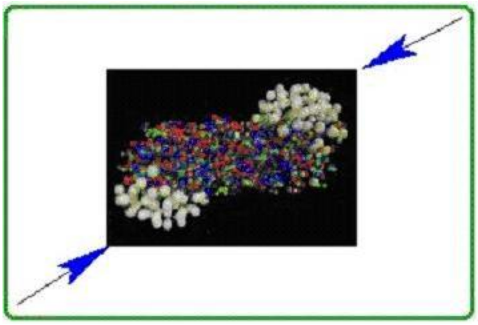

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Emittance growth due to crab cavity ramping for LHC beam-1 lattice

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Abstract

In LHC upgrade scenarios using global crab crossing, it is desired to turn on the crab cavity only at top energy. Turning on the crab cavity could increase the emittance of the stored beam, since the transverse kick of the crab cavity excites betatron oscillations. For a sufficiently slow ramping speed of the crab cavity voltage, however, the changes in z-dependent closed orbit are sufficiently adiabatic that the emittance growth becomes negligible. In order to determine the safe ramping speed of the LHC crab-cavity voltage, the dependence of the emittance growth on the ramping speed is estimated via a 6D particle-tracking simulation.

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INTRODUCTION

In LHC upgrade scenarios using global crab crossing, it is desired to turn on the crab cavity only at top energy. Turning on the crab cavity could increase the emittance of the stored beam, since the transverse kick of the crab cavity excites betatron oscillations. For a sufficiently slow ramping speed of the crab cavity voltage, however, the changes in z-dependent closed orbit are sufficiently adiabatic that the emittance growth becomes negligible.

In order to determine the safe ramping speed of the LHC crab-cavity voltage, the dependence of the emittance growth on the ramping speed is estimated via a 6D particle-tracking simulation.

SIMULATION

The 6D particle tracking simulation is performed by the Strategic Accelerator Design code (SAD)[1].

The optics used in this tracking simulation has been translated into SAD language from the LHCB1 collision optics version 6.503 described in MAD-X format. The ideal lattice is considered without any nonlinear magnetic field errors. The crab cavity is inserted as a thin element at a position 35 m upstream of IP4. Neither the beta function nor the betatron phase at this location are optimized for the crab crossing.

The initial Gaussian particle distribution is generated on normal coordinates with the nominal emittance using a pseudo random number generator. In order to suppress the artificial betatron oscillation arising from the statistical distribution of a small number of particles, the 1st order moments of the distribution are subtracted from the generated coordinates. The particle distribution is then transformed from normal coordinates to physical coordinates using both the coordinate transformation matrix and the closed orbit at the starting point[2]

The particle distribution is tracked by SAD around the ring. The three normal-coordinate emittances are calculated by

$$\epsilon_x = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}\sigma_{21}} \tag{1}$$

$$\epsilon_y = \sqrt{\sigma_{33}\sigma_{44} - \sigma_{34}\sigma_{43}} \tag{2}$$

$$\epsilon_z = \sqrt{\sigma_{55}\sigma_{66} - \sigma_{56}\sigma_{65}}, \tag{3}$$

where σ_{ij} denotes a component of the beam Σ matrix containing the second moments of the normalized distribution. The 1st, 2nd, 3rd, 4th, 5th, and 6th normal coordinate correspond to the physical variables x, p_x/p_0, y, p_y/p_0, z and $\triangle p/p_0$, respectively.

In order to emulate the crab cavity voltage ramping, the crab cavity voltage is varied linearly in time, on every turn within the pre-defined ramping period. Both the transformation matrix from the physical coordinates to the normal coordinates and the 6D closed orbit are updated with every crab cavity voltage change.

The major simulation conditions are summarized in Table 1.

Table 1: Simulation condition

Simulation Model	
Tracking	6D Tracking on SAD without Synchrotron Radiation
Base Optics	
Optics Model	LHCB1 Collision Optics (V6.503 @ 2008/07/14)
Acceleration Voltage	16 MV
Crab Cavity	
Location	35 m upstream of IP4
Frequency	400 MHz
Harmonic Number	35640
Crabbing Angle @ ip5	285 μrad
Particle Distribution	
Distribution Shape	6D Gaussian
Number of Particles	10^4
Transverse Emittance(1σ)	5.0×10^{-10} m · rad
Longitudinal Emittance(1σ)	6.7×10^{-6} m · rad

Figure 1 presents the simulated relative horizontal emittance growth, computed in normal coordinates, while the crab-cavity is ramping up and down. In Fig. 1, the crab cavity is turned on at turn 0 and its voltage is linearly increased up to the nominal voltage. The ramping periods is indicated by the color of the markers. After a period at flat top, the crab cavity is slowly turned off again between turns 2000 and 2100. In the fast ramping cases with a ramp-period of 1, 2 and 5 turns, corresponding to the green, blue

[1] SAD is a computer program complex developed in KEK since 1986 for accelerator design, simulation and operation. The detail information is obtained from the official web site(http://acc-physics.kek.jp/SAD/).

[2] The closed orbit change between before and after ramping is negligible, less than 10 nm. The SAD calculation supports the modelling of more general time variations, like a crab phase sweeping.