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Magnet Shuffling (Sorting)

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Magnet Shuffling (Sorting)

We do NOT have the general rules for shuffling magnets.

1. Each machine is different.
2. How to define "figure-of-merit".
3. How "bad" magnets are.

A. My experience with Tevatron. (& main Ring)

Remember that our magnets were rather "primitive" compared to what can be built now.

Final judgement NOT yet available — late '86.

B. Recent "revision" in connection with the SSC aperture question.

Tevatron Superperiod = 2 (6 but two High β's)
772 dipoles, 216 quadrupoles
$\nu_{H,V} \simeq 19.4$ (19.6)
β_{arc} = 25m ~ 100m ; max β ≃ 230m
$\beta^* = 1$m achieved

Correction System (spools)

a) H. & V steering dipoles
Very good position monitors ($\lesssim \frac{1}{4}$ mm)
closed orbit $\lesssim \frac{1}{2}$ mm

b) Trim quads — 2 families for ν_H, ν_V

c) Skew quads — 2 families, $|\nu_1 - \nu_2| \lesssim 3\times10^{-3}$
The second family needed with low β.

d) Chromaticity sextupoles — 2 families

Not powered.

a) $2\nu_H,\ 2\nu_V = 39$

b) $\nu_H + \nu_V = 39$

c) $3\nu_H,\ \nu_H + 2\nu_V = 58$

d) $3\nu_V,\ 2\nu_H + \nu_V = 58$

} may be used as "non-linear lens" for the study.

The first question asked (by DOE. HEPAP, . . .)

"Are the magnets good enough?"

"Yes, provided that - - - - - -"

1) Standard analysis (no beam tracking)

2) A set of criteria for $\{b_n, a_n\}$ as well as on $|\Delta B_y/B_0|$, $|B_x/B_0|$ at 1". (inner coil radius = 1.5")

For example, $|b_2| \leq 6 \times 10^{-4}/(in)^2$ at 4kA.

Problems

1. Large b_1 and a_1 (coil position rel. to cryostat)

2. Very bad magnets coming out — what to do?

"Prove that, with this magnet in, the doubler will not work. Then, you can reject the magnet."

Out of desperation —— shuffling

4000 A ($\simeq$ 900 GeV)

in $10^{-4}/(\mathrm{in})^n$

	– Used –		– Built –	
	av.	σ	min.	max.
b_1	.10	.53	−3.9	+3.7
a_1	.19	.57	−1.3	+4.2
b_2	1.0	3.6	−16.5	+12.1
a_2	.37	1.3	−4.2	+4.7
b_3	−.26	.85	−4.7	+3.0
a_3	−.09	1.6	−6.2	+5.7
b_4	−.69	1.5	−5.6	+3.5
a_4	−.07	.5	−1.9	+2.4

Design: b_6 +6.6 ; b_8 −15.6

b_{10} +4.7

Rules (arbitrary, more or less) of the shuffling.

1. Ignore $\Delta\int B \cdot dl$ (closed-orbit distortion)

2. Very limited shuffling of quads.
   (gross errors in $\int B' dl$)

3. Ignore $\Delta p/p \neq 0$ effects (e.g. $X_p \cdot \beta_H, \ldots$)

4. b_2, a_2, and a_3 only; at 4 kA ($\simeq$ 4 T)
   In particular, b_4 not used —
   In storage studies, fifth-integer resonances prominent if crossed.

5. First-order resonance driving terms
   — only one specific harmonic component for each resonance.

6. Try to balance within a relatively short distance in phase.
   70°/cell, 8 dipoles/cell.
   Never more than 4 cells at a time. — practical limit as well.

7. "Figure-of-merit"

Given $\sigma(b_n)$ or $\sigma(a_n)$, calculate the "expected" magnitude of driving terms. Then, try to beat that.

Initially, we just wanted to avoid a major blunder. – Later, we were more ambitious.

Actual procedures

8 ~ 32 dipoles

1. Take care of really bad ones "manually".
2. The rest by computer – many (but by no means all) arrangements tried.
3. Out of dozen or so candidates, select one — some "subjective" judgement here.

4000 A ; $\nu_H = 19.43$, $\nu_V = 19.42$

772 dipoles used

Res. Driving terms (first-order treatment)

		"200 rings" Av. σ	Tevatron
b_2	$3\nu_H = 58$	57.5 ± 29.4	2.6
	$\nu_H + 2\nu_V = 58$	45.1 ± 23.3	16.0
a_2	$3\nu_V = 58$	21.2 ± 12.0	10.8
	$2\nu_H + \nu_V = 58$	17.2 ± 9.1	5.6
a_3	$3\nu_H + \nu_V = 78$	164 ± 87	19.
	$\nu_H + 3\nu_V = 78$	176 ± 96	36.
	($3\nu_H + \nu_V = 77$	186 ± 90	70.)

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① "Figure-of Merit" is NOT unique.

② What if we had to shuffle with b_1 + a_1 ?

– Critical comments –

1. How much better than not shuffling.
Without tracking, difficult to answer quantitatively.
   – Ease of commissioning –
   – Ease of operation –
   – Storage capabilities –

2. Replacing magnets — degradation
"Day One" performance.
As we gain operational experience, we can tolerate more errors.
So far, ~dozen replaced.
Remember that "warmup-cooldown" requires a few days, at least.
We may rearrange a few warm dipoles if necessary.

Question of Aperture (SSC)

"First-order resonances are easy to avoid. The aperture limitation comes mostly from the phase-space smears. They are caused predominantly by sextupoles"

Action-angle formalism.

1. First-order, (I, a).
   No resonance : $I = \text{const.}$

2. Second-order $(I, a) \to (J, b)$.
   No resonance. $J = \text{const.}$ but $I \neq \text{const.}$

many harmonics contribute to the smear but the first-order terms are still important.

$$\frac{A_m}{(m-\nu)}, \quad \frac{A_m}{(m-3\nu)}, \text{ etc.}$$

Advantage - disadvantage of

"frequency-domain" vs "time domain".

Gluckstern's scheme

One parameter only (two parameters. b_2 & a_2
e.g. b_2 very difficult)

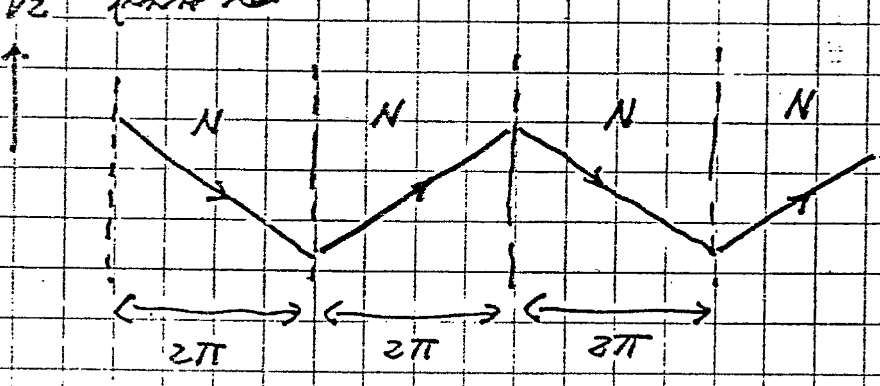
Simple principle.

$\nu_H = \nu_V = \nu$;

Eliminate as many harmonics as possible near ν and 3ν.

$\nu \simeq M$ (phase advance/ring $\simeq 2\pi \cdot M$)

N dipoles/2π $\rightarrow$ total $(N \cdot M)$ dipoles.



measure N dipoles and install at a time.

allowed harmonics : $\frac{M}{2}$, $\frac{3}{2}M$, $\frac{5}{2}M$, . . .

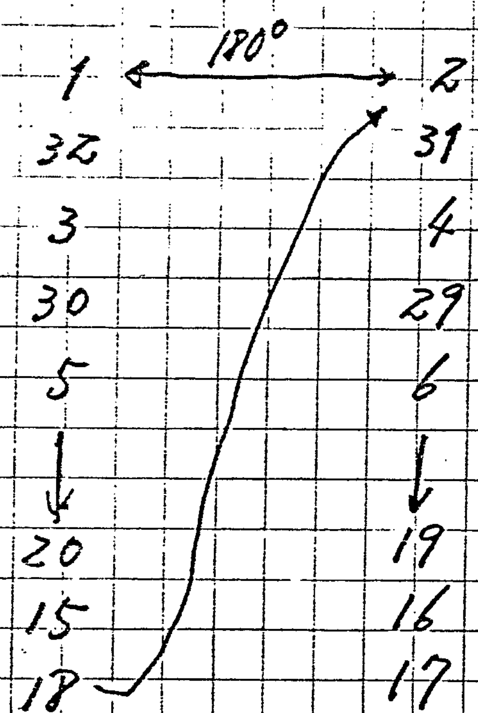
Problems : (1) insertions.

(2) Phase advance not $(2\pi) \times$ integer in each arc.

(3) fluctuations from group to group.

Within 2π (e.g. 90°/cell, 4 cells
60°/cell, 6 cells.)
(80°/cell, 9 cells.)

<u>example</u> (90°/cell, 4 dipoles/half cell, $N = 32$)



smear reduction
$\simeq (5-6)$

~~exam~~ Ex.
"RHIC" 90°/cell, $N = 8$. (or 16 or 24 . . .)

expected smear reduction $\simeq 3$ (?)

Tracking studies by N. Gelfand show large variations in the smear depending on the arrangement.

RHIC

1. Is one-parameter shuffling useful?
2. One harmonic component instead of "smear" — Does this help enlarge the aperture?
3. Is it likely to build "many" bad magnets? (Average and σ are not the whole story.)
4. Correction system — what kinds, how many.

As usual, there is no unique answer.