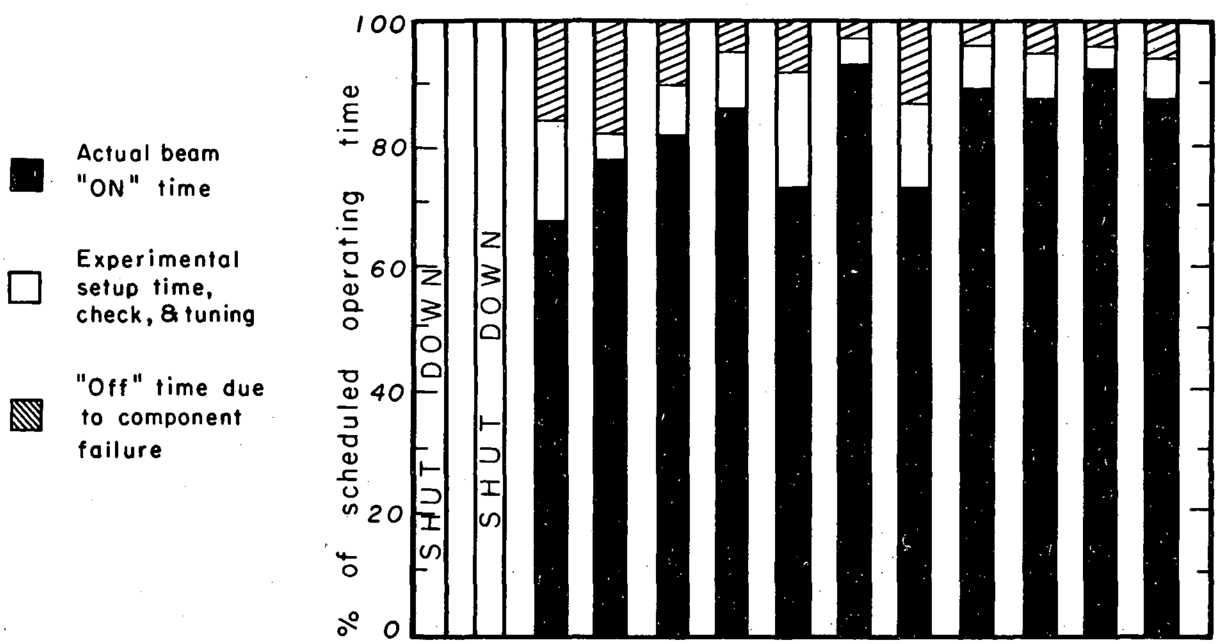

Week of		12/27	1/5	1/12	1/19	1/26	2/2	2/9	2/16	2/23	3/2	3/9	3/16	3/23
Crew hours		120	168	168	168	168	168	144	168	168	168	168	168	144
Turn on & maintenance time	(h)	0	30	0	13	10	10	20	10	10	10	10	10	14
Scheduled operating time	(h)	0	0	168	155	158	158	124	158	158	158	158	158	130
Scheduled Bevatron test time	(h)	0	0	1	.18	14	14	80	22	14	14	14	14	14
Scheduled shutdown time	(h)	120	138	0	0	0	0	0	0	0	0	0	0	0
Holiday	(h)	124	0	0	0	0	0	24	0	0	0	0	0	24

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Fig. 1. Bevatron operating schedule.

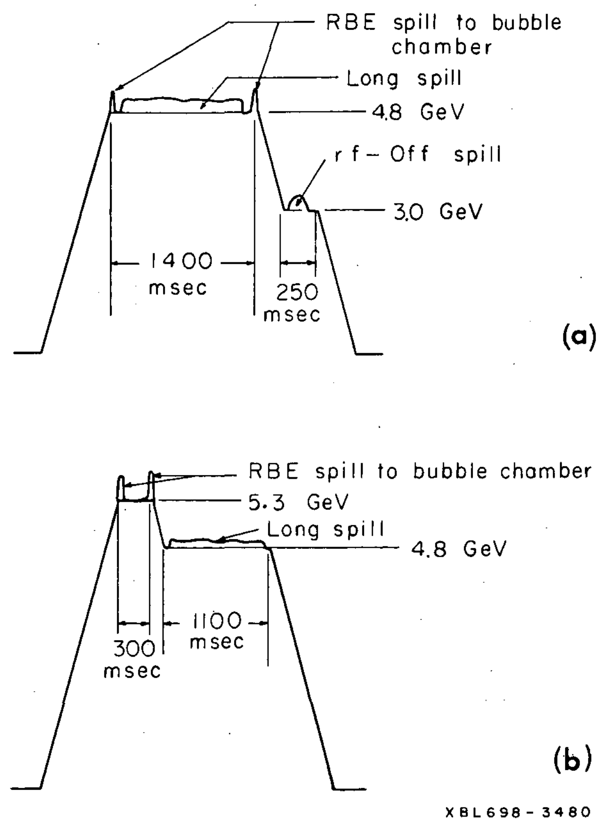

Fig. 2. New pulsing modes used this quarter. (RBE = rapid beam ejector.)

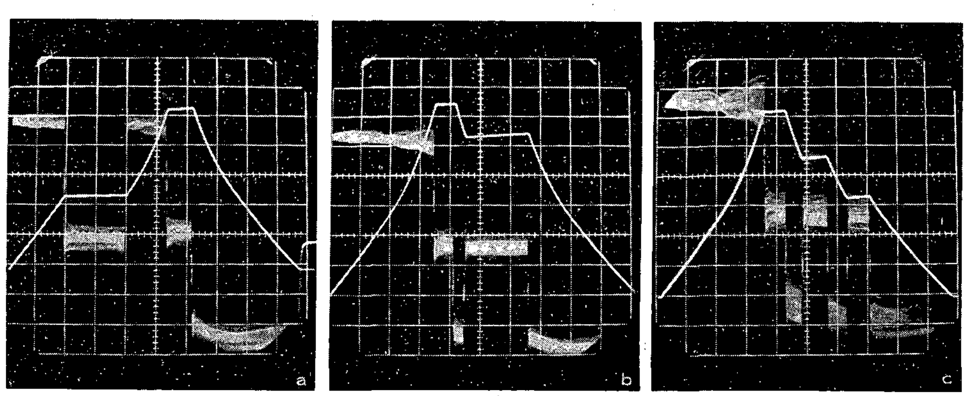

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Fig. 3. Magnet voltage and current waveforms for various types of operation: (a) mezzanine and flattop, (b) flattop and back porch, (c) flattop and double back porch.

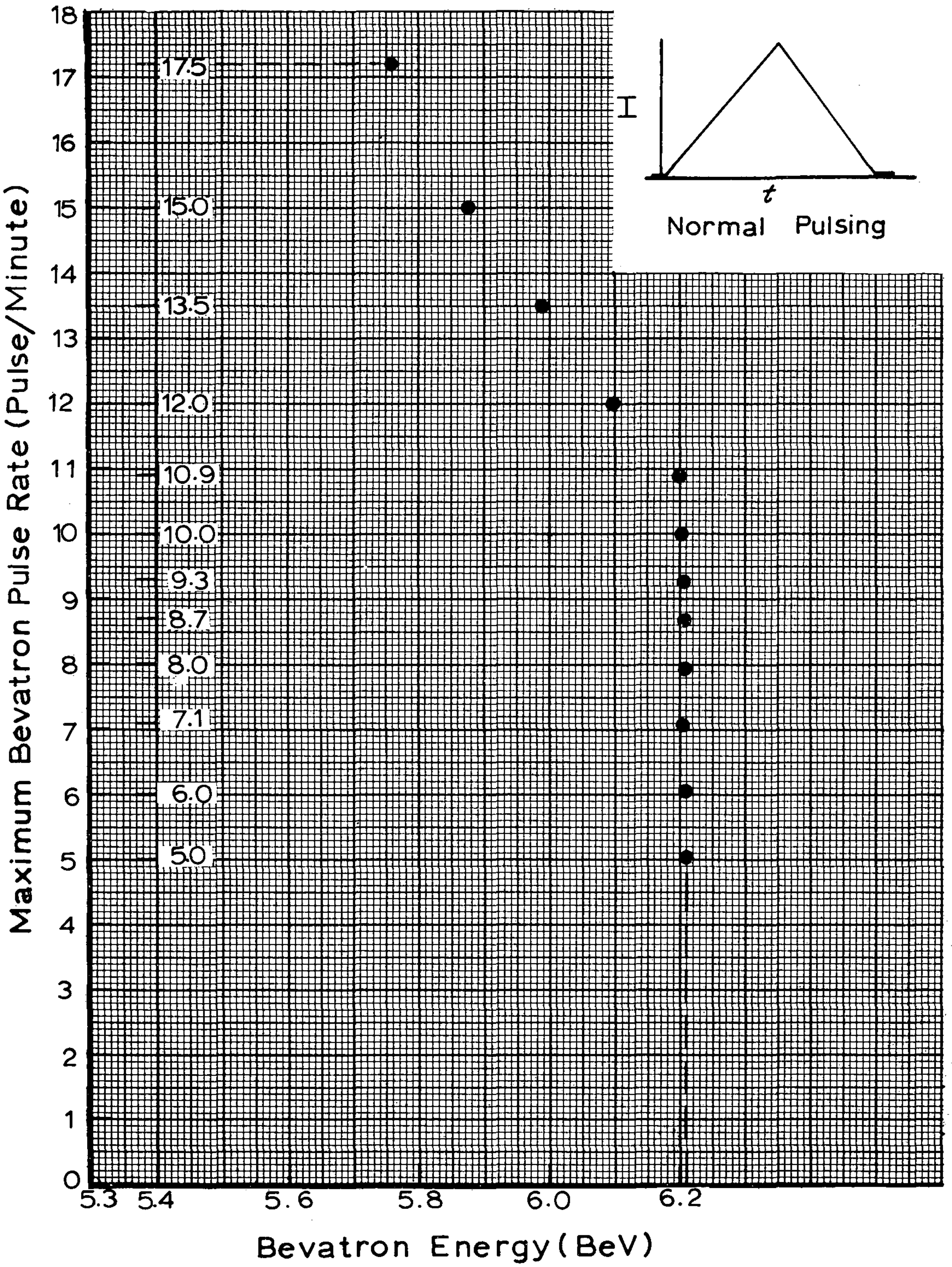

Fig. 4. Full-load normal pulsing at Tap #5 excitation.

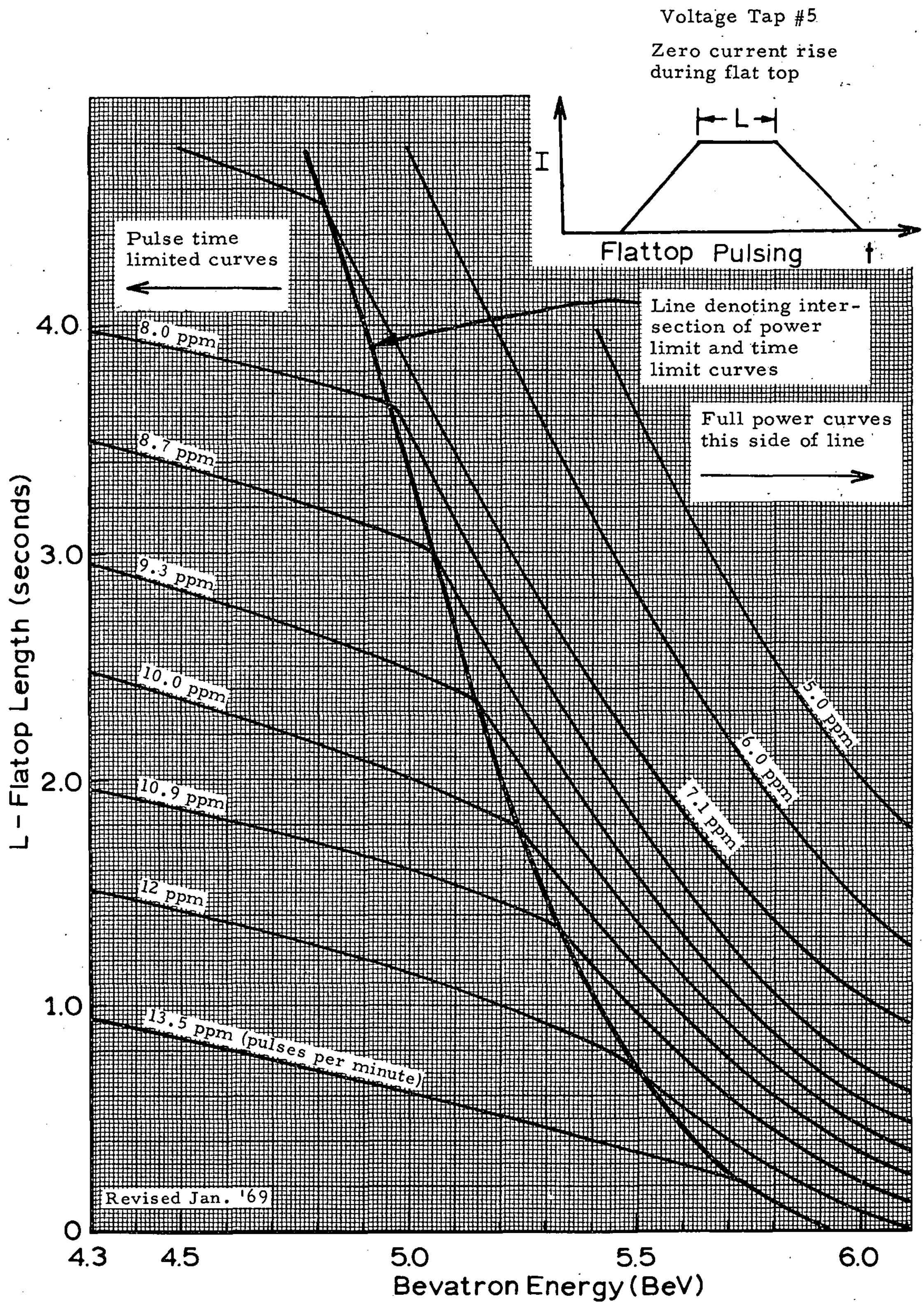

Fig. 5. Full-load flattop pulsing at Tap #5 excitation.

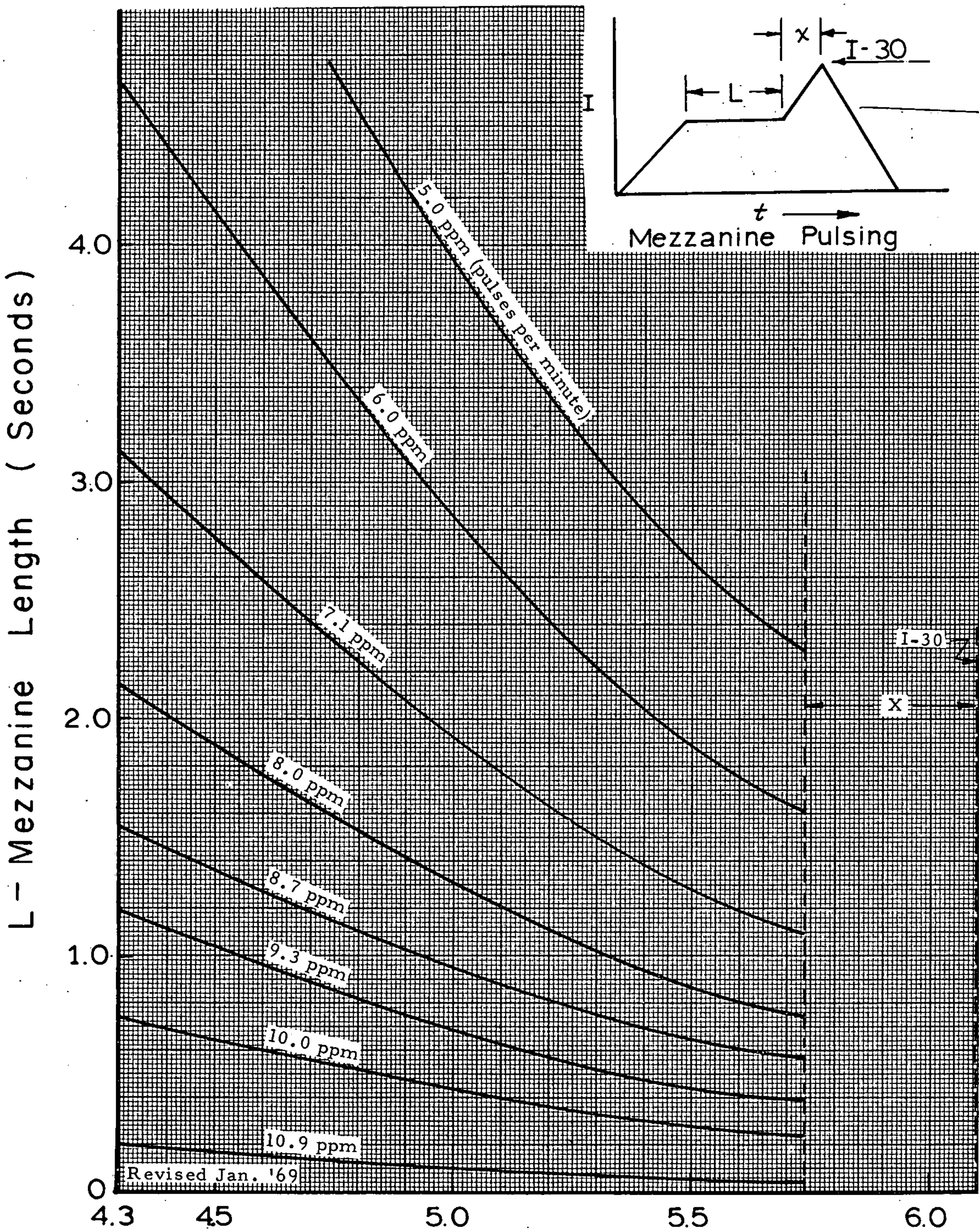

Fig. 6. Full-load mezzanine pulsing at Tap #5 excitation.

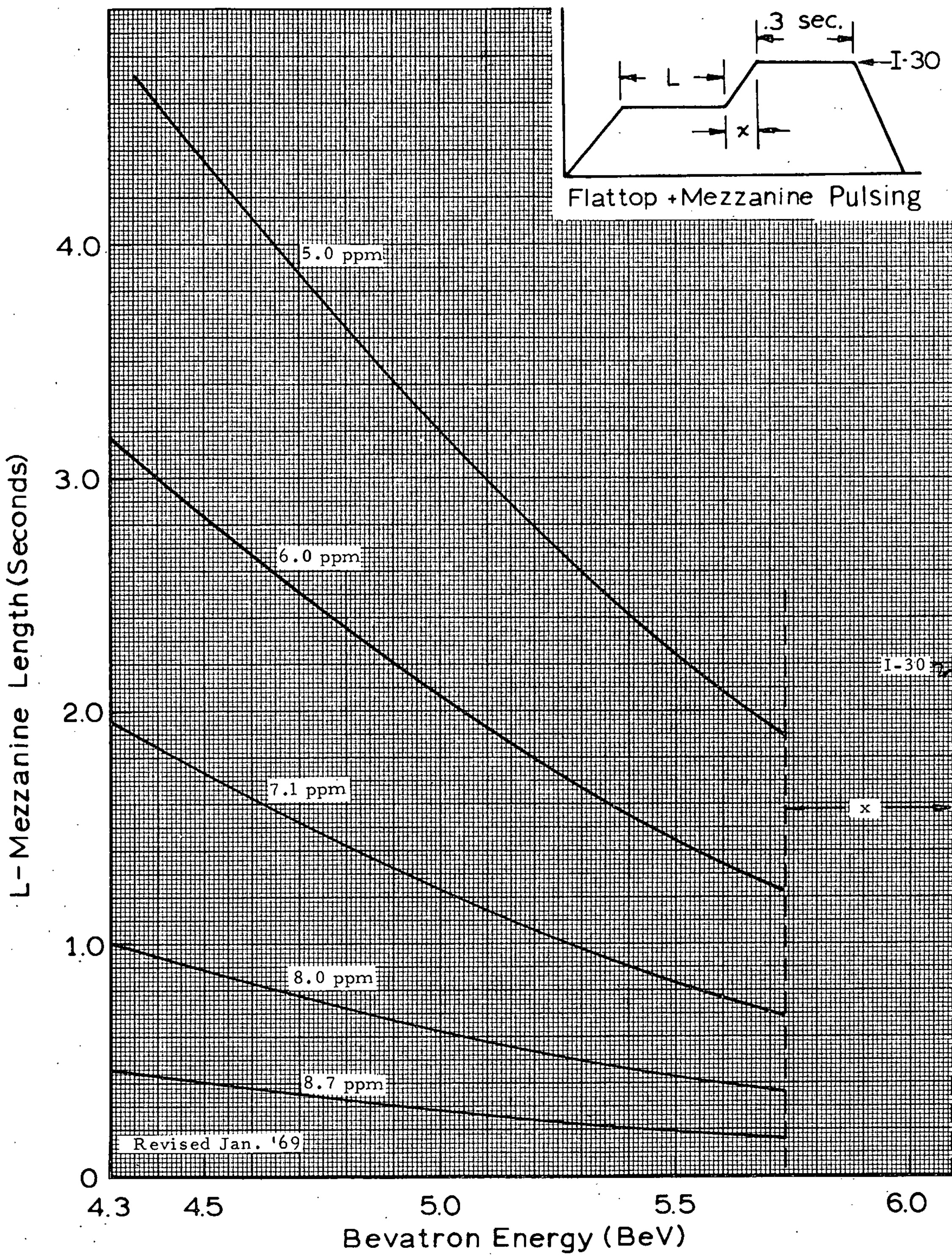

Fig. 7. Full-load flattop plus mezzanine pulsing at Tap #5 excitation.

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