Title
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ABSTRACT

An extraction system employing betatron resonance at $\nu_R = 2/3$ has been studied for the Bevatron. A single perturbing magnet coincident in azimuth with the first septum will be used. The usable growth rate of the radial amplitude is limited by vertical growth through the coupling at $2\nu_z - \nu_R = 1$. This limitation, together with the general behavior of the beam, was first studied through a linear theory then checked by computer calculations. An energy loss target may be used in combination with the resonance process to aid in jumping the first septum. A trial system is installed in the Bevatron and results of tests will be reported.

A more efficient extraction system for the Bevatron is desired in order to reduce irradiation of the accelerator and to provide more beam for experiments. The ν-value of 2/3 occurs at a convenient radius in the aperture and we have started the development of a resonant extraction system employing that resonance.

THE PERTURBATION

The extraction system studied has a local perturbation magnet introduced on the plunging mechanism carrying the first magnet of the existing energy-loss extraction system. The C-shaped magnet has three windings: (1) a septum winding 1 cm wide; (2) gradient windings to produce a rising field at the inner-radius side of the circulating beam; and (3) a small bump coil to control the region of stable betatron motion. The fields of the latter two coils are shown in Fig. 1. Note that with the closed-orbit placed in the region of the bump, the linearly-rising field that produces the growth of betatron amplitude is confined to one side of the orbit.

CALCULATIONS

This asymmetric perturbation with a linearly-rising region permits a simple linear calculation of the betatron motion of particles that pass through that region once each three turns. Assuming that particles are in unperturbed field two of the three passes, the motion is that of a three-turn trajectory with betatron frequency 3ν perturbed by a single quadrupole. The quadrupole strength is characterized by a constant γ defined by

$$2\gamma = \beta_x \frac{dx'}{dx}$$

where β_x is the radial betatron function and dx'/dx is the angular deflection per unit displacement produced by the perturbation. For a given unperturbed closed orbit position and deviation from resonance $\Delta\nu = \nu - 2/3$, a three-turn orbit through the unstable fixed point is defined and the motion about that orbit is linear. The transformation for three-turns is:

$$\begin{pmatrix} x \\ \beta_R x' \end{pmatrix}_{n+3} = \begin{pmatrix} \cosh\mu & \beta_P \sinh\mu \\ \frac{1}{\beta_P}\sinh\mu & \cosh\mu \end{pmatrix} \begin{pmatrix} x \\ \beta_R x' \end{pmatrix}_n$$

where

$$\cosh\mu = \cos 6\pi\nu_R + \gamma \sin 6\pi\nu_R$$

$$\beta_P \sinh\mu = \sin 6\pi\nu_R$$

Using this model, the growth of radial displacement from the fixed point at the perturbation may be calculated and this is plotted for negative $\Delta\nu$ in Fig. 2.

The three-turn linear model is not applicable if the particle passes twice through the perturbation in three turns. When this occurs, the resonant exponential growth is arrested and reverses at a finite amplitude. The limiting conditions beyond which this takes place may be calculated from the slope of the asymptotes of the linear motion about the unstable fixed point; that limit is shown in Fig. 2 and it restricts the usable conditions for extraction.

To study this limiting behavior and other non-linear effects we used a computer program having the actual perturbing-field shape. In the usable region of Fig. 2 this produced typical phase diagrams such as that in Fig. 3. An example of the arrested growth outside the usable region is shown in Fig. 4.

For ν greater than 2/3 this limitation on growth rate is less severe and at first sight extraction with positive $\Delta\nu$ seemed more attractive than the negative side of resonance. In this case in the Bevatron, however, a serious interference is introduced by the non-linear coupling resonance at $2\nu_Z - \nu_R = 1$. This non-linear coupling also was analyzed using the three-turn linear model. With the radial motion in resonance at $\nu_R = 2/3$, the coupling resonance occurs when the vertical motion is near 2-1/2 oscillations per three turns. In this case the width of the stopband and the vertical growth rate may be calculated from the quadrupole strength γ of the perturbation. The occurrence of this resonance has been checked by the computer program and confirmed later by experiments in the Bevatron where vertical blow-up of the beam occurred during the radial resonance with $\Delta\nu > 0$.

SPILLOUT CONTROL

A small time-programmed bump was added to the perturbation near the stable closed orbit in order to control the advance of the unstable fixed point into the circulating beam during spillout without altering the large-amplitude trajectories near the extraction septum. In the Bevatron it is particularly important to keep the closed orbit stationary during spillout because of a significant radial variation of ν-value. It is also expected that this control of the spillout will be useful to suppress unwanted time-variation and ripple modulation in the extracted beam.

AUXILIARY ENERGY-LOSS TARGET

The probability of only marginally adequate radial growth per three turns may be partially offset by using a thin energy-loss target to intercept particles that would strike the septum. This target would be located one-half oscillation upstream and on the side opposite the septum. To assure that particles of all momenta are deflected beyond the septum, the thickness of this target must absorb a momentum ΔP_t equal to the momentum spread of the beam ΔP_b plus that needed to deflect the particles across the septum width w.

$$\Delta P_t = \Delta P_b + \frac{1}{2} \left(\frac{dp}{dr}\right) w$$

The target may be tapered radially to provide an appropriately smaller energy-loss to incident particles of larger amplitudes.

FIRST EXPERIMENTS

The test perturbation and septum magnet has been installed in the Bevatron and resonant growth with $\nu = 2/3 - 0.02$ has been produced. A gold foil irradiated at the first septum has indicated that all the beam grows to a 5-inch amplitude and has a jump per turee turns of about 3/4 inch. These results are in satisfactory agreement with our calculations. Therefore, we are encouraged to continue work on this system as a feasible improvement of the Bevatron beam extraction.

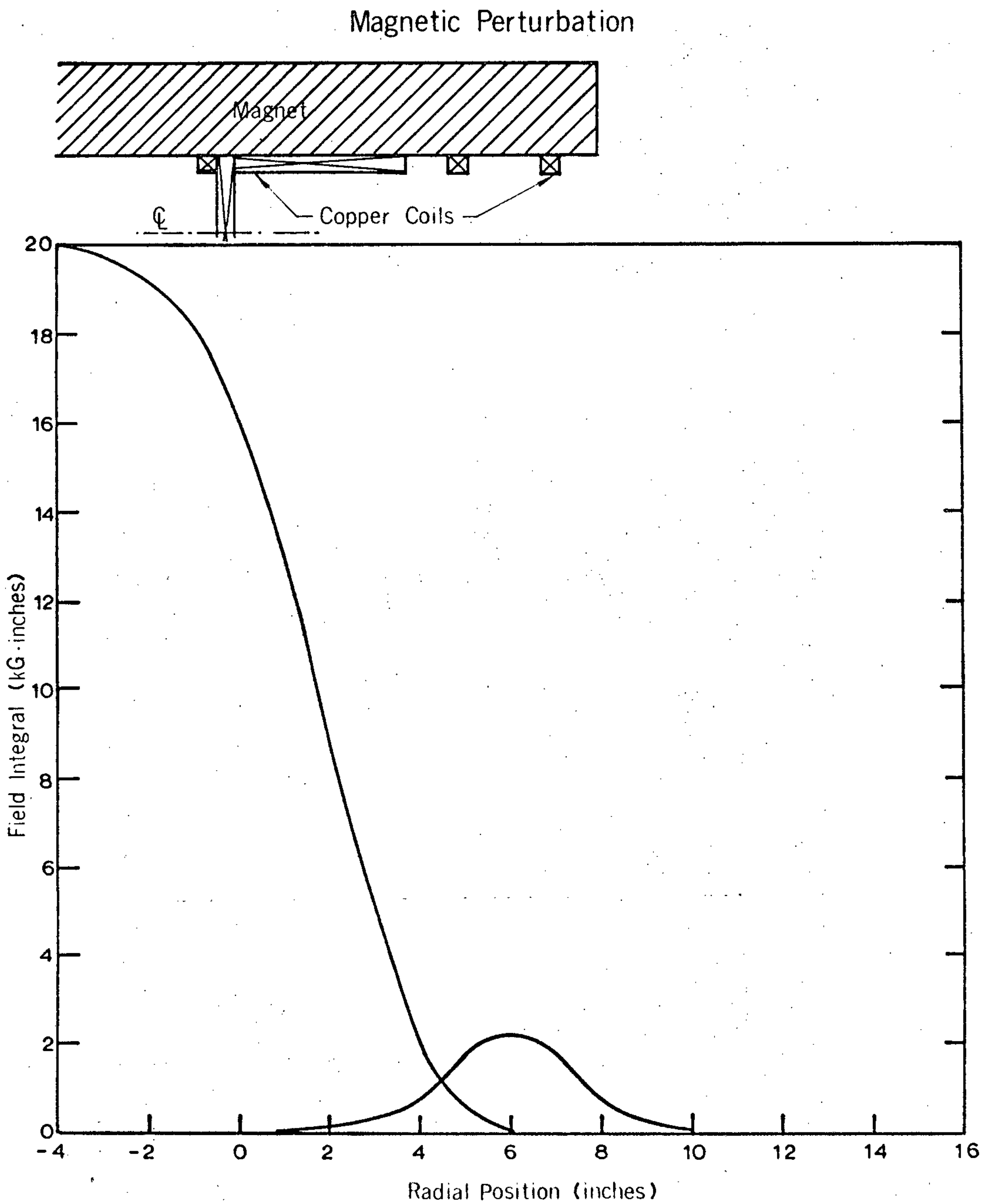

Fig. 1

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Radial Growth Rate in Three-Turn Linear Model

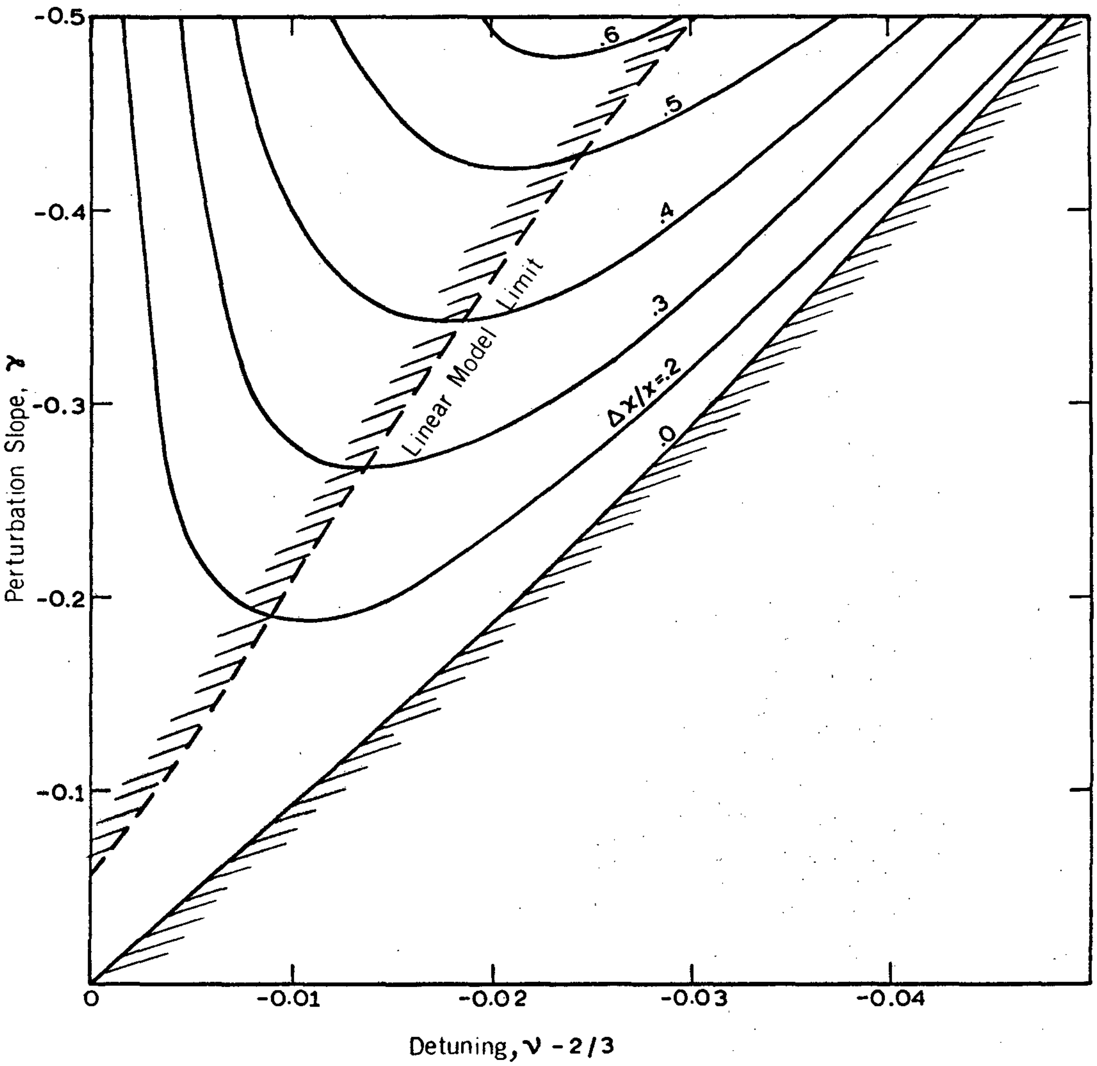

Fig. 2

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Coordinates of Particles on Successive Turns

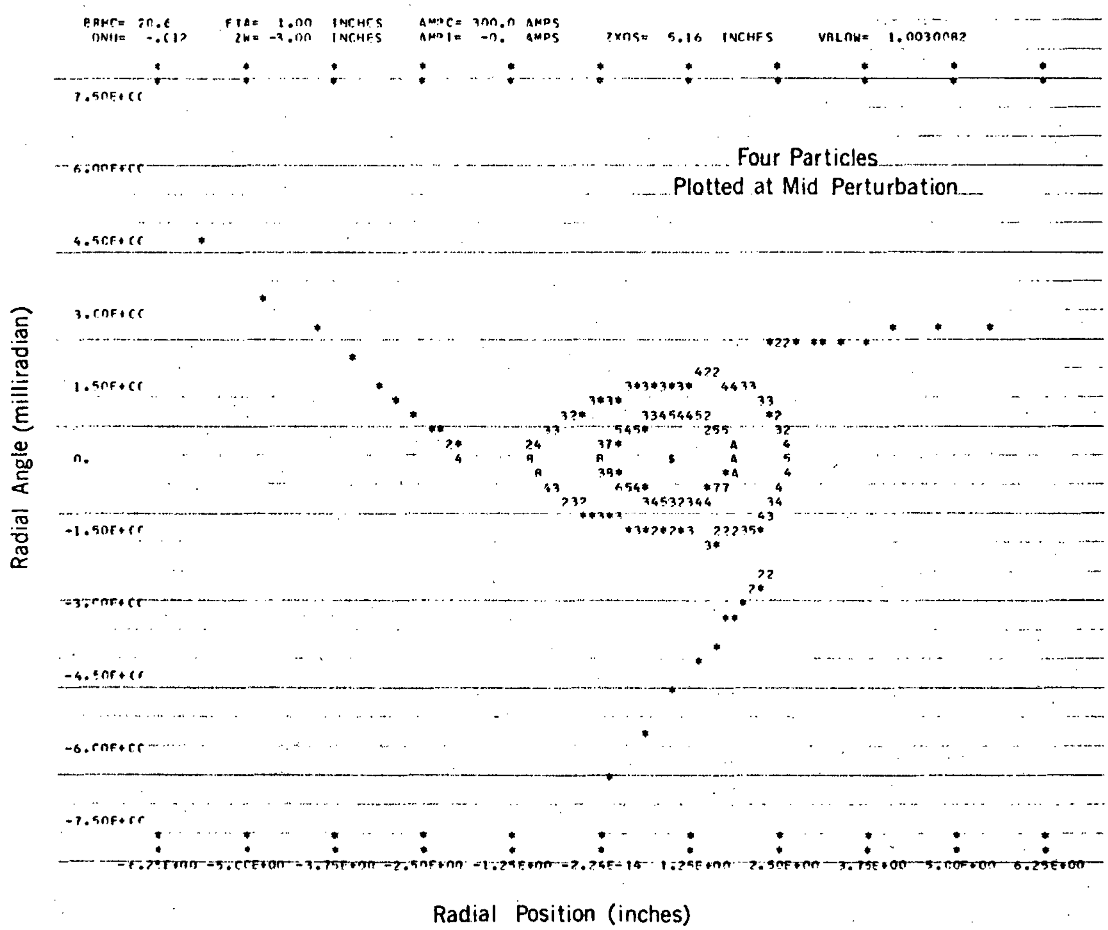

Fig. 3

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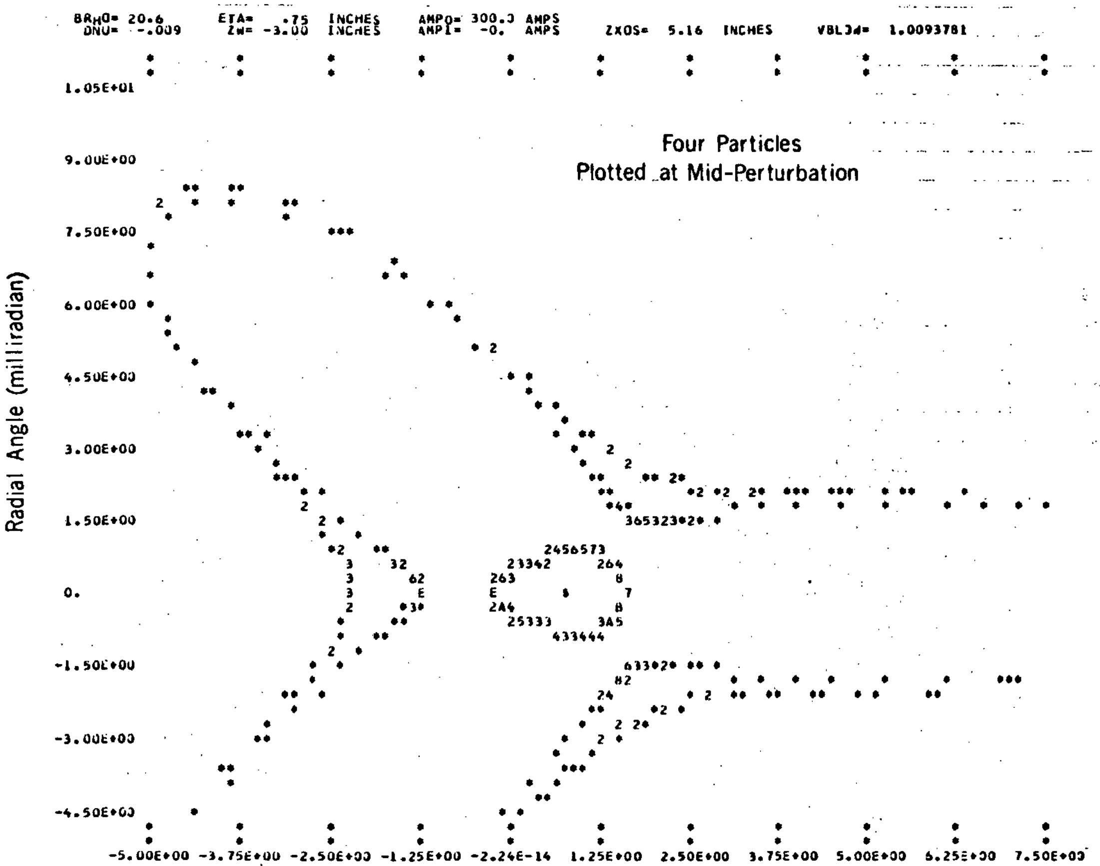
Coordinates of Particles on Successive Turns
Showing Arrested Growth of Amplitude



Radial Position (inches)

Fig. 4

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