Impact of a relative roll in a Q2 pair

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February 7, 2002

I examine some of the optics issues related to a relative roll in a Q2 pair

1 Lattice

Version 5.1 of the LHC lattice with two low-beta IPs (IP1 and IP5) at $\beta^* = 0.5$m was used.

2 Minimum tune split

Roll of a quadrupole introduces coupling. A measure of this coupling is the minimum tune split

$$\Delta\nu_{min} = \frac{\sqrt{\beta_x\beta_y}}{\pi}\frac{B'L_q}{(B\rho)}\Delta\psi \tag{1}$$

where $\Delta\psi$ is the roll angle. The requirement on the allowed coupling *before correction* is

$$|\Delta\nu_{min}| \leq 0.05 \tag{2}$$

Operational experience shows that with larger minimum tune splits, diagnostics is complicated which makes the correction of coupling difficult.

We assume that if there is a relative roll between Q2a and Q2b, the effect will be partially compensated during installation by having them rolled in opposite directions with respect to the beam axis. If $\Delta\psi_{rel}$ is the relative roll of the pair, the individual roll angles of Q2a and Q2b are

$$\Delta\psi(Q2a) = -(\Delta\psi_{rel} - \Delta\psi(Q2b)) \tag{3}$$

We assume that in each of the 4 pairs (Q2a, Q2b), the quadrupoles Q2a are rolled in the same direction and similarly Q2b.

Figure 1 shows the minimum tune split as a function of the roll angle in Q2b. We observe that the tune split is within the allowed band provided the roll of Q2b is within the limits

$$0.75\ [\mathrm{mrad}] \leq \Delta\psi(Q2b) \leq 1.05\ [\mathrm{mrad}] \tag{4}$$

with a minimum around $\Delta\psi(Q2b) = 0.9$ mrad.

Figure 2 shows the tune split when the relative roll angle is limited to 1 mrad. The allowed band is now

$$0.27\ [\mathrm{mrad}] \leq \Delta\psi(Q2b) \leq 0.60\ [\mathrm{mrad}] \tag{5}$$

with a minimum around 0.44 mrad.

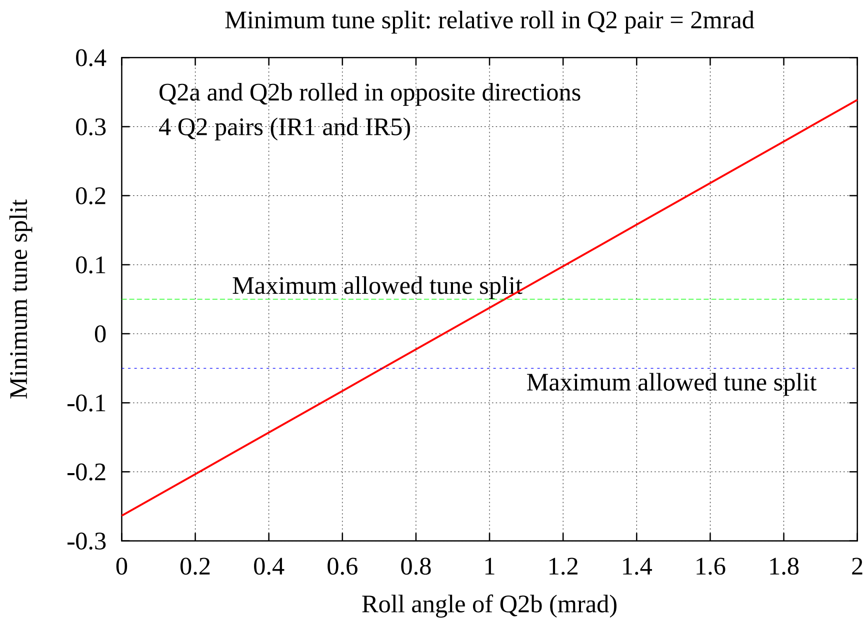

Figure 1: Mimimum tune split as a function of the roll in Q2b. The relative roll angle between Q2a and Q2b is constant at 2 mrad.

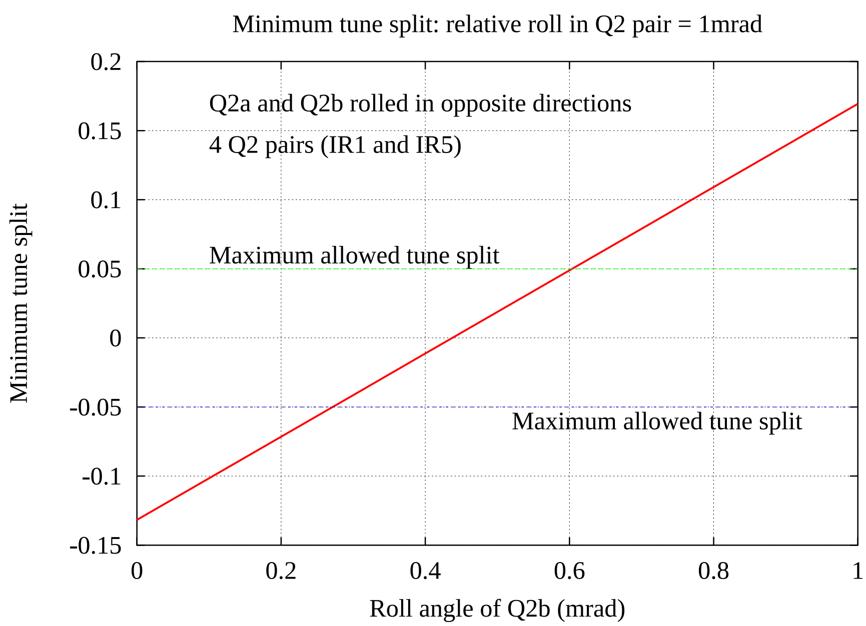

Figure 2: Same as above but with the relative roll limited to 1 mrad.

3 Dynamic aperture with rolls

In this case all the uncertanties were chosen with the negative sign.

$$b_n = \langle b_n \rangle - db_n + \mathrm{ran}(b_n) \tag{6}$$

$$a_n = \langle a_n \rangle - da_n + \mathrm{ran}(a_n) \ , \qquad \forall n \tag{7}$$

We studied two cases with a relative roll of 2 mrad: (1) Equal and opposite rolls of 1 mrad, (2) Roll of +1.5 mrad in Q2a and a roll of -0.5 mrad in Q2b. Particles were tracked for 1024 turns and 10 seeds. The results are seen in Figures 3 and 4.

	$\langle DA \rangle \pm \sigma(DA)$ 1024 turns
No rolls	11.2 $\pm$ 0.8
$\Delta\psi(Q2a) = 1.0\mathrm{mrad} = -\Delta\psi(Q2b)$	11.2 $\pm$ 0.8
$\Delta\psi(Q2a) = 1.5\mathrm{mrad}$, $\Delta\psi(Q2b) = -0.5$ mrad	11.2 $\pm$ 0.8

Table 1: Average values of the dynamic aperture (DA) for the cases studied.

At these numbers of turns, there is no impact on the DA.

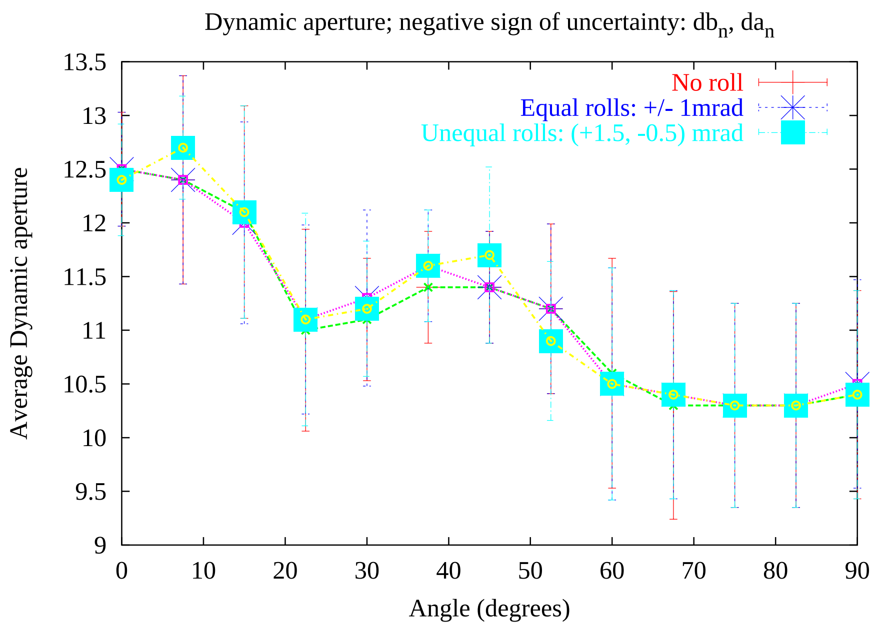

Figure 3: (color) Average dynamic aperture (10 seeds, 1024 turns) with (1) no rolls (2) equal and opposite rolls of 1 mrad in Q2a and Q2b and (3) $\Delta\psi(Q2a) = +1.5$ mrad and $\Delta\psi(Q2b) = -0.5$ mrad. The differences are negligible.

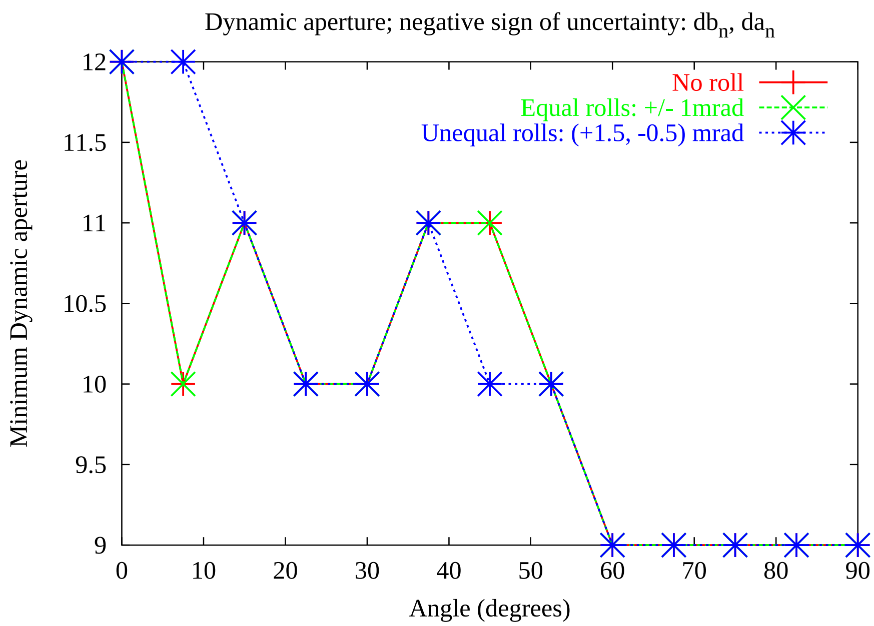

Figure 4: (color) Minimum dynamic aperture for the same cases as above.