

## Magnet Shuffling (Sorting)

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**MAGNET SHUFFLING (SORTING)**

**S. Ohnuma**

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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  $\beta$ 's)

772 dipoles, 216 quadrupoles

$$\nu_{H,V} \approx 19.4 \quad (19.6)$$

$$\beta_{arc} = 25m \sim 100m ; \quad \max \beta \approx 230m$$

$$\beta^* = 1m \text{ achieved}$$

## Correction System (spools)

a) H. & V steering dipoles

Very good position monitors ( $\approx \frac{1}{4}$  mm)

closed orbit  $\approx \frac{1}{2}$  mm

b) Trim quads — 2 families for  $\nu_H, \nu_V$

c) Skew quads — 2 families,  $|\nu_1 - \nu_2| \approx 3 \times 10^{-3}$

The second family needed with low  $\beta$ .

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  $|B_y/B_0|, |B_x/B_0|$  at 1".  
(inner coil radius = 1.5")

For example,  $|b_z| \leq 6 \times 10^{-4} / (\text{in})^2$  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 ( $\approx 900 \text{ GeV}$ )

- 4 -

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

- Used -

- Built -

av.

$\sigma$

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:  $b_6 + 6.6$  ;  $b_8 - 15.6$

$b_{10} + 4.7$

-5-

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

1. Ignore  $\Delta\beta \cdot dL$  (closed-orbit distortion)
2. Very limited shuffling of quads.  
(gross errors in  $\beta' \cdot dL$ )
3. Ignore  $\Delta p/p \neq 0$  effects (e.g.  $X_p \cdot \beta_H, \dots$ )
4.  $b_2, a_2,$  and  $a_3$  only; at  $4kA$  ( $\approx 4T$ )  
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.  
 $70^\circ/\text{cell}, 8 \text{ dipoles/cell}.$   
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.

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Actual procedures

$8 \sim 32$  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.

$$4000 A; \quad V_H = 19.43, \quad V_V = 19.42 \quad \text{---} \text{---}$$

772 dipoles used

Res. Driving Terms (first-order treatment)

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

- 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 dipoles  
if necessary. warm

# 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)  $\rightarrow$  (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.

$$\frac{A_m}{(m-2)}, \frac{A_m}{(m-3)}, \text{ etc.}$$

Advantage - disadvantage  $\curvearrowright$

"frequency-domain" vs "time domain"

# Gluckstern's scheme

One parameter only (two parameters,  $b_2 \neq a_2$   
e.g.  $b_2$  very difficult)

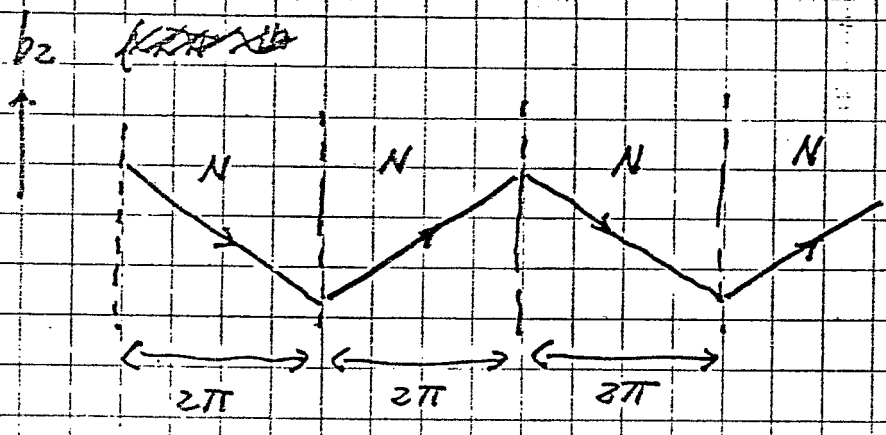
Simple principle:

$$V_H = V_V = V;$$

Eliminate as many harmonics as possible  
near  $V$  and  $3V$ .

$V \approx M$  (phase advance/ring  $\approx 2\pi \cdot M$ )

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



measure  $N$  dipoles  
(and install  
at a time.

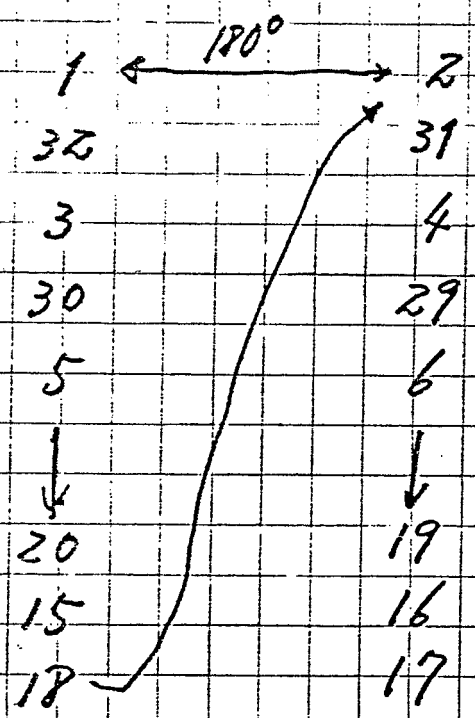
allowed harmonics:  $\frac{M}{2}, \frac{3}{2}M, \frac{5}{2}M, \dots$

## problems

- (1) insertions.
- (2) phase advance not  $(2\pi) \times$  integer  
in each arc.
- (3) fluctuations from group  
to group.

Within  $2\pi$  (e.g.  $90^\circ/\text{cell}$ , 4 cells  
 $60^\circ/\text{cell}$ , 6 cells.)  
( $80^\circ/\text{cell}$ , 9 cells.)

example ( $90^\circ/\text{cell}$ , 4 dipoles/half cell,  $N = 32$ )



smear reduction  
 $\approx (5-6)$

~~exam~~  
"RHIC"  $90^\circ/\text{cell}$ ,  $N = 8$ . (or 16 or 24...)

expected smear reduction  $\approx 3(?)$

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  $\sigma$  are not the whole story.)
4. Correction system — what kinds, how many.

As usual, there is no unique answer.