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Operation of the 1/4 Scale Model Bevatron V.

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E. J. Lofgren

October 25, 1949

Berkeley, California

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OPERATION OF THE 1/4 SCALE MODEL BEVATRON, V

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By the end of August most of the urgently required answers had been given by the 1/4 scale Bevatron and operations were reduced to one shift. By October 18 regular operations were discontinued. During this final period the most important work was in connection with the new r.f. system including the effect of r.f. rise time. Measurements were made of the frequency of the betatron oscillations. Previously reported data such as the effect of tank pressure on beam were extended and improved.

Radio Frequency System

The new accelerating system consists of an oscillator with a ferroxcube reactor driving a self tuning 200 watt amplifier. The oscillator is mounted at the magnet shunt and the reactor is immersed in a constant temperature oil bath. A manganin wire of 0.06 ohm shunted by wires of higher resistance makes a single loop through the ferroxcube core and is connected directly across the 0.001 ohm magnet shunt. The fraction of the magnet current in the manganin wire provides a reactor saturating flux varying with magnet current. The slope of this variation and its linearity is adjusted by changing the effective resistance of the manganin wire and the L - C ratio of the oscillator. The correct starting frequency is achieved by adjusting the constant current through an auxiliary saturating winding. In addition corrections can be made to the frequency curve if necessary by currents through this auxiliary winding derived from the magnet shunt. These corrections may be of the order of 5 percent. The acceleration voltage may be varied up to 1900 volts peak and a modulated power supply permits changing the rise time and shape of the r.f. envelope.

The essential difference between this and the old system is that here a portion of the magnet current directly links to the oscillator reactor and only a correction is derived from a shunt voltage amplifier. In the old system the entire saturating current was derived from such an amplifier. In operation this results in very much greater stability. In fact the beam may be obtained in the morning without any adjustment of the previous day's settings.

R. f. Rise Time

We have varied the initial shape and rise time of the r.f. envelope and have found that there is an optimum shape. It was possible to vary the rise time from 50 μs to several ms and to have a linear rise, a convex curve, or a concave one. The latter with a rise time about 825 μs as shown in Fig. 1a gave a beam 75 per cent greater than any other shape. All other shapes gave the same beam to about 10 per cent, but one shape, Fig. 1b, was used as the standard of comparison. If the controls were optimized with the standard shape and then the concave shape introduced the only significant change required was that the time from the start of injection to r.f. on had to be decreased by 460 μs from 1275 μs. The steep rise in the latter part of the curve was essential. Variations of more than ± 5 percent in rise time would cause a discernible loss of beam.

R. f. Voltage

In Fig. 2 the beam normalized to the value at maximum voltage is given as a function of r.f. volts. The tank aperture was 6 in. x 18 in. The threshold is 600 volts which is in poor agreement with the calculated value of 390 volts based upon a measured initial rate of rise of magnetic field of 4.3 gauss per millisecond and 8.8° between accelerating gaps. In this experiment the r.f. rise time curve had been adjusted to the optimum shape described in the previous section at the higher voltage. This shape may not have been optimum at the lower voltages and may have caused the disagreement. The flattening off at 1400 volts was observed on other occasions and is not a function of rise time curve at all.

Pressure Effects

Investigations of the variation of beam with pressure at several final energies and for two tank apertures have been completed. The pressures are averages of the readings of Western Electric ion gages in each of the four pump manifolds using a calibration of 10^{-4} mm. per μa at 1.16 ma. emission in the large aperture case and 10^{-5} mm. per μa at 11.6 ma. in the small aperture case. The charge in the accelerated beam is measured with an integrator of time constant 60 ms. The curves are given in Fig. 3 and the pressures to reduce the beam to 1/e are given below in Table I.

Table I

Aperture in inches	6 x 18	9 x 26
Energy		
2 1/2 Mev	$2.0 \cdot 10^{-6}$ mm.	$2.8 \cdot 10^{-6}$ mm.
4 Mev	$1.8 \cdot 10^{-6}$ mm.	$2.1 \cdot 10^{-6}$ mm.
6 1/2 Mev	$1.7 \cdot 10^{-6}$ mm.	$1.7 \cdot 10^{-6}$ mm.

Betatron Oscillations

H. R. Crane has measured the oscillation frequencies of the injected beam in his synchrotron by applying a perturbing r.f. field perpendicular to the beam. At certain frequencies the amplitudes of oscillation are built up and the beam is lost. We have carried out the same experiment using 18 inch square plates 7 inches apart placed above and below the beam to excite the vertical oscillations and 18 inches long by 6 inch high plates 19 inches apart to excite the radial oscillations. We could apply up to about 1200 volts r.f. at an adjustable frequency to these plates. At first the perturbing oscillator was left on at an arbitrarily set frequency and as the free oscillations passed through this frequency the beam was lost if the vertical mode was excited or driven more rapidly into the collecting probe if the radial mode had been increased. There were also complicated weaker harmonic responses. Later these were avoided after finding out approximately what the fundamental frequency was and pulsing the perturbing oscillator on just before the expected response.

Since the oscillating ions are rotating with a frequency, f, one would expect perturbing frequencies, $f_p = f \pm f_{v,r}$ where $f_{v,r}$ stands for vertical or radial oscillation frequency. In 12 separate determinations at 7 different perturbing frequencies applied in the radial direction we found that $f_p/f = 0.319 \pm .023$ r.m.s. In 8 determinations at 4 different frequencies applied in the vertical direction we found $\frac{f_p}{f} = 0.143 \pm .005$ r.m.s. For the vertical oscillation we also have one perturbing frequency for which $\frac{f_p}{f} = 1.86$.

From the relation between perturbing, rotational, and oscillation frequencies we can tabulate the ratios $\frac{f_r}{f}$ and $\frac{f_v}{f}$, as shown in Table II. The theoretical values were calculated by Lloyd Smith.

Table II

	Measured	Theoretical value	Theoretical value not including effect of stray field
$\frac{f_r}{f}$	0.68 ± .02 r.m.s. deviation	0.67	0.71
$\frac{f_v}{f}$	0.857 ± .005 r.m.s. deviation	0.86	0.875

Sensitivity to Controls

The experiment to determine the sensitivity of the beam to the controls which was briefly described in the previous report has been carried out with the smaller aperture, 6 in. x 18 in., and has been extended to include the slope of the frequency-magnetic field relation. In every case after an optimum beam accelerated to about 6 Mev was obtained a single control was changed in each direction until the beam was reduced by a factor of two. The results are given in Table III.

Table III

Control	Nominal Value	Change to reduce beam to 1/2
Inflector voltage	25.2 kilovolts	± 2%
Peaking transformer signal to injector	Triggers at 540 amperes	+ 0.19% - 0.22%
Time of r.f. on after start of injection	1.28 ms	+ 24% - 19%
Starting frequency	380 K.c.	+ .32% - .34%
Slope of the frequency-magnetic field curve	1160 c.p.s./gauss	+ .82% - 1.07%

As noted in the section on r.f. rise time the nominal value of the r.f. on time is a function of rise time curve shape. The observations here were made with a linear rise about 300 μs long. In the last entry the nominal value of slope is calculated from the orbit dimensions. The changes were determined by measuring the differences in magnet current at which the oscillator went through a frequency of 1 megacycle as the slope was moved from optimum to values on the high and low side giving one-half the beam. It should be emphasized the good operation requires tolerances about 1/4 as great as these half values.

Efficiency

The largest beam which has been accelerated to 6 Mev with a 6 x 18 inch tank aperture is $3.5 \cdot 10^{-11}$ coulombs. The injected beam measured at the exit of the inflector (see UCRL 452, Fig. 3, for its dimensions) is about 11 μa for 850 μs or $9 \cdot 10^{-9}$ coulombs. The particle efficiency of the machine is therefore about 1/3 percent. Since in the final Bevatron the injection energy will be high enough (about 10 Mev) to make scattering losses negligible and since the inflector tip need not increase in size while the linear dimensions of the aperture go up by a factor 4 it is not unreasonable to expect a particle efficiency of the order of several percent.

The operators during this period consisted of E. Lofgren, D. Nielson, R. Richter, R. Robertson, and D. Sewell. The new radio frequency system was developed and installed by W. Baker, Q. Kerns and J. Reidel.

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R.F. RISE TIME CURVES

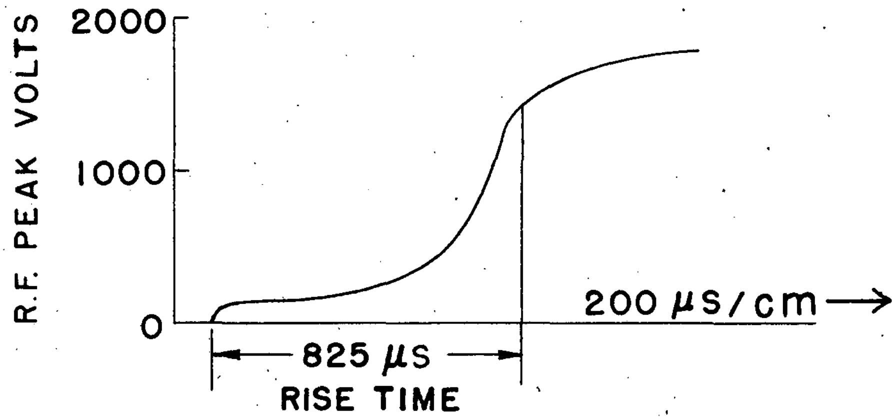

FIG. 1(A)

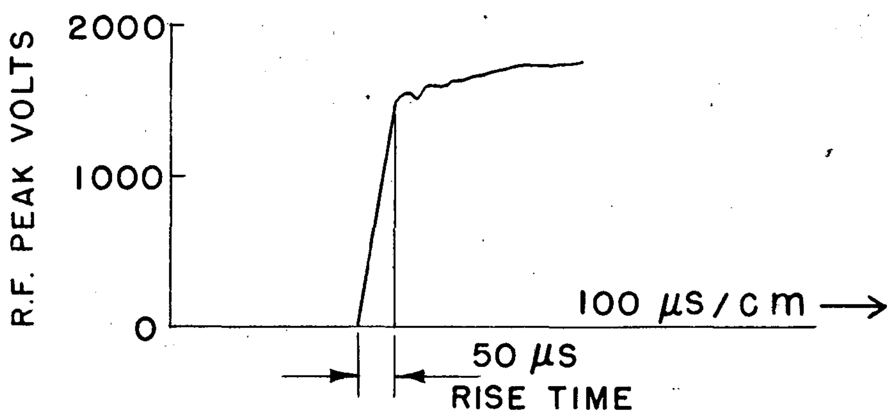

FIG. 1(B)

ACCELERATED BEAM VS. R.F. VOLTS

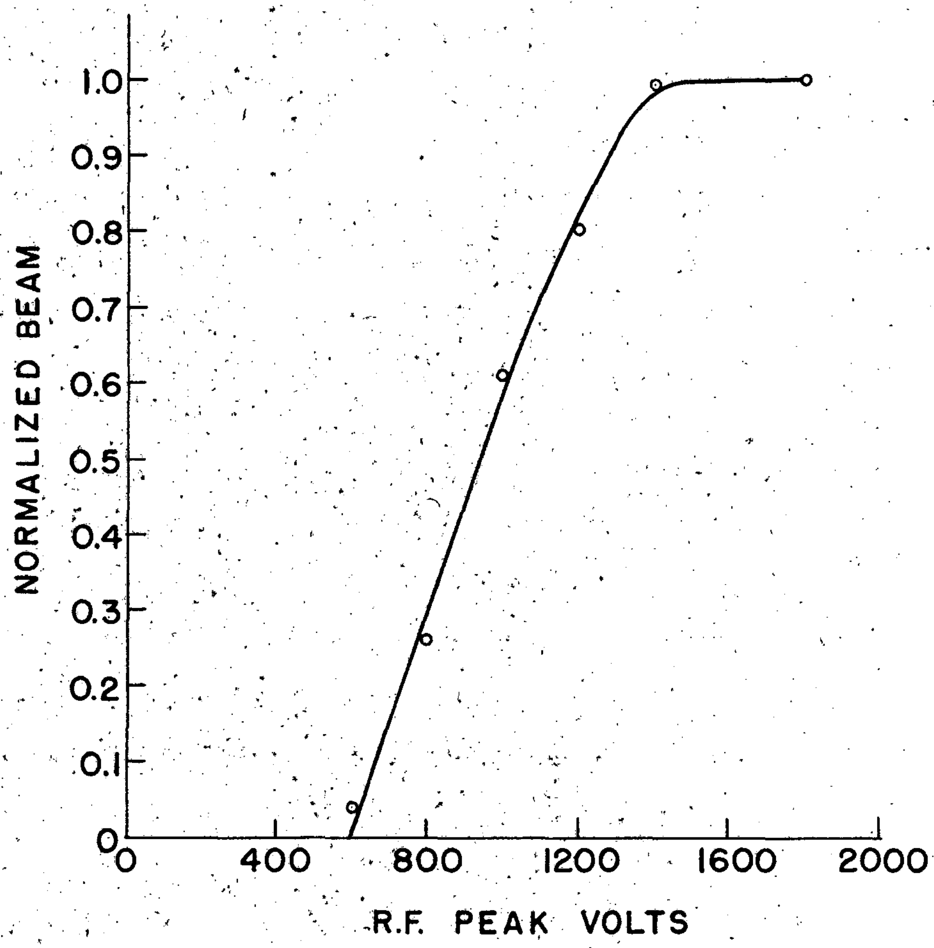

FIG. 2

14255-1

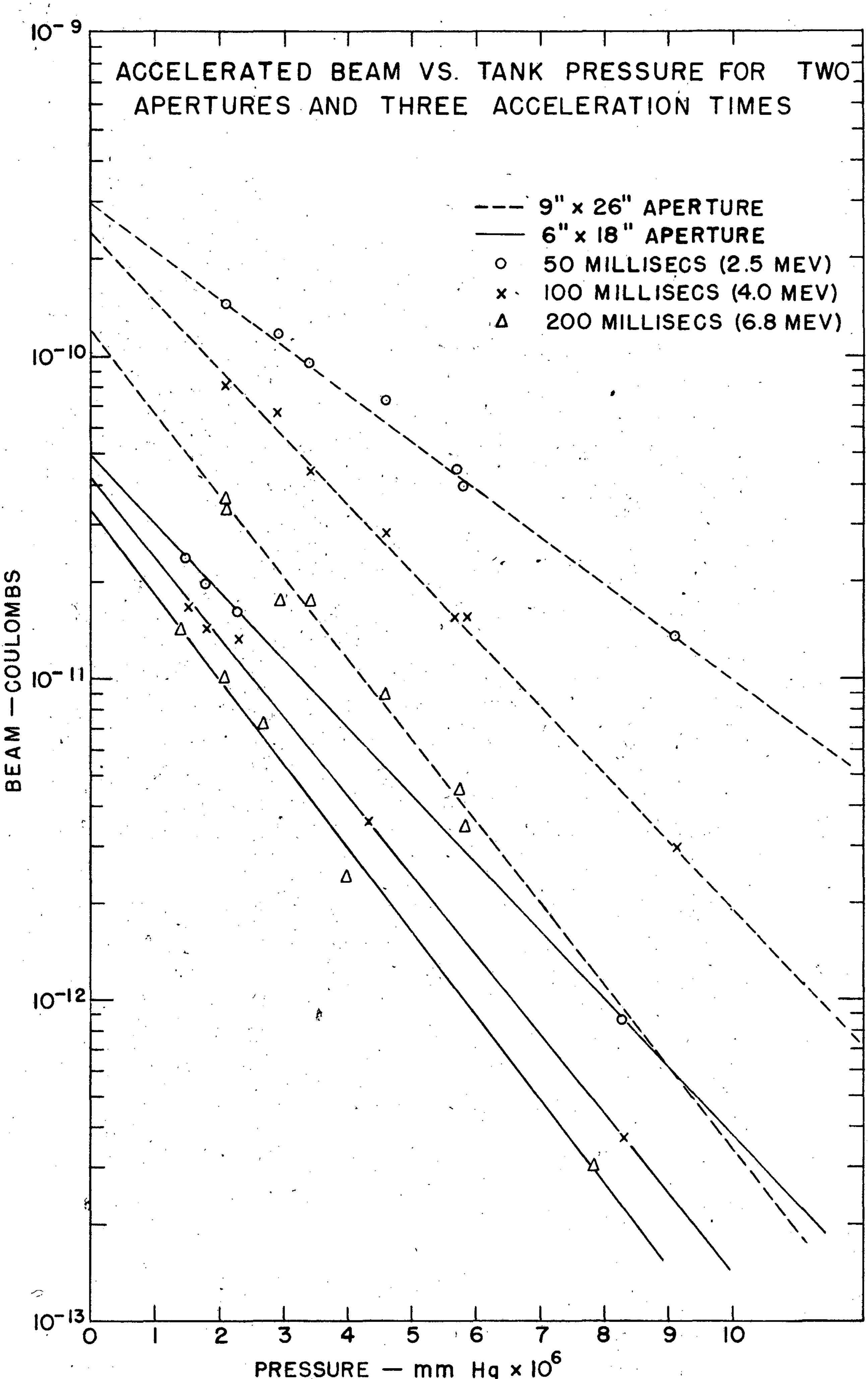
ACCELERATED BEAM VS. TANK PRESSURE FOR TWO APERTURES AND THREE ACCELERATION TIMES
9" x 26" APERTURE
6" x 18" APERTURE
50 MILLISECS (2.5 MEV)
100 MILLISECS (4.0 MEV)
200 MILLISECS (6.8 MEV)
BEAM — COULOMBS
PRESSURE — mm Hq x 10^6
10^-9
10^-10
10^-11
10^-12
10^-13
0
1
2
3
4
5
6
7
8
9
10

FIG. 3

14256-1