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CORRECTION OF THE COUPLING RESONANCE IN INTERSECTING STORAGE ACCELERATORS

G. PARZEN

September 22, 1978

ACCELERATOR DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

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MASTER

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ADDENDUM

BNL 50949

Insert to pages 18-19

Table III (Continued)
Process Economics Data^a
Sector: Synthetic Fuels

Technology/ Process	Unit Size ^b (10 ⁹ Btu/ day)	SRI Data					Suggested Data ^g				Comments ^h
		SOC ^c ('75 \$/ 10 ⁶ Btu/ yr)	SOC (\$/10 ⁶ Btu/yr)	TCI ^d (10 ⁶ \$)	SOC ^e (\$/10 ⁶ Btu)	Effi- ciency ^f	SOC (\$/10 ⁶ Btu/yr)	TCI (10 ⁶ \$)	SOC (\$/10 ⁶ Btu)	Effi- ciency	
13. Syncrude from LS/ LBtu coal	250	9.06	10.33	925	1.01	0.66	12.25	1085 (950- 1220)	0.55 (0.45- 0.65)	0.65 (0.63- 0.67)	H coal process operating in syncrude mode is as- sumed to be the basis for these estimates. SRI :R = 0.08; Y = 4 Suggested:R = 0.05; Y = 5
14. Syncrude from HS/ HBtu coal	250	8.90	10.15	910	0.97	0.67	11.97	1060 (920- 1200)	0.53 (0.40- 0.65)	0.66 (0.64- 0.68)	

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ABSTRACT

It is noted that correction of the coupling resonance, $\nu_x - \nu_y = 0$, in intersecting storage accelerators with superconducting magnets requires two families of correcting skew quadrupoles with two independent power supplies. A possible location for the two families is suggested, and results are given for the required strengths of the skew quadrupoles and the required accuracy of the corrections. The results are applied to the ISABELLE storage accelerator.

I. INTRODUCTION

The correction of the coupling resonance $\nu_x - \nu_y = 0$ requires a set of skew quadrupoles around the accelerator. It is often assumed that the correction of this resonance requires only one family of skew quadrupoles, with one independent power supply to cancel out the zeroth harmonic of the driving field for this resonance. This is roughly true for many accelerators for which $\Psi_x \approx \Psi_y$, where Ψ is the betatron phase, but it is not true for separated function accelerators for which Ψ_x differs appreciably from Ψ_y even though $\nu_x \approx \nu_y$, and especially for superconducting accelerators where one of the main error fields driving this resonance arises in the dipoles where Ψ_x differs most from Ψ_z . In separated function accelerators if one assumes that $\Psi_x = \Psi_y$ at one of the quadrupoles, then one can see the Ψ_x differs from Ψ_y in the following dipoles, because of the large difference between β_x and β_y at the quadrupole, and the rate of change of Ψ with distance goes like $1/\beta$. In superconducting dipoles, there is a relatively large skew quadrupole error field that drives the coupling resonance, which is due to errors in the positioning of the main dipole coil.

Because of the difference between Ψ_x and Ψ_y , the driving integral of the coupling resonance has both a real and imaginary parts, and two families of skew quadrupoles are required to cancel out the quadrupoles. These two families need to be located around the ring at places where $\Psi_x - \Psi_y$ for one family differs by roughly $\pi/2$ from the $\Psi_x - \Psi_y$ for the second family. A convenient location for these two families of quadrupoles, where this condition on $\Psi_x - \Psi_y$ is likely to be roughly fulfilled, is to put them in or near the quadrupoles which are just on either side of the crossing point in intersecting storage accelerators like ISABELLE, with one family on one side of the crossing point and the other family on the other side of crossing point. The phase shift difference $\Psi_x - \Psi_y$ near the crossing point is given by (see Section II)

$$\Psi_x - \Psi_y = \tan^{-1} (s/\beta_x^*) - \tan^{-1} (s/\beta_y^*),$$

where β_x^* and β_y^* are the β - functions at the crossing point. Because β_x^* and β_y^* usually differ considerably at the crossing point, the above result for $\Psi_x - \Psi_y$ is not zero and changes sign on either side of the crossing point, so that $\Psi_x - \Psi_y$ can differ considerably for two points on opposite sides of the crossing point.

II. THEORY

The strength of the $\nu_x - \nu_y = 0$ resonance is determined by the integral¹

$$C = \frac{1}{2\pi} \int ds (\beta_x \beta_y)^{\frac{1}{2}} \frac{1}{B\rho} \frac{\partial B_x}{\partial x} \exp. [i (\Psi_x - \Psi_y - \epsilon\theta)] . \quad (2.1)$$

$\epsilon = \nu_x - \nu_y$ and is the distance of the tune from the resonance line. $\theta = s/R$, where R is the average radius of the accelerator. Ψ_x and Ψ_y are the betatron phases,

$$\Psi_x = \int_0^s ds/\beta_x, \text{ and } \Psi_y = \int_0^s ds/\beta_y.$$

The quantity C can be interpreted as the resonance width and determines the

1. G. Guignard, CERN 77-10 (1977).

degree of coupling between the horizontal and vertical motions, and also the shift in the ν -values. If we assume that $\epsilon \simeq .01$, then the $\epsilon\theta$ term can be neglected.

One sees from (2.1) that the resonance is driven by the random skew quadrupole field errors. In order to correct out the coupling resonance, one needs skew quadrupoles located around the ring which can be adjusted to cancel the value of C produced by the random skew quadrupole field errors. In general, C has both real and imaginary parts, and 2 families of skew quadrupole with 2 independent power supplies are required to cancel C . An exception to this is an accelerator for which $\Psi_x \simeq \Psi_y$, or for which $\Psi_x \simeq \Psi_y$ at those locations where most of the skew quadrupole field errors occur. In separated function accelerators, if one assumes $\Psi_x = \Psi_y$ at one of the quadrupoles then one can see that Ψ_x differs from Ψ_y in the following dipoles, because of the large difference between β_x and β_y at the quadrupole, and the rate of change of Ψ with distance goes like $1/\beta$. In superconducting dipoles, there is a relatively large skew quadrupole error field due to errors in the positioning of the main dipole coil. The above indicates that accelerators which have separated function lattices and superconducting dipoles require 2 families of skew quadrupoles to correct the coupling resonance.

The two families of skew quadrupoles needed to correct the coupling resonance have to be located around the ring at places where $\Psi_x - \Psi_y$ for one family differs by roughly $\pi/2$ from the $\Psi_x - \Psi_y$ for the second family. A convenient location for these two families of quadrupoles, where this condition on $\Psi_x - \Psi_y$ is likely to be roughly fulfilled, is to put them in or near the quadrupoles which are on either side of the crossing point in intersecting storage accelerators like ISABELLE, with one family on one side of the crossing point and the other family on the other side of the crossing point. Since near the crossing point β_x and β_y vary like

$$\beta_x = \beta_x^* + s^2/\beta_x^* , \quad (2.2)$$

$$\beta_y = \beta_y^* + s^2/\beta_y^* ,$$

where β_x^* , β_y^* are the β -functions at the crossing point, then one finds for $\Psi_x - \Psi_y$

$$\Psi_x - \Psi_y = \tan^{-1}(s/\beta_x^*) - \tan^{-1}(s/\beta_y^*) \quad (2.3)$$

Because β_x and β_y usually differ considerably at the crossing point, the above result for $\Psi_x - \Psi_y$ is not zero and changes sign on either side of the crossing point, so that $\Psi_x - \Psi_y$ can differ considerably for two points on opposite sides of the crossing point. For the ISABELLE lattice, $s = 30$ m from the crossing point to the first quadrupole, $\beta_y^* = 7.5$ m, $\beta_x^* = 30$ m, and one finds that $\Psi_x - \Psi_y$ changes by $.34\pi$ between the two quadrupoles which are on either side of the crossing point.

It will now be assumed that the two families of correcting skew quadrupoles are placed near or at the quadrupoles on either side of each crossing point. The corrections to the left of the crossing point will produce the field $B = B_0 a_{1,L} x$, and those to the right the field $B = B_0 a_{1,R} x$, where B_0 is the main dipole field. The contribution to the width of the coupling resonance due to the correctors can be calculated from Eq. (2.1) as

$$C = \frac{1}{2\pi} NL (\beta_x \beta_y)^{\frac{1}{2}} [(a_{1,L} + a_{1,R}) \cos \bar{\Psi} + i (a_{1,L} - a_{1,R}) \sin \bar{\Psi}] , \quad (2.4)$$

where N is the number of crossing points, L is the length of each corrector, $\bar{\Psi} = \Psi_x - \Psi_y$ at the left corrector and can be computed from Eq. (2.3). Eq. (2.4) can be solved for $a_{1,L}$ and $a_{1,R}$ and gives

$$a_{1,L} = \frac{1}{2} [C_R / \cos \bar{\Psi} + C_I / \sin \bar{\Psi}] / (NL(\beta_x \beta_y)^{\frac{1}{2}} / 2\pi) , \quad (2.5)$$

$$a_{1,R} = \frac{1}{2} [C_R / \cos \bar{\Psi} - C_I / \sin \bar{\Psi}] / (NL(\beta_x \beta_y)^{\frac{1}{2}} / 2\pi) ,$$

where C_R and C_I are the real and imaginary parts of C.

In order to estimate the required capacity of the skew quadrupole correctors, it is assumed that the rms values of C_R , C_I and $|C| = [C_R^2 + C_I^2]^{\frac{1}{2}}$ due to random field errors are known. The required capacity $a_{1,L}$ and $a_{1,R}$ may then be estimated by

$$a_{1,L} = SF \times C_{rms} [1/\cos^2 \bar{\Psi} + 1/\sin^2 \bar{\Psi}]^{\frac{1}{2}} / (NL(\beta_x \beta_y)^{\frac{1}{2}} / 2\pi) , \quad (2.6)$$

where SF is some safety factor and C_{rms} is the rms value of $|C|$.

Accuracy of Correction

The required accuracy of the power supplies for the skew quadrupole correctors is determined primarily by the degree of coupling that can be tolerated. If the width of the resonance $|C|$, is corrected with an error of ΔC , then the remaining coupling between horizontal and vertical motions is given roughly by¹

$$x/y = \Delta C / (2|\nu_y - \nu_x|) . \quad (2.7)$$

If it is assumed that a remaining coupling of .01 can be tolerated, then the required accuracy is given by

$$\Delta C / C \leq .02 |\nu_y - \nu_x| / C \quad (2.8)$$

Another effect of errors in the correctors is to produce a shift to the ν - values of the normal modes. This is a second order effect and is probably negligible compared to the (x,y) coupling. The shift in ν - value is given roughly by

$$\Delta \nu = (1/4) \Delta C^2 / |\nu_x - \nu_y|$$

If it assumed that only 1% coupling is permitted, and ΔC is given by Eq. (2.8), then ν can be written as

$$\Delta \nu \approx 1 \times 10^{-4} |\nu_y - \nu_x| \quad (2.9)$$

Thus the ν - shift due to errors in the corrector power supply will be quite small of the order of 10^{-6} for $|\nu_y - \nu_x| \approx 10^{-2}$.

III. APPLICATION TO ISABELLE

The variation of $\Psi_x - \Psi_y$ with distance near the crossing point is shown in Fig. 1 for the ISABELLE accelerator. Also shown are the location of the quadrupoles closest to the crossing point, Q1, Q2 and Q4. One sees that the two families of correcting skew quadrupoles can be placed at either the Q1 quadrupoles or the Q2 quadrupoles since $\Psi_x - \Psi_y$ differs considerably from one side of the crossing point to the other for either Q1 or Q2. On the other hand Q4 is not a good choice since $\Psi_x - \Psi_y \approx 0$ at Q4 on either side of the crossing point.

The width of the coupling resonance in ISABELLE due to random field errors be computed from the expected field errors, giving the result²
 $C_{rms} = .015$.

The required capacity of the correcting skew quadrupoles can be computed from Eq. (2.6). Assuming that the correcting skew quadrupoles are located at Q1, have a length of 2.2 m and a safety factor of SF=3, one finds the required capacity of $a_{1,L} = a_{1,R} = 2.4 \times 10^{-3}/\text{cm}$. The same result holds if the correcting skew quadrupoles are located at Q2.

The required accuracy in power supplies for the correcting skew quadrupole is given by Eq. (2.8). Assuming that $|\nu_y - \nu_x| \approx .01$, one finds the tolerance on the remaining resonance width after correction of $\Delta C = 2 \times 10^{-4}$. With a safety factor of 3, the correction quadrupoles have a capacity to correct a resonance width of $C = .09$ or 400 GeV, and thus the required accuracy of the power supply at 400 GeV is 2×10^{-3} . In order to be satisfactory at 30 GeV also, the required power supply rating is 1×10^{-4} .

The remaining shift in the ν - value after correction may be computed from Eq. (2.9). For $|\nu_y - \nu_x| = .01$, one finds $\Delta\nu = 10^{-6}$.

It has been noted by R. Chasman and M. Month³ that the correctors for the coupling resonance will have to correct not only the coupling introduced by field errors in the accelerator but also the coupling introduced by the vertical dispersion correction system. At present, it is planned to correct the vertical dispersion at the crossing points by vertical displacement of the closed orbit⁴ and it has been found in computer simulation studies using the CLOSORB program that this method of correcting the vertical dispersion does not affect the coupling present by very much.

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2. A result for the width of the coupling resonance was found by A. Chao, Proc. 1975 ISABELLE Summer Study, BNL 20550, p. 386, for the 200 GeV ISABELLE. The result given in this paper was found by G. Parzen through a computer simulation study of the 400 GeV ISABELLE using the CLOSORB program.
3. R. Chasman and M. Month, BNL Accelerator Dept. Report ISA 76-10 (1976).
4. G. Parzen, BNL Accelerator Dept. Report, ISA 78-10, (1978).

Figure 1. -