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CORRECTION AND ADJUSTMENT MAGNET SYSTEM
Progress Report for Meeting of 1 Dec 1978

1. This is a "progress report" only; dipoles, quads, sextupoles, octupoles - presumably the large systems - are considered, but many more calculations need to be done on these.

2. No treatment yet of skew elements, decupoles, etc.

3. Adjustment strengths tend to grow as machine requirements are assessed and the layout develops. In particular, the colliding beam aspects are not fully incorporated as yet.

4. Only effects likely to be dominant are included here. Random field errors are ignored except for their influence on the trim dipoles. Systematic terms are taken to be one-half of the limits stated in the Magnet Criteria Goals for magnets with serial numbers 160 and above.

5. No treatment of power supplies, controls, costs, etc. as yet.

6. No consideration of beam stacking.

OCTUPOLES

Correction

A systematic octupole moment in the dipoles leads to an amplitude dependent tune shift, which can be troublesome during resonant extraction. Take $|\langle b_3 \rangle| = 0.8\times10^{-4}/\text{inch}^{-3}$.

$$\Delta\nu_x = (3/16\pi)[x^2 A_x - 2y^2 A_{xy}] \qquad A_x \propto \langle b_3 \rangle \int \beta_x^2 dz$$

$$\Delta\nu_y = (3/16\pi)[-2x^2 A_{xy} + y^2 A_y] \qquad A_{xy} \propto \langle b_3 \rangle \int \beta_x \beta_y dz$$

where x and y are the amplitudes of the horizontal and vertical oscillations respectively. Take x=1 inch, y=0, then

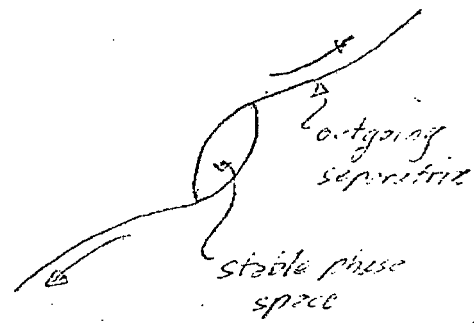
$$\Delta\nu_x = 0.046 \quad ; \quad \Delta\nu_y = 0.075$$

To compensate these tune shifts would require about 2.4 kG-in (measured at 1 inch radius) of octupole at the 90 standard cell F locations and about 5.8 kG-in at the 90 standard cell D locations; i. e.

$$O_F = 2.4 \text{ kG-in}, \quad O_D = 5.8 \text{ kG-in}$$

Extraction

Need 39th octupole harmonics. If octupoles alone were to be used to establish the separatrices and produce the step size at the septum, one would require about 150 kG-in at the F stations. Fortunately this is not the intended mode of half-integer extraction. With quad harmonics as well, the requirement shrinks to



$$O_F \approx 10 \text{ kG-in}$$

Present Correction Package

$$O_F = O_D = 29 \text{ kG-in}$$

Conclusion

Looks good - there is an adequate adjustment range for extraction, after taking into account the need to produce pure harmonics which will increase the above estimates somewhat.

*Here, and on the following sheets, I have changed the strengths stated on 1 December to match those given in a recent revision by Francois Kircher.

SEXTUPOLES

Correction

A systematic sextupole moment in the dipoles contributes to the chromaticity. Taking $|\langle b_2\rangle| = 3.2\times10^{-4}/\text{inch}^2$

$$|\Delta\xi_x| = 84, \quad |\Delta\xi_y| = 78$$

to be compared with the natural chromaticity of -22. To compensate, would imply sextupole strengths at the F and D locations of

$$S_F = -3.14\times10^4 \langle b_2\rangle \Rightarrow \quad |S_F| = 10 \text{ kG-in}$$

$$S_D = -5.08\times10^4 \langle b_2\rangle \Rightarrow \quad |S_D| = 16 \text{ kG-in}$$

Extraction

Chromaticity control (1.5 x natural) implies

$$S_F = 7 \text{ kG-in} \quad ; \quad S_D = -13 \text{ kG-in}$$

In addition, need 58th harmonics for third-integer extraction:

$$S_F \simeq 19 \text{ kG-in (typical)}$$

Present Correction Package

$$S_F = S_D = 44 \text{ kG-in}$$

Conclusion

Looks close - inclusion of adjustment range for extraction and creation of pure harmonics can put it over the edge even without considering random effects.

TRIM QUADS

Correction and Diagnosis

For diagnosis of machine behavior and adjustment of the operating point, assume the need for sufficient trim quad strength for $\Delta\nu = \pm 0.4$. Then

$$Q_F = Q_D = 26 \text{ kG-in}$$

Suppose magnet errors can be absorbed by this strength. Note

$$|\langle b_1 \rangle| = 1.3\times10^{-4} \text{ inch}^{-1} \Rightarrow |Q_F| = |Q_D| = 5 \text{ kG-in}$$

Extraction

Tune shifts ($\Delta\nu_y=0$) $\nu_x=19\frac{1}{3}$	$\Rightarrow$	Q_F = -3.6 kG-in, Q_D=-1 kG-in
$\nu_x=19\frac{1}{2}$	$\Rightarrow$	Q_F = 5.0 kG-in, Q_D=1.5 kG-in
39th Harmonics		Q_F = 5 kG-in (typical)

Colliding Beams

A "simple" low-beta insertion raises the tune by about one-half integer. For example, the Collins version (TM-649) raises the tune by 0.44 at β^*=5m. To compensate

$$Q_F = Q_D = -29 \text{ kG-in}$$

if all trim quads can be used. But if phase advance in one or more sectors must be held constant (e.g., for the aborts) then larger strength is required in the remaining sectors.

Present Correction Package

$$Q_F = Q_D = 52 \text{ kG-in}$$

Conclusion

Possibly adequate for 1 interaction region, depending on the layout of the Doubler. (Note that the trim quad strength has already been increased by a factor of two due to colliding beam implications.) Inadequate for two interaction regions.

TRIM DIPOLES

Correction and Diagnosis

The rms orbit distortion at a point in the normal lattice can be written

$$\langle x^2 \rangle^{1/2} = \frac{1}{4}\left[a^2 + \frac{5}{4}b^2\right]^{1/2} \text{ inches}$$

where a is the unit of dipole error, 0.1% in $\Delta B/B$ or 1 mrad of rotation for the vertical, and b is the unit of quadrupole misalignment, 0.01 inches. For a=1 & b=2, $\langle x^2 \rangle^{1/2} = 0.45$ inch and there will be a 50% chance of a peak greater than 1 inch; that is, the peak orbit distortion will likely be in the region of non-linear fields.

To correct locally

$$\left(\int B\,dl\right)_{rms} = 23\,(a^2 + 0.31\,b^2)^{1/2} \text{ kG-in}$$
$$= 34 \text{ kG-in for } a=1,\ b=2$$
$$\Rightarrow \sim 100 \text{ kG-in for 40\% odds of success at 100 locations.}$$

Correction programs usually need somewhat larger amounts to converge - a simulation needs to be done.

Suppose that the capability for full aperture exploration need only be provided at injection, and that whatever results at 1000 GeV is acceptable. If the injection energy is 150 GeV, then 72 kG-in would be needed to sweep ± 1.5 inches. At 1000 GeV, this range would turn into a little less than ±6mm.

Extraction

Extraction calculation indicate that the orbit in both planes should be smooth to about ±2 mm. Even if substantial magnet motions were possible, this would be a difficult requirement to satisfy quickly. Again, simulations must be performed.

Present Correction Package

$$D_H = D_V = 98 \text{ kG-in}$$

Conclusion

Inadequate - need at least a factor of two increase. But any capability for quadrupole translation and dipole rotation must be explored.

COMMENTS

1. Main disappointment - I have spent a disproportionate amount of time since this study began looking at sextupole and octupole strengths in the hope of reducing them. No success.

2. Disturbing feature - There are a large number of weak elements, hence no opportunity to make functional groups in the hope of reducing cost and complexity.

3. Suspicion - The situation will not improve as time goes on. Examination of colliding beam requirements will put further pressure on the correction and adjustment system. Any consideration of stacking will change the demands dramatically.

4. Recommendation - I think that it would be a good thing to admit consideration of the case where the main magnets are shortened enough to provide about 60 inches for a separate dipole-quad package.