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March 6, 1970

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BEVATRON OPERATION AND DEVELOPMENT. 64
October through December 1969

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March 6, 1970

ABSTRACT

The Bevatron provided beam to 18 experiments this quarter and during two months of operation accelerated 2.4×10^{18} protons. Eight experiments were completed. Resonant extraction studies are reported, and the plans to make the system operational are discussed. The new computer control system for the main motor generators is duscussed.

I. MACHINE OPERATION AND EXPERIMENTAL PROGRAM

The Bevatron operation record is shown in Fig. 1. The beam was on 88.1% of the scheduled operating time. The beam was off 5.5% of the scheduled operating time because of equipment failure and 6.4% of the time for experimental setup, tuning, and routine checks. The machine operated 2 months of this quarter and during this time accelerated 2.4×10^{18} protons.

During the period covered by this report we provided beam for 13 primary experiments and 5 secondary experiments, a total of 18 experiments. Eight experiments were completed this quarter. Five of the eight experiments were continuing experiments from the previous quarter and three of the experiments were started and completed this quarter. Three of the experiments--numbers 72, 87, and 122--were done in the 25-inch hydrogen bubble chamber. Experiment No. 119 was done by the UCLA (Nefkens)–LRL (Crowe) groups in the same setup as had been used for their experiment No. 88. Experiment No. 119 was a study of $\pi^- p \rightarrow \pi^0 n$.

Experiment No. 117, a collaborative effort of the UC Davis (Lander) and the University of Washington (Cook) groups, was done at the third focus of the external proton beam (EPB) in Channel I. The experiment was a study of p-nucleus scattering. The experiment was started and completed this quarter and used the beam channel and equipment set up for Experiment No. P-39, which was also completed this quarter. Experiment No. 107, done by the LRL Segrè-Chamberlain (Stiening) and University of Chicago (Hildebrand) groups, was completed this quarter. This experiment, a study of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, was done at the second focus of EPB Channel I.

The Bevatron operated 85 12-hour periods out of a scheduled 101 12-hour periods. During this time we integrated 282 12-hour periods of data taking and 188 periods of tuneup for primary experiments. An additional 30 12-hour periods were integrated by secondary experiments for a total of 500 12-hour periods for high energy physics.

The primary magnet pulsing mode this quarter employed a 1500-msec flattop at an energy of 4.9 GeV. The pulse rate was 10.9 pulses per minute. In general, the 25-inch bubble chamber took two beam spills per Bevatron pulse. The first beam spill came just after the start of flattop and the second beam spill came just before the end of flattop. The long beam spill for counter experiments came between two spills for the bubble chamber. The long spill was shared simultaneously by the two internal beam targets and the EPB channel targets. The two internal targets provided secondary beams to two primary experiments and one secondary experimental beam line. The EPB targets provided beam for up to five primary experiments in Channel I and one primary counter experiment in Channel II.

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

II. Shutdown

The Bevatron was shut down on November 27 at 0800 for the Thanksgiving holidays. The machine remained shut down through December and was expected to resume operation early in January. The shutdown was unusually long, and was related to budgetary cutbacks this fiscal year. The timing of the shutdown was chosen to coincide with the holiday season in order to minimize the number of interruptions to the experimental program. The major job that was scheduled for this shutdown was the installation of the new septum section of EPB Channel I. This modification in essence removes the second-focus target station from Channel I and relocates it in a new and completely independent backstop area. A wide choice of multiple secondary beams will emanate from this target station, in contrast to the single beam of limited characteristics that originated at the Channel I second-focus target. The septum beam split allows simultaneous beam sharing at the two Channel I backstop target areas without degradation of the beam by passing through an "upstream" target. Complete details of the new system will be covered in the next Bevatron Quarterly Report.

The extended shutdown period provided the time for a thorough inspection of the main motor generators as well as the routine quarterly maintenance. Routine maintenance was done on the Bevatron and associated equipment.

For a short period during the shutdown the Bevatron vacuum tank was open to air. Measurements were made to determine the approximate electrical impedance of the pole tips in the beam aperture. These measurements were taken to check the fit of the Bevatron to a calculation for the vertical instability of the proton beam due to the "resistive wall amplifier" effect.

During this shutdown the beam-induction electrode system was also examined. This system is used to measure the number of protons in the internal circulating beam. Slight modifications were made in the electronics to reduce vhf ringing. At the same time, the entire system was recalibrated. The recalibration showed that the recently quoted values for beam intensity should be multiplied by a factor of 1.18 to obtain the actual values.

III. BEVATRON DEVELOPMENT AND STUDIES

The bulk of the effort this quarter on Bevatron development was again devoted to resonant-extraction studies. A progress report is given below. Control of the main motor generators was put under computer control this quarter. The details of this are described in Section IV.

A. Vertical Beam Clipping

Vertical beam clipping by the M1 extraction magnet, as previously reported,[1] was studied in more detail. At high beam intensities (4×10^{12} particles per pulse) about 20% of the circulating beam is lost vertically when the M1 magnet is plunged into position for beam extraction. The M1 magnet has two coils placed above and below the circulating proton beam to perturb the beam for the resonant extraction process. These coils from a ±1.75-in. vertical aperture for the beam. Clipper measurements of the beam starting at injection showed a normal damping of vertical betatron oscillations for the first 250 msec. During the next 50 msec the beam grew vertically. The beam again followed a normal damping curve from about 300 msec after injection to the end of the acceleration (1700 msec). This beam growth was independent of intensity but seemed to be a function of radial beam position. Although it is possible to affect this phenomena by beam-tracking changes, it has not been possible to eliminate it. The beam is larger vertically at high intensities because the injected beam intensity is adjusted by vertical clippers.

New high-current pulsed pole-face-winding power supplies are under construction for the resonant extraction studies. These supplies will also be able to apply field corrections at the time of early beam growth. When they are available corrections will be made to reshape the guide field in an attempt to eliminate the vertical growth.

B. Resonant Extraction

With the principles of resonant extraction for the Bevatron understood, the work for the past few months has been directed towards improving the system. It is the intent of the program that the system will be in routine operation in the near future.

Recent extraction measurements have verified the calculated extraction efficiency. They have also illustrated a possible transport problem in the west tangent tank area. The beam width in the west tangent tank area is wider during resonant extraction that is for the energy-loss extraction system. Beam-clipping problems in this area were reported in detail in the preceding quarterly report.[1]

Resonant extraction has been accomplished for a number of different operating conditions. Beam has been successfully extracted at 5.74 GeV and for two radii at 4.81 GeV. A 250- to 500-μsec spill, for bubble chambers, has been shown to be no problem when the spiller coil S1 is used.

Because of a vertical growth of the beam[2] when the rf voltage is turned off, it may be necessary to spill the beam with the rf voltage on. To reduce beam structure to acceptable levels it will be necessary to eliminate noise from the low-level rf stages. This work is in progress.

IV. BEVATRON MOTOR GENERATOR

A. The Computer Control System, now on line in the Bevatron motor generator room, provides four basic features to simplify the control of magnet pulsing. These features are:

(a) A profile input routine that reduces set-up time.

(b) The ability to analyze a profile prior to pulsing.

(c) A method of direct entry of the new profile to the active profile.

(d) An analysis of power-supply response to the active profile.

To provide these features a computer program called "BMAG" is used in one of the four Bevatron PDP-8 digital processors. The system includes associated peripheral input-output equipment.

The program provides a total of 17 operational functions that may be requested by teletype key commands.

A brief description of the basic functions follows.

Profile Input

The pulse profile of the Bevatron magnet may include combinations of mezzanine, flattop, and back porch constant-current regions (see Fig. 2). In the past these periods have been defined as constant current regions starting at a particular time past a current level marker. The level was chosen by the operator by controlling a series of time delays after the current level was reached. In the more complex profiles as many as 11 variables were adjusted to provide the proper profile.

In the BMAG program, the PDP-8 is asked to sample, each millisecond, the magnet field as a function of the integral of $\dot{B}$. When a selected value is reached a control pulse is transmitted to the Bevatron power supply. This pulse switches the proper high-voltage cubicles into either rectification or inversion, depending upon the required pulse profile. Figure 2 also shows the cubicle switching used to provide mezzanine, flattop, and back-porch pulses. A simple pulse matrix of five pulses can define the most complex profile that is considered functional at the Bevatron.

The method of entering the pulse profile to the computer is indicated below. The operator, at the keyboard, types "F," which is the command to the computer. The computer prints out "profile," and the operator responds by typing a profile number. The computer then asks for the first field value. The operator types a response; the computer then asks for a time, and the operator types it in. This proceeds, the operator entering only numerical values, until all the profile information is in core.

Output	Typed in
F ← Keyboard command	
PROFILE= 5	
FIELD= 7	Fields in kG
TIME= 500	
FIELD= 12	
TIME= 300	Times (lengths of flat zones) in msec
FIELD= 10	
TIME= 200	
FIELD=	

Profile Analysis Prior to Pulsing

When a new pulse profile is requested some of the operational parameters that must be known are (a) motor power demand, (b) pulse length, (c) whether repetition rate is maximum, (d) whether the pulse length is too long for a full power repetition rate, (e) what magnet current represents the requested field. The analysis portion of the program calculates the answers to these questions prior to selection of the profile as an operational mode.

An analysis readout of a 1.56-sec 5163-A flattop is shown below. This mode was one of the Bevatron's operational modes during October.

Here the operator types "A" and the computer responds with a request for a profile number. When that number has been typed in, the computer proceeds to produce the following printout.

```
A
PROFILE=    4
RRMAX=      11.016  ← Maximum repetition rate
MW/MOTOR           2.720  ← Megawatts

     ZONE   FIELD(KG)   TIME(MS)    AMPS

      1.     12.560      1561.      5163.
      2.                 1560.
      3.       .000      1824.         .

PULSE LENGTH       4946.
```

Entering the Active Profile

When the computer operator has determined that the requested profile is valid and within the pulsing capabilities of the power supply, the profile may be selected for pulsing. As many as ten independent profiles may be stored in memory locations in the PDP-8. Entry and recording capability by paper tape are also provided.

The change-of-profile technique is represented below.

```
B ←――――――――― Operator entries
PROFILE=  4 ↙
RRMAX=   11.016
****TIME****   12.156
PROFILE        4.  IN USE
```

Active Profile Analysis

When the Bevatron is pulsing with the selected profile, the program offers the ability to analyze the power supply and magnet response to the computer-controlled excitation.

Of immediate interest to the power-supply operator is the actual field value obtained at the start of a flat zone. This value is actually defined by turnoff sequences initiated by the control pulse. The program is written to read and record "B" values 10 msec into the flat zones. Upon command the computer will correct for the difference between the profile entry value and the actual value, if this much accuracy is required.

In addition to B values, the changes in speed of the 124-ton rotating shafts of the two motor generators are monitored in this mode. This reading is made to insure that centrifugal forces due to speed changes are within present specifications.

No pulsing modes are allowed that demand speed ranges of more than 70 rpm per pulse.

The active profile analysis readout is shown here:

```
X
****TIME****   12.171
    ZONE   FIELD   ERROR    AMPS    DI/DZ    TIME   SPEED  DS/DP

      1.    .000    .000       .        .       .    886.      .
      8.  12.567    .007   5168.    5168.   1587.    855.   -30.
     12.  12.771    .211   5337.     169.   1530.    850.   -36.
SHALL I CORRECT ?:N
```

Operational Results

The computer-controlled pulser has been used exclusively since its installation on October 9. There have been only a few operational problems, and these were easily rectified within the body of the program.

Additional features that have been included in BMAG and are of importance to the operator include:

(a) An exclusive warm-up profile that is easily changed to higher or lower current levels.

(b) Automatic "crash-off" features that switch the power supply into full inversion if a field higher than the profile entry is sensed.

(c) Routines to convert current readings to equivalent kilogauss, and kilogauss required to current. This conversion provides ease of profile input if either current or kilogauss is requested.

(d) Routines to eliminate human error as to profile inputs.

(e) The ability to use a simulator to check out all responses to the computer control prior to pulsing the magnet.

After even this short a period of operation it is evident that the motor generator room has entered the era of computer control quickly and easily. The results substantiate the original concepts that, with the use of the PDP-8 digital processor, the Bevatron power supply could be made more versatile and reliable.

B. The magnet pulsing record is shown in Table II.

References

1. Kenneth C. Crebbin and Don M. Evans, Bevatron Operation and Development. 63, UCRL-19399, Nov. 21, 1969.

2. Kenneth C. Crebbin, Bevatron Operation and Development. 62, UCRL-19299, Aug. 27, 1969.

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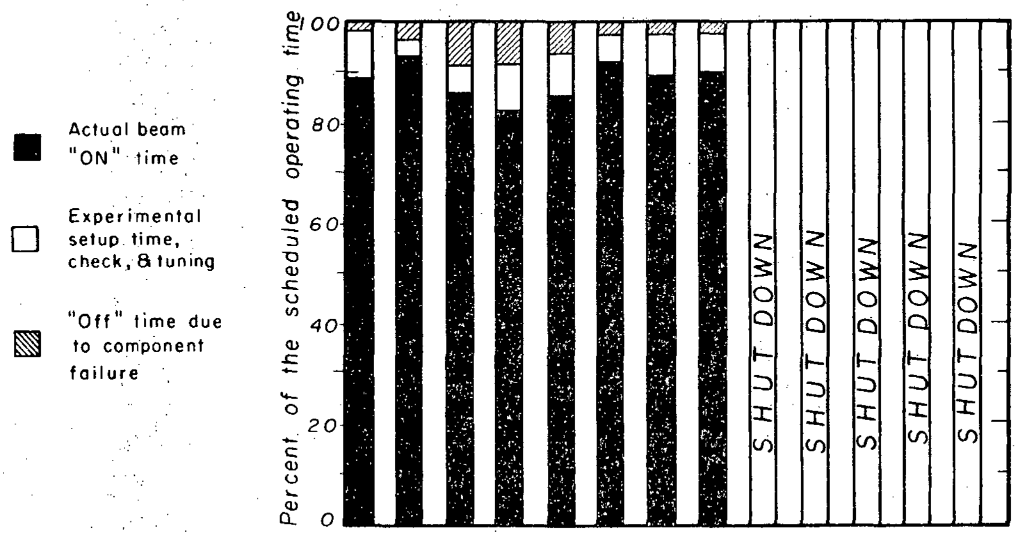
Table I. Summary of Bevatron Experimental Research Program October through December 1969.

Groups	Experiment location	Dates: Run	Dates: Start	Dates: End	Experiment	Beam Time: This quarter October-December: 12-Hour periods	Beam Time: This quarter October-December: Hours	Beam Time: Start of run through December 1969: 12-Hour periods	Beam Time: Start of run through December 1969: Hours	Pulse Schedule	Primary or secondary experiment
Internal Group											
Powell-Birge (Kalmus)	EPB 25-in. BC	72	2/21/68	11/26/69	π^+p interactions	22	220	173	1819	1:1	P
LRL-Lofgren (Wenzel)	EPB X1F3	82	5/21/69	In progress	$K_L^0 \to \mu^+e^-, e^+e^-, \mu^\mp e^\pm$, branching ratios	75	777	91	987	1:1	P
Moyer-Helmholz (Kenney) Group A (Pripstein)	Internal north area straight section	84	8/9/69	In progress	Study of $\pi^-p \to \pi^0\pi^0$	57	615	78	872	1:1	P
Powell-Birge (Gidal)	EPB 25-in. BC	87	11/26/68	11/14/69	π^+p interactions	17	184	69	726	1:1	P
LRL-Miller	EPB XIIF3	95	5/25/69	In progress	$K^0\mu3$ charge asymmetry	38	427	70	781	1:1	P
Nuclear Chem. Hyde-Poskanzer	EPB XIF2	104	9/21/66	In progress	Production of light fragments from p-nucleon collisions	18	164	284	3209	1:1	P
LRL-Segrè Chamberlain (Stiening) U. Chicago (Hildebrand)	EPB X1F2	107	6/14/69	11/26/69	Study of $K^+ \to \pi^+\nu\bar{\nu}$	95	993	185	1998	1:1	P
Trilling-Goldhaber (Kadyk)	EPB 25-in. BC	122	9/23/69	10/9/69	Study of d interactions	10	112	12	145	1:1	P
LRL-Miller	Internal west area straight section	P-32 (95)	5/31/68	In progress	$K^0\mu3$ charge asymmetry tests for Exp. #95	1	20	32	412	1:1	S
LRL-Lofgren	Internal west area straight section	P-33	10/11/68	In progress	Preliminary counter checks for Exp. #82	0	2	50	625	1:1	S
LRL-Alvarez (Derenzo)	Internal west area straight section	P-41	10/21/69	In progress	Tests for liquid Argon Wire spark chamber	1	8	1	8	1:1	S
External Groups											
U. Hawaii (Cence) LRL-Moyer-Helmholz (Perez-Mendez)	EPB XIF3	60	1/14/69	In progress	Ke_4 decays	36	291	199	2176	1:1	P
UCLA (Nefkens) LRL (Crowe)	Internal west area straight section	88	12/5/68	10/30/69	$\pi^-p \to n\gamma$ differential cross sections	21	262	260	2860	1:1	P
UCLA (Schlein) CIT (Gomez) NAL (Malamud)	EPB 25-in. BC	112	2/16/69	In progress	Study of $K\pi$ system	41	418	118	1226	1:1	P
U. C. Davis (Lander) U. of Wash. (Cook)	EPB X1F3	117	10/24/69	11/26/69	P nucleus scattering	49	519	49	519	1:1	P
UCLA (Nefkins) LRL (Crowe)	Internal west area straight section	119	10/31/69	11/17/69	Differential cross section for $\pi^-p \to \pi^0$	29	317	29	317	1:1	P
UCSD (Masek)	Internal west area straight section	P-38	8/13/69	11/26/69	Counter trigger study for a proposed experiment	0	0	19	234	1:1	S
U. of Wash. (Cook)	EPB X1F3	P-39	8/27/69	10/24/69	Testing equipment for Exp. #96	22	244	38	438	1:1	S

Table II. Bevatron Motor Generator Set Monthly Fault Report.

	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
1969																													
Jan.	3979	-	1	3979	-	-	-	-	3307	-	-	-	-	-	-	-	241713	7	15	10987	5144	3	5	643	254786	10	21	8219	1
Feb.	661	-	-	-	-	-	-	-	1740	-	-	-	21868	2	1	7289	280881	5	8	20063	18290	2	1	18290	323440	9	10	17023	1
March	-	-	-	-	-	-	-	-	120914	-	-	30228	4212	8	1	4212	247406	1	5	24741	1738	1	2	579	374270	10	8	20793	0
April	1022	-	-	-	-	-	-	-	1625	2	-	812	7288	1	-	7288	276881	7	4	25171	1220	2	1	407	288036	12	5	16943	0
May	316	-	-	316	-	-	-	-	9263	1	1	4632	7928	2	-	3964	344117	2	2	86029	7544	1	5	1257	369168	6	9	24611	1
June	-	-	1	-	-	-	-	-	5927	-	-	-	10989	-	1	10989	373406	7	5	31117	1793	-	2	897	392115	7	8	26141	0
July	-	-	-	-	-	-	-	-	16007	-	-	-	859	1	-	859	26576	-	6	4429	-	-	-	-	43442	6	1	6206	4
Aug.	1479	-	-	-	-	-	-	-	164051	10	5	10937	44654	2	1	14885	103805	1	1	51903	3576	-	-	-	317565	7	13	15878	1
Sept.	2559	-	-	-	-	-	-	-	109279	3	3	18213	18741	1	-	18741	212857	1	3	53214	100	-	-	-	343536	6	5	31231	0
Oct.									124002	3	2	24800	860				275575	5	4	30619					400437	6	8	28603	
Nov.									56848	1	1	28424	8778	1		8778	290193	2	3	58039					355819	4	4	44477	
Dec.													Shutdown																

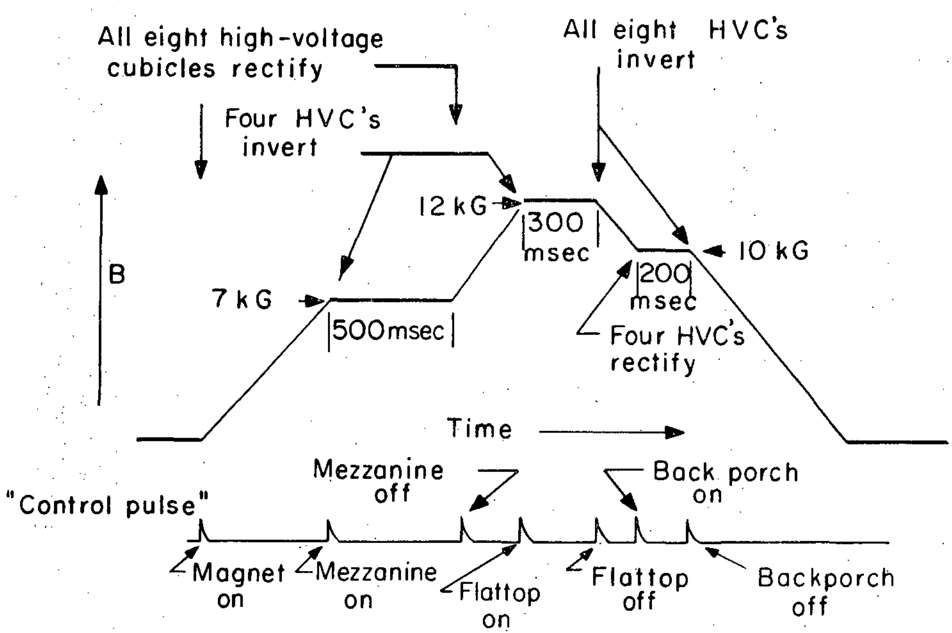


Week of		10/5	10/12	10/19	10/26	11/2	11/9	11/16	11/23	11/30	12/7	12/14	12/21	12/28
Crew hours		168	168	168	169	168	168	168	120	80	80	80	40	48*
Turn on & maintenance time	(h)	10	10	10	10	10	10	10	0	0	0	0	0	0
Scheduled operating time	(h)	158	158	158	159	158	158	158	104	0	0	0	0	0
Scheduled Bevatron test time	(h)	18	14	14	16	14	16	14	0	0	0	0	0	0
Scheduled shutdown time	(h)	0	0	0	0	0	0	0	16	80	80	80	48	0
Holiday		0	0	0	0	0	0	0	48	0	0	0	32	32

*recorded as vacation time

XBL705-2802

Fig. 1. Bevatron operating schedule.



XBL705-2803

Fig. 2. A Bevatron pulse profile.

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