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BEVATRON OPERATION AND DEVELOPMENT. I

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I. Injector

February 1953 - April 1954

Introduction

The bevatron requires an intense source of high-energy protons. The machine should accept monoenergetic protons for a duration of approximately 500 microseconds once every 6 seconds. To satisfy the requirements of small loss due to scattering by the gas in the accelerating chamber, a 9.9-Mev linear accelerator has been built and operated.[1]

A 500-kilovolt Cockcroft-Walton generator is used to inject 2 ma peak proton current into the linear accelerator. Focusing grids intercept approximately one-half of the injected beam. Additional losses, including radial defocusing and acceptance phase angle, result in a peak accelerated beam of 50 microamperes. The energy spread has not been measured but an upper limit is less than ± 30 kev.

The Cockcroft-Walton Generator

The original model of the cascade rectifier high-voltage generator was operated with the filaments and plate voltage supplied by two 60-kc oscillators. The unit was insulated by using oil-filled containers and cooled by circulating the oil. It was subsequently replaced because it was too complex for this application.

Since it is desirable that the stored energy of the high-voltage terminal be sufficient so that its potential remains nearly constant during the 500-microsecond pulse, larger coupling condensers should be used. This allows the plate voltage supply frequency to be lower. The generator now consists of 12 pairs of RCA 8013A air-cooled rectifier tubes arranged on lucite shelves, Fig. 1. The filaments of the rectifier tubes are heated by 60-kc power coupled through a ferroxcube-core cascade transformer. The plate voltage is supplied by an 800-cycle motor generator and is coupled through the pyranol condensers, each rated 20 kv, 0.25 microfarads.

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[1] Bruce Cork, The Bevatron 9.9-Mev Proton Linear Accelerator, University of California Radiation Laboratory Report No. UCRL-2385, June, 1954.

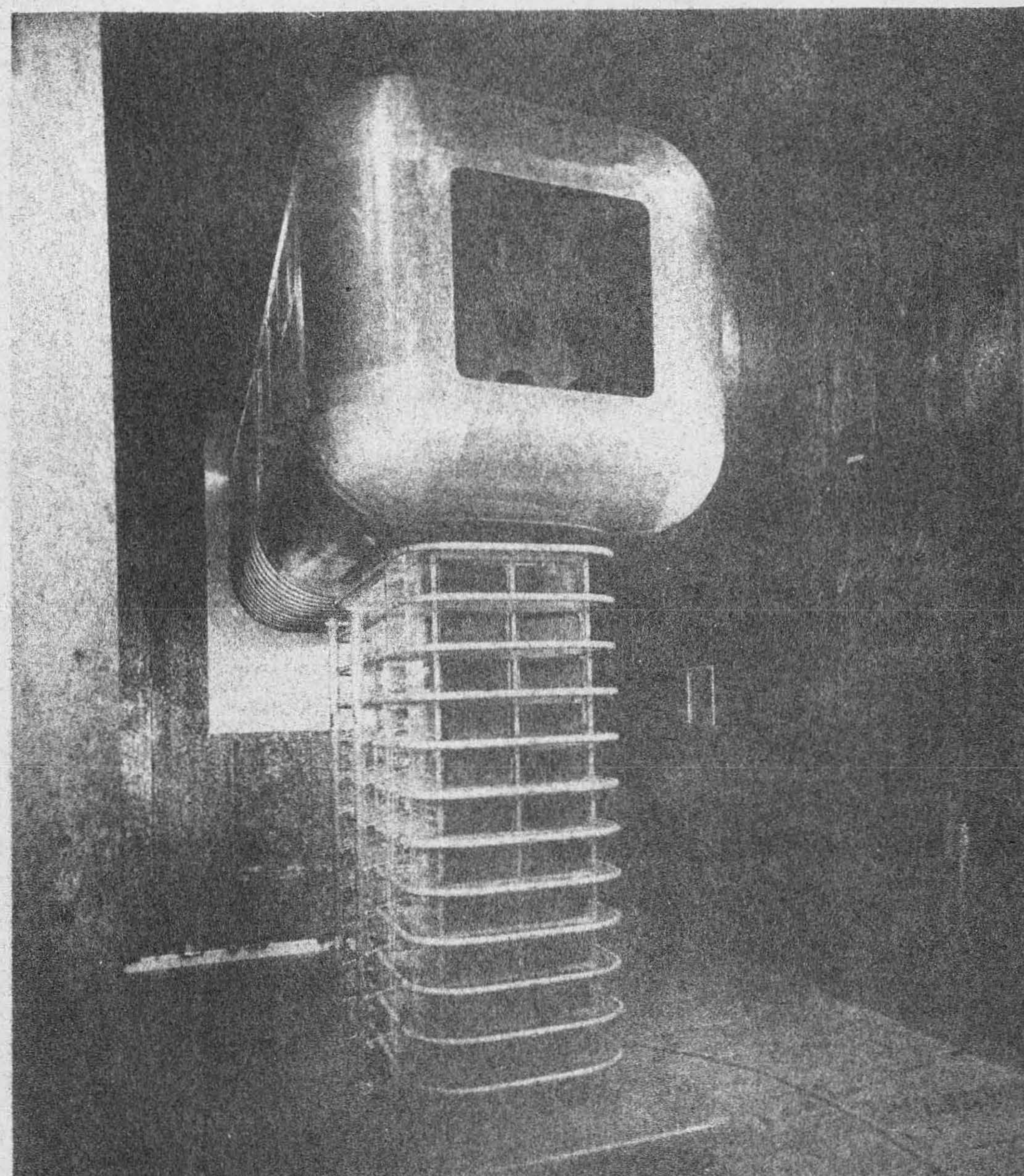

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Fig. 1. The 500-kilovolt Power Supply and High-Voltage Shell.

The ion source and power supplies are located inside a duraluminum shell 4 feet on a side and 6 feet long. The present source is a cold cathode, axial type, arranged to give 2 milliamperes of protons with 35 kev energy. The proton beam is accelerated along the horizontal accelerating tube which is 6 feet long and consists of 27 sections. The insulating sections are made of zircon and the accelerating electrodes are made of spun stainless steel.

The voltage is stabilized by obtaining a signal from a 2000-megohm resistance divider. This signal is used to regulate the field of the 800-cycle generator. Also, a signal can be applied to the grid of a 304 TH voltage-regulator tube arranged to raise or lower the potential of the entire stack of Cockcroft-Walton coupling condensers. This regulator has a response time of 50 microseconds, thus corrections can be made during the 700-microsecond beam pulse.

The Linear Accelerator

The proton linear accelerator has a cylindrical cavity 18.2 feet long and 42-1/4 inches in diameter. It operates in the axial electric (0, 1, 0) mode at 202.5 megacycles. The protons are injected along the axis and are accelerated as they cross the gaps between each of the 42 drift tubes, Fig. 2. The spacing between drift tubes is made equal to $\beta\lambda$ where β, the ratio of the velocity of protons to the velocity of light, is 0.030 at injection and 0.144 at the exit of the linear accelerator.

The entrance aperture of the accelerator is 1/2 inch in diameter; the exit aperture is 3/4 inch in diameter. To reduce the radial component of velocity of the proton beam, focusing grids are used. These are 0.002-inch-thick tungsten ribbons mounted on edge at the entrance of each drift tube.

The resonant cavity is mounted in a cylindrical vacuum tank 20 feet long and 54 inches in diameter. The tank is evacuated with a 20-inch-diameter mercury diffusion pump.

The peak power of 500 kw required to excite the cavity is supplied by three Eimac type 3W 10,000 A3 triode oscillators. An Eimac 4W 20,000 tetrode oscillator is now used as a preexciter. These oscillators are being developed by a group working with Jack Franck.

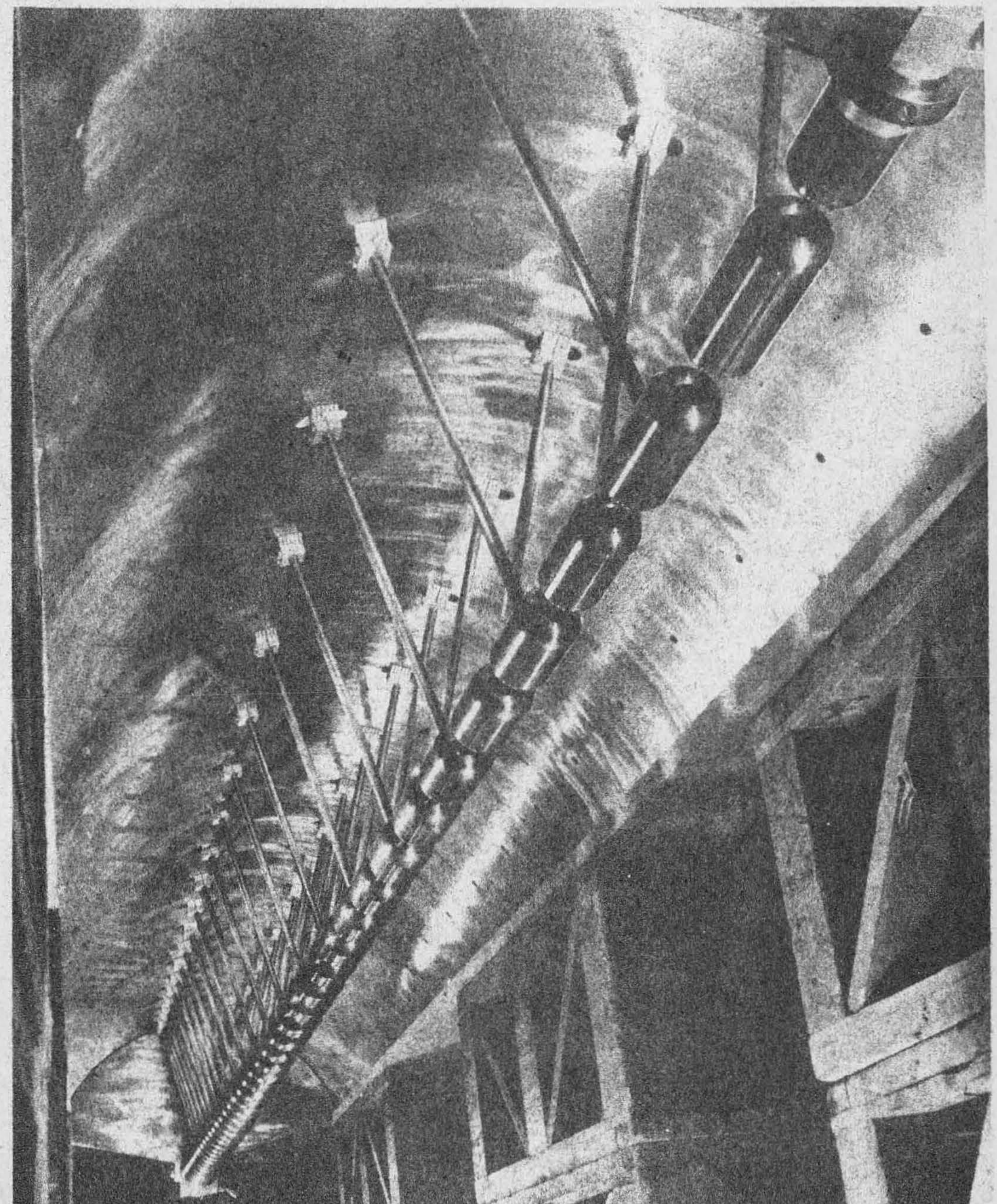

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Fig. 2. Axial Drift Tubes, Looking Toward the Entrance End.

Auxiliaries

To reduce the divergence of the proton beam, four magnetic quadrupoles[2] are located at the exit of the linear accelerator. These require a gradient of 700 gauss per inch and a power of 80 watts for maximum beam through the deflection plates at the entrance to the bevatron.

The electrostatic inflector deflects the proton beam through an angle of 35°, with a radius of curvature of 18 feet. The electrodes are 132 inches long, spaced with a gap of 7/8 inch, and require a potential difference of 78 kv to deflect the 9.9-Mev beam.

Operation

The 0.5-Mev accelerator was first operated during February 1953. Since the stored energy of the Cockcroft-Walton generator is so great, 2500 joules, no attempt has been made to spark it to ground. Surge resistors have been installed to limit the discharge current to 80 amperes, but the supply has never sparked directly to ground. On several occasions, the pressure in the accelerating tube has inadvertently been allowed to become great enough so that a glow discharge occurred. The accelerating tube was not damaged and no difficulty has been encountered in holding voltage.

The linear accelerator has been operated since May 1953. Although some initial sparking occurred at high level, no difficulty was encountered in building up radiofrequency voltage across the drift tubes. After a few hours' operation at slightly higher than optimum voltage gradient in the cavity, sparking is very rare at optimum gradient.

During the first few months of operation the accelerator was used as a source of 9.9-Mev protons for proton-proton scattering[3] and proton-alpha scattering experiments.[4] The machines have been very reliable,

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[2] Bruce Cork and Emergy Zajec, Quadrupole Focusing Lenses for Charged Particles, University of California Radiation Laboratory Report No. UCRL-2182, April 1953.

[3] Bruce Cork and Walter Hartsough, Proton-Proton Scattering at 9.7 Mev, University of California Radiation Laboratory Report No. UCRL-2373, October 1953.

[4] Bruce Cork and Walter Hartsough, Elastic Scattering of 9.7-Mev Protons by Alpha Particles, University of California Radiation Laboratory Report No. UCRL-2590, May 1954.

with approximately 50 hours' operation each week. The vacuum tank and cavity had not been opened for the first year after initial operation. Recently the cavity was opened to install new coupling loops for the new pre-exciter.

Measurements show that the optimum injected energy from the Cockcroft-Walton generator is 460 kv, rather than the design value of 450 kv. If the injection energy differs from the otpimum value by ±40 kv, the accelerated beam current is reduced to half value.

The energy of the accelerated protons was measured by scattering from helium through an angle of 30°. Measurements were made of the amount of aluminum absorber required to stop the scattered protons. The measured energy was 9.88 ± 0.1 Mev, and the energy spread was less than 0.1 Mev. Range straggling limited the accuracy of measurement of the energy spread to the above value.

The electrostatic deflection plates make the 35° inflector a very good energy selector. It is observed that twice as much beam strikes the central 1/4-inch strip of the faraday cup as strikes each 1/4-inch-wide strip on either side of the center. From this it is calculated that the energy spread is less than ± 32,000 volts.

During typical operation, the Cockcroft-Walton accelerator will give 2.0 milliamperes peak of accelerated protons. With this injected beam current, the accelerator will accelerate a peak beam current of 50 microamperes. The transmission of the focusing grids is estimated to be 50 %. Assuming no losses due to radial defocusing, the acceptance phase angle is then 20°. Measurements have been made to determine the synchronous phase angle by measuring the threshold value of the rf voltage on the drift tubes for full-energy acceleration. The ratio of this voltage to the value for maximum beam is approximately equal to the cosine of the synchronous phase angle. This measurement gives a synchronous phase angle of 25° or an acceptance phase angle of approximately 75°. Thus, an additional loss--probably due to radial defocusing--causes a further loss to approximately one-fourth of the expected current.

Some work is being done on a buncher to increase the acceptance phase angle. Also, work is being done on an improved ion source.

II. Operation

February - May 1954

Introduction

A description of the bevatron is not necessary here; the main features of the structure are evident in the figures. Figure 3 is a wide angle photograph taken from above the straight section which contains the inflector. Figure 4 is a schematic plan view which shows the relationship of the main parts. Figure 5 is a simplified cross section through the magnet. Note that the magnet pole tips are inside the vacuum tank and that the access space provides a place for the installation of target mechanism.

On February 2 beam was injected into the bevatron with a static magnetic field. It was detected on probes 180° around the machine. In subsequent steps multiple turns were observed, then the experiment was repeated with a dynamic magnetic field, and finally the accelerating rf was turned on. Acceleration for a few milliseconds was accomplished on February 15. A succession of improvements in timing, frequency control, detection instrumentation, and operating technique was reflected in increasing beam energy until a maximum of 6.1 Bev was reached on April 1. A week later a short circuit occurred in the stator windings of one of the generators, and there has been no operation since then.

Operation

The accelerated beam was detected on a scintillator-photomultiplier probe inserted radially into one of the straight sections from the inside of the magnet (See Fig. 4.) The observed general characteristic as shown in Figure 6, is a continual loss of beam during acceleration and a final burst which spirals into the probe about ten milliseconds after the accelerating rf is turned off. Induction electrodes, which pick up a signal from the circulating bunch of protons, were also used. This is an extremely useful signal because it does not require interception of the beam. However, the steady attrition of the beam made this signal useless for energies higher than 0.35 Bev.

Nuclear emulsions have been inserted into the beam, and from them it is possible to estimate that there are 10^5 or 10^6 protons per pulse.

No proven explanation for the beam loss has been found. A careful study of the rf system was just getting under way at the time of the generator

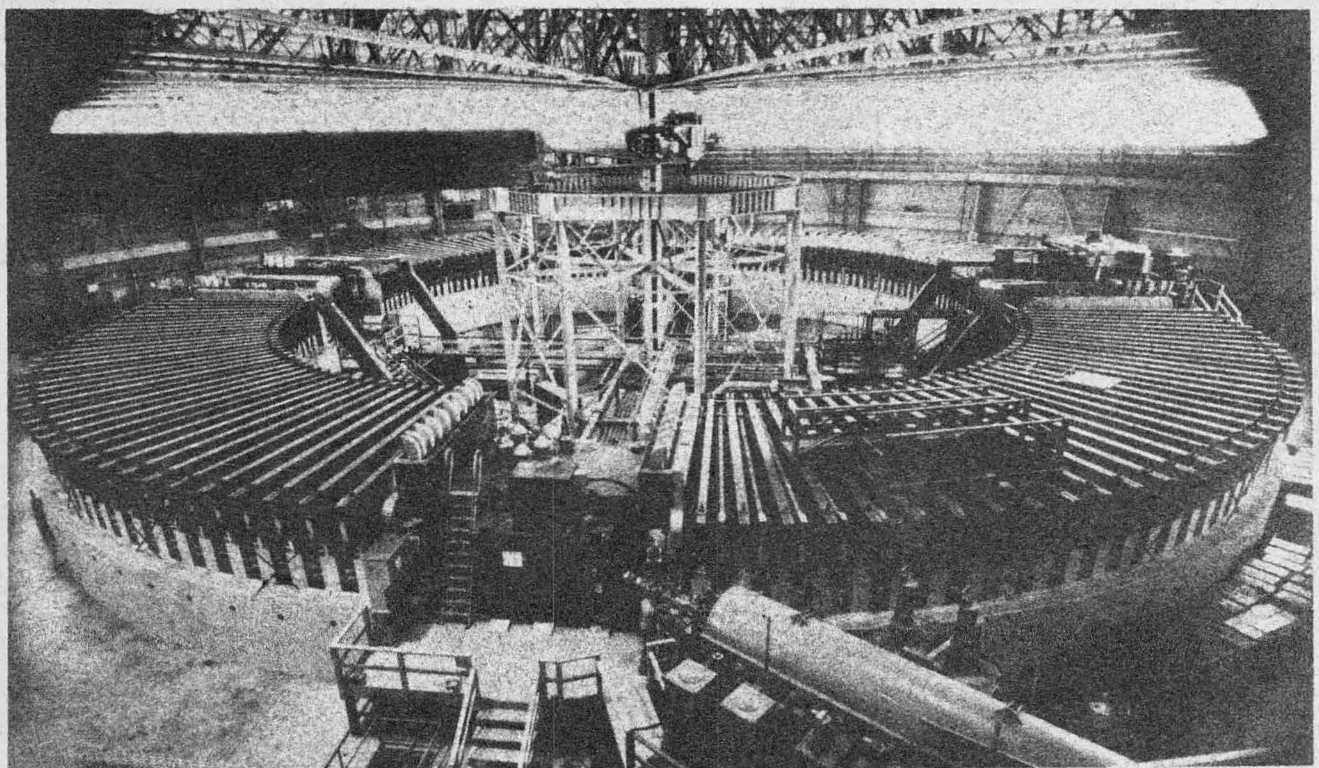

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Fig. 3. General View of the Bevatron. Injector in the foreground.

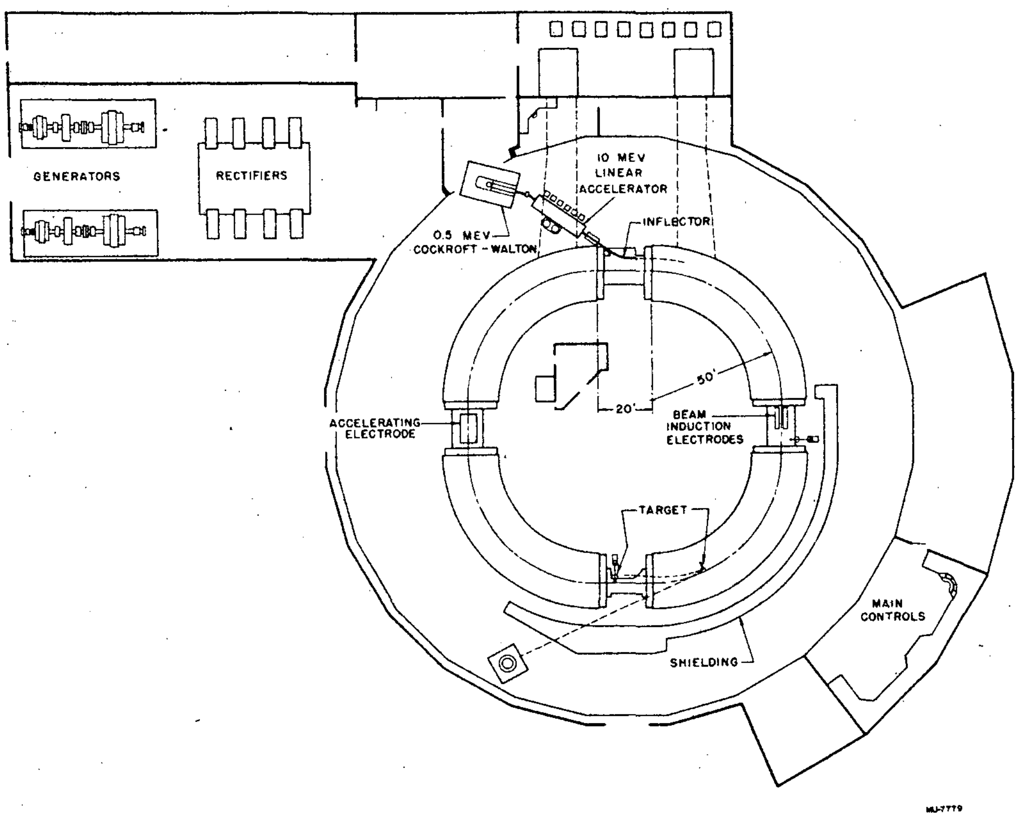

Fig. 4. Schematic plan view.

failure. Some improvement had been made by diminishing an extraneous modulation which was found on the rf at the power amplifier. However, the attrition was still greater than expected by a factor of 100, and the possibility of troubles other than rf was actively investigated. The vacuum is about 10^{-5} mm, and with injection at 10 Mev only about 20 percent of the beam should be lost because of scattering. The alignment of the magnet was also checked, with interesting results, as given in the next section.

Magnet

When the magnetic field was measured in October-November 1953, the median plane of field coincided with that of magnet to within 0.1 inch. During operation, however, it was shown by the use of aperture-defining vanes that the beam position was about 3/4 inch above the geometric median plane. This experiment was done at the injector straight section. A survey was then made of the relative elevation and slope of each sector of the magnet. It was found that the western half of the magnet had settled by an amount up to about 5/8 inch. This is the region adjacent to which the caissons for the shielding foundation had been drilled. The magnet has been realigned to about 1/10 inch by using the foundation jacks provided for that purpose. It remains to be determined by operation whether or not any beam loss was caused by the lack of a flat field.

Magnet Power Supply

On April 7 a generator fault occurred during single-generator operation which resulted in a small fire at one end of the stator windings. Inspection showed that in addition to the burned area at the end there was a short to the stator laminations near the center of one slot. Repair required the replacement of 10 coils and the removal of fused portions of stator laminations. The bearing alignment of the machine was also corrected when a check showed it to out by about 5 times tolerance. A magniflux inspection of the high-stress regions of the shaft showed no damage. The repairs to the rotation machinery were largely completed by the end of May.

Before the fault it had become increasingly apparent that something might be wrong with the power supply other than the inevitable need for operational adjustments. During the period of magnetic field measurement, November-December 1953, there were 7605 pulses with 31 faults of all kinds, or 245 pulses/fault. During the period of operation, February-April 1954, there were 219,107 pulses on runs when the current never exceeded 1600 amp. There were 67 faults or 3270 pulses/fault. During the same period there were 53,088 pulses on days when at some time the current exceeded 1600 (but usually not equal to the 8000 amp rating) with 89 faults. The rate was 600 pulses/fault. Not more than 1 fault in 5000 pulses at full load should be expected.

Test operation of the remaining generator after proper monitoring equipment had been installed showed that there were spikes of about 9 kv with a rise time of 1.5 μsec at the generator connections. These rise times are considered excessively short by Westinghouse, and surge capacitors have been installed that increase the rise time to about 10 μsec.

In addition, surges of about a thousand volts have been observed on the grids of the ignitrons. They are known to cause failure of the associated rectox units and it is believed that they may be due to high ignitron pressure. Several steps have been taken to correct this situation. First, the cooling water system, which has always been heavily loaded with rust, has been purged and a deoxygenator has been installed. Second, the ignitrons have been carefully checked for leaks, which in some cases were repaired here but which in 5 cases were in the anode seal and required factory work. These have not yet been returned. In addition about half the ignitrons have an excessive rate of rise of pressure, even though no leaks have been found. It is believed that they are gassy due to insufficient bakeout, either at the factory or at installation. We are therefore carrying out an extended program of outgassing. The vacuum pumps are being cleaned to bring them up to specified pumping speed.

Extensive checks are also being made of the ignitron control circuits. This work is not yet complete.

The bevatron group consists of Duward Cagle, Warren Chupp, Bruce Cork, Robert Gisser, Walter Hartsough, Harry Heard, Marjorie Hirsh, E. J. Lofgren, Ross Nemetz, Robert Richter, Howard Smith, William Wenzel, Glenn White, and Emergy Zajec. The engineering work closely associated with operation has been carried out by groups headed by William Baker, C. A. Harris, D. A. Mack (electrical), and William Salsig (mechanical).

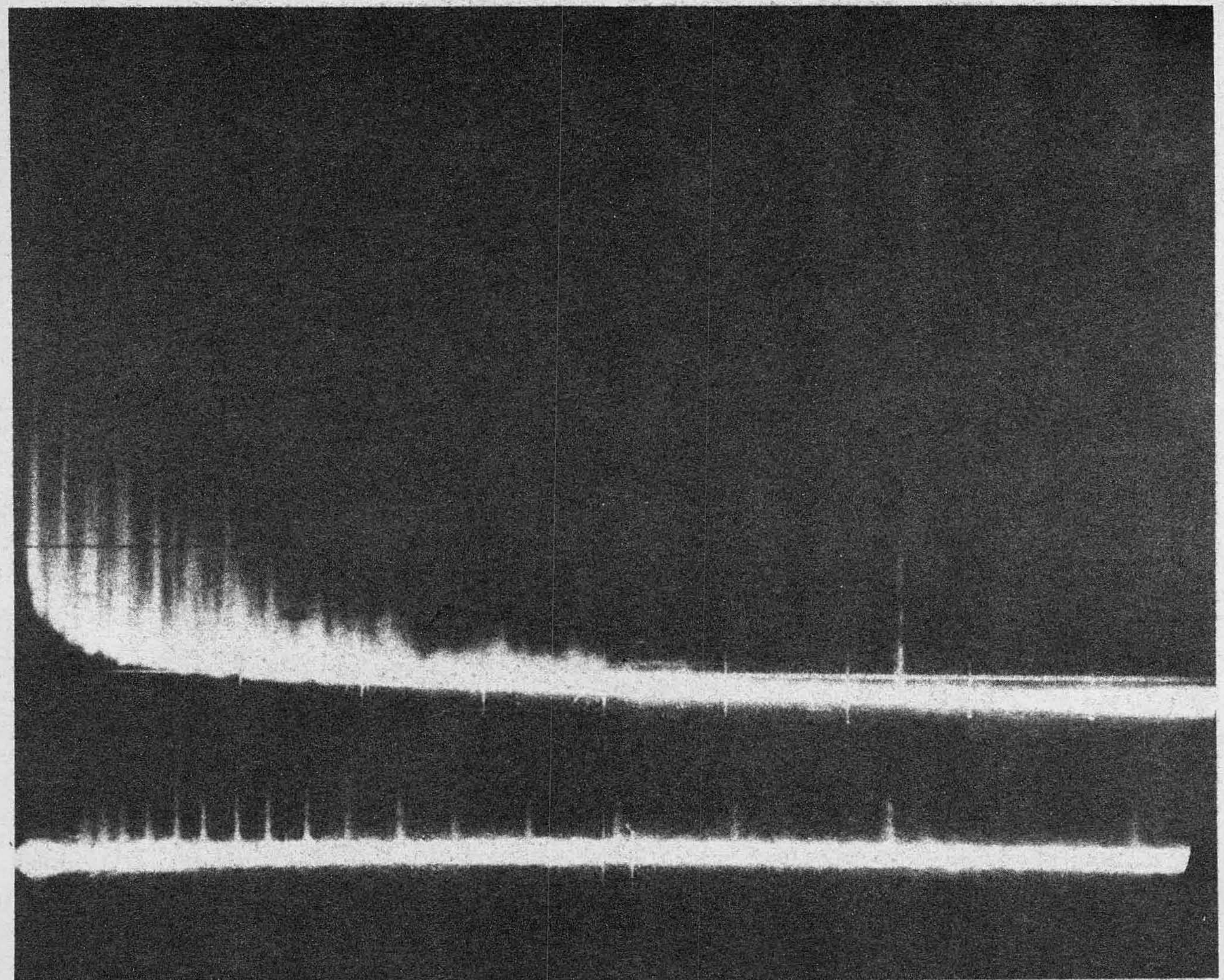

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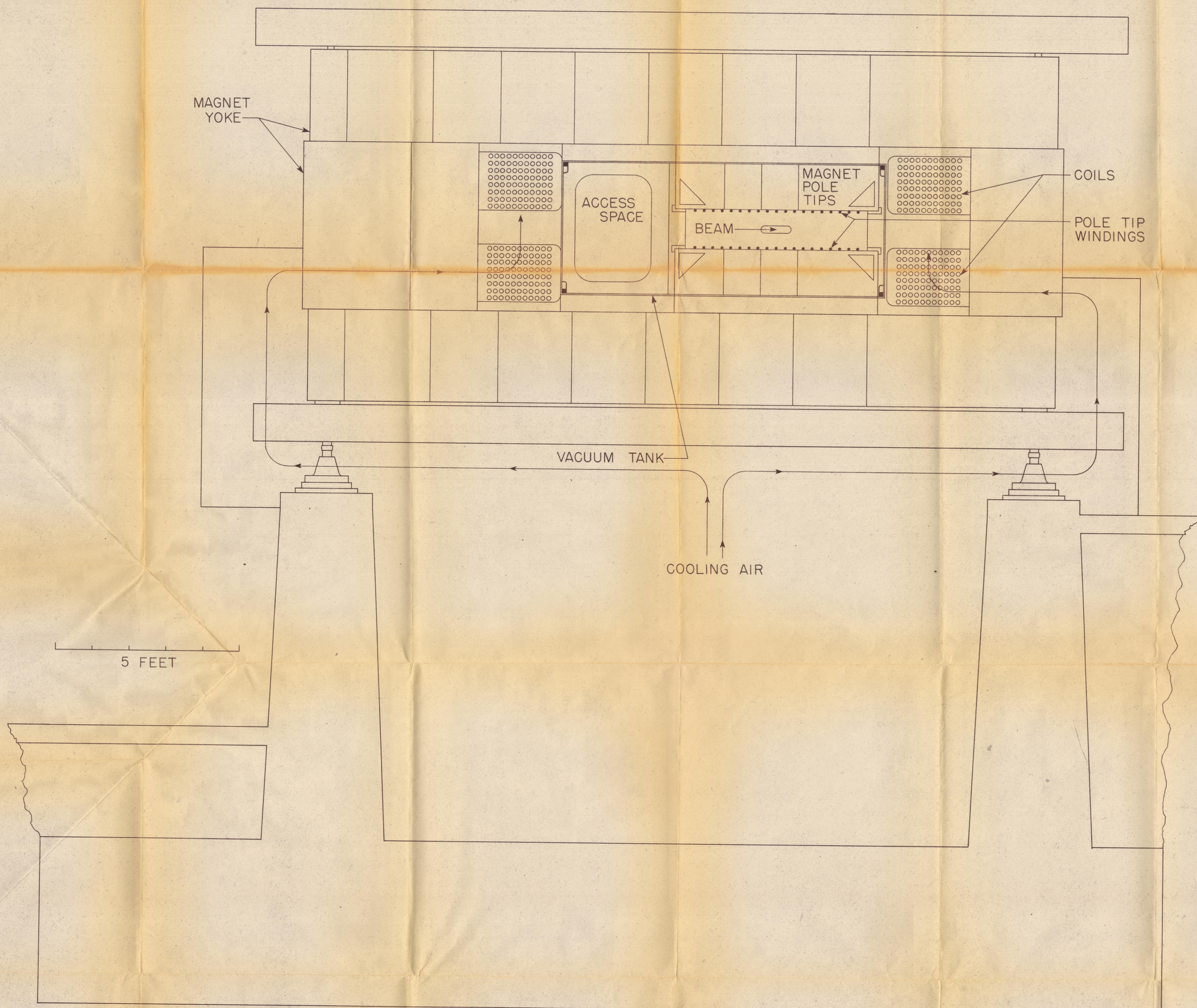
Fig. 6. The upper trace shows the beam intercepted on a scintillator-photomultiplier probe. The left portion is beam spilled out during acceleration. The spike at the right is the beam which spirals into the probe after the rf is turned out. The lower trace are markers of discrete values of magnet current, which provide a measure of the energy of the beam indicated on the upper trace.



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