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BEVATRON OPERATION AND DEVELOPMENT XXXIV - May and June 1962

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BEVATRON OPERATION AND DEVELOPMENT.

XXXIV

May and June 1962

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April 4, 1963

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Contents

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ABSTRACT

There were two continuing experiments that used the 72-inch hydrogen bubble chamber: K^- interactions in hydrogen at 1.2 to 1.95 BeV/c and $\pi^\pm$ differential scattering. The study of polarization of μ mesons from $K\mu^3$ and $K\pi^2$ decay by using spark chambers was completed. Three new experiments were started and finished: peripheral interactions and pion-pion cross section (4 BeV/c, π^- beam), muon scattering (2 BeV/c, π^- beam), and eta production (π^- beam).

Of the scheduled operating time, the beam was on for 87.4% of the time, 1.1% of the time was used for experimental setup, and equipment outage took 11.5% of the time.

The machine was shut down for two days to change the experimental setup.

On June 23, the Bevatron was turned off for the start of the seven-months-shutdown improvement program.

External beam was achieved with the new two-magnet extraction system. It was estimated that about one-half of the circulating beam was extracted.

Flat-top operation of the magnet current was achieved by delaying the changeover time between the two separate power-supply units. New equipment for magnet ripple reduction was successfully tried at the same time, which permitted this type of flat-top operation to be used. Immediately prior to the June shutdown, flat-top operation accounted for a large percentage of the total operation.

The new linear-accelerator injector was successfully operated and achieved 15 mA of protons at 19.2 MeV.

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I. OPERATION

The Bevatron operation record is presented in Fig. 1 and Tables I and II.

II. SHUTDOWNS

The machine was shutdown from 8 AM, May 15 to midnight, May 16 to change experimental setup. On June 23 the Bevatron was turned off for the start of the seven month shutdown. The major jobs will be the installation of a new higher energy injection system and the construction of new foundations for the complete shielding of the Bevatron.

III. IMPROVEMENT PROGRAM

A. External Beam

W. A. Wenzel

The beam is extracted from the Bevatron with a two-magnet extraction system.* The plunging mechanisms were not available, so the magnets were moved manually to their correct extraction position near the center radius of the Bevatron. The Bevatron was then retuned, for half-aperture operation. The maximum beam for these tests was between 10^8 and 10^9 protons per pulse.

The deflected beam emerges from the Bevatron in the west straight section through a 0.020-in. aluminum window at a radius 30 in. outside that of the circulating beam. The mean angle of emergence is about 3.5 deg.

The size of the beam and its divergence have been measured with the use of x-ray photographs of the beam profile at various distances from the exit window. Figure 3A, exposed at the exit window with a circulating beam intensity of 10^8 protons, shows the size of the emerging beam. Figures 3(B) and 3(E) were obtained with a circulating beam intensity of 10^9 protons, 3(E) was exposed at the window, and 3(C) was exposed directly behind a 6-in copper

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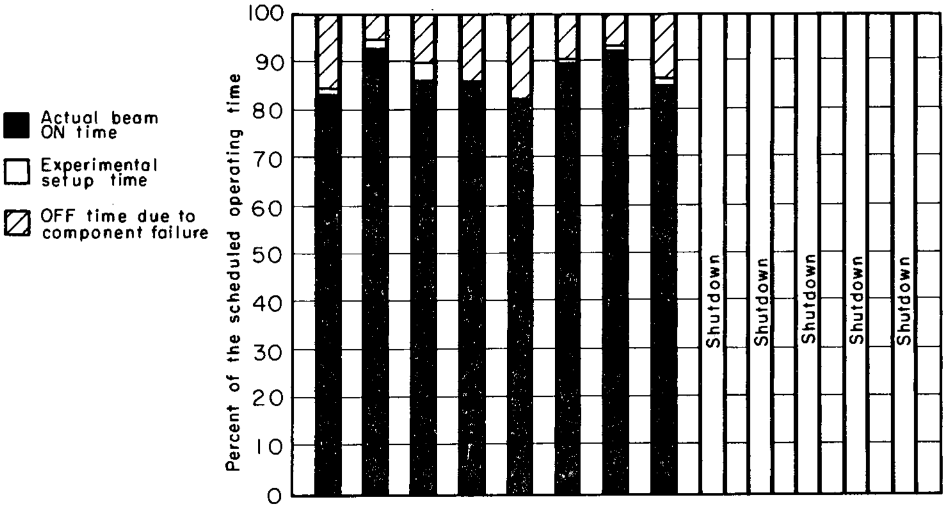
*W. A. Wenzel, Bevatron External Beam Program, Lawrence Radiation Laboratory Internal Report BEV-763, Aug. 31, 1962 (unpublished).



Week of	4/29	5/6	5/13	5/20	5/27	6/3	6/10	6/17	6/24	7/1	7/8	7/15	7/22
Crew hours	167	168	168	168	144	168	168	168					
Turn-on and maintenance time (h)	5	5	1	5	5	5	5	5					
Scheduled operating time (h)	157	158	118	163	134	146	139	127					
Scheduled Bevatron test time (h)	5	5	9	0	5	17	24	16					
Scheduled shutdown time (h)	0	0	40	0	0	0	0	20					
Holiday (h)	0	0	0	0	24	0	0	0					

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Fig. 1. Bevatron operating schedule, May and June 1962.

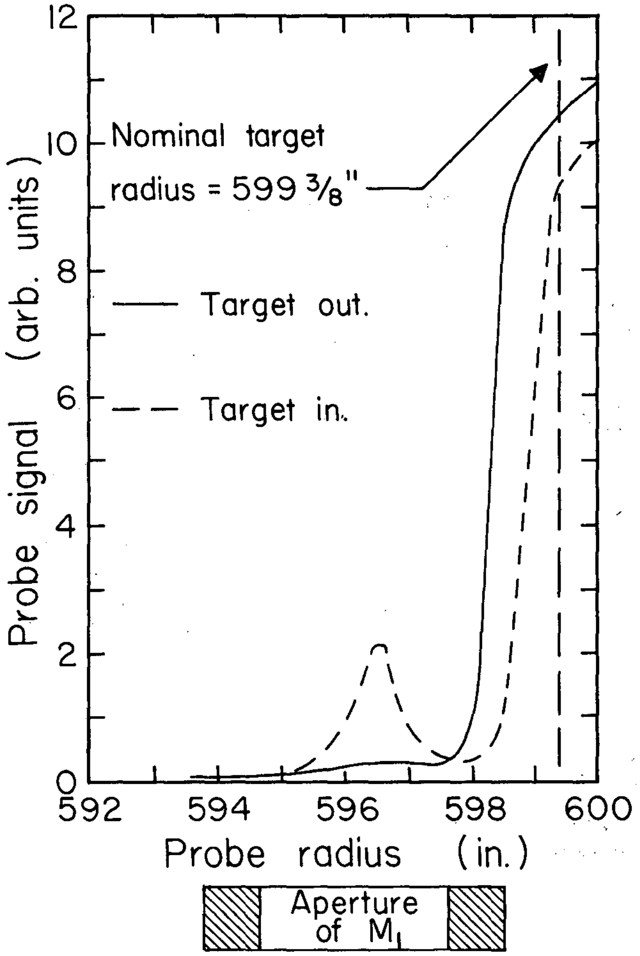

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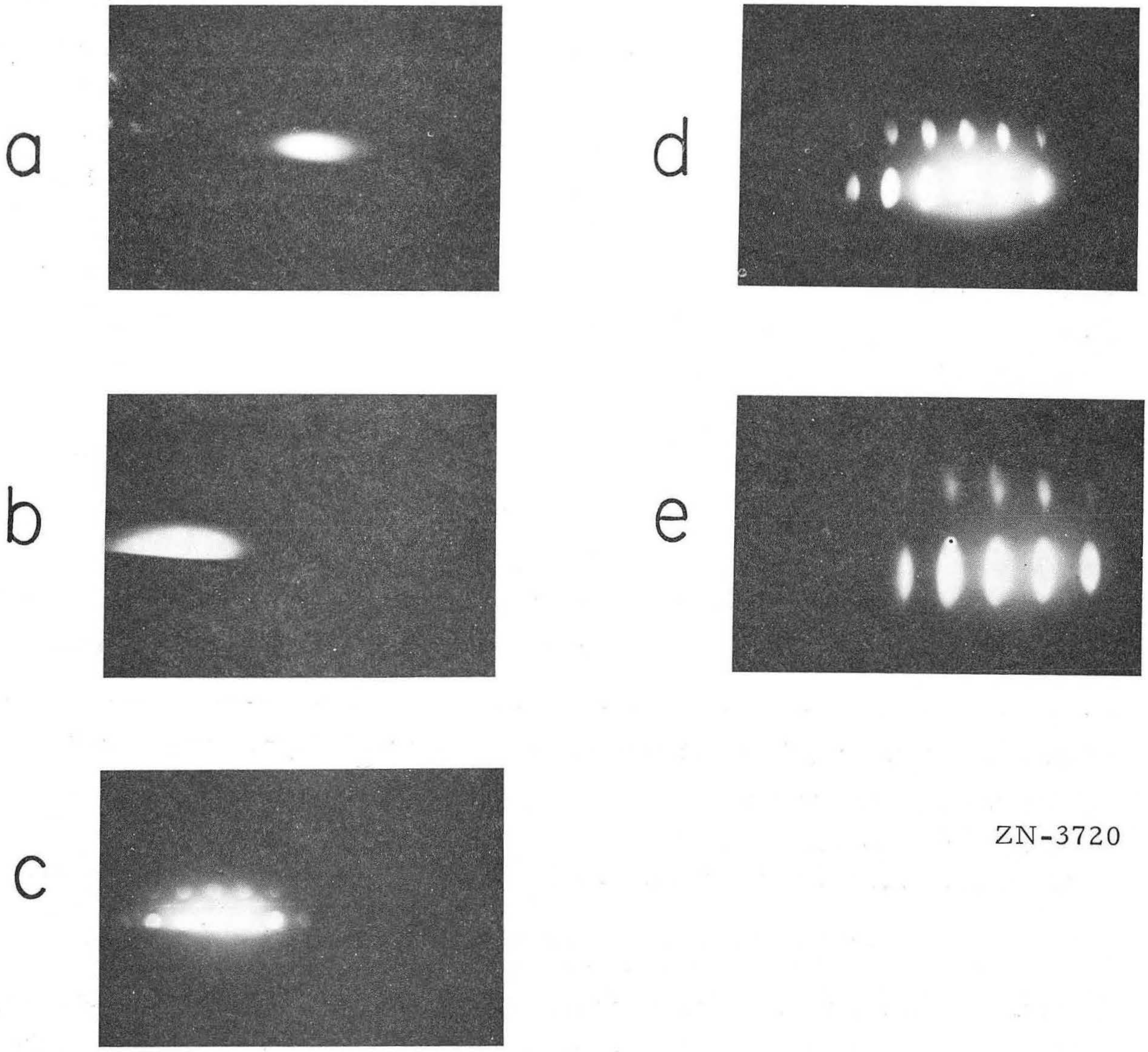
Fig. 2. Radial distribution of deflected beam at east tangent tank.



ZN-3720

Fig. 3. Photographs of external beam.

Table I. Beam record

Week of (1962)	Number of 8-hour shifts	Total integrated beam (10^{15}) protons)
Apr. 29 - May 5	19	7.9
May 6 - 12	21	12.0
May 13 - 19	16	9.8
May 20 - 26	21	12.7
May 27 - June 2	16	10.2
June 3 - 9	20	11.7
June 10 - 16	21	14.6
June 17 - 23	19	8.2
June 24 - 30	----------- Shutdown	----------
July 1 - 7	----------- Shutdown	----------
July 8 - 14	----------- Shutdown	----------
July 15 - 21	----------- Shutdown	----------
July 22 - 28	----------- Shutdown	----------

Maximum beam amplitude at full energy = 2.3×10^{11} protons per pulse
Maximum injected beam = 700 μA
Average beam per 8-hour shift = 5.7×10^{14} protons

Table II. Analysis of the total lost beam time due to component failure (%)

Month (1962)	Injector	Magnet power supply	rf accelerating system	Other
May	54	16	7	23
June	55	33	1	11

collimator with 1/4-in. holes. Figures 3(D) and 3(E) were placed 5 ft and 11 ft, respectively, from the collimator. In spite of the obvious misalignment of the collimator [Fig. 3(C)], it is possible to estimate the vertical and horizontal divergence of the beam from the patterns of Figs. 3, (C), (D), and (E). In this way it is found that a well-defined vertical source exists about 5 ft upstream from the exit window, and an apparent horizontal source about 30 ft away. From the spot size of Fig. 3(A), the vertical divergence is about 0.6 in./60 in. = 10 milliradian full width. The horizontal angular divergence is about 2 in./360 in. = 5.5 milliradian.

The intensity of the extracted beam was not measured directly; however, it can be estimated from Fig. 2. The scintillator probe intercepts the circulating beam when it is extended beyond radius 599-3/8 in. (nominal radius for the energy-loss target). Because the probe is 2 in. thick in the beam direction, single traversals will be made by the circulating protons for probe radii less than 601 in. Therefore the ratio, γ, of the intensity of the deflected to that of the circulating beam is given by

$$\gamma = \frac{1}{I_0 W} \int I(R)\, dR \approx 0.5,$$

where I_0 is the intensity of the probe signal obtained in the circulating beam (R = 600 in.), W is the radial width of the scintillator probe (3/8 in.), and I(R) is the intensity of the deflected beam (area between the dotted and solid curves of Fig. 3 near R = 593 in.). In this way it is estimated that about half the circulating beam was extracted.

B. Bevatron Magnet Flat-Top Operation

H. W. Vogel

1. History

The provision for maintaining a relative constant current at maximum field for a period of 100 msec or longer was first tried in 1956. At that time the means of maintaining a constant magnet current was by extending the change-over period of the magnet power-supply voltage of each machine simultaneously. The main difficulties with this system were: (a) the excessive ripple structure induced in the proton beam by the magnet voltage ripple; (b) the severe duty applied to the ignitron tubes, causing an excessive fault rate; (c) the mechanical shock excitation to the motor generator shaft that required evaluation.

In early 1962 a system of obtaining the flat-top (FT) period by delaying the change-over time between the two separate power-supply units was successfully tried. The magnet voltage ripple effect was suppressed by recently installed ripple-reduction equipment.

2. Operation

The two separate and independently controlled units of the magnet power supply received gated information from a magnet pulser; the gates determine the period of positive power-supply voltage.* The magnet voltage during the accelerating period is approximately 14 kV for I_{av}=4.75A/msec

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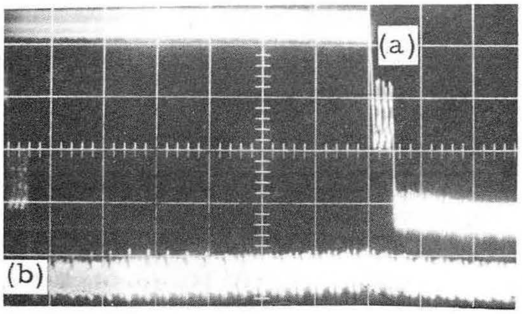
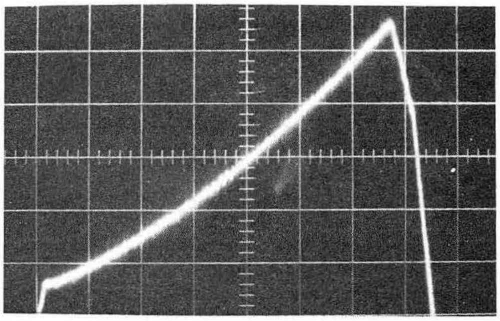
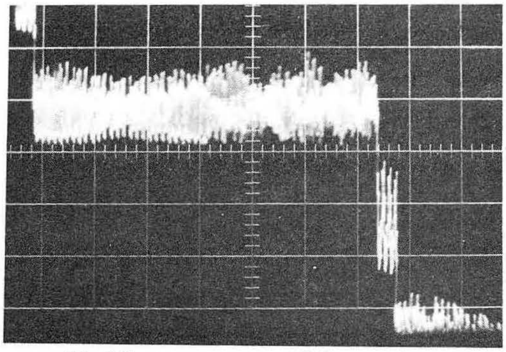
*Typical operating voltages and current are shown in Fig. 4.



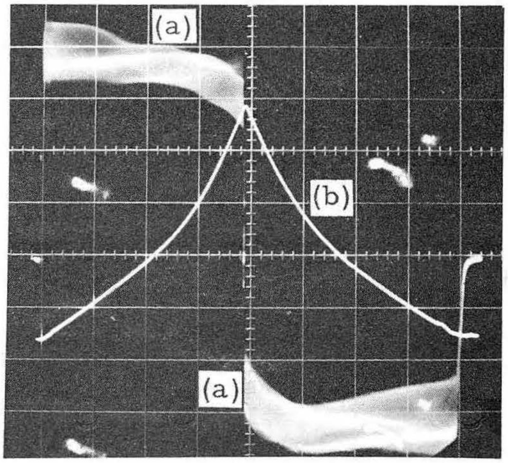
(a) A-machine FT voltage
(b) B-machine FT voltage
3500 V/division (V)
50 msec/division (H)
Trigger 1P30



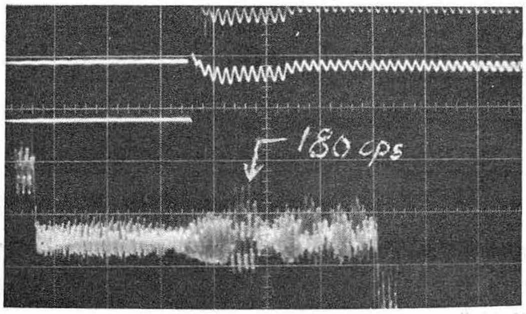
Magnet FT current
50 A/division (V)
50 msec/division (H)
Trigger 1P30



Half-magnet FT voltage
1000 V/division (V)
50 msec/division (H)
Trigger 1P30



Normal magnet pulse
(a) Half-magnet voltage
2000 V/division (V)
(b) Magnet current
8400-A crest value
500 msec/division (H)
Trigger - 40 msec



Half-magnet FT voltage,
without 180-cps filters
in relay overlap circuit
2000 V/division (V)
50 msec/division (H)
Trigger 1P30

ZN-3721

Fig. 4. Magnet current and voltage for flat-top operation.

at I = 8400 A. The specifications for the FT were: (a) 300 A rise above 8333 A in 350 msec; (b) B increases 150 G with $\dot{B}_{av}$ 450 G/sec ± 10%; (c) the start time for the FT period shall not have a jitter of more than 5 msec. The power supply voltage during the FT period is the sum of the IR system losses and the magnet inductance voltage; the total IR drop at 8400 A is 2100 V, and the inductance voltage for FT is about 2000 V. Thus the power-supply voltage is about 4000 V. The magnet voltage is controlled by a sum-and-difference regulator acting on the generator ac voltage. Because the total magnet voltage is the sum of two supplies, it is possible to obtain the same sum voltage but with a controllable difference to compensate for the asymmetry in the two power supplies. The power-supply voltage is also determined by the firing angle of the ignitron tubes. The negative voltage during inversion has a fixed (open loop) and a variable (closed loop) control value. The adjustment of the magnet current slope during FT is obtained by controlling (a) the inversion firing angle, (b) the generator ac voltage, (c) the rectification firing angle (not required at present).

The turn-on jitter is below the required 5 msec. The FT "on" signal is obtained by delaying from I pip 29.

The ground connection for normal operation is located at the center of the magnet quadrants I and II, Fig. 5. For the FT mode it is necessary to alternately switch the ground connection between the centers of the separate power supplies to minimize the voltage transients produced by the imbalance of the system voltage. The grounding information is coded to the corresponding machines by the magnet pulser. The grounding vacuum relays are switched with an overlap just at the end of FT, to the next alternate position. During the time the two grounding points on the power supply are connected, there is a large 180-cps ripple noticed in the magnet voltage. The magnitude is too high to be suppressed by the ripple-reduction equipment, thus a dual 180-cps filter is used to suppress the effect of this ripple, one filter always remaining in the ground return circuit.

The extended period of full-load operation during the pulse increases the duty cycle per pulse. It is necessary to reduce the repetition rate of the magnet pulsing to compensate for this effect. Normal operation at full field is 11 pulses per minute (ppm) and for FT operation, the repetition rate is reduced to 9 ppm.

The motor controls for the power-supply units require a different manual preprogramming of their timing controls than is needed for normal pulsing. Provisions have been made to insert another control point when and if it is necessary to limit the line current to the motor.

3. Present Status

The number of FT pulses accrued since November 1961 has been 170,650. Immediately prior to the June shutdown, FT operation accounted for a large percentage of the total operation.

The secondary controls for the motor accounted for the largest number of pulsing interruptions due to motor over-current trips. More precise programming is required.

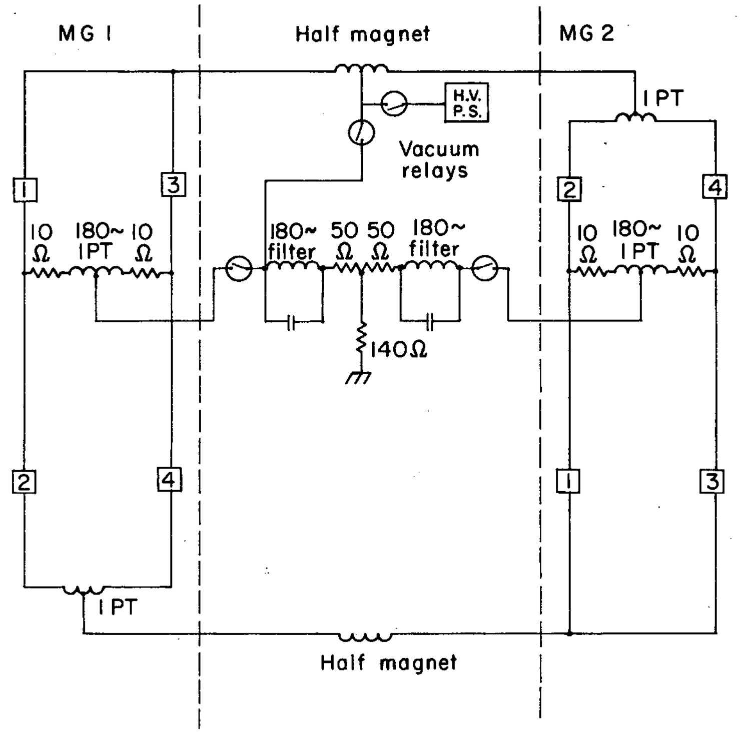


Fig. 5. Bevatron magnet flat-top grounding system.

The slope of the magnet current during FT period is not linear $\left(\frac{dI}{dt} \neq K\right)$, and is defined by $\frac{dI}{dt} + \frac{R}{L} I = V_{(t)}$. An evaluation is being made to determine the cause and provide corrective measures.

The failure of ignitron tubes in the power supply occurred at an alarming rate because of the severe electrical duty. It was necessary to minimize the use of advanced firing angles during inversion for voltage control and to utilize more ac generator-voltage control. Commutation reactors have been considered for the generator phase bus to ameliorate the tube failures.

C. Ripple-Reduction Equipment

H. D. Lancaster

1. General Description

The Bevatron ripple-reduction equipment is composed of four identical pieces of gear, one for each quadrant (see Fig. 6). It is necessary to reduce ripple in each quadrant separately, because the capacitive currents flowing at ripple frequencies create different ripple patterns in the quadrants.

Each unit has two main functions: (1) to keep the current in the driven windings zero when large low-frequency voltages are induced by the main-field change, and (2) to produce ripple-frequency currents in the driven windings that will cancel the ripple in the main field as seen by the $\dot{B}$ loop. The driven windings are pole-face windings located at the outer edge of the pole faces. The windings on the upper and lower pole faces are connected in parallel, giving an effective one-turn loop.

The first of these two functions is performed by a current regulator. A 5 mV/A shunt in series with the driven windings detects any current change and feeds this information back to the input of the amplifier that drives the windings. This amplifier has a dc gain of approximately 20,000. For the normal induced voltage of 32 V in the driven windings, the current then will be 320 mA. This is small enough so that it does not affect the beam appreciably. The current regulator has a voltage feedback loop which is used to stabilize the current loop and to remove voltage ripple introduced into the driven windings by the actuator power supplies. The voltage feedback loop has a high-frequency bandwidth of approximately 10 kc.

The second function is accomplished by taking the $\dot{B}$ loop signal, amplifying it, and sending it into the input of the current regulator. This signal tells the current regulator what current waveform to put into the driven windings so as to cancel the ripple signal on the $\dot{B}$ loop. This control loop has a gain of 100 at the ripple frequencies of 180 and 720 cps. The gain falls off on both ends of the frequency spectrum; it has a value of one at approximately 40 cps and approximately 20 kc.

2. Status

All of the ripple-reduction equipment was installed and working prior to the June shutdown. The requirement that $\dot{B} > 0$ was verified by looking at beam spill during the flat-top period. The only problem was a 600-cps ripple

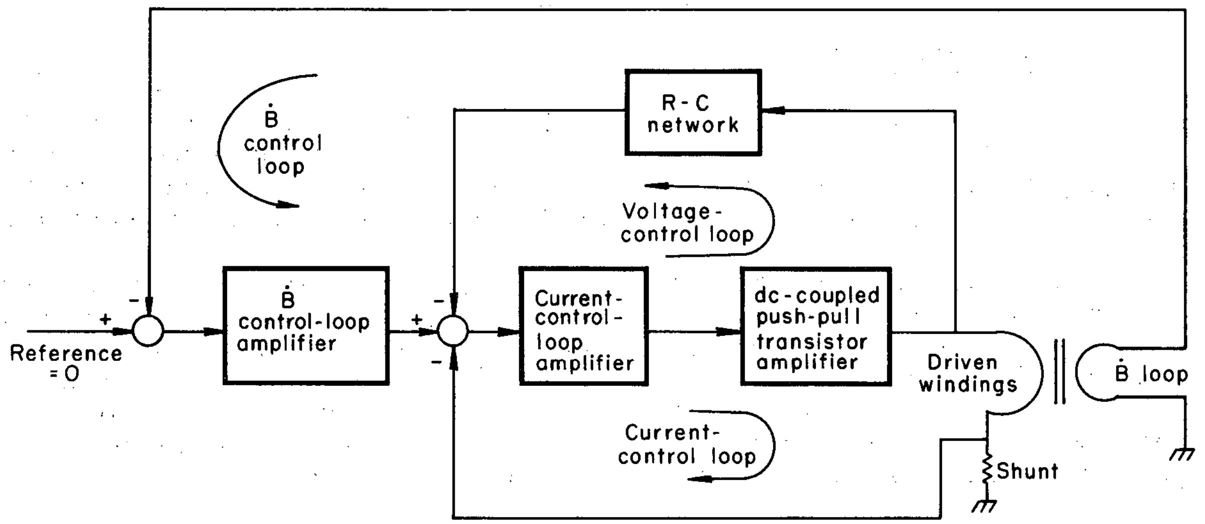


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Fig. 6. Schematic block diagram of the ripple-reduction system of one quadrant.

component found in the field during FT. This ripple seemed to be related to the grounding of the motor generator sets and of the ripple-reduction equipment. Since the equipment will be located in a new area when permanently installed, we decided to wait and see how severe the problem is after final installation.

Final installation is scheduled to be finished by December 15, 1962. A new control and interlock chain is being installed, which will facilitate maintenance and main-control-room operation. Debugging time required after installation is estimated at 4 to 6 weeks.

D. Linac Injector Mark II

R. M. Johnson

During this period the assembly of linac II was completed in building 64. We began the operation of all components together and the first proton beam was accelerated successfully to full energy, 19.2 MeV.

Early in May we started preexciting the tank with rf. Some time was required to excite the tank high enough to run the oscillators. However, this operation went quite well considering the outgassing of the tank surfaces that occurred. As the vacuum pressure went lower the rf oscillators worked progressively better.

By May 25 we had a concrete-blockhouse radiation shield built at the exit of the linac, and eight oscillators were running well on the tank. We then injected the first 10 mA of protons into the linac and accelerated 1 mA into the blockhouse. The beam was at first only 100-μsec long with a 1 msec rf envelope and injected beam. The short beam was due to gas loading which cleared up after a few days of running. Some sparking was seen at the early drift tubes but no appreciable damage was found.

The energy was measured to be the design value of 19.2 MeV, to 1/2%, but using a temporary spectrometer magnet.

The tank rf accelerating-field flatness was adjusted with the tuning loops.

In June we continued to run the linac beam into the blockhouse and measured its properties. We also increased the output to 15 mA with 75-mA input. After installing the buncher cavity we were able to accelerate 15 mA with 50-mA input. Quite a bit of time was spent trouble-shooting noise pick-up on our current transformer beam monitors. This trouble was cleared up to a large extent by using double-shielded signal cables and amplifiers.

IV. RESEARCH

The experimental program for this quarter is shown in Table III.

V. MAGNET POWER SUPPLY

The record of magnet pulsing appears in Table IV.

Table III. Summary of Bevatron experimental research program, January through June 1962

Group	Start of experiment	End of experiment	Experiment	Beam time (start of run through June 1962) 12-hour periods	hours	Pulse schedule	Primary or secondary experiment
Internal groups							
Alvarez	8-29-61	6-6-62	K^- interactions in hydrogen, by using the 72-inch hydrogen bubble chamber (1.2 to 1.95 BeV/c).	143 75	1569 838	1:1 1:1	P S
Alvarez	9-1-61	In progress	$\pi^\pm$ differential scattering, by using the 72-inch bubble chamber.	(Included in above totals)			
Lofgren	1-7-62	(pri.)2-12-62 (sec.)3-14-62	K^--p scattering experiment, by using spark chambers (0.33 to 1.4 BeV/c).	36 59 7	408 604 65	1:1 1:1 1:2	P S S
Chamberlain, Lofgren, U. C. L. A.	2-17-62	4-15-62	β decay of Σ hyperons, by using a hydrogen Cerenkov counter (660-MeV/c K^-).	16 8 7	178 91 55	1:1 1:1 1:2	P S S
Lofgren	6-4-62	6-23-62	Peripheral interactions and pion-pion cross section (4-BeV/c π^-).	27 25	309 241	1:1 1:1	P S

Table III. (cont.)

Group	Start of experiment	End of experiment	Experiment	Beam time (start of run through June 1962) 12-hour periods	hours	Pulse schedule	Primary or secondary experiment
External Groups							
Institution and experimenter							
U. of Wash. Masek	2-13-62	2-22-62	Test of spark-chamber performance in a 200- to 300-kg pulsed magnetic field, by using stray beam from Alvarez experiment target.	4	43	1:1	S
Cal. Tech. Tollestrup	4-7-62	5-15-62	Study of polarization of μ mesons from $K\mu^3$ and $K\mu^2$ decay, by using spark chambers. (500-to 600-MeV/c K^+).	27	294	1:1	P
				14	174	1:1	S
U. of Wash. Masek	4-25-62	5-15-62	Test of counters for a future experiment.	5	68	1:1	S
Space Sci. Dt. Philco Corp. Rinehart	5-19-62	5-24-62	Calibration of a counter telescope behind the Lofgren Group experiment.	-	---	1:1	P
U. of Wash. Masek	5-23-62	6-23-62	Muon scattering (2-BeV/c π^-).	41	442	1:1	P
				17	192	1:1	S
Cal. Tech. Tollestrup	6-2-62	6-13-62	Eta production, π^- beam.	12	134	1:1	S

Table IV. Bevatron motor-generator set monthly fault report.

	4 to 6 pulses per minute				7 to 9 pulses per minute				10 to 17 pulses per minute				Totals					
	1500 to 6900 A		7000 to 9000 A		1500 to 6900 A		7000 to 9000 A		1500 to 6900 A		7000 to 9000 A			Faults				
MONTH	Pulses	Faults	Pulses	Faults	Pulses	Faults	Pulses	Faults	Pulses	Faults	Pulses	Faults	Pulses (P)	Arc-backs	Arc-throughs	Total (F)	P/F	Ignitrons replaced
(1961)																		
Jan.	2001	--	1200	--	5099	--	--	--	6671	--	277091	59	292062	24	35	59	4951	--
Feb.	--	--	--	--	--	--	--	--	4431	--	345853	45	350284	9	36	45	7784	--
Mar.	--	--	--	--	--	--	--	--	3941	--	396827	51	400768	10	41	51	7857	--
April	--	--	--	--	--	--	--	--	4364	--	398449	55	402813	20	35	55	7323	--
May	--	--	--	--	--	--	--	--	2752	--	416350	61	419102	16	45	61	6870	--
June	--	--	--	--	--	--	--	--	9781	--	343112	38	352893	7	31	38	9287	--
July	--	--	--	--	--	--	--	--	3891	--	373182	41	377073	11	30	41	9197	--
Aug.	--	--	--	--	--	--	--	--	10235	--	322324	53	332559	15	38	53	6275	--
Sept.	--	--	--	--	--	--	--	--	5010	--	351237	44	356247	7	37	44	8097	--
Oct.	--	--	--	--	--	--	--	--	1308	--	110165	11	11473	11	--	11	1044	--
Nov.	1080	--	--	--	6684	--	--	--	11633	--	235942	45	255339	10	35	45	5675	{ Flywheel shutdown
Dec.	--	--	--	--	838	3	2905	2	2477	--	317347	48	323567	16	37	53	6105	
(1962)																		
Jan.	--	--	--	--	--	--	--	--	4911	--	383584	50	388495	23	27	50	7769	--
Feb.	4254	--	--	--	4452	--	40560	15	5194	1	240330	55	294790	30	41	71	4151	--
Mar.	--	--	--	--	--	--	77234	18	--	--	133160	10	210394	25	3	28	7514	{ Shutdown 15-31
April	856	--	--	--	--	--	27304	4	--	--	279795	85	307955	17	72	89	3460	{ Shutdown 1-4
May	--	--	--	--	--	--	--	--	1885	3	399670	47	401555	13	37	50	8031	--
June	--	--	--	--	--	--	7387	2	--	--	307969	28	315356	12	18	30	10511	{ Shutdown 24-31

ACKNOWLEDGMENTS

Edward J. Lofgren is the Bevatron Group Leader; William A. Wenzel is the Alternate Group Leader. Walter D. Hartsough, with Glen R. Lambertson and Wendell Olson assisting, is in charge of Bevatron Operation. Members of the Operating Crew are: Robert W. Allison, G. Stanley Boyle, Robert W. Brokloff, Ashton H. Brown, Duward Cagle, Norris D. Cash, Frank W. Correll, Ferdinand Dagenais, John R. Ellisen, Robert Gisser, William Kendall, William Lee, Wayne Logan, David Loucks, Kenneth Morgan, Martin E. Scolnick. The following members of the Operating Group are carrying out support and development projects: Robert Anderson, Trancuilo Canton, Warren Chupp, Bruce Cork, Kenneth Crebbin, Walter Hartsough, Rudin Johnson, Leroy Kerth, Glen Lambertson, Fred Lothrop, Ross Nemetz, Douglas Pounds, Robert Pratt, Robert Richter, Joseph Smith, William Wenzel, Glenn White, Emery Zajec, and Theodore Zipf. Engineering Groups were headed by Edward Hartwig, Electrical Engineering; Clarence Harris, Electrical Coordination; Harold Vogel and Gordon Harding, the Motor Generator Group; and William Salsig, Mechanical Engineering. Donald Milberger was in charge of the Electrical Maintenance Group.

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