POSSIBLE BRICK WALL EFFECT AT 400 GeV IN ISABELLE

G. Parzen

MASTER

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ACCELERATOR DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

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ABSTRACT

The distortion of the working line, due to space charge forces, is estimated. It is found that the brick wall effect may occur at 400 GeV, due to working line distortion because of electron neutralization of the beam. The smallness of the beam at 400 GeV makes it difficult to correct the working line distortion by exciting octupole correction coils.

INTRODUCTION

The brick wall effect¹ (a transverse collective instability) can occur when the working line, which is usually a straight line in the absence of space charge detuning, is distorted by space charge force so that $d\nu/dp \approx 0$ at some point on the working line. A simplistic view is that the part of the beam near that part of the working line where $d\nu/dp \approx 0$ does not have the required ν -spread to stabilize the beam.

At 30 GeV in ISABELLE, the space charge forces are strong enough to produce considerable distortion of the working line. The curvature introduced into the working line can be corrected using the octupole correction coils.

At 400 GeV the detuning due to the space charge forces of the beam acting in itself is small since it decreases like $1/\gamma^2$. However, there is a detuning due to electron neutralization of the beam which is roughly constant with energy, which is comparable to the small ν -spread in the beam, and which might be able to produce considerable distortion of the working line. Because of the small size of the beam, correction of the curvature in the working line would require a very strong octupole correction coil, much stronger than is available in the present ISABELLE design. Correction of this possible brick wall effect at 400 GeV can be done using the sextupole coil to increase the slope of the working line, although this has the disadvantage of making the working line larger and possibly making it more difficult to avoid nonlinear resonances.

The purpose of this note is to point out the possible existence of a transverse collective instability at 400 GeV, and that the subject deserves further detailed study as to whether the effect will actually occur and as to how much sextupole correction is required to correct it.

1. W. Schnell, Proc. 8th Int. Conf. High Energy Accelerators, Geneva, (1971); K. Hübner, E. Keil, B. Zotter, ibid., 295; E. Keil, Proc. Russian Nat. Conf., 328, (1972); B. Zotter, CERN Report, CERN-ISR-TH/72-36 (1972); M. Month and K. Jellett, Nucl. Instrum. Methods 113, 453 (1973).

30 GeV Stack

At 30 GeV the stack, without space charge detuning, will have a momentum spread $\Delta p/p = 0.01 = \pm 0.005$ and a ν -spread of $\Delta \nu \approx 0.02$, corresponding to a chromaticity of $\gamma_p \approx 2$, and the working line is a straight line as shown in Fig. 1a.

The ν -shift due to the direct space charge forces of the beam acting in itself were computed by Chao, Herrera and Month² for the 200 GeV ISABELLE and updated by Herrera for the 400 GeV ISABELLE. The total ν -shift at the center of the beam is given as $\Delta \nu = 0.014$ at 30 GeV. The ν -shift due to the $X_p = 0$ region of the beam does not contribute to the working line distortion since the ν -shift does not depend on the momentum $\Delta p/p$. It is assumed here that the part of the ν -shift due to the $X_p \neq 0$ region is about half the total shift, or $\Delta \nu = 0.007$ as more precise results are not available at present. The variation in the space charge ν -shift across the beam depends on various assumptions about the charge distribution in the beam. A pessimistic assumption is to say that particles near the center of the beam are shifted by $\Delta \nu = 0.007$, and that particles near the ends of the beam have $\Delta \nu = 0$, which gives the distortion in the working line shown by the dashed line in Fig. 1a.

The dependence of ν_y on the momentum is roughly approximated by

$$\Delta \nu_y = -0.014 + 0.007 \delta^2,$$

where $\delta = (\Delta p/p)/(\Delta p/p)_{\max}$, and $(\Delta p/p)_{\max} = 0.005$, and Δp is measured relative to the momentum at the center of the beam.

The distortion due to image forces is expected to be smaller than the above result due to the direct space charge forces of the beam.

In the present ISABELLE design, the octupole correction coil can produce a ν -shift at 30 GeV of 0.12 from $\Delta p/p = 0$ to $\Delta p/p = 0.005$, compared to 0.007 required to correct the space charge distortion.

2. A. W. Chao, J. C. Herrera and M. Month, Proc. ISABELLE Summer Study, Brookhaven, BNL 20550 418 (1975).

400 GeV Stack

At 400 GeV, the stack has a momentum spread of about $\Delta p/p = 1.4 \times 10^{-3} = \pm 0.7 \times 10^{-3}$, and a ν -spread, without space charge detuning, of about $\Delta \nu = 4.5 \times 10^{-3} = \pm 2.2 \times 10^{-3}$ corresponding to a chromaticity of $\gamma_p = 3$. Without space charge effects, the working line is a straight line shown in Fig. 1b.

The space charge detuning due to the beam acting in itself is very small, since it decreases like $1/\gamma^2$. However, there is an appreciable detuning due to neutralization of the beam by electrons, and this ν -shift at 400 GeV is estimated to be $\Delta \nu = 2 \times 10^{-3}$ for the particles near the center of the beam.² It is assumed here that the part of the ν -shift due to the $x_p \neq 0$ region of the beam is also $\Delta \nu = 2 \times 10^{-3}$, since the electrons tend to be trapped in the dipoles. We again take the pessimistic assumption that particles near the center of the beam are shifted by $\Delta \nu = 2 \times 10^{-3}$ due to $x_p \neq 0$ region of the beam and that particles near the ends of the beam have $\Delta \nu = 0$ due to the $x_p \neq 0$ region of the beam, which gives the distortion in the working line shown by the dashed line in Fig. 1b.

The dependence of ν_y on momentum may be approximated by:

$$\nu_y = \nu_0 + \Delta \nu_0 + \Delta \nu_1 \delta + \Delta \nu_2 \delta^2,$$

$$\Delta \nu_0 = 2 \times 10^{-3}$$

$$\Delta \nu_1 = 2.2 \times 10^{-3}$$

$$\Delta \nu_2 = -2 \times 10^{-3},$$

$$\delta = (\Delta p/p) / (\Delta p/p)_{\max} \text{ and } (\Delta p/p)_{\max} = 0.70 \times 10^{-3}$$

The distortion of the working line shown in Fig. 1 is only a very rough estimate. The actual distortion of the working line may be quite different and depends on beam parameters which are not known at present. In Fig. 1, it was assumed that the horizontal ν -shift is about half the vertical ν -shift.

Because of the smallness of the beam, it is difficult to correct the curvature with an octupole correction coil. The octupole correction coil in the present ISABELLE design, $b_3 = 4.5 \times 10^{-5}/\text{cm}^3$ capacity, can produce at 400 GeV a $\Delta v = 1.8 \times 10^{-4}$ from $\Delta p/p = 0$ to $\Delta p/p = 0.7 \times 10^{-3}$, and thus its capacity is too small by a factor of 11 to correct the above curvature.

This estimate of the ability of the octupole correction coil to correct the quadratic term in $v(p)$ is on the pessimistic side, as it assumes that the quadratic terms in $v_x(p)$ and $v_y(p)$ have the same sign and magnitude.

At present, it is planned to correct the working line distortion by using the b_2 correction coils. By increasing the chromaticity, one can increase the slope $dv/d\delta$ and, in particular, one can make $dv/d\delta \geq \Delta v_1$, which is the required slope in the absence of space charge forces. One can show that $dv/d\delta \geq \Delta v_1$, if Δv_1 is increased to $\Delta v_1 + 2|\Delta v_2| = 0.0062$, or if the chromaticity γ_p is increased to $0.0062/0.7 \times 10^{-3}$, or $\gamma_p = 8.9$, which can be done with $b_2 = 6.2 \times 10^{-5}/\text{cm}^2$. By increasing the chromaticity, the v -spread in the beam is increased from $\Delta v = 0.0044$ to $\Delta v = 0.012$, a factor of 3.

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