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Fractional Tune Dependence of Dynamic Aperture for LHC at Collision

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Abstract

This report investigates the dependence of LHC dynamic aperture and tune footprints at collision on the choice of the betatron working point when the source of nonlinearity is from the Insertion Region Triplet Quadrupoles. It is found that the average DA can be increased by $2.5 - 3\sigma$ by minor detuning from the third integer resonance.

1 Introduction

A main source of nonlinearity of the beam at the LHC collision is the errors of the high-β IR quadrupoles. Previously, 6-D particle tracking with version 5.1 of the collision lattice and quadrupoles errors from version 1.2 of the magnet error table [1] has been performed. It was found that the (10^5 turns) average dynamic aperture is 10.2σ and the tune spread at 6σ can be as large as 4×10^{-3}, significantly worse than the target value of dynamic aperture of 12σ and tune spread of 1×10^{-3}. Thus it is important to improve the nonlinear perfomance of the accelerator. One compensation method is to use the nonlinear correctors near the IR quadrupoles to compensate for the nonlinear kicks generated by the quad errors [2]. Other ways to reduce the nonlinear effects include improving the quality of field of the quadrupoles and to optimize the working point of the machine.

In this report we study the dependence of the DA and tune spreads on betatron tunes. The nominal betatron tune values at the collision LHC lattice are 63.31 in the horizontal direction and 59.32 in the vertical direction. The fractional part of both tunes is close enough to the third integer resonance. So, one of the questions has been to find out how strong is the sensitivity to this resonance and whether one can increase dynamic aperture by minor detuning from the resonance.

2 Tracking Setup and Machine Model

Version 5.1 of the LHC collision lattice with nominal crossing angles and beam separations has been used for tracking. The collision lattice involves 4 LHC interaction regions with specific crossing angles , β^* and the beam separation. The configuration is shown in Table 1.

	IP1	IP2	IP5	IP8
sep. [mm]	0	1.5	0	1.5
angle[μrad]	$\pm$150 v	$\pm$150 v	$\pm$150 h	$\pm$100 v
β_x^*,β_y^* [m]	0.5,0.5	15,10	0.5,0.5	13,15

Table 1: Interaction point configuration parameters

We restrict our investigation using 1000 turn tracking. Previous study indicates that 10^5 turn tracking further reduces DA by about 0.5σ. The initial coordinates for the particles are choosen on five directions in the transverse X-Y plane with a step size of 1σ. The initial particle momentum p_x, p_y are set to be equal to zero. Post-tracking analysis determines the maximum aperture (survival aperture) below which there are no particle losses.

Ten seeds of magnet errors habe been created based on the error table version 1.2. We excluded from consideration only sqew quadrupole component of the errors assuming that coupling in the ring is completely compensated. After IR quad errors were introduced to the lattice the arc quadrupoles have been used to retune the machine to the desired working point. The arc sextupoles have been used to correct the chromaticity t0 2.0 in both X and Y planes. The tracking is 6 dimensional with the RF system operates at nominal value.

3 Results

3.1 Survival aperture

In order to find the change in survival aperture we scan the betatron tune area between 0.28 and 0.32 for both the horizontal and vertical tunes. The final results for survival aperture averaged over all 10 seeds and all 5 directions in the transverse plane are shown in Table 2.

	0.28	0.29	0.30	0.31	0.32	ν_y
0.28	13.32	12.52	12.74	12.96	12.42	
0.29	12.42	13.00	12.92	12.86	12.14	
0.30	12.54	12.38	12.90	12.16	11.48	
0.31	12.42	12.44	12.30	11.42	10.72	
0.32	11.86	11.66	11.34	10.38	9.78	
ν_x						

Table 2: Average survival aperture versus fractional part of the betatron tunes from 1000 turn tracking

The survival aperture at nominal working point (0.31, 0.32) can be improved by 2–2.5σ by small detuning from the third integer resonance. It is noted also that the survival aperture has a little more sensitivity to the shift of the horizontal tune than to the vertical one. The working point (0.28, 0.31), which is the nominal working point at injection, looks especially good. At Figure 1 the survival aperture results averaged over 10 seeds are drawn for different directions in the transverse plane. The results for 3 different working points (including the nominal working point) are shown.

Table 3 demonsrates the minimum survival aperture found at given betatron tunes. There is also an obvious increase by 3–4σ.

	0.28	0.29	0.30	0.31	0.32	ν_y
0.28	10	10	11	9	8	
0.29	9	10	10	10	7	
0.30	9	8	9	9	8	
0.31	8	8	8	5	8	
0.32	7	6	6	6	6	
ν_x						

Table 3: Minimum survival aperture versus fractional part of the betatron tunes from 1000 turns tracking

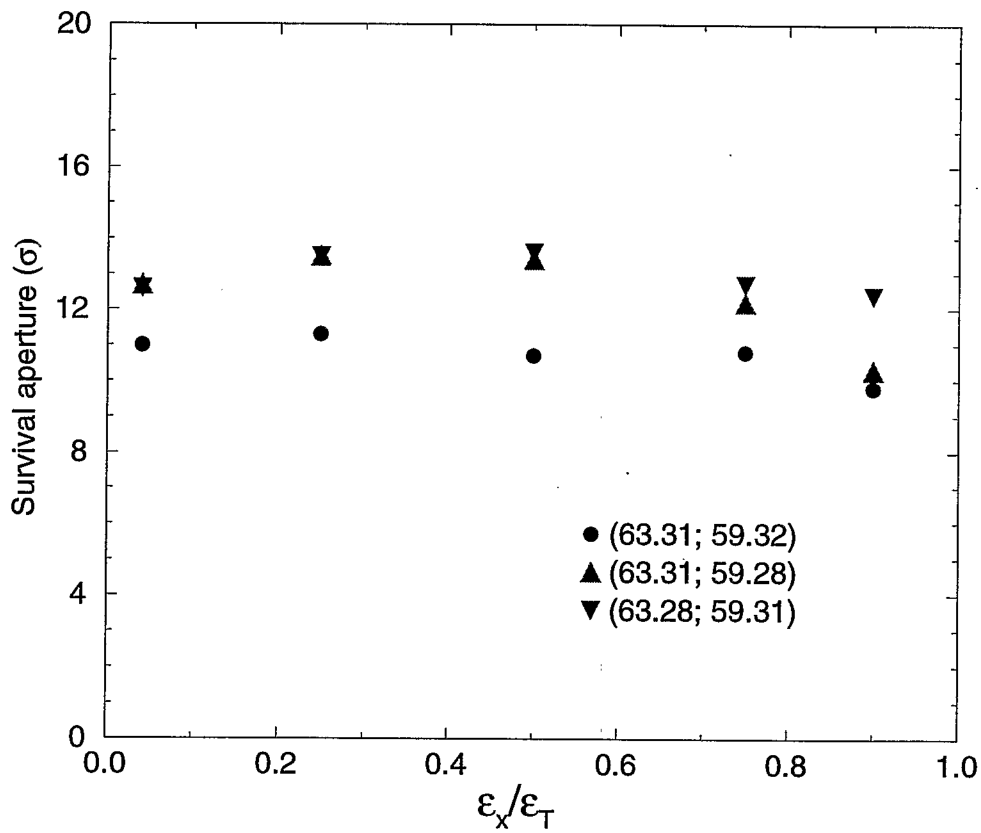

Figure 1: The survival aperture versus a direction in transverse plane. The data averaged over 10 seeds are shown for three different working points. 0.0 corresponds to the vertical direction while 1.0 is horizontal.

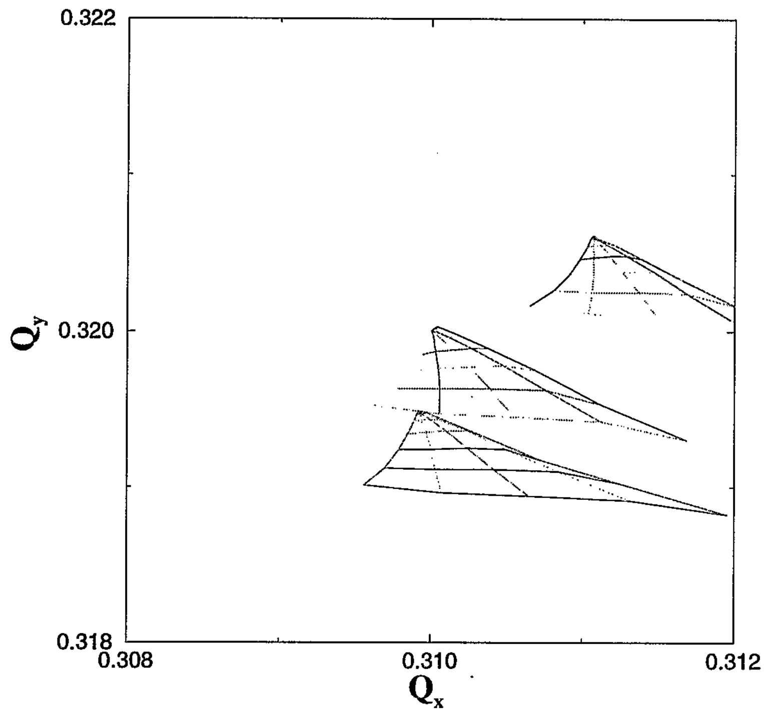

Figure 2: The tune footprints for particles with 0 and $\pm 2.5\sigma_p$ energy deviation. Transverse amplitudes are taken up to 6σ.

3.2 Tune footprint

To confirm that the change of the survival aperture is purely an effect of detuning from the resonance, we checked whether the tune footspread changes with betatron tunes. In contrast to the DA, the tune footspread produced by the nonlinear errors of the IR quads is not expected to depend on the working point.

It was found that the tune footspread practically does not depend on betatron tunes in the specified area $[0.28 - 0.32]$. The typical footprints are shown in Figure 2 and the footprint sizes are about 2×10^{-3} in the horizontal direction and 7.5×10^{-4} in the vertical direction.

4 Discussion

The survival aperture of LHC at collision can be, in principle, improved by a slight change of the betatron working point of the collider. The increase of the survival aperture are due to detuning from third integer resonance.

On the otherhand, beam-beam effect, an important effect at collision has not been included in this study. Optimization of the working point must be carried out by fully taking into account the impact of both beam-beam and magnetic field nonlinear effects.

Acknowledgments

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References

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