

# The Residual $\beta$ -Shift Due to Random Skew Quadrupole Errors

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The Residual  $\nu$ -Shift Due to Random  
Skew Quadrupole Errors

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①

The  $\nu$ -shift due to the random  $a_1$

The random  $a_1$  introduces two coupled modes with  $\nu$ -values  $\nu_1$  and  $\nu_2$ .  
The  $x$ -motion and the  $y$ -motion now have ~~the~~ both  $\nu$ -values  $\nu_1$  and  $\nu_2$ .

$$x = ( ) e^{i\nu_1 \theta} + ( ) e^{i\nu_2 \theta}$$

$$y = ( ) e^{i\nu_1 \theta} + ( ) e^{i\nu_2 \theta}$$

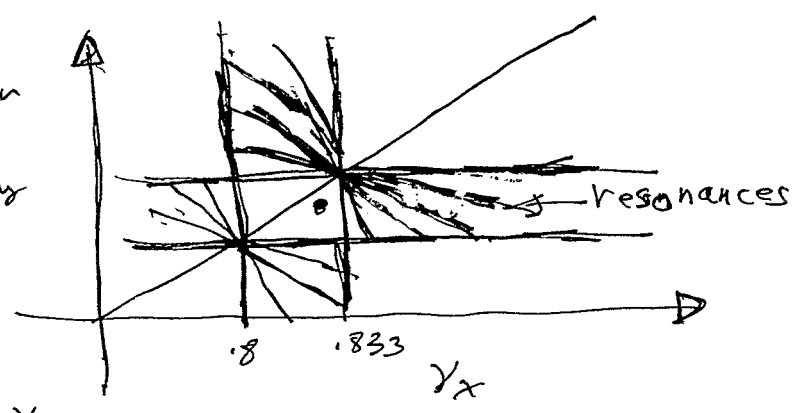
The  $\nu_1, \nu_2$  can differ appreciably from the original  $\nu_x, \nu_y$ .

Is this  $\nu$ -shift due to  $a_1$  dangerous?

Review of the  $\nu$ -shift due to random  $b_1$

The  $b_1$   $\nu$ -shift is easier to understand.

The resonances <sup>lines</sup>  $n_x \nu_x + n_y \nu_y = \text{integer}$  are considered dangerous if a time modulation of the  $\nu$ -values is present.



a  $\nu$ -shift due to  $b_1$

~~shift~~ which shifts  $\nu_x, \nu_y$

out of the resonance free box is considered dangerous.

(2)

$\nu$ -shifts due to  $a_1$

In this case the  $\nu_x, \nu_y$  diagram is not as useful, I think ~~(it is still true)~~ that, just as in the  $\nu$ -shifts due to  $b_1$  case, one needs to avoid the resonance lines  $n_1 \nu_1 + n_2 \nu_2 = \text{integer}$ . This becomes difficult when the shift in  $\nu_1$  and  $\nu_2$  becomes comparable to  $33 \times 10^{-3}$ .

The expected  $\nu$ -shifts in KHC are

$$\begin{aligned} |\nu_1 - \nu_2|_{\max} &\approx 100 \times 10^{-3} & \text{for } \beta^* = 6 \\ |\nu_1 - \nu_2|_{\max} &\approx 250 \times 10^{-3} & \text{for } \beta^* = 2 \end{aligned}$$

The  $\nu$ -shifts due to  $a_1$  cannot be corrected with  $b_1$  correctors such as QF and QD.

The  $\nu$ -shifts due  $a_1$  and  $b_1$  are given by

$$|\nu_1 - \nu_2| = 2 \left\{ \left( \frac{\nu_x - \nu_y}{2} \right)^2 + (\Delta \nu_{11})^2 \right\}^{1/2}$$

$$\Delta \nu_{11} = \frac{1}{4\pi p} \int ds (\beta_x \beta_y)^{1/2} a_1 \exp(i\psi_x - i\psi_y)$$

$$\nu_{av} = (\nu_1 + \nu_2)/2 = (\nu_x + \nu_y)/2$$

where  $\nu_x, \nu_y$  are  $\nu$ -values when  $a_1 = 0$ .

Above correct to first order in  $a_1$ .

$b_1$  correctors can be used to move  $y_x, y_y$   
 The best one can do is make  $y_x = y_y$  and  
 then  $|y_1 - y_2| = |\Delta y_1|$   
 $y_{av}$  can be controlled using the  $b_1$  correctors.

### Global Correction System

Two families of skew quads  
 can be adjusted to make  $\Delta y_1 = 0$

This should correct the  $y$ -splitting to

$$|y_1 - y_2| = |y_x - y_y|$$

# Results for the Global Correction System

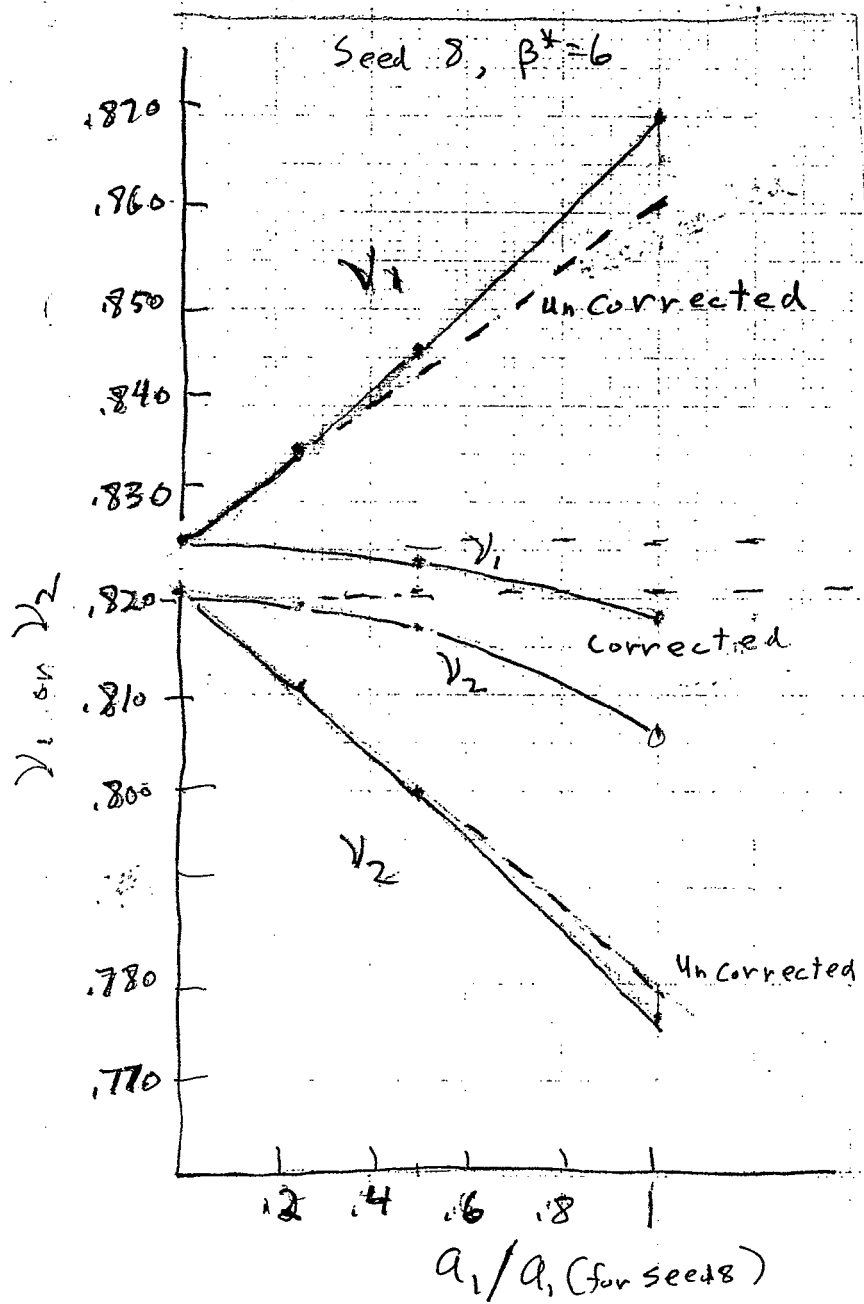
 $\beta^* = 6$  $\beta^* = 2$ 

	Un Corrected			Corrected				UnCorrected			Corrected		
$N_{seed}$	$v_1, v_2$	$ v_1 - v_2 /10^{-3}$		$v_1, v_2$	$ v_1 - v_2 /10^{-3}$			$v_1, v_2$	$ v_1 - v_2 /10^{-3}$		$v_1, v_2$	$ v_1 - v_2 /10^{-3}$	
1	.844, .801	43		.825, .819	6			.854, .796	58		.828, .822	6	
2	.868, .789	79		.822, .811	11			.935, .707	228		.838, .819	19	
3	.855, .795	60		.826, .820	6			.869, .783	86		.829, .825	4	
4	.864, .783	81		.824, .815	9			.883, .772	111		.830, .823	7	
5	.841, .820	21		.832, .818	14			.872, .778	94		.836, .820	16	
6	.824, .815	9		.828, .820	8			.848, .805	43		.832, .821	11	
7	.836, .818	18		.830, .822	8			.847, .840	7		.852, .834	18	
8	.872, .772	100		.820, .805	15			.895, .741	154		.828, .818	20	
9	.845, .805	40		.826, .821	5			.866, .785	81		.828, .822	6	
10	.854, .811	43		.827, .821	6			.891, .749	142		.827, .822	5	

In a fair number of machines, there is a large residual  $|v_1 - v_2|$ . In 3 cases for  $\beta^* = 6$  and for 5 cases for  $\beta^* = 2$ , the residual  $|v_1 - v_2|$  is about  $11 \times 10^{-3}$  to  $20 \times 10^{-3}$ .

This appears to be due to terms in  $|v_1 - v_2|$  which go like  $q_1^2$  or higher powers of  $q_1$ .

$\gamma_1, \gamma_2$  versus  $Q_1$





## Local Correction System

It appears that the correction of the residual  $|V_1 - V_2|$  requires a more local correction system.

A possible local correction is the  $a_1$  correctors near QD in the arcs.

Using these correctors, assuming each  $a_1$  corrector can be individually powered, the following  $|V_1 - V_2|$  was achieved

$\beta^* = 6$		
Need	Global Correction	Local Correction
	$ V_1 - V_2 /10^{-3}$	$ V_1 - V_2 /10^{-3}$
8	15	6.4
5	13	6.6
2	10	5.0
$\beta^* = 2$		
8	20	7.2
7	18	7.5
6	11	6.8
5	16	4.0
2	19	7.5
Further correction could be achieved by making $V_x = V_y$ using $b_1$ correctors.		

## Some Unsolved Problems

- 1) How well can 4-families of  $Q_i$  ~~correctors~~ correctors per sextant do?
- 2) What measurements can one do to help set the local  $Q_i$  correctors?
- 3) Can one correct the residual  $(V, -V/2)$  and the reduction in  $A_{SL}$  due  $Q_i$  simultaneously with the same  $Q_i$  correctors.