Longitudinal alignment tolerances for HL-LHC IT?

M. Fitterer and S. Fartoukh

Acknowledgments: R. De Maria and M. Giovannozzi

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Motivation

EN-MEF-SU (Survey) is starting to design the alignment system for the HL-LHC IT:

-> new alignment system should also include measurements of the longitudinal position (not included in current system)

-> Request by EN-MEF-SU (Survey) to specify longitudinal alignment tolerances for the IT

Optics distortions due to long. misalignment

longitudinal misalignment of quadrupoles results (mainly) in beta-beating. Assuming $3\Delta\sigma_s$ longitudinal alignment error (Gaussian error distribution), the peak beta-beating is in first order given by (see LHC Project Note 866):

$$B_{x,y}^{\mathrm{classX}} = \chi_{x,y}^{\mathrm{classX}} \sigma_{\Delta_s}^{\mathrm{classX}}, \text{ with}$$

$$\chi_{x,y}^{\mathrm{classX}} = \frac{3}{2\sqrt{2}\sin 2\pi Q_{x,y}} \sqrt{\sum_{i \in \mathrm{classX}} {K^{(i)}}^2 \left({\beta_{x1,y1}^{(i)}}^2 + {\beta_{x2,y2}^{(i)}}^2 - 2\beta_{x1,y1}^{(i)} \beta_{x2,y2}^{(i)} \cos 2\Delta\mu_{x,y}^{(i)} \right)}$$

where the IT is seen as one class of magnets. $\beta_{1/2}$ is the beta function at the entrance and exit of the quadrupole and $\Delta\mu$ the phase advance over the quadrupole.

Limits on peak beta-beat (given by S. Fartoukh):

- injection:
  1% peak beta-beat
- pre-squeezed optics (β*=44 cm):
  20% peak beta-beat
- squeezed optics **and** assuming a correction of the pre-squeezed optics to <7 %:
  20% peak beta-beat

Sensitivity of different optics

peak beta-beat assuming $3\Delta\sigma_s$ longitudinal alignment error is given by:

$$B_{x,y}^{\text{classX}} = \chi_{x,y}^{\text{classX}} \sigma_{\Delta_s}^{\text{classX}}, \text{ with}$$

$$\chi_{x,y}^{\text{classX}} = \frac{3}{2\sqrt{2}\sin 2\pi Q_{x,y}} \sqrt{\sum_{i \in \text{classX}} K^{(i)2} \left({\beta_{x1,y1}^{(i)}}^2 + {\beta_{x2,y2}^{(i)}}^2 - 2\beta_{x1,y1}^{(i)} \beta_{x2,y2}^{(i)} \cos 2\Delta\mu_{x,y}^{(i)} \right)}$$

peak beta-beating considering the contribution form all IT magnets in IR1 and IR5 and $3\sigma_{\Delta s}$:

optics	Sensitivity parameter $\chi_{x,y}$ [m^{-1}]		$\sigma_{\Delta s}$ [mm] for peak beta-beat($3\sigma_{\Delta s}$)=1%	$\sigma_{\Delta s}$ [mm] for peak beta-beat($3\sigma_{\Delta s}$)=20%
	hor. b1/b2	vert. b1/b2		
injection 6	2.54/2.54	2.68/2.68	3.73	-
pre-squeeze	36.58/36.57	37.60/37.58	-	5.32
round	107.32/107.24	110.33/110.16	-	1.82
flat	155.69/155.29	160.21/159.86	-	1.25
sround	161.05/160.86	165.56/165.15	-	1.21
sflat	232.24/231.21	239.31/238.38	-	0.84

Proposal

optics	Sensitivity parameter $\chi_{x,y}$ [m^{-1}]		$\sigma_{\Delta s}$ [mm] for peak beta-beat($3\sigma_{\Delta s}$)=1%	$\sigma_{\Delta s}$ [mm] for peak beta-beat($3\sigma_{\Delta s}$)=20%
	hor. b1/b2	vert. b1/b2		
injection 6	2.54/2.54	2.68/2.68	3.73	-
pre-squeeze	36.58/36.57	37.60/37.58	-	5.32
round	107.32/107.24	110.33/110.16	-	1.82
flat	155.69/155.29	160.21/159.86	-	1.25
sround	161.05/160.86	165.56/165.15	-	1.21
sflat	232.24/231.21	239.31/238.38	-	0.84

=> request 1-2 mm as longitudinal alignment error tolerance?????

BACKUP SLIDES

Check with MC simulations

peak beta-beat with analytical formula:

optics	Sensitivity parameter $\chi_{x,y}$ [m^{-1}]		$\sigma_{\Delta s}$ [mm] for peak beta-beat($3\sigma_{\Delta s}$)=1%	$\sigma_{\Delta s}$ [mm] for peak beta-beat($3\sigma_{\Delta s}$)=20%
	hor. b1/b2	vert. b1/b2		
injection 6	2.54/2.54	2.68/2.68	3.73	-
pre-squeeze	36.58/36.57	37.60/37.58	-	5.32
round	107.32/107.24	110.33/110.16	-	1.82
flat	155.69/155.29	160.21/159.86	-	1.25
sround	161.05/160.86	165.56/165.15	-	1.21
sflat	232.24/231.21	239.31/238.38	-	0.84

Monte Carlo simulation for "opt round" considering the contribution from all IT magnets in IR1/5 and assuming a Gaussian distribution with $\sigma=\sigma_{\Delta s}$ and 1000 seeds.

$\sigma_{\Delta s}$	Beam	beta-beat [%] (hor./vert.)				
		maximum	mean	std	rms	3 rms
1 mm	B				84	11.18/11.51
	B				63	11.74/10.88
5 mm	B				3.64	68.71/70.92
	B				3.02	71.49/69.07
10 mm	Beam 1	1962.91/1759.21	46.11/44.46	92.55/95.44	105.58/1.07	310.15/213.2
	Beam 2	1815.21/1590.12	46.04/44.48	75.44/78.39	88.38/90.13	265.15/270.4

➪ good agreement with the analytical formula for small misalignments (< few mm). For larger misalignments, the analytical formula underestimates the rms peak beta-beat as expected.