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BEVATRON OPERATION AND DEVELOPMENT. VII

August, September, October 1955

Walter Hartsough

December 16, 1955

Printed for the U. S. Atomic Energy Commission

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Contents

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ABSTRACT

The major physics research effort this quarter was directed toward the detection of the antiproton. Negative particles of proton mass were first counted on September 22, 1955. On October 19, 1955 the discovery and identification of the antiproton was announced. Total cross-section measurements for π^+ and π^- mesons continued. A study was made of neutron interactions and of the γ-ray decay products of mesons. Proton-proton scattering was done at 2 Bev and 4 Bev using counters, and at 5.5 Bev using a 35-atmos diffusion cloud chamber. Emulsion exposures to protons were made for three groups outside the laboratory.

The bevatron facilities were improved this quarter by the addition of a heavy-duty inner-radius platform at the experimental area. New thin windows, an improved plunging beam clipper, a new 4-in. quadrupole-magnet set, and a new 12-by-60-in. analyzing magnet were added to the experimental facilities.

Improvements were made in magnet-current stabilization and in reliability of the radiofrequency-accelerating systems.

The beam was successfully tracked during a step in peak magnet current, and for a short time into inversion.

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INJECTOR

During this quarter, most of the effort on the injector was concentrated on improving the beam-transmission efficiency of the present system by minimizing the effect of a magnetic perturbation at the ion source. This field is the result of magnetization of the ion-gun steel enclosure by the bevatron stray magnetic field.

Many attempts have been made in recent months to compensate for the effects of this magnetic field, which deflected the beam from the axial direction. The location of the ion gun was repeatedly adjusted, together with the double focus-bending magnet, to direct the beam along the axis of the linear accelerator. Small permanent magnets were placed near the ion source in an attempt to steer the beam. These efforts proved to effect only temporary cures, as the disturbing field varied according to the recent magnet-pulsing history of the bevatron.

The following program was initiated as a permanent solution to the problem. The ion-gun column was shortened by the removal of two insulators. This increased the energy gain per ft of the beam from 120 kv per ft to 140 kv per ft. The beam at the exit of the ion source was magnetically shielded (Fig. 1), and a careful alignment was made of the complete injection system. The result of the modifications and alignment was a 50% increase in transmission efficiency. The operation of the injector is summerized in Table I.

The injection system was further modified by enlarging the aperture of the components between the ion gun and the linear-accelerator bunching cavity. This will allow a greater range of ion-source focus adjustment.

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*Preceding report: UCRL-3212.

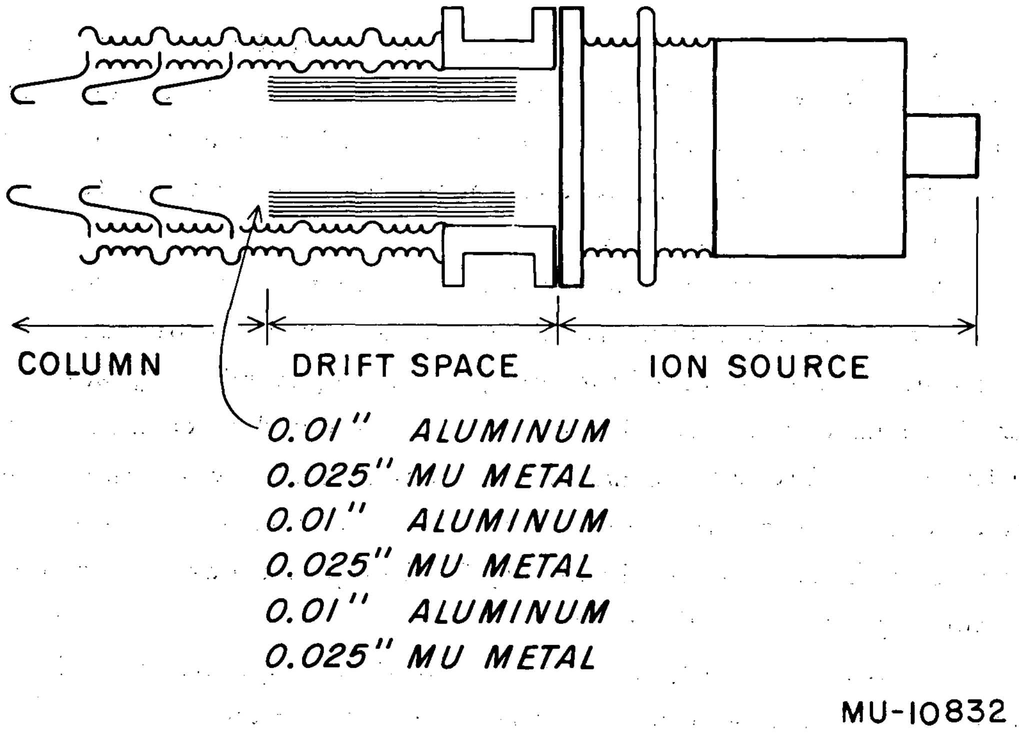


Fig. 1. Ion source - magnetically shielded drift space.

The problems of voltage division along the ion-gun column was again investigated because of the increase in column voltage gradient. The existing transflex sheathed pyrolytic film resistors, however, proved satisfactory in operation.

The ion-source arc-pulse supply again was the cause of trouble during this period. The new relay-type pulser[1] has not been entirely satisfactory. It was necessary to increase the voltage of the supply to insure reliable arc-firing conditions. Because of this increased voltage requirement, the 275C relays were operated at twice their rating; contact life was therefore reduced.

The original cathode-follower arc supply was improved by increasing the 304 TL grid bias and by providing a pulse-length clipper in the grid circuit. Secondary grid emission, one result of limited tube shelf life, may also have been the source of much trouble. Up to this time, the 304TL tubes have been war-surplus stock. The improved arc pulser has supplied on test a 1.2-msec pulse at 400 v, 4 amp. A new pulse-line type arc pulser is in the process of construction. It consists of a 20-ohm line, 1.4 msec long, and is designed to deliver 1500 either to a step-up transformer or directly to the arc.

Replacement of temporary wiring in the high-voltage shell continued.

[1] Harry G. Heard, Bevatron Operation and Development. VI, University of California Radiation Laboratory Report No. UCRL-3212. November 18, 1955.

Table I

Injector Performance

Week of	Ion gun total beam (ma)	Proton beam at exit of Bevatron inflector (μa)	Transmission efficiency %
8-1-55	10	200	2.0
8-8-55	11	220	2.0
8-15-55	12	220	1.8
8-22-55	10	195	1.9
8-29-55	10	200	2.0
9-5-55	10	Shutdown	- -
9-12-55	8.5	105	1.2
9-19-55	8.6	130	1.5
9-26-55	6.8	138	2.0
10-3-55	6.0	121	2.0
10-10-55	6.0	92	1.5
10-17-55	3.1	128	4.1
10-24-55	8.0	250	3.1

EXPERIMENTAL FACILITIES

Arrangement of Experimental Area

Figure 2 shows the arrangement of the experimental area during the latter part of this quarter. The major change was the assembly of the antiproton time-of-flight measurement equipment by the placement of an additional 4 in. quadrupole set and a 12-by-60-in. analyzing magnet along the calculated trajectory. The channels in the shielding wall directly opposite the west straight section were used variously to bring out meson beams, negative-particle beams, and γ-ray beams.

One additional flip-coil-type target was installed at 5°. Figure 2 gives a description and the location of all the experimental-area targets.

New Inside Radius Heavy-Duty Platform

A new heavy-duty platform was installed at the west inside-radius experimental area. It is capable of supporting loads up to 1000 lb per ft^2.

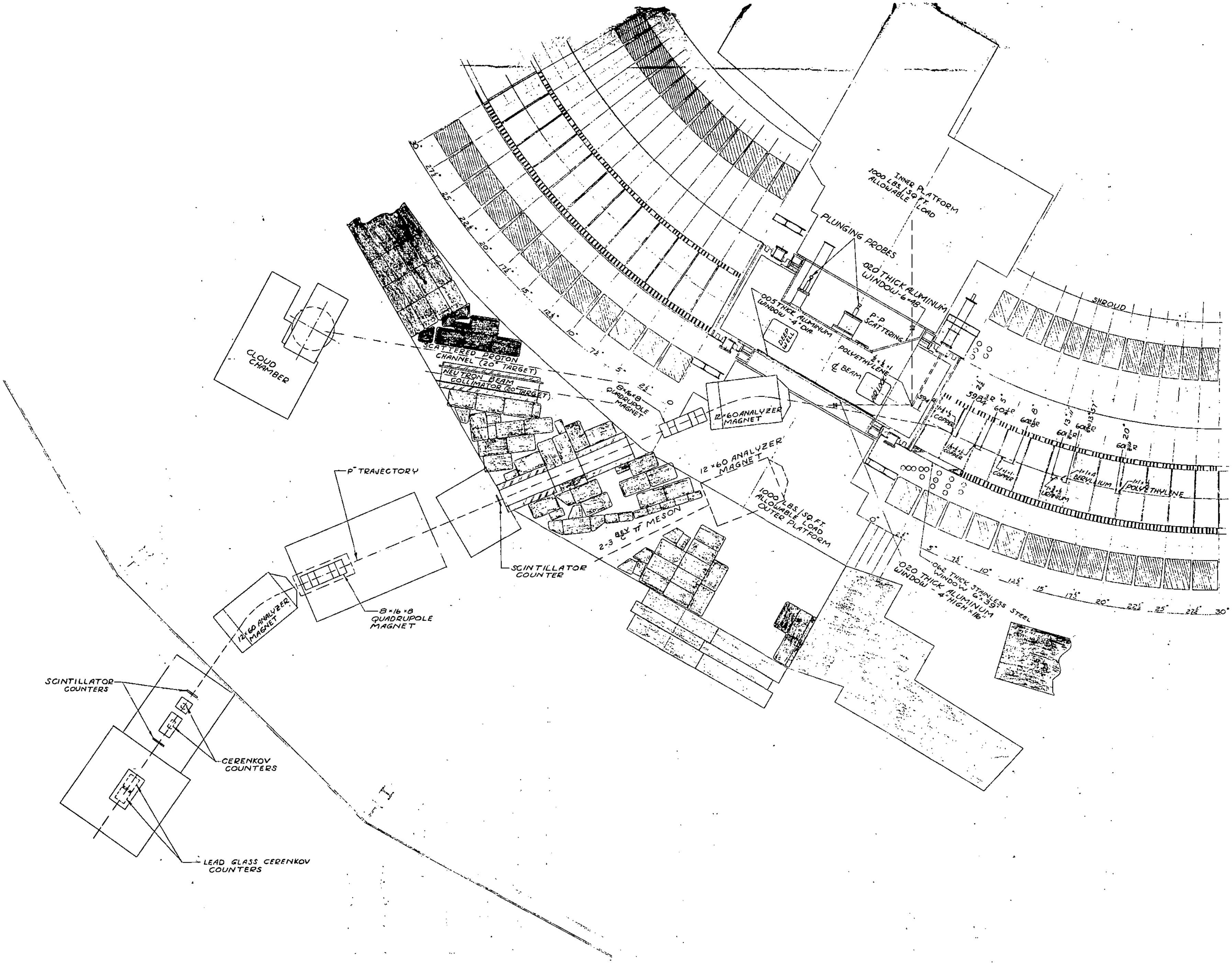
Thin Windows

The 0.094-in.-thick aluminum window, 12 by 132 in. on the west outside-radius beam slot was replaced by a 0.020-in.-thick aluminum (52SO) window, 4 by 116 in. A 0.005-in.-thick, 4-in.-diameter aluminum window is also provided at the north end of this beam slot.

The 0.094-in.-thick aluminum window, 6 by 48 in. on the west inside re-entrant section was also replaced by a 0.020-in.-thick aluminum (52SO) window.

Plunged Beam Clipper

The east copper clipper was modified in the following manner: The thickness of the leading 4 in. was increased from 2 in. to 4 in. The radial dimension and height remained unchanged (12 by 8 in. high).



ZN-1452

Fig. 2. West target area experimental facilities. Top View.

New Experimental Magnets

A second 4-in.-diameter quadrupole-magnet set was constructed and is now in use in the Segrè antiproton setup. This set contains two 8-in. units and one 16-in. unit.

A second 12-by-60-in. analyzing magnet was also completed and installed in the Segrè antiproton mass spectrometer.

BEAM MONITORING

Shielded Beam Induction Electrode

Several attempts were made to reduce the rf pickup on the east induction electrode signal. Better shielding was provided on the rf driver unit. The pole-face windings were bypassed to ground. Unnecessary rf monitoring cables were eliminated. The induction-electrode signal cables were carefully shielded. In spite of these measures, the rf pickup was still at an undesirably high level.

To further shield the electrode, 6-in. extensions were added to the beam apertures in the ground shield.

Recent measurements indicate this additional shield effected at 15-db reduction in rf pickup. The induction electrode now contributes no detectable rf pickup.

SCATTERED EXTERNAL PROTON BEAMS

Two external proton beams have been used in recent experiments. In both cases the protons were scattered from targets near the entrance of the west straight section.

The first was a beam scattered at 11° from the 20° polyethylene flip target. The calculated energy was 5.3 Bev. The observed flux of protons (cloud chamber) was 30 per 10 in.^{2} for 1×10^9 protons per pulse in the internal beam.

The second was a beam scattered from the polyethylene target at the entrance of the west straight section. This beam (1Bev/c) was used to calibrate the antiproton setup. The measured intensity was 200 protons per in.^{2} per 10^{10} protons in the circulating beam.

MAGNET

Pole-Face Windings

The circumferential pole-face winding consists of 21 tygon-sheathed copper tubes, equally spaced on each of the upper and lower magnet pole tips. The tube ends are brought through the bevatron vacuum wall at each of the four tangent tanks for the purpose of making electrical and water connections.

Recent vacuum leaks in the pole-face-winding tubes prompted an examination of these windings to determine the nature and cause of the vacuum leaks. During the shutdown of September 5, many places were noted where arcs or glow discharge had occurred between the windings and the surrounding support structure.

The fact that these burned spots generally occurred at the termination of the tygon insulation suggested that the discharges were caused by local high pressures, which were the result of gas exhaust from the space between the copper tubing and the insulating sheath. A more probable explanation, however, was that the magnet had been pulsed at a time when the tank vacuum was in the micron range.

The windings were electrically connected as a series network, with appropriate values of dividing resistances, to produce the desired current distribution. The circuit was self-excited; a potential of 600 v was necessary to produce the optimum correction current. To minimize the possibility of arc in the future, the pole-face windings were reconnected in a parallel network, instead of a series network. The maximum voltage from winding to support is now 200 v. The network resistance values for this new circuit were calculated to adjust the n-value of the field at injection to 0.65. These values were then adjusted empirically to obtain maximum beam survival.

Beam vs Aperture

The width of the inner-radius field was investigated by measuring beam amplitude vs the inflector-electrode radial position. No loss in beam was observed as the inflector was moved to 622 in. radius (centerline of the magnetic aperture is at 599-3/8 in. rad.). The east beam induction electrode becomes an obstruction at 622-1/2 in. radius. A beam clipper at 581 in. radius is the inner radius obstruction. The width of the good magnetic field at injection is, therefore, probably greater than 41 in. This is to be compared with a width of 36 in. with the previous pole-face-winding correction.

MAGNET POWER SUPPLY

During this quarter, the magnet pulsing record showed a large increase in full-current pulsing at pulse-repetition rates of 10 and 11 pulses/min (Table II). This increase in operation at high pulse rates was the result of careful regulation of ignitron water temperature and improvement in the ignitron firing circuits. It represents an appreciable increase in average current load on the ignitrons. The pulse record suggests an increase in ignitron fault rate at the high pulse rates; however, at this time, it is not known whether this indication is significant.

Fluctuations in Magnet Voltage

A fluctuation in magnet voltage was observed which correlated with a jitter in the radiofrequency turn-on time. Simultaneous measurements indicated no jitter in the motor-generator-set synchronization. This suggested that the source of fluctuation may be the time at which generator excitation is applied with respect to the point of synchronization.

If ϕ_1 and ϕ_2 are two adjacent phase angles of one generator, and ϕ'_1 and ϕ'_2 are the two corresponding phase angles of the other generator, the point of synchronization determines the angles, $\phi_1 = \phi_1 - \phi'_1$, and $\phi_2 = \phi'_1 - \phi_2$ ($\phi_1 - \phi_2 = \phi'_1 - \phi'_2 = 30^{\circ}$, and $\phi_1 + \phi_2 = 30^{\circ}$). In general, $\phi_1 \neq \phi_1$, and $\phi_1 \neq \phi_2$. Because of the resulting asymmetry between ϕ_1 and ϕ_2, application of generator excitation voltage during ϕ_1 produces a different magnet-voltage rise time than would be obtained if excitation had been applied during ϕ_2.

Table II

Ignitron fault rate

	5 to 7 pulses per minute						7 to 10 pulses per minute						10 to 17 pulses per minute					
	1500 to 6000 amp			6000 to 8000 amp			1500 to 6000 amp			6000 to 8000 amp			1500 to 6000 amp			6000 to 8000 amp		
Month	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F
1954																		
Oct	103	0	---	3111	27	115	11200	47	239	16200	114	142	80300	24	3348	2363	35	68
Nov	3434	8	429	5146	42	122	255	0	---	33200	259	128	29100	18	1617	7237	39	186
Dec	310	2	155	35600	122	292	1640	18	91	1529	39	39	19600	12	1630	0	0	0
1955																		
Jan	1757	4	439	42500	193	220	0	0	0	9480	60	158	55400	36	1538	259	3	86
Feb	793	0	---	19600	76	258	431	4	108	19800	97	204	39000	29	1347	9817	44	223
Mar	434	0	---	14900	16	933	456	0	---	37500	64	586	48400	39	1240	16400	51	232
Apr	948	0	---	19600	39	503	425	1	425	16700	38	440	102500	8	12800	9587	18	533
May	0	0	---	14500	34	427	34	0	---	58400	171	341	76400	15	5094	3400	9	379
June	0	0	---	8500	2	4249	0	0	---	9700	9	1075	132800	4	33194	12500	14	896
July	0	0	---	300	1	341	0	0	---	10300	9	1144	137700	25	5510	15800	22	720
Aug	0	0	---	6469	9	719	580	2	290	70832	62	1142	48037	1	48037	18473	10	1847
Sept	86	0	---	0	0	---	0	0	---	33269	44	756	44798	10	4480	341	0	---
Oct	1361	0	---	1289	0	---	0	0	---	54562	88	620	38136	1	38136	29305	56	523

The generator excitation voltage itself may also contribute to the fluctuation in magnet voltage, as its rate of rise is an appreciable fraction of the time of a generator phase period (0.5 msec). Thus, a small jitter in time between the phase pulse and the application of excitation voltage may cause a jitter of as much as 0.5 msec in the firing of the first ignitron. Careful setup of optimum operating conditions and continual monitoring have reduced the aforementioned fluctuation to a tolerable level.

Stabilization of Peak Magnet Current

A fluctuation in magnet-current pulse length was investigated as a possible source of radiofrequency jitter. The pulse length was observed to vary by as much as 20 msec. This corresponded to a 200-amp (2.5%) fluctuation in peak current.

The magnet pulse length is the sum of three time intervals: an adjustable time of about 0 to 2 sec, a 20-msec fixed delay, and a variable delay of 0 to 20 msec. The last delay depends upon the arrival of the next synchronizer pulse. It is the synchronizer pulse that actually terminates the rectification period; therefore, a jitter in the arrival of the synchronizer pulse relative to the last 20-msec gate could produce a fluctuation of 20 msec in the magnet pulse length. Careful adjustment and monitoring of existing equipment now allow a pulse-length reproducibility of 1 part in 2×10^4.

Motor-Generator-Set Bearing Alignment

On October 24 strain-gauge measurements were taken on the motor-generator-set shafts. The measurements indicated that the strain in the shafts of both motor-generator sets exceeded by 50% to 100% the limit of 10 μin. per in. set by Westinghouse Electric Company.

During a test run, temperature recordings were made of the bearing temperatures of both machines. The No. 3 bearing of the east machine ran at 80°C (15°C higher than the other bearings). A noise was noted in the No. 3 bearing of the west machine. During the subsequent shutdown for bearing alignment, the No. 2 and No. 3 bearings of each machine were rolled out and inspected. The No. 2 bearing of the west machine and the No. 3 bearing of the east machine were badly wiped. These bearings were repaired, surfaced, and reinstalled.

Comparison of the strain-gauge readings with gap measurements on the bearings indicated that the strain-gauge measurements in the range of 10 to 20 μin. per in. were not reliable. Use of an optical method of bearing alignment is now under investigation.

Oil-flow and temperature monitoring were installed for each bearing. The bearing temperatures are now recorded continuously.

BEAM DYNAMICS

N-Value Study

A series of quantitative measurements of n-values was made by use of the proton beam induction electrode signal to detect resonances. At least two resonances (at 50 msec and at 200 msec) were noted, which could be corrected by additional pole-face-winding current. Table III summarizes the results of the measurements and indicates the time at which the additional current correction was applied. Figure 3 shows, schematically, the method that was used to apply the correction current.

Table III

Pole-face winding correction currents

PFW Current at "Injector on" (amp)	Location of Resonance from "RF On" (msec)	Additional Current Correction (amp)	Start of Current Correction from "Magnet On" (msec)
3.34	50	1.2	20
3.50	200	3.4	100
2.40	155	---	---
0 - 3.85	650	0 - 50	

The resonance at 650 msec was not sensitive to large changes in n-value, but was very sensitive to the amplitude of the final radiofrequency voltage. This resonance is probably due to phase noise in the radiofrequency system.

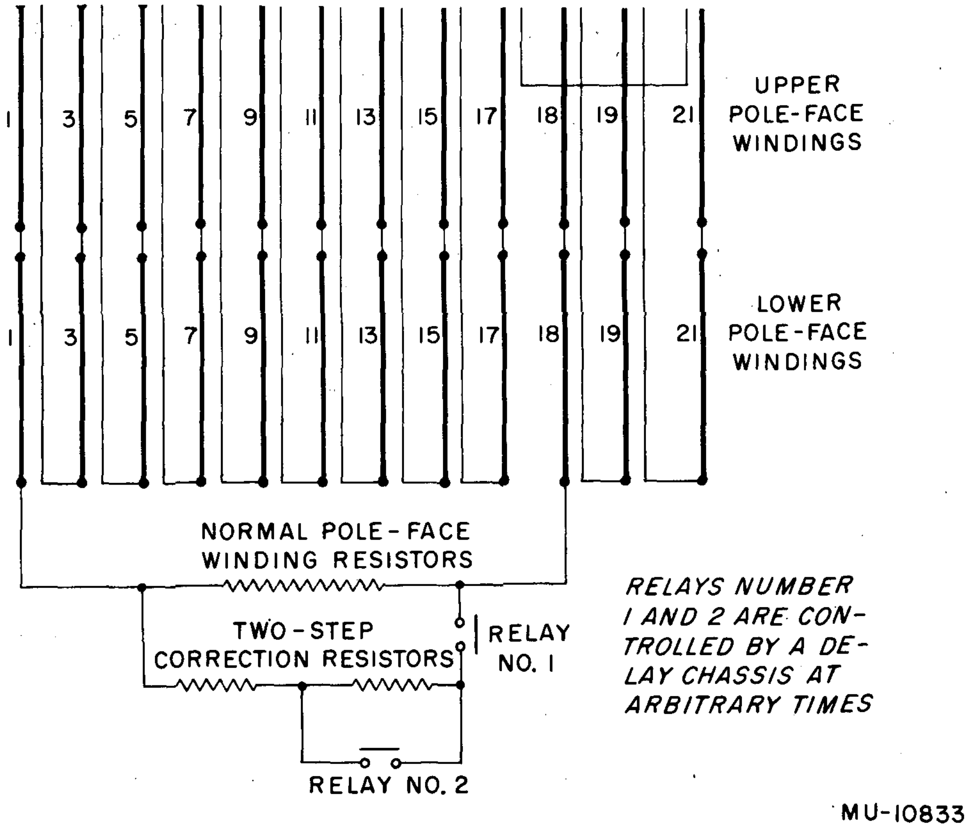


Fig. 3. Schematic of two- step pole-face winding correction.

Removal of the two resonances at 50 msec and 200 msec did not impove the beam survival.

Synchronous Beam During Peak Magnet Current Step

The dwell of magnet current at peak value was successfully lengthened to 80 msec by controlling the rate of inversion at peak current. The magnet voltage was held at the proper value by programming the time at which the ignitrons inverted; the remaining tubes continued to rectify. The magnet current at 8300 amp was held constant during this step to better than 1 part in 1000. Table IV illustrates the type of operation that was obtained.

Table IV

Peak Magnet Current Step

Peak Magnet Current (amp)	Peak Current Ripple (parts per 1000)	Average Current Ripple (parts per 1000)
2000	5	2
2500	3	2
4000	2	1
6000	1	1
7000	0.7	0.7
8000	0.6	0.6
8300	1.2	0.8

A beam was accelerated to full energy and successfully tracked through the magnet current step, and remained synchronous for a short time into inversion. This beam was lost to the outside radius.

RADIOFREQUENCY TRACKING EQUIPMENT

Spare Magnet-Current Shunt

The spare magnet-current shunt (west shunt) was tested and found not to match the existing slope-control equipment. The output voltage of this shunt differed from the output of the regularly used east shunt by about 1%. The resistance range of the slope-control box was not sufficient to compensate for this difference.

Spare Master Oscillator Reactor

The new ferroxcube-core master-oscillator reactor was constructed and tested. The choice of the particular ferroxcube material was based on its high Q. Tests disclosed that this new reactor does not match the correct frequency-tracking curve. The existing curve-correction equipment does not have sufficient range to compensate for this tracking error.

A degaussing scheme has been proposed to correct the core of this new reactor.

Radiofrequency Driver

A new radiofrequency driver is under construction. This is to be a wide-band amplifier, and will replace the reactor-tuned driver now in service. It has been determined that a source of radiofrequency-tracking error is a feedback loop between the present driver and the reactor-tuned final amplifier. This loop is through the interelectrode capacitance of the tubes. The new wide-band driver should eliminate this source of error.

Neon Bulbs

Many of the bevatron electronic circuits employ neon bulbs to adjust voltage levels to the desired values. Production nonuniformity and change of characteristics with age of the neons has resulted in unreliable operation of these circuits. Wherever possible, therefore, the neons have been removed from critical circuits and resistors have been substituted. In some cases, where it has been impractical to replace the neon bulbs, the pigtail-type bulb has been replaced by the bayonet type. The bayonet type neons have proved more uniform and reliable.

DEVELOPMENT

Increase in Acceptance Time

To take advantage of the possible increase in acceptance time of the bevatron[1], an investigation was made of the problems involved in lengthening the linear accelerator radiofrequency pulse. The main oscillator pulse line was lengthened from 600 to 1380 μsec. The normal pulse-repetition rate of 2.2 pulses/sec was reduced to 1.1 pulses/sec because of design limitations in the pulse-line charging supply. Although satisfactory operation was obtained, the low pulse rate increased the difficulty of tuning.

Automatic Tracking Equipment

An improved model of an automatic beam-tracking system[1] was tested. This new unit was not sensitive to beam amplitude over a range of 2000:1; this is to be compared with a previously reported range of 20:1. The increased range is sufficient for all but internal emulsion experiments, which require 10^7 protons per pulse or less.

Further development, however, is necessary. The radial locus of the magnetic center of the bevatron gap--and therefore the optimum radial location of the beam--shifts during the acceleration cycle. If the reference point for the radial-position information is changed in a predetermined fashion, the beam could be made to track in the region of best magnetic field. Modification of this unit is in progress.

RADIATION

Personnel Protection

The access gates to the east straight section and the linear accelerator platform are now interlocked to prevent the exposure of personnel to the high neutron radiation from the linear accelerator.

A beam cup is inserted between the ion gun and the linear accelerator, and the linear-accelerator radiofrequency high-voltage interlock chain is interrupted when one of the access gates is opened. The scheme, however, allows work to be continued on these platforms with the radiofrequency high voltage "on", if a beam cup is first inserted ahead of the linear accelerator.

BEVATRON SHUTDOWNS

The bevatron was shut down from September 5 to September 13, and from October 26 to October 29. The first was a scheduled shutdown for installation of new equipment, repairs, and maintenance. The second was a shutdown primarily of the motor-generator sets for bearing inspection and alignment.

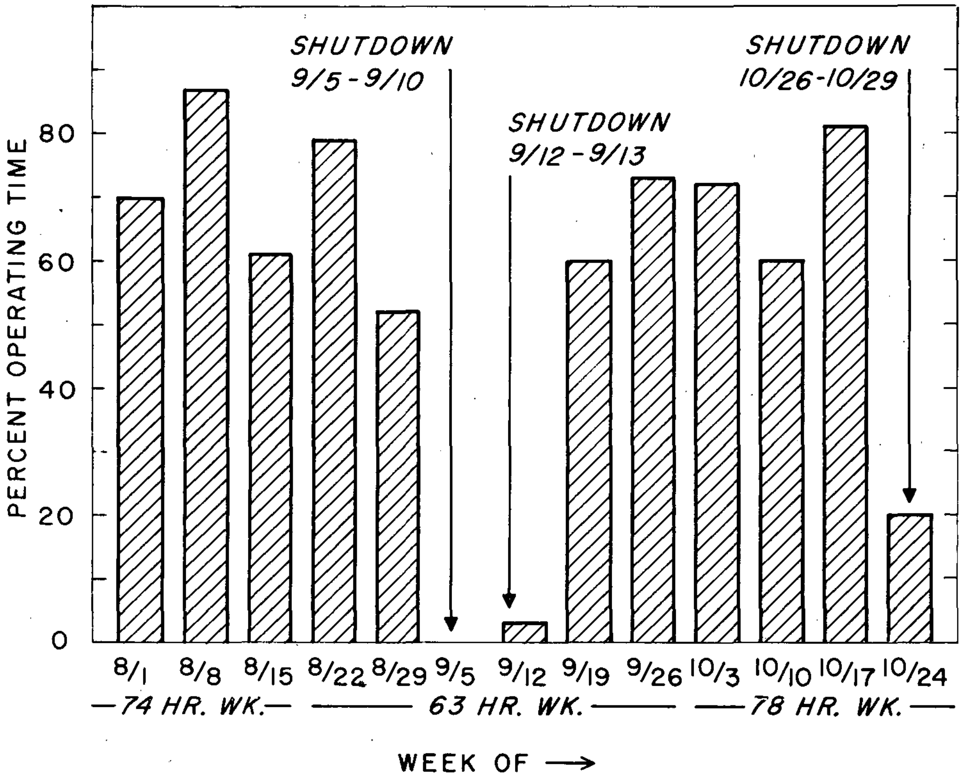
In addition to the installation of new experimental facilities as discussed above, the following were some of the jobs completed during the shutdowns. The fast target, the plunging mechanisms, and the flip-coil target assemblies were carefully checked and reconditioned. The contacts on the magnet-shorting switch were changed. An air-distribution system was installed to distribute refrigerated air to the back of the main control-room racks. The ignitron-anode seals were high-voltage checked.

OPERATING AND RESEARCH PROGRAM

The scheduled operating hours were decreased from 77 to 65-1/2 hours per week on August 22. This curtailment of research activity was in accord with a 10% reduction in the AEC operating budget. On October 3 the operating hours were increased from 65-1/2 to 81, as additional funds were made available for bevatron operation. Figure 4 summarizes the operation during this quarter. The operating hours per week indicated on the graph are reduced by the magnet-power-supply warmup time (1/2 hour per day). The vertical bars, therefore, represent a percentage of the scheduled effective hours for physics research.

The maximum beam amplitude this quarter at 6.2 Bev was 2×10^{-10} protons per pulse at 11 pulses per minute. An integrated proton beam of 1.3×10^{13} protons per hour was therefore possible.

Figure 5 shows the best and the typical values of survival efficiency of the bevatron beam. The straight line represents the best recorded values.



MU-10834

Fig. 4. Beavtron operating time August - October 1955.

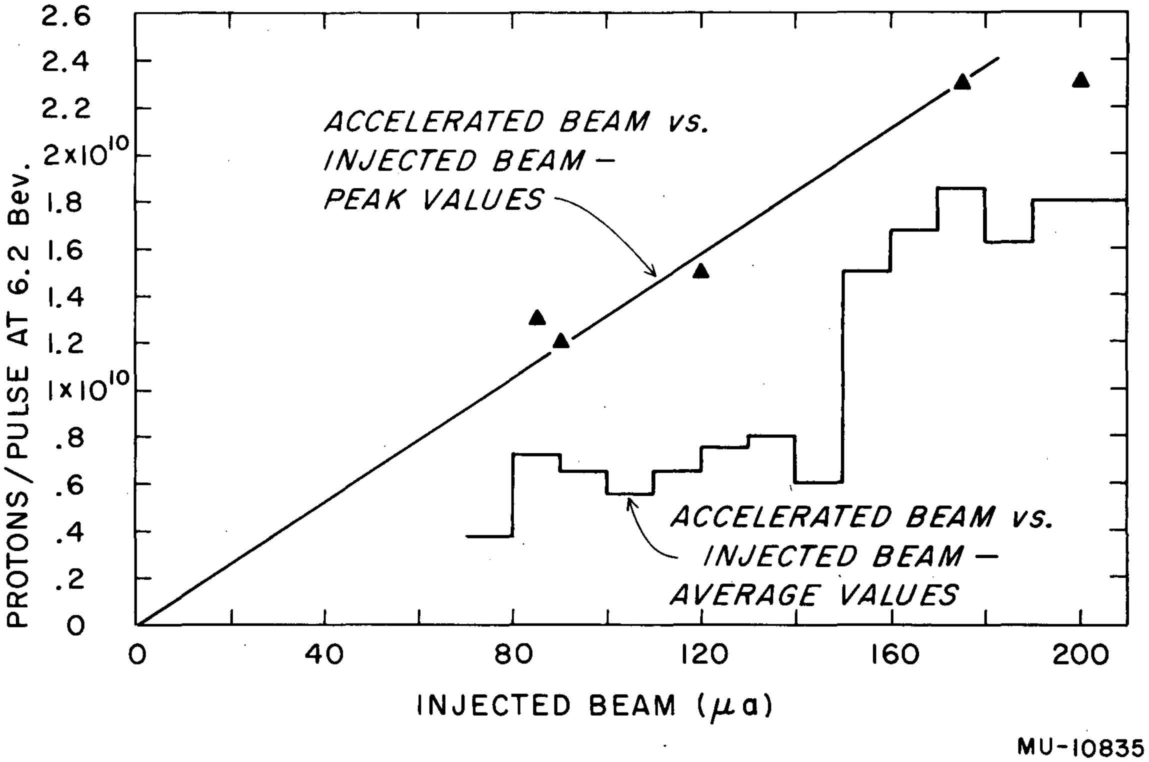


Fig. 5. Bevatron performance beam-survival efficiency.

The major research effort this quarter was directed toward the detection of the antiproton. On September 22 the Segrè Physics Research Group counted negative particles of proton mass in the analyzed and focused negative-particle beam from the 2.5° target (1.19 Bev/c). The arrangement of the mass spectrometer and counting equipment is fully described by O. Chamberlain, E. Segrè, C. Wiegand, and T. Ypsilantis.[2] Announcement of the discovery and identification of the antiproton was made on October 19, 1955.

A summary of the total research activity appears in Table V.

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[2] O. Chamberlain, E. Segrè, C. E. Wiegand, T. J. Ypsilantis, "Observation of Antiprotons," Phys. Rev. <u>100</u>, No. 3, 947 (1955).

Table V

Bevatron Experimental Research Program
August, September, October 1955

INTERNAL GROUPS

Group Experimenters	Experiments
BARKAS	
Barrett	Emulsion exposures, neutron spectrum, and neutron interactions.
Cole	Assessment of new Eastman Kodak nuclear emulsions.
LOFGREN	
Cork, Horwitz, Murray, Wenzel	P^- detection, using a multi-Cerenkov counter telescope.
Cork, Wenzel	P-P scattering, using counters; 2 Bev, 4 Bev.
Cork, Horwitz, Murray, Wenzel	P^- annihilation investigation, using counters.
Heard	Beam resonance, n-value study.
MOYER	
Bostick, Cence, Wikner	Study of deflected particle flux between Bevatron magnet slabs.
Osher, Parker	Decay products of mesons and hyperons, using a γ-ray spectrometer.
Osher, Parker	Excitation function for associated production of π^0 mesons.
Brabant, Wallace	γ-ray spectrum from π^0-meson decay, using a γ-ray spectrometer.
Bostick, Kaplan, Wikner	π^- total cross section, using counters (2.8 Bev/c). Emulsions in π^- beam (2.8 Bev/c).
Wikner	π^+ total cross section, using counters.
POWELL	
Fowler, Lander	P^- search, using a cloud chamber.
Maenchen, Wright	P-P scattering of 5.5-Bev protons in 35-atmos diffusion cloud chamber.

INTERNAL GROUPS

Group	Experimenters	Experiments
SEGRÈ	Chamberlain, G. Goldhaber	Antiproton search, emulsion exposure.
	Chamberlain, Steiner, Ypsilantis, Wiegand	P^- detection and counting; mass measurement and excitation function (1.19 Bev/c).
WINSBERG	Benioff	Polyethylene target bombardment.
	Shudde	U, Al, Pt foil bombardment.
	Winsberg	Al, Mn foil bombardment.
VAN ATTA	Ise, Pyle	π^- total cross-section measurement in Cu and C, using a cloud chamber.
LIVERMORE NUCLEAR FILM GROUP	Violet, White	Emulsion exposures, neutron spectrum, and neutron interactions.

EXTERNAL GROUPS

Experimenter	Institution	Experiments
CÜER	University of Strasbourg Strasbourg, France	Internal emulsion exposures at proton beam energies of 2 Bev, 4 Bev, 6.2 Bev.
LORD	University of Washington	Internal emulsion exposures at 6.2 Bev. Emulsions in π^- beam (2.8 Bev/c).
TICHO	UCLA	Emulsion exposures, neutron spectrum, and neutron interactions.

ACKNOWLEDGMENTS

The Bevatron operating group consists of Robert Anderson and Robert Richter as crew chiefs; Norris Cash, Duward Cagle, Frank Correll, Robert Gisser, William Kendall, Ross Nemetz, Howard Smith, Glenn White, and Emery Zajec as crew members. Harold Vogel was the engineer in charge of the motor generator sets. The Bevatron group leader is E. J. Lofgren, and under him Harry Heard, with Walter Hartsough assisting, is in charge of operations. Special development projects were carried out by Bruce Cork, Harry Heard, Nahmin Horwitz, and William Wenzel. The mechanical engineering group was headed by William Salsig; the electrical engineering group by Clarence Harris and Marion Jones. Jerome Russell directed the electronic development group.

This work was done under the auspices of the U. S. Atomic Energy Commission.