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BEVATRON OPERATION AND DEVELOPMENT. VI

Harry G. Heard

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BEVATRON OPERATION AND DEVELOPMENT. VI

Contents

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[*] Preceding Reports: UCRL-3033, UCRL-2954

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Harry G. Heard

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ABSTRACT

A large fraction of the effort on high-energy physics this quarter was devoted to the study of K particles. Ten of the fourteen external laboratory groups, as well as seven of the internal laboratory groups, used the $K^{\pm}$-beam facilities. These experiments included measurements of lifetimes, modes of decay, and excitation functions. Counters and cloud-chamber techniques were used in addition to nuclear emulsions. Measurements of total and differential cross-sections for π^- mesons continued. Work on proton-proton scattering was extended to 4.8 Bev. Radiochemical investigations of spallation products in light and heavy elements were extended.

A new target plunger, a 4-inch quadrupole magnet, and two new steel collimators were added to the experimental facilities.

Accelerator development this quarter included experiments on increasing the acceptance time of the Bevatron, self-tracking of the radiofrequency equipment, and the substitution of an analogue computer for the 30-point curve corrector.

BEVATRON OPERATION AND DEVELOPMENT. VI

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INJECTOR

Most of the effort on the injector this quarter was concentrated on improving the reliability and average performance of existing equipment. While the peak and average value of the injected beam did not vary significantly from the values previously reported,[1] the integrated number of protons injected into the Bevatron aperture continued to increase as temporary equipment was replaced with better-constructed and better-engineered units.

The two main sources of injector outage have been the faulty operation of the pulsed arc supply and the short life of the pyrolytic film resistors which distribute the voltage on the ion-accelerating column. Both these sources of trouble have developed as a result of the increased beam output of the injection equipment. The original cathode-follower arc pulser was not designed to furnish the magnitude of output currents that are required by the improved ion sources. Loss of ion column resistors has been due to the increased voltage gradient which resulted from reducing the over-all length of the ion column.

While revisions have been made in the existing cathode-follower arc pulser which have improved its operation, a spare unit has also been constructed. This new arc pulser is considerably simpler than the previous design in that mercury relays rather than vacuum tubes perform the switching functions. Initial tests of this unit indicate that greater reliability can be expected.

The solution to the resistor-loss problem in the high-voltage ion column is less clear. For several months the clamps on the ends of the column-divider resistors have undergone a series of revisions with the assumption that sparking at this junction was the cause for resistor loss. No clamping configuration was found that solved this problem. A new approach was tried which appears to have eliminated resistor loss. Each resistor is jacketed with a plastic (Transflex) tube which covers the entire carbon spiral portion of the resistor. It was felt that this insulating layer would help to distribute the surface charge on the resistor and thereby reduce the local surface gradients. Whether the surface gradients are the cause of resistor failure is not clear; however, the technique has been very effective in preventing resistor loss.

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[1] Edward J. Lofgren and Harry G. Heard, Bevatron Operation and Development. V, University of California Radiation Laboratory Report No. UCRL-3033, August 28, 1955.

EXPERIMENTAL FACILITIES

Arrangement of Experimental Area

Figure 1 shows the general arrangement of the experimental equipment at the end of this quarter. The shielding wall was rearranged to add a scattered-proton channel and two antiproton channels. Scattered protons from the 13° and 20° targets are bent by the 12-by-60-inch analyzing magnet so as to clear the yoke structure of the Bevatron magnet. Two independent trajectories were being set up to search for antiprotons. The major magnet arrangements and the calculated trajectories are shown in this sketch.

There are now four targets that are actuated by coils rotating in the Bevatron's magnetic field. The locations of these targets and their target materials are shown in Fig. 1. Targets are good for at least 10^5 operations. A new bearing design is under study which should extend the operating lifetime.

Quadrupole Magnet

One of the new 4-inch-diameter quadrupole magnet sets was completed and placed in service at the end of this quarter. This magnet set, which contains two short 8-inch units and one long 16-inch unit, is shown in Fig. 2.

A maximum field gradient of 4000 gauss per inch can be attained with this lens set for a field of 7500 gauss at the center of a pole tip and 1/8 inch from its surface. These magnets are water-cooled and dissipate approximately 70 kw per set.

New Collimators

Two steel collimators have been constructed for general use in Bevatron experiments. These collimators are 5 feet long in the beam direction. They have a 12-by-18-inch aperture and have walls that are 4 inches thick on the sides and 3.5 inches thick on the top and bottom.

Quick-Release Target Plunger and Air Lock

A new and greatly improved plunger has been developed for the target station at the west inside straight section. This new mechanism, shown in Fig. 3, was designed to permit rapid target changes. All the time-consuming operations of the target change were analyzed prior to the construction of this mechanism. Quick-release toggle-type devices were designed to replace functions that required excessive time. These devices, which are self-locking, also require a minimum of tools and handling. The success of this design may be measured in terms of the reduction in target-change time. At present this over-all interval is approximately 5 minutes and is limited by the pumping time of the air lock. This represents a factor of 6 to 8 in reduction of target-change time.

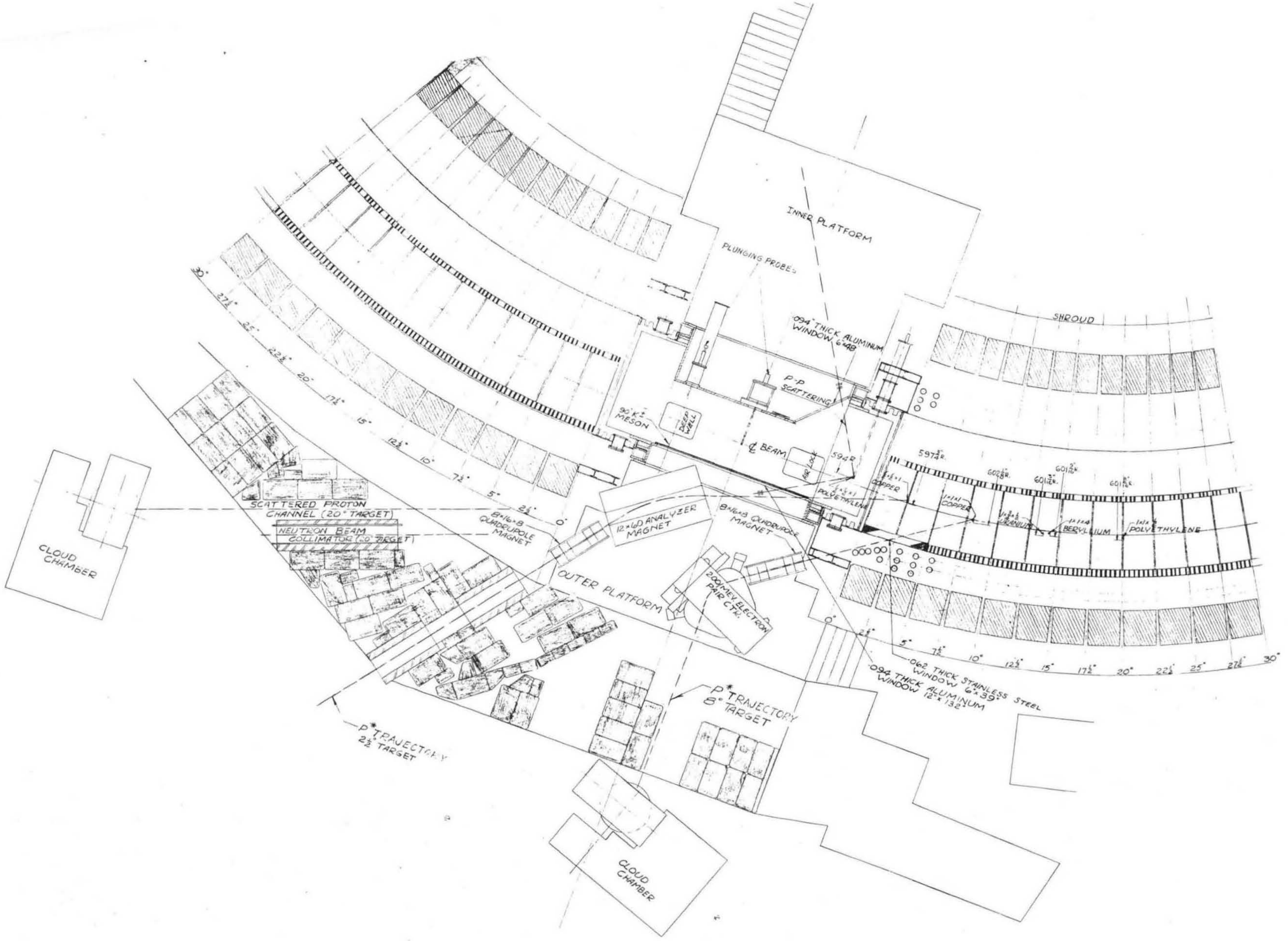

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Fig. 1. West target area--top view.

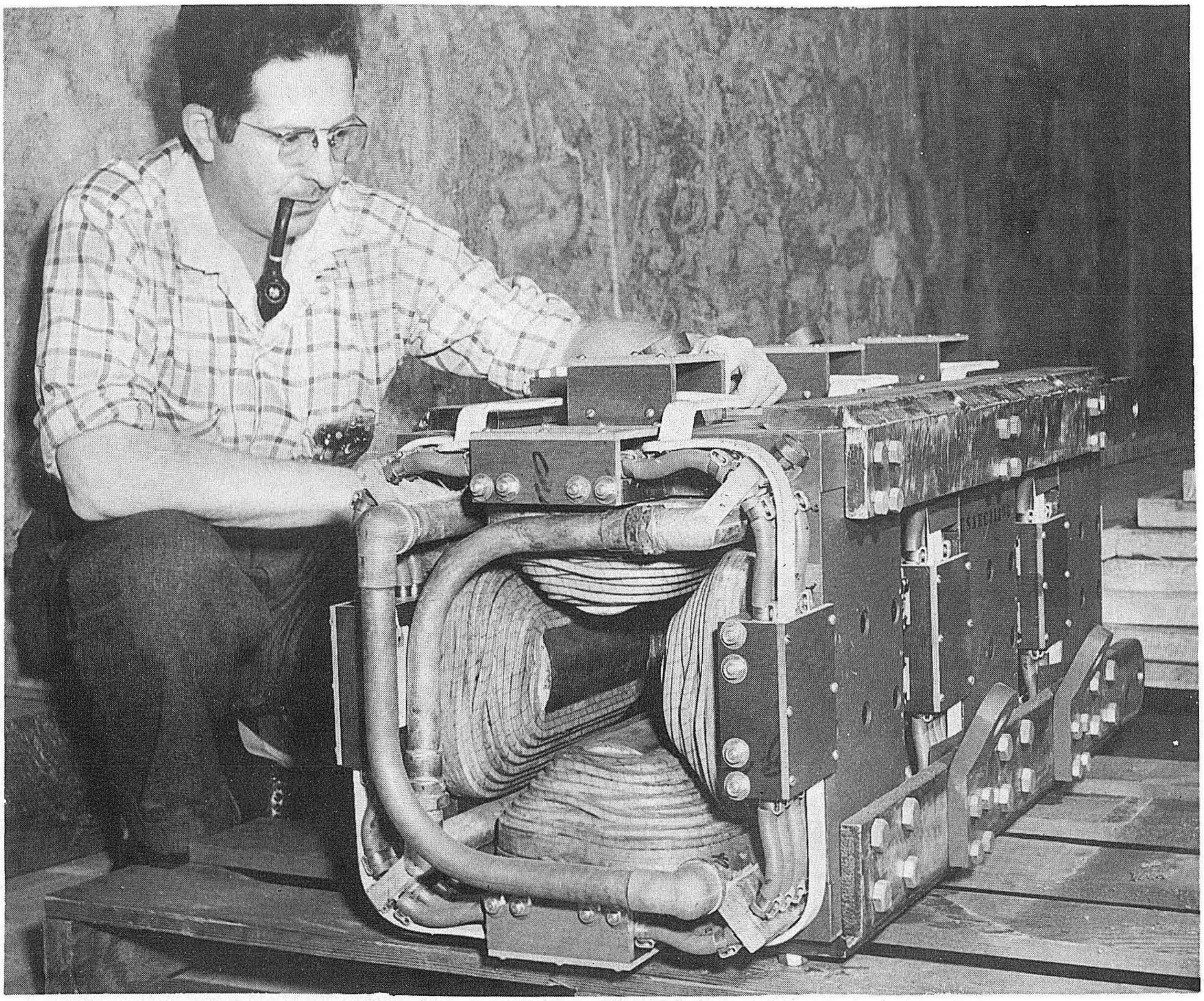

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Fig. 2 **Four-inch quadrupole lens set.**

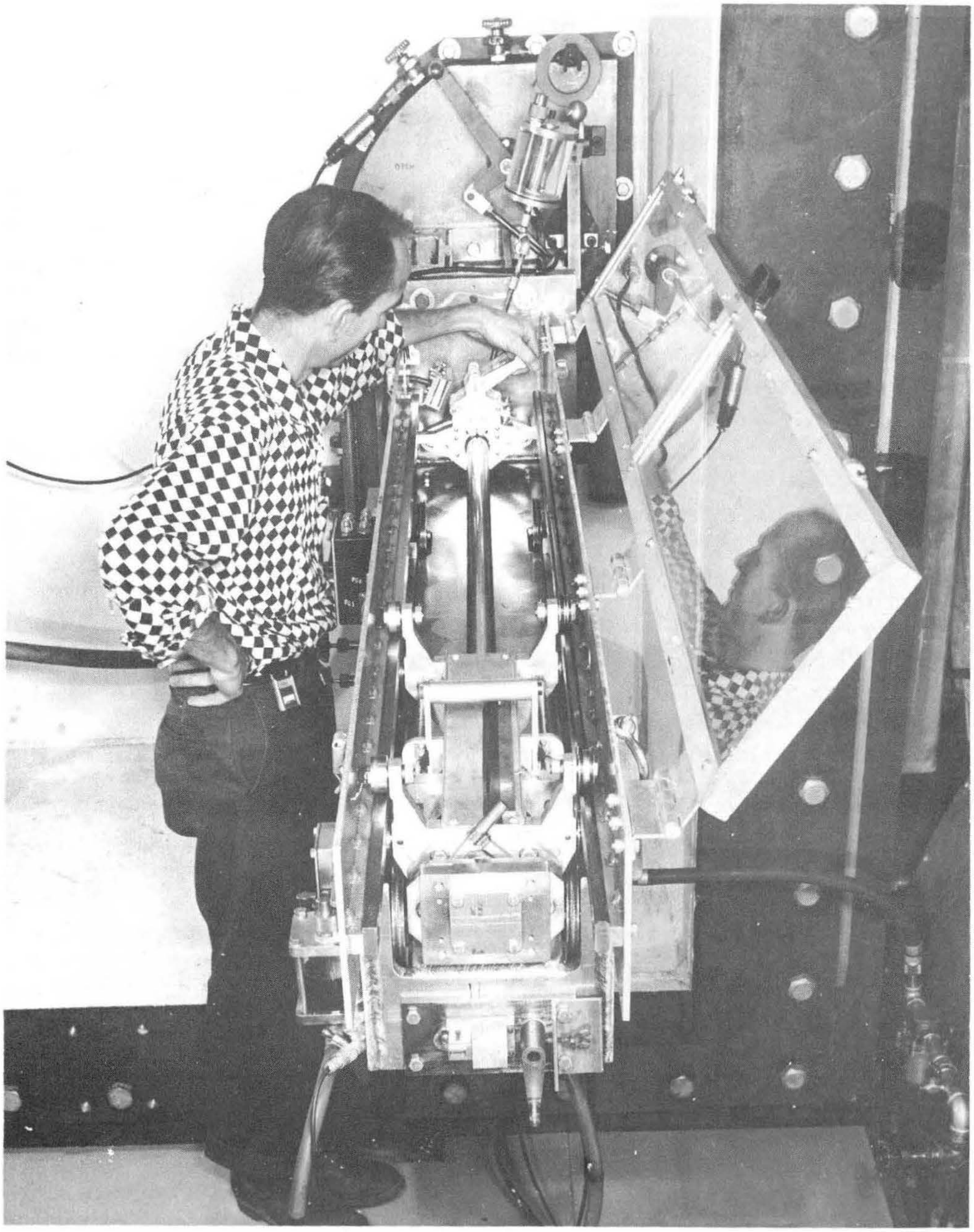

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Fig. 3. Air-ram-driven plunger with quick-disconnect facilities.

CONTROLS AND MONITORING

Injection and Radiofrequency Timing

An improved technique has been developed for monitoring injection timing, rf-turnon timing, and start frequency. This technique depends upon the simultaneous display of the time dependence of three important parameters in a definite relation to injection time. A Tektronix-531 oscilloscope and 53-C plug-in amplifier are the key components; they present as two separate sweeps the signals from two separate inputs. The fact that this display is obtained from a 100-kc chopper permits the simultaneity of events to be established within 10 microseconds. A trigger from the peaking strip that initiates injection also initiates the sweep. The upper beam in this display carries the rf-turnon timing marker and the frequency-marker pips. The lower beam carries a signal from a collector electrode located on the back side of the inflector. This electrode is located at a point, as shown in Fig. 4, at which it will intercept a major fraction of the beam that would ordinarily strike the back of the inflector.

Using this technique, one may quickly adjust the injection parameters for the full range of injection and initial tracking conditions. The correct injection timing is obtained by adjusting the bias current on the injection peaking strip so as to cause injection to occur at such time as to obtain a signal on the inflector collector electrode. The range of possible injection timing is next established by noting the variation in amplitude of this signal with injection time. Correct rf-turnon time is then obtained by adjusting the bias current in the rf-turnon peaking strip until the corresponding pip occurs at the end of the inflector signal. The correct start frequency is established by a simultaneous variation of the slope, trim, and bias controls such that the 358-kc frequency marker is brought into alignment with the rf-turnon marker. The proper adjustment of these injection parameters produces a display as shown in Fig. 5. The bias, trim and slope controls have a marked effect on the frequency-tracking curve. Each control has a range of variation which depends upon the desired beam steering. The simultaneous adjustment of these controls to permit the desired beam-position control and to match initial tracking conditions may easily be achieved by this new monitoring technique.

Three-Channel Beam-Amplitude Control

The temporary three-channel beam-control chassis developed during the previous quarter was replaced with a new rack-mounted unit. To date this new unit has not functioned as well as the developmental model. Most of the trouble is associated with the unreliable operation of the amplitude-comparison circuit. The desirability of multichannel beam-amplitude control accentuates the need for further development of this facility.

Beam-Induction Electrode

Another beam-induction electrode was constructed to provide an experimental unit that could be used to yield an absolute calibration. This unit, which was placed in the east straight section at the exit of the northeast quadrant,

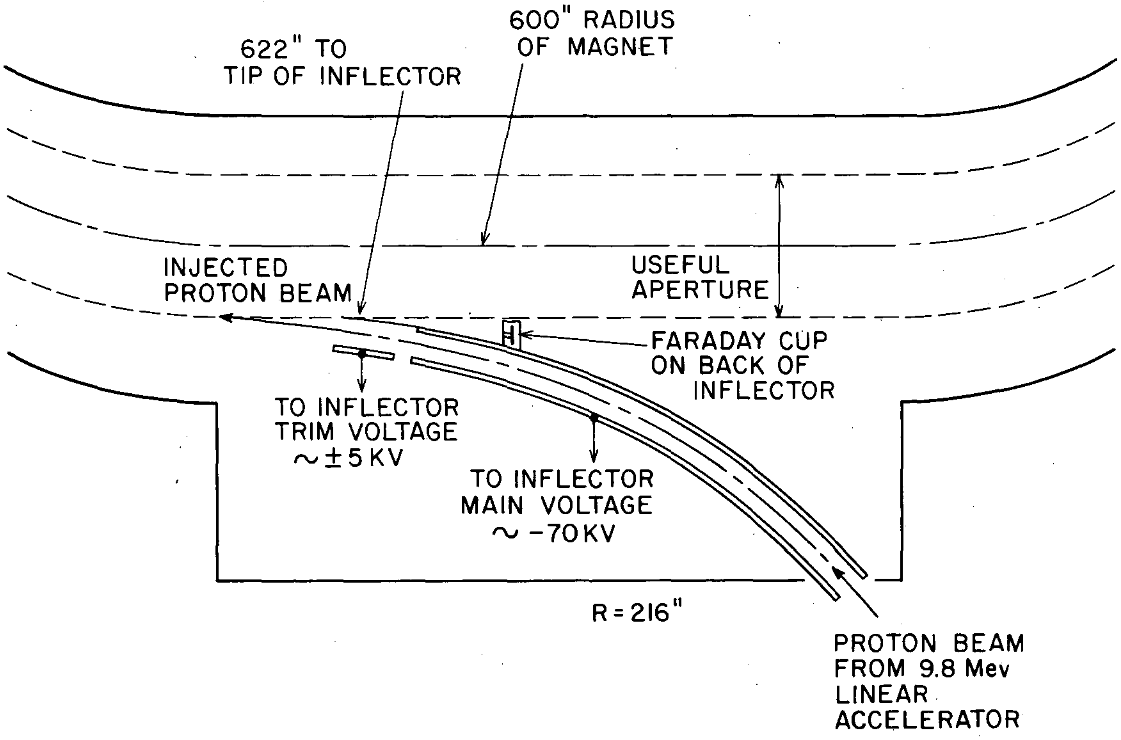

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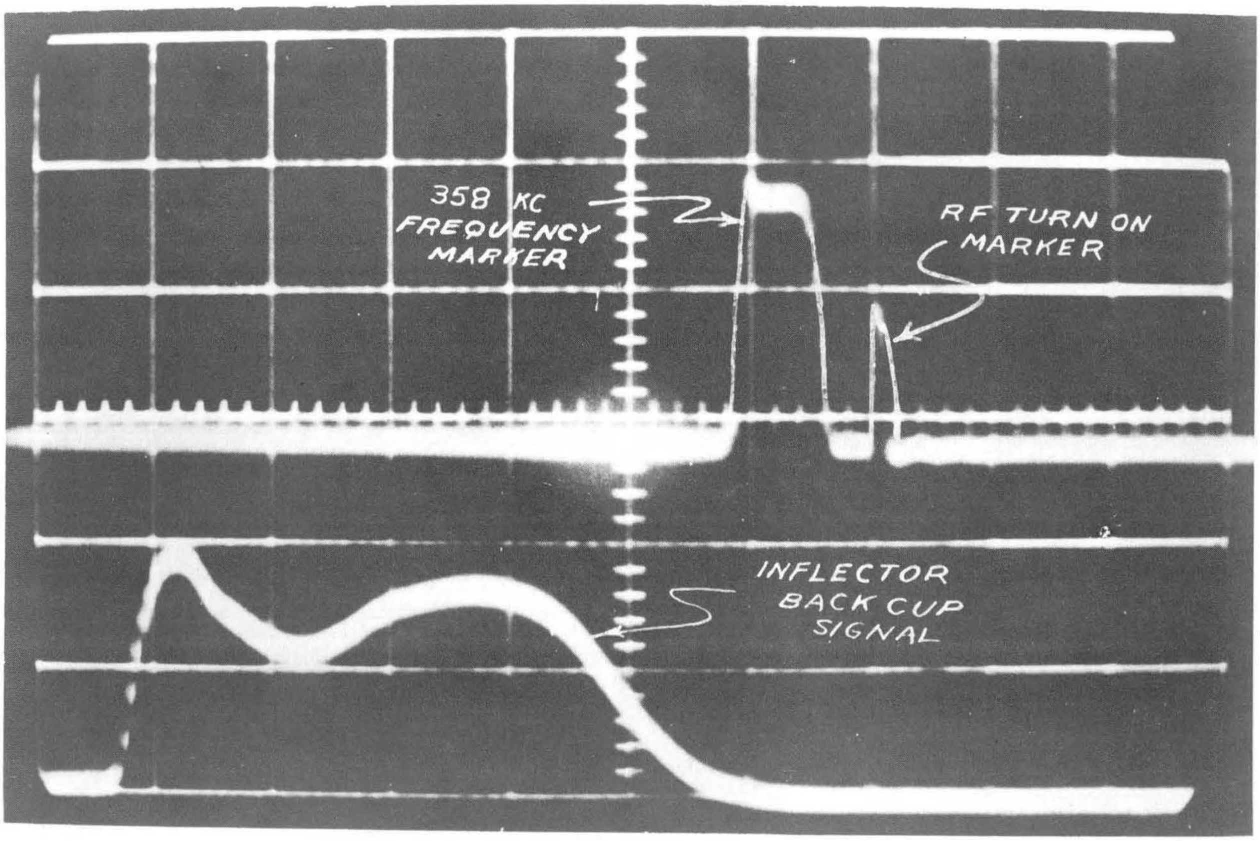
Fig. 4. Top view of east straight section, showing location of inflector and inflector-back cup.



ZN-1418

Fig. 5. Injection-timing display.

is shown in Fig. 6. It consists of an electrode that is almost completely enclosed by an outer shield. The outer structure was designed to act as a guard electrode and to provide shielding from induced interference due to the rf of the linear accelerator, inflector supply, and Bevatron drift tube, as well as ignition-switching transients. The geometry of this unit should permit a reasonably accurate absolute calibration. The measured capacity of this electrode to its surroundings is 355×10^{-12} farad.

Preliminary measurements indicated that the proximity of this unit to the high-level rf equipment caused a higher background of rf pickup than was anticipated. This coherent signal has the same frequency as the fundamental of the beam-induction electrode, so that filtering presents some special problems. Work is progressing on providing better shielding of the high-level tracking equipment.

VACUUM—DRY-AIR SYSTEM

There has been a recovery period of the order of 10 to 15 days following each Bevatron shutdown during which the maximum beam intensity at full energy has been of the order of 0.5 to 1.5×10^9 protons per pulse. This lengthy recovery period, which is due to gas scattering, is associated with the relatively long pumping time of the vacuum envelope (see Fig. 7 for the period May 2 to June 15). During the first few evacuations of the vacuum liner, it became evident that the major factor affecting the pumping time of the aperture was that associated with the removal of condensable vapors. Water vapor is particularly objectionable in that it is absorbed by hygroscopic material from the moist air during shutdowns. Also, oil diffusion pumps have a much lower pumping speed for water vapor than for most gases. Accordingly, a program was initiated to provide an air-drying system for the Bevatron.[2] This system, which is designed to provide 25 to 75 liters per second of air with a water content of 3.6×10^{-3} gram per liter, was used to flush the vacuum liner during two of the three shutdowns this quarter. Fig. 7 shows that the over-all pumping time was reduced by a factor between two and three. Additional improvements were made in this system to reduce the defrosting time and decrease the amount of oil vapor entrained in the dry air by the addition of a scrubber tank.

RADIOFREQUENCY TRACKING EQUIPMENT

The program of improving the high-level rf equipment continued this quarter with two significant advances. Phase modulation was reduced in the driver reactor by the addition of another feedback loop and by better filtering of supply voltages. Additional circuit improvements were made in the 1000-amp saturating supply for the final-amplifier reactors, which permitted operation at higher drift-tube voltages. Previously, the upper limit set by circuit

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[2] Kenow H. Lou, Bevatron Air-Drying System, University of California Radiation Laboratory Mech. Eng. Note 4901-02-M5, July, 1955.

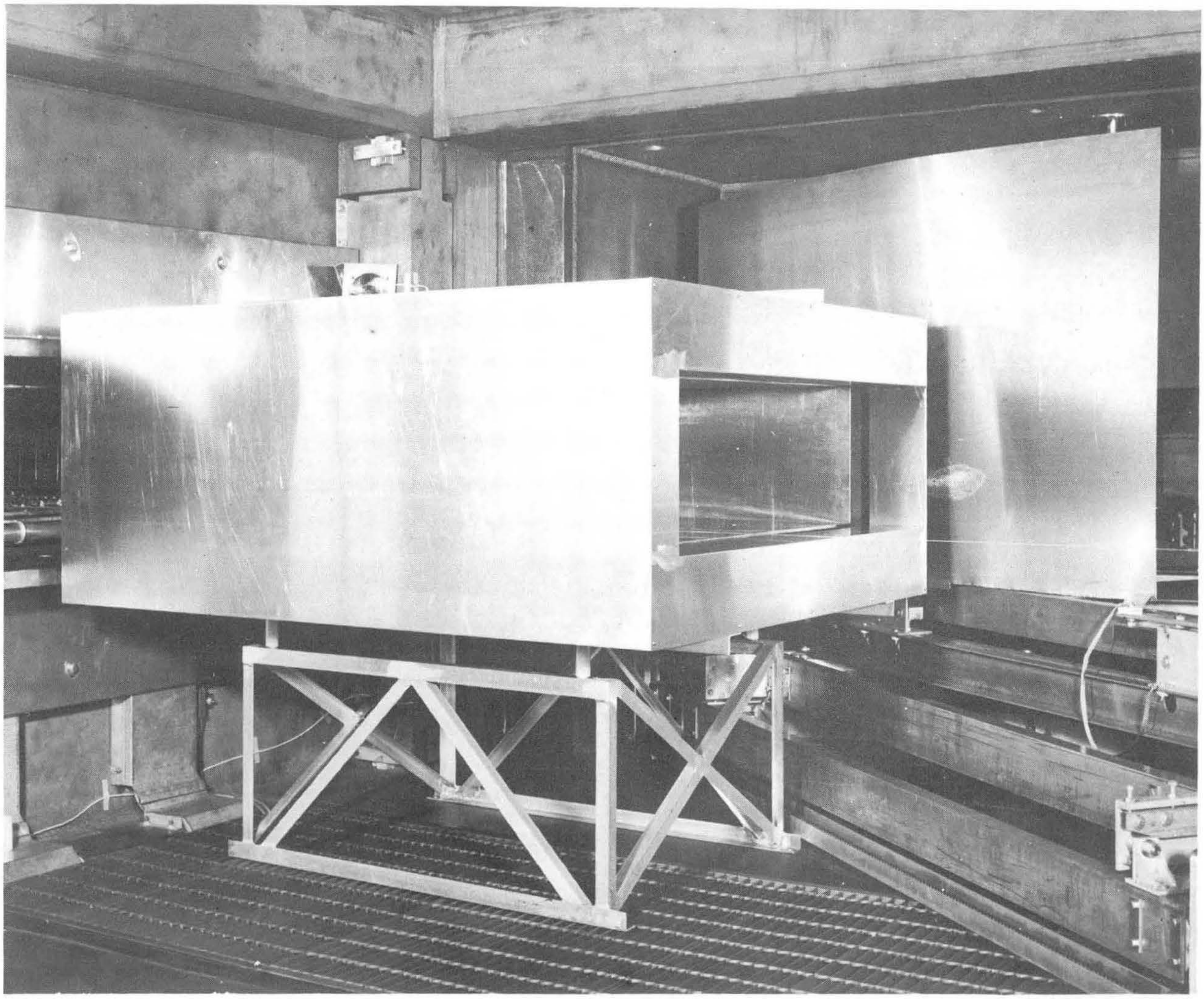

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Fig. 6. Shielded beam-induction electrode in east straight section.

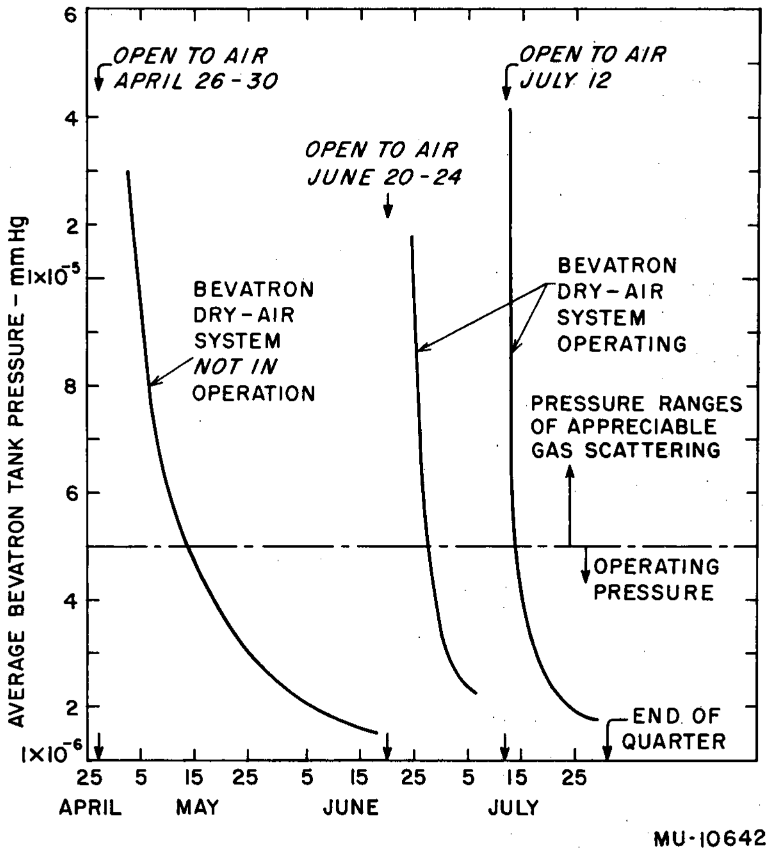

Fig. 7. Bevatron pumpdown curves with and without dry-air-circulating system.

difficulties was 20 kv. It is now possible to operate at 38 kv without exceeding equipment ratings at a magnet pulse rate of 12 pulses per min. Both of these changes have reduced beam losses.

A source of intermittent trouble developed this quarter, which has not yet been localized. There is an intermittent drift in start frequency which sometimes amounts to as much as 1%. This drift usually develops after several hours of operation at peak operating energy of the Bevatron. Additional regulators have been added to the master-oscillator-filament circuit to eliminate this fluctuation. They provided some improvement, but quite evidently have not stopped the drift. Further investigation of this trouble continues.

BEVATRON MAGNET AND POWER SUPPLY

Motor-Generator Equipment

This quarterly period showed much progress in minimizing the inversion faults related to the magnet power supply. See Table I. A major reason was the use of zig-zag-connected transformer to add two excitation voltage vectors at 30 electrical degrees, the resultant feed to the outer grids of the ignitron tubes to reduce the voltage notch that occurs at the firing time. This voltage notch is the result of commutation and is tightly coupled to all circuits that use the generator voltage. It was also determined that the temperature of the ignitron water was fluctuating due to the proportional temperature regulators. Any changes in loading would produce a change of up to 4°C in the cooling-water temperature. This effect was more pronounced at 40° C than at 50°C. The temperature was raised to 50° C to stabilize the tube-firing characteristics with respect to ambient temperature.

Residual-Field Measurements

Fluctuations in the residual field of the Bevatron magnet have a first-order effect on injection timing, rf tracking, start frequency, and rf-turnon timing. The residual field at the time of injection depends upon the peak magnet current, the duration of the rest period between magnet pulses, and the rate of rise and fall of magnet current during rectification and inversion. There is a pronounced hysteresis or memory effect accompanying any abrupt change in equilibrium conditions. This latter characteristic can cause loss of tracking and timing for many magnet pulses following a fault in the motor-generator excitation equipment. Such faults trip a shorting switch across the magnet, causing the magnet current to decay exponentially, rather than approximately linearly with time. This change in excitation causes a large enough change in the ferromagnetic state of the iron to preclude correct injection timing and beam tracking immediately following a fault. The difficulty may persist for as many as ten magnet pulses.

Measurements have been made of the magnitude and reproducibility of the residual field between magnet pulses. Figure 8 shows the time variation of the residual field. These data correspond to a peak current of 2000 amp and a pulse rate of 17 pulses per min, and were obtained by sweeping the

Table I

Ignitron fault rate

	5 to 7 pulses per minute						7 to 10 pulses per minute						10 to 17 pulses per minute					
	1500-6000 amp			6000-8000 amp			1500-6000 amp			6000-8000 amp			1500-6000 amp			6000-8000 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

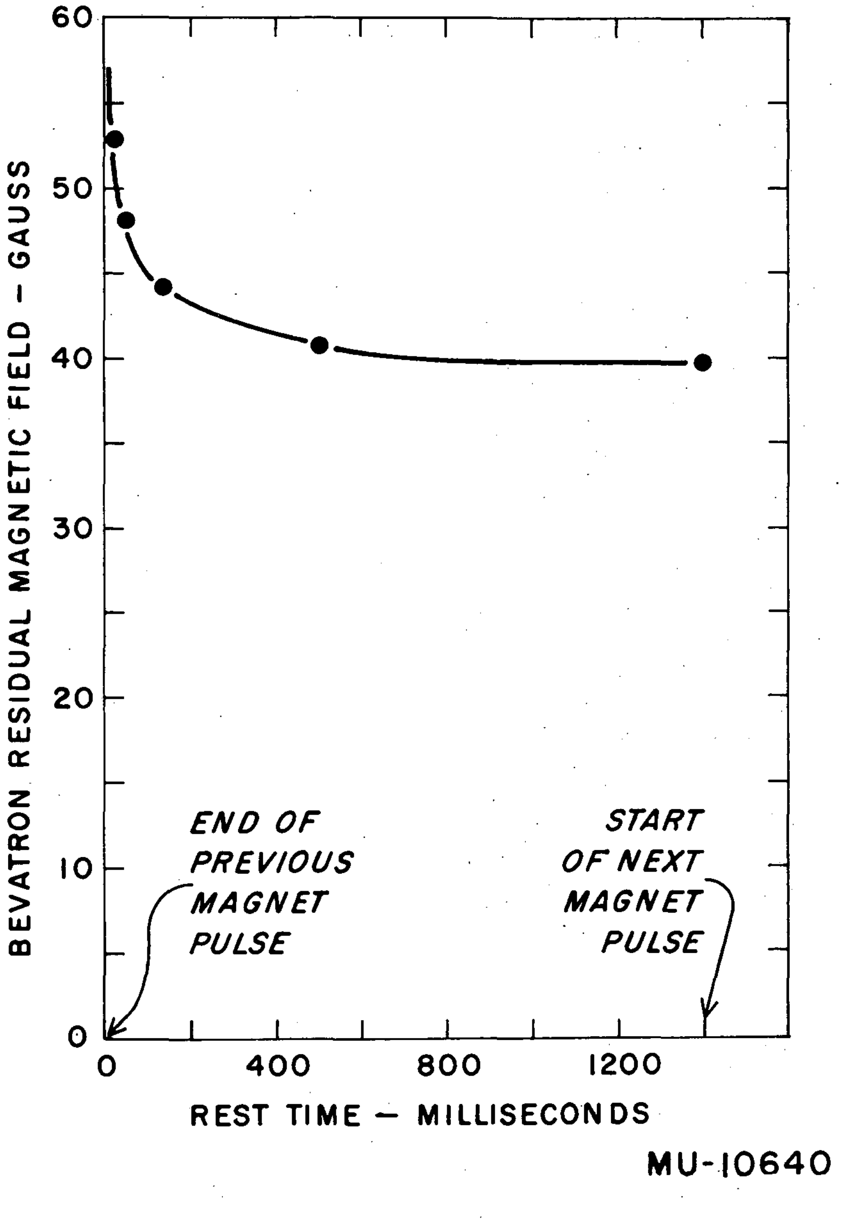

Fig. 8. Time variation of Bevatron magnetic field as measured in peaking-strip well in northeast quadrant. Magnet pulsing continuously to 2000 amp at 17 pulses per minute. Magnet excitation voltage 16.05 kilovolts.

peaking-strip regulator at a 60-cycle rate. Note the decay of residual field is neither a simple exponential nor a power-law function. For the conditions of this observation, the average magnitude of the residual field at the start of magnet excitation was39.90 ± 0.04 gauss. The maximum observed fluctuation from this value during ten consecutive pulses was 0.11 gauss, corresponding to a variation of approximately 0.3%. This fluctuation in residual field represents a fluctuation in the injection field of approximately 0.04% and a corresponding change in the start frequency of

$$\partial \omega = \partial B \left(\frac{\frac{\Delta \omega}{\Delta t}}{\frac{\Delta B}{\Delta t}} \right) = 0.111 \left(\frac{597.9 \times 10^{3}}{212.2} \right) = 126 \text{ cycles}$$

or a relative change of $\left(\frac{\partial \omega}{\omega_{\text{rf on}}} \right) = \frac{126}{3.58 \times 10^{5}} = 3.5 \times 10^{-4}$ or 0.035%.

The actual fluctuation in start frequency due to the variations in the residual magnetic field of the Bevatron magnet will be less than this when the master oscillator tracks on the magnet current, as the magnet-current and magnetic-field fluctuations give rise to frequency fluctuations which are correct to first order. This accounts for the difference between the calculated fluctuation in start frequency, 0.035%, and the measured value, 0.01%.

It is worth noting that if the frequency tracked the field directly through the use of an integrated B signal, this error would be further reduced. One would never expect this error to become zero even with an ideal integrator because of the type of frequency-tracking elements being used. Despite temperature regulation and degaussing, the ferroxcube elements in the master-oscillator reactors do have ferromagnetic properties that give rise to residual field effects. The properties of this core material will ultimately limit the accuracy of the field-tracking system.

More residual-field measurements will be made to include the variation of residual field with (a) magnet current (b) magnet pulse rate and (c) rate of change of residual field immediately following a fault. At the time of these measurements it was only necessary to determine whether or not fluctuations in residual field were causing such errors in injection timing and rf tracking as to result in substantial beam loss. It was obvious from the above data that this was not the source of trouble.

BEAM LOSS

For several days after the June 20 shutdown the beam amplitude remained small, but not inconsistent with the peak amplitude of the injected beam and the average pressure in the Bevatron vacuum liner. When the beam intensity did not increase as the vacuum improved, an intensive search was begun to determine the cause. Two separate effects were observed which correlated with beam loss. There was an effect associated with the pulse-repetition rate and peak current of the magnet. There appeared to be an optimum set of magnet-pulsing conditions that would permit the acceleration of the largest fraction of injected beam. During the next two weeks a large number of careful measurements were completed, and two sources of random beam loss were found. One was due to incipient breakdown of one of the spark gaps, which protect one of the magnet-current shunts. The other was due to a random overshoot of the magnet-excitation voltage at the start of a magnet pulse. This trouble was traced to the electronic ripple synchronizer of the main motor-generator units.

Continued measurement of all of the electrical parameters did not reveal any significant variations from normal operation that would cause a repetition-rate effect. The order of accuracy in these measurements was $1/10^4$ in most cases. It was established that there was an optimum phase of the magnet-voltage ripple that corresponded to the capture of the largest fraction of the beam. There did not appear to be very gross errors, that is, in excess of 1/2%, in the magnetic field at injection time. The survival of the beam after initial acceleration indicated that no serious errors existed in the field-gradient or frequency—field-tracking relation. After exhaustive measurements of all electrical parameters had given negative answers, the Bevatron was shut down and opened for inspection. Every portion of the aperture was checked for obstructions before and during magnet pulsing. A lamp bracket was found in the west straight section which interfered by 7/16 inch with the projected position of the outermost edge of the inflector in the east straight section. The only portion of the beam that could miss this bracket during injection would be that portion whose betatron amplitudes precessed around the obstruction. The sensitivity of the beam to magnet-ripple voltage was explained by the effect of the magnetic-field ripple in causing some of the circulating beam to miss this obstruction. The bracket was repositioned, and when the Bevatron vacuum liner was pumped down again, full beam amplitude returned.

DEVELOPMENT

Analogue Computer

An extremely simple analogue computer has been devised to synthesize the error signal required of the 30-point curve corrector. This analogue device consists of three multivibrators and appropriate resistor-condenser networks which generate the approximate error signal for the master-oscillator bias supply. When triggered at the appropriate magnet current from a peaking transformer, the computer generates a time-dependent signal, independent of the magnet current or magnetic field. The approximation of the error signal of the 30-point curve corrector was synthesized in three steps by the time constants of the three multivibrators, each of which is amplitude-independent to first order.

Whereas this unit was originally developed to be used in conjunction with the 30-point curve corrector, it now virtually replaces this item unless special beam steering is required. The original curve corrector, mostly because of its electronic complexity, has been a source of considerable loss of operating time and sometimes a source of poor operation. The relative merits of these two units are compared in Table II.

Table II

Comparison of Merits of Tracking Units

30-Point Curve Corrector	Analogue Computer
1. Stability a function of peak magnet current.	1. Stability independent of magnet current.
2. Adjustments not sufficiently reproducible on day-to-day tuning.	2. Adjustments easily reproducible.
3. Thirty adjustments required for good tracking.	3. Three major and 5 minor adjustments permit good tracking.
4. Introduces switching transients.	4. No switching transients.
5. Requires all 30 current marks plus reset trigger for operation.	5. Independent of current marks. Triggers on one peaking transformer.
6. Permits control of beam position at 30 current increments.	6. No control of beam steering except at 3 points.

Increase in Acceptance Time

A preliminary theoretical investigation of the variation of acceptance time with rate of rise of Bevatron magnetic field indicated that one could expect to increase the amount of injected charge in the machine if the rate of rise of field were reduced. This was experimentally verified early in this quarter. An over-all reduction in the rate of rise by a factor of 5 to 8 was produced by causing half the tubes in each ignitron bank to rectify while the others were inverting. The conduction angle of the grid voltage on the ignitrons could be continuously varied so as to produce almost any desired rate of rise of field. In order to investigate the increase in acceptance time, the injection timing was varied throughout the period of low rate of change of field. It was found possible to inject and pick up the beam at periods of the order of 5 to 8 times the initial acceptance time of the machine.

There is one major engineering problem that must be solved before this technique can be utilized to its full advantage. Partial rectification and inversion caused an unduly large six-phase ripple current to appear in the magnet. The resulting ripple in magnetic field causes the gross beam position to vary within the aperture, and, therefore, causes some beam loss on the inflector. Several schemes for reducing this ripple are now under study.

There are several important advantages, in addition to a longer acceptance time, to be gained by control of magnetic-field rate of rise. The rate of change of field might be programmed in a nonlinear fashion in order to damp oscillations. If the phase-oscillation amplitudes in the circulating beam are driven at a time when the magnetic field is held at a constant value, an essentially monoenergetic beam can be caused to strike a target over a period of 100 to 200 milliseconds.

Self-Tracking Experiment

A preliminary model of a new automatic beam-tracking scheme was tested. This system was designed to give arbitrary beam positioning at arbitrary times during the acceleration cycle. In addition, it was to be capable of handling beam pulses of varying amplitude. Radial-position information was obtained from the split-induction electrodes in the south straight section. These radial-position signals were amplified separately and peak detected, and their difference was taken. The peak-detected signals were crossed and used to control the gain of the amplifiers for opposite electrodes. The difference signal was used to phase-modulate the bias supply of the master oscillator, thereby providing automatic frequency correction.

Beam was tracked to full energy with this device with no loss in amplitude that could be traced to the tracking system. The loop on the synchrotron oscillations was not closed, so that phase errors in the rf system were not corrected. By a change in value of program bias, the beam was shifted to any desired position within the good-field portion of the magnet aperture. Variations in beam amplitude of 20:1 did not affect the tracking, but it was evident that an amplitude range of 1000:1 would be desired if this unit were used to conjuction with the relay-controlled operation selector. Construction of a unit to permit this much larger beam-amplitude variation will be started in the immediate future.

RADIATION

Figure 9 shows the results of a preliminary survey of the fast-neutron flux in the Bevatron building (neutrons with energy between 0.25 Mev and 20 Mev). The numbers give the flux in Mev/cm^2 sec. The currently accepted tolerance is 20 Mev/cm^2 sec for a 40-hour week. These measurements were made over a period of six months under varying conditions of beam energy, intensity, repetition rate, targets, etc. The measured fluxes have been extrapolated to a common value of energy, intensity, and repetition rate. It is these extrapolated values that are shown. As yet, the effect of using different targets has not been studied.

Radioactive Targets

During the close of this quarter, the peak and average intensities of the Bevatron were higher than they have ever been before. The integrated beam intensity over a two-hour period on one run was of the order of 1.3×10^{13} protons.

Radiation Interlocks and Warnings

Radiation warning and personnel protection have been improved by the installation of radiation-interlocked physical barriers in those areas where

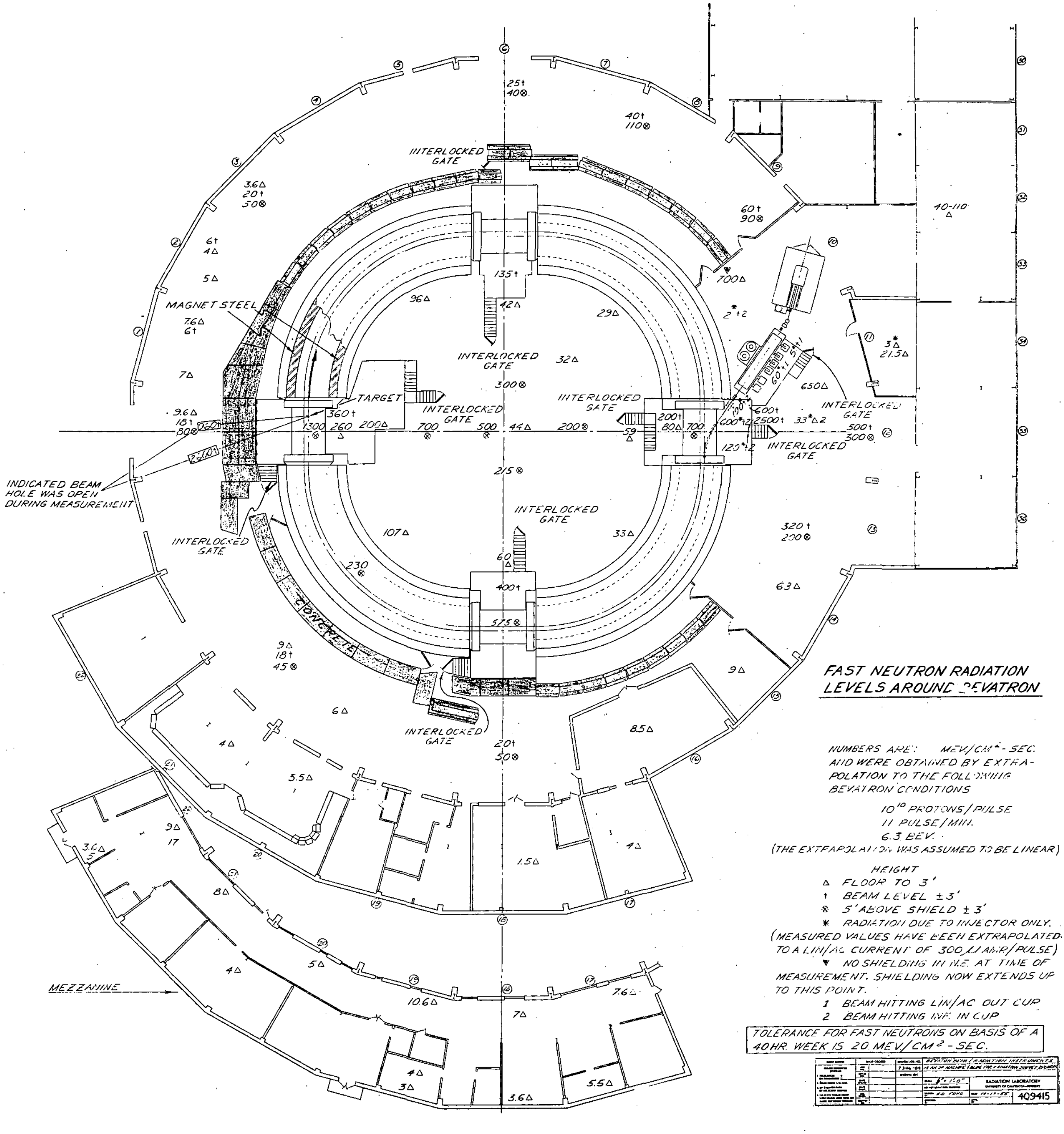

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Fig. 9. **Fast-neutron radiation levels in the Bevatron building.**

the fast-neutron flux is high. This keyed system provides a double interlock which can operate from the main control room, as well as at the entrance to each restricted area. Both interlocks turn off the high-level rf to prevent acceleration.

BEVATRON SHUTDOWNS

The Bevatron was shut down for installation of new equipment, for repairs, and for maintenance from April 26 to May 2, from June 20 to June 27, and on July 12. A large number of repair and maintenance jobs were completed which were necessary to keep the Bevatron in operating condition and to improve its reliability. In addition, the new shielded induction electrode was installed in the east straight section, and the variable-radius plunging meson target. Pier foundations were poured for a new heavy-duty west-inside-radius platform. Air locks were placed on the transition tanks on the outside radius of the west and north tanks. Liquid nitrogen traps were added to these units to further reduce pumping time of the vacuum envelope. After pumpdown, these locks may be used for the insertion of special target assemblies. Another flip target was added to the aperture during the June shutdown. Details of this target have been discussed above. The inner-radius cover plate of the west straight section was removed and surfaced to permit installation of the 9-by-13-inch air lock and new plunger mechanism. The 12-by-18-inch air lock was relocated and aligned, and now contains the earlier plunging mechanism. With these two facilities we can now make two bombardments successively and without long interruption of operations.

RESEARCH PROGRAM

As the result of a coordinated effort, twelve external and three internal groups obtained emulsion exposures in the $K^{\pm}$-meson beams of the Bevatron this quarter. Each exposure required between 3 and 8×10^{12} protons of equivalent Bevatron operating time. The arrangement of experimental equipment was exactly the same as described in detail by Birge, Haddock, Kerth, Peterson, Sandweiss, Stork, and Whitehead.[3] In brief, $K^{\pm}$ particles were observed at 90° to the target in the laboratory system. A magnetic quadrupole-lens set focused the $K^{\pm}$ particles which were collimated, and momentum was analyzed by a large pair-spectrometer magnet. Emulsions were placed on the exit side of the latter magnet. This experimental arrangement was also used by the Alvarez and Lofgren groups to investigate the K-τ-particle flux with photomultiplier counters. A complete outline of the experimental program appears in Table III, and a summary of operating time in Fig. 10.

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[3] Robert W. Birge, Roy P. Haddock, Leroy T. Kerth, James R. Peterson, Jack Sandweiss, Donald H. Stork, and Marian N. Whitehead, "Bevatron K-Mesons," Phys. Rev. 99, No. 1, 329 (1955)

Table III

Breakdown of Bevatron experimental time

INTERNAL GROUPS

Group Experimenters	Experiments
ALVAREZ	
Crawford, Good, Stevenson	Search for delayed particles K - τ counting
BARKAS	
Heckman, Smith	$K^{\pm}$-emulsion exposures $E_K = 92$ Mev
Inman	Capture of disintegration products in emulsions
LOFGREN	
Chupp, S. Goldhaber	$K^{\pm}$-particle-excitation function $K^{\pm}$-emulsion exposures $E_K = 84$ Mev
Horwitz, Murray, Wenzel	K - τ counting
Horwitz, Murray	$C^{12}(p, pn)C^{11}$ cross section
Horwitz, Murray	Transition curve for C with 6.0-Bev protons
Murray	Energy calibration of Bevatron
Crandall	Diffraction scattering of protons on C, CH_2, Al, and Cu
Cork, Wenzel	Absolute calibration of induction electrode
Cork, Wenzel	Proton-proton scattering, 1 to 4.8 Bev
Heard, Windsor	Automatic tracking, analogue tracking of Bevatron
Heard, Vogel	Increasing acceptance time of Bevatron
MOYER	
Brabant, Cence, Jester, Wallace	(n, γ) Reaction survey with total-absorption γ-ray Cerenkov counter
Bostick, Kaplan, Wikner	(π^-, p) Cross sections vs energy
POWELL	
Elliott, Fowler, Lander	π^-, K^- interactions in Pb in expansion cloud chamber

INTERNAL GROUPS

Group	Experiments
Experimenters	
POWELL	
Fowler, Maenchen, Wright:	p-p scattering of 5.5-Bev protons in 35-atmosphere diffusion cloud chamber
Fowler, Maenchen, Wright:	(π^-, p) interactions at 4.5 Bev
RICHMAN	
Birge, Kerth, Sandweiss, Stork	$K^{\pm}$-emulsion exposure
SEABORG	
Barr	Spallation products of Cu, Al
Benioff	" " Ta, Al
Grover	" " Ta, Al
Hyde, Barr	" " Cu, Ta, Al
Kalkstein	" " CH_2, Al
Shudde	" " U, Al
VAN ATTA	
Ise, Pyle	π^- total and differential cross sections vs Z
Ise, Pyle	$K^{\pm}$-meson search with cloud chamber
Ise, Pyle	n, p cross section
LIVERMORE FILM GROUP	
S. White	K^--emulsion exposure; 315-Mev/c momentum
S. White	Emulsion exposure to negative-particle flux from 8° target

EXTERNAL GROUPS

Experimenter	Experiments
Institution	
COCCONI	
Cornell University	$K^{\pm}$-emulsion exposure; E_K = 114 Mev
FRY	
University of Wisconsin	K^--emulsion exposure; E_K = 114 Mev $K^{\pm}$-emulsion exposure; E_K = 114 Mev

EXTERNAL GROUPS

Experimenter Institution	Experiments	
HERTZ		
University of Sydney Sydney, Australia	π^- exposure; p direct-beam exposure;	4.8 Bev 6.2 Bev
HILL		
University of Illinois	p direct-beam exposure	6.2 Bev
NEY		
University of Minnesota	$K^{\pm}$-emulsion exposure	
OREAR		
Columbia University	$K^{\pm}$-emulsion exposure;	$E_K = 114$ Mev
PEVSNER		
Massachusetts Institute of Technology	$K^{\pm}$-emulsion exposure;	$E_K = 84$ Mev
POWELL		
University of Manchester Manchester, England	K^+-emulsion exposure;	$E_K = 114$ Mev
PUPPI		
University of Bologna, Italy	K^+-emulsion exposure;	$E_K = 114$ Mev
TICHO		
University of California at Los Angeles	K^--emulsion exposure;	$E_K = 114$ Mev
YEKUTIELI		
Weizmann Institute, Israel	$K^{\pm}$-emulsion exposure;	$E_K = 84$ Mev
ZORN		
Brookhaven National Laboratory	$K^{\pm}$-emulsion exposure;	$E_K = 84$ Mev

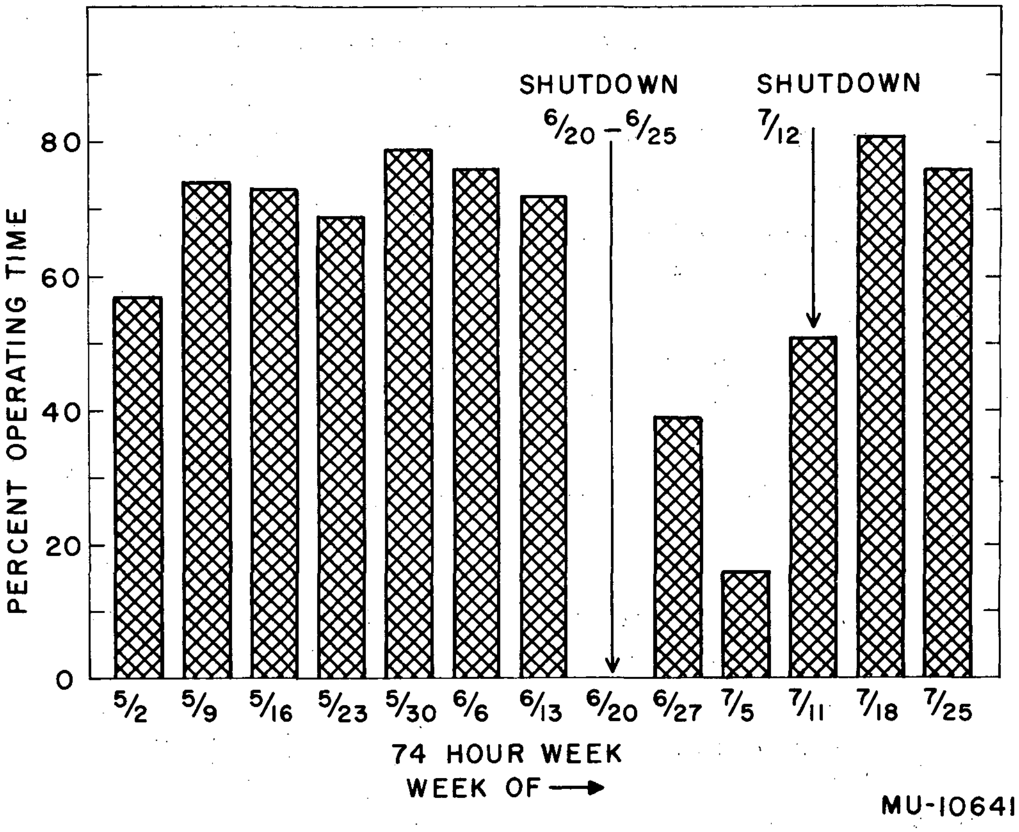

Fig. 10. Summary of Bevatron operating time, May, June, July 1955.

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The Bevatron operating group consists of Robert Anderson and Robert Richter as crew chiefs, and Duward Cagle, Frank Correll, Robert Gisser, William Kendall, Ross Nemetz, Howard Smith, Glen White, and Emery Zajec as crew members. The group leader is E. J. Lofgren, and under him Harry Heard, with Walter Hartsough assisting, is in charge of operations. Accelerator development was carried out by Warren Chupp, Bruce Cork, Harry Heard, Nahmin Horwitz, Joseph Murray, and William Wenzel. Engineering was done by teams headed by William Salsig (mechanical), Clarence Harris and Marion Jones (electrical), and Harold Vogel (magnet power supply).

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