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OPTICS FLEXIBILITY IN THE LHC AT TOP ENERGY

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CERN, Geneva, Switzerland

Abstract

Flexibility of the LHC optics at top energy has been studied, in terms of betatron tune tunability, mainly for the high-beta optics that requires tunability of the order of half a unit. It has been shown that the tunability at top energy is good enough for the high-beta optics. The results obtained in this study could be useful for other optics and operation modes.

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Abstract

Flexibility of the LHC optics at top energy has been studied, in terms of betatron tune tunability, mainly for the high-beta optics that requires tunability of the order of half a unit. It has been shown that the tunability at top energy is good enough for the high-beta optics. The results obtained in this study could be useful for other optics and operation modes.

INTRODUCTION

The study of the LHC optics flexibility in terms of its capability to compensate for changes in betatron tunes at top energy was triggered by the needs of special operation modes, namely the so-called high-beta optics [1]. Since the constraints from physical apertures are significantly relaxed at top energy, thanks to the adiabatic damping of transverse emittances, the flexibility in tunes could be of the order of half a unit per insertion region (IR). In this paper, the tunability range at top energy of IR2, IR4, IR8 as well as that of the main arcs is presented.

HIGH-BETA OPTICS AND TUNE COMPENSATION

The high-beta optics are special optics for the absolute luminosity measurement in ATLAS and TOTEM experiments [2, 3]. The β^* will be about 2600 m in ATLAS and 90 m for the first stage of the TOTEM physics programme, while in a second stage it will be 1540 m. These values have to be compared against the nominal β^* of 0.55 m.

The increase of β^* from its value at injection results in a loss of betatron tune. Such a loss should be compensated by changing the optics in other parts of the machine. After acceleration to top energy we start to modify the optics of IR1 and/or IR5 in the process of squeezing or rather un-squeezing in the case of high-beta. The IR1/IR5 phase advance compensation will have to be performed simultaneously in order to keep the tunes constant.

The loss in betatron tune due to the special optics will be roughly 0.1 in the horizontal and about 0.5 in the vertical plane for ATLAS. This asymmetry is generated by the constraints imposed by the Roman Pots, for which the phase advance from the interaction point (IP) to the detectors should be 90 degree in the vertical plane.

The luminosity measurements will be performed at top energy with a beam of normalized transverse emittance of 1 μm in both planes and up to 156 bunches in each ring. We assume, that there will be no collisions in ALICE (IR2) and LHCb (IR8) during the special runs with the high-beta optics, thus making it possible to use IR2 and IR8 for the tune compensation.

TUNABILITY SURVEY

Hardware Constraints

There are several constraints coming from hardware;

- The beta function and the dispersion function should be bound to satisfy the aperture constraints.
- The quadrupole strength is limited within 3% to 100% of the magnet nominal specifications.
- The independently powered insertion quadrupoles (Q4-Q10) should fulfil the following constraints imposed by the three-lead powering scheme, $0.5\ I_1 < I_2 < 2.0\ I_1$, where I_1 and I_2 are the excitation currents for the Beam1 and the Beam2 magnets, respectively.

The first constraint is not very restrictive, as transverse emittances at top energy are rather small (and even smaller than usual for the luminosity measurement). In the second constraint, the lower limit of the quadrupole strength is imposed to ensure the stability of power supply. In order to fullfil the third constraint, the quadrupole strength is further limited from 50% to 100% in this study. It is worth mentioning that for the optics matching the quadrupoles from Q4-Q10 can be used together with trim quadrupoles located in Q11-Q13.

IR2 and IR8

During the tunability survey, the gradient of the inner triplet (Q1 to Q3) is fixed to be 205 T/m at top energy, whereas it is about 220 T/m at top energy equivalent during the injection process (LHC optics version 6.500). This is due to the multiple constraints on the phase advance (septum, kickers and injection protection devices). Therefore, it is planned to reduce the triplet strengths before reaching top energy at constant β^*. The optics between the inner triplets are kept as in injection optics, that is at 10 m β^* and zero dispersion.

In order to ease optics matching, the whole IR is devided into left and right parts. Figure 1 shows the result of survey for the left and right parts of IR2 Beam1.

The results from left and right parts are finally combined as shown in Fig. 2, while the result for IR8 Beam1 is reported in Fig. 3.

Since the strong constraints for the injection optics are not relevant anymore, the tunability ranges are rather large. The same overall surface is covered by the tunability range for IR2 and IR8. However, IR8 is less useful for the tune

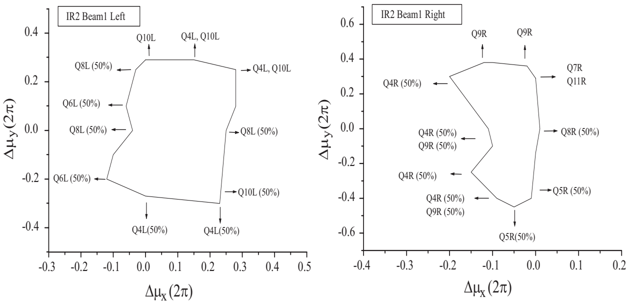


Figure 1: Tunability range for IR2 left and right part (Beam1). The quadrupoles limiting the tunability range are also shown. Q12 and Q13 are also limiting in most cases.

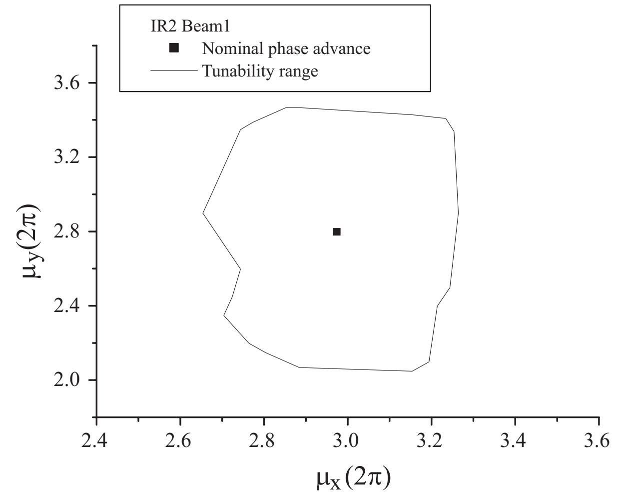


Figure 2: Tunability range for IR2 (Beam1). The nominal phase advance is for the injection option with the triplet strength at about 220 T/m.

compensation because of the higher nominal phase advances.

A typical optics for tune compensation, in which the vertical phase advance is increased by 0.5 in units of 2π while the horizontal one is left unchanged, is shown in Fig. 4. The compensation optics is not so different from the injection one, thus implying that the aperture at top energy is much larger than the nominal requirements.

IR4

IR4 accommodates the rf cavities, the feedback systems and beam instrumentation. The IR4 optics can also be used to some extent for tuning, both at injection and top energy, since none of these systems impose strong constraints on the optics. As an example, the tunability at injection energy was studied and shown in the LHC design report [4].

Since the center of IR4 is not a waist point for beta function, the strategy used for IR2 and IR8 is not valid, and the whole IR is examined at one time. The dispersion function and its derivative are, however, kept zero within the long straight section so as not to introduce any perturbation to the beam due to non-zero dispersion at the location of rf cavities. The result for top energy is shown in Fig. 5 together with one for injection energy which is obtained using the latest version of LHC optics, which contains changes after the LHC design report. IR4 features a tunability range comparable to IR2 in the direction of tune compensation.

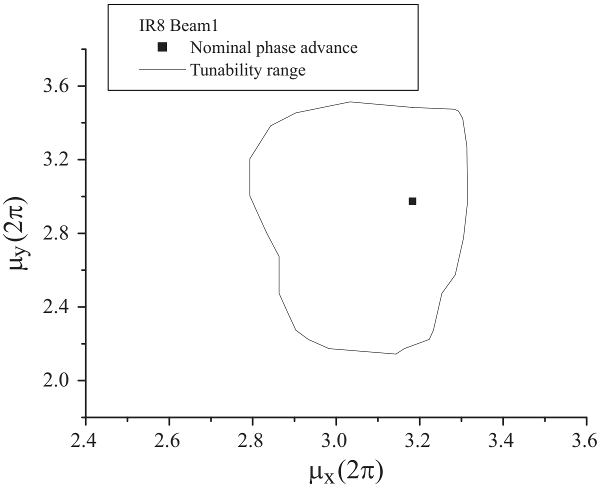


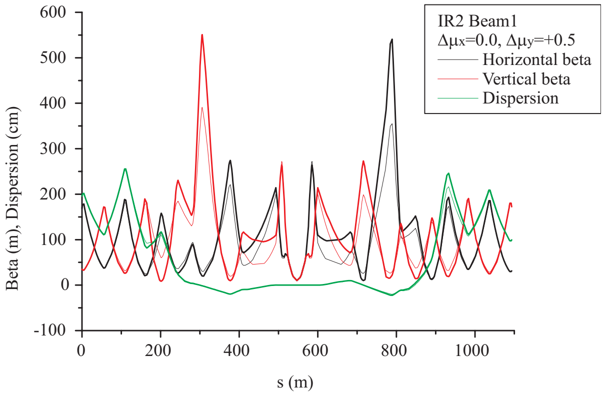
Figure 3: Tunability range for IR8 (Beam1). The nominal phase advance is for the injection option with the triplet strength at about 222 T/m.

Main Quadrupoles

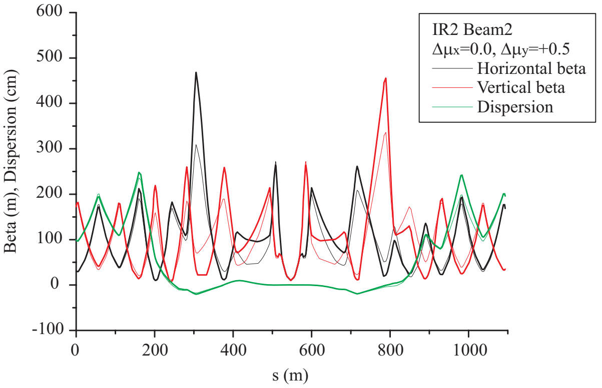
The main quadrupoles also allow in principle to compensate the loss in betatron tune in the insertions. The phase advances within one arc are 5.5 and 5.1 in units of 2π (horizontal and vertical, respectively). Thus a variation of the main quadruple strength of 1% roughly corresponds to a change in betatron tune of 0.05 in one arc, and 0.4 in total. Figure 6 shows the change of betatron tune for various sets of strength of the main quadrupoles. As shown in Fig. 6, it is possible to change the betatron tune up to one unit by changing the quadrupole strength by $\pm 10^{-4}\ \mathrm{m}^{-2}$. Larger tune changes by the the main quadrupoles will significantly change the boundary conditions for the IRs and require a re-matching of all IRs to keep the beta-beating at tolerable levels.

DISCUSSION

Our tunability studies of IR2, IR4, IR8, and the main arcs show that there is enough flexibility to compensate for the tune variations induced by the special high-beta optics in IR1 and 5. We believe that operationally it would be simpler if the number of IRs simultaneously used for tuning is at the minimum required. Furthermore, simpler or more flexible operation is expected by separating the tune compensation for ATLAS and TOTEM, that is, to use IR2 for ATLAS and to use IR8 for TOTEM, for example. Furthermore, given that optics with higher phase advances for IR2



(a) IR2 Beam1



(b) IR2 Beam2

Figure 4: Typical opics for tune compensation. $\Delta\mu_x = 0.0$, $\Delta\mu_y = 0.5$. The thin lines indicate the injection optics, while the thick ones indicate the compensation optics.

and 8 were obtained keeping the nominal optical conditions at the IPs, the experiments housed in these insertions could run even during the periods scheduled with high-beta optics in IR1 and 5. We believe that the tune compensation based on the change of the arcs is less appealing, since it would require the re-matching of all IRs.

This optics flexibility study was triggered by the needs of high-beta optics. The results should also be relevant for other optics and operation modes. For instance, the tunability of IR4 could help to integrate crab cavities considered within the framework of upgrade studies.

CONCLUSIONS

The optics flexibility of the LHC lattice at top energy has been studied in terms of betron tune tunability. This topic is important not only per se, but also for the implementation of the high-beta optics for the absolute luminosity measurements in IR1 and 5. The main focus is on IR2, IR4, and IR8. Parenthetically, the tunability with IR4 at injection energy was re-assessed as wellusing the latest version of LHC optics. Indeed, the tune change imposed by the large β^* can be compensated for by using one of the three insertions under study. The results obtained in this study should also be useful for other optics or operation modes.

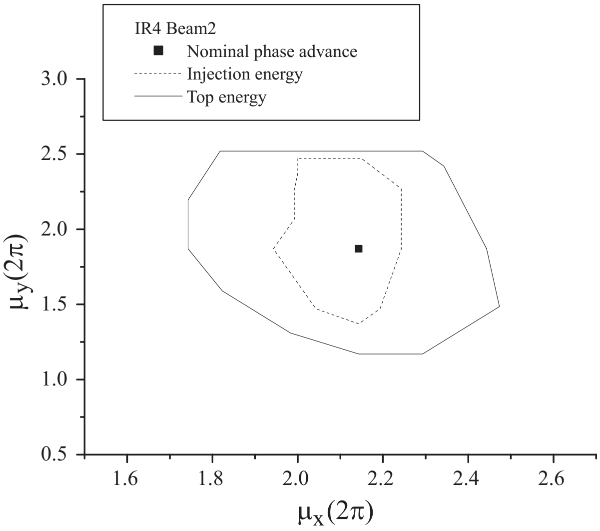


Figure 5: Tunability range for IR4 (Beam2).

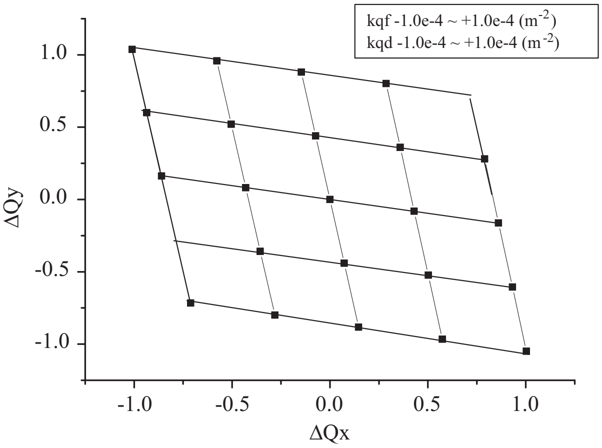


Figure 6: Tunability range of the main arcs. The nominal quadrupole strength is 0.00899 m^{-2} in focusing magnet and -0.0086 m^{-2} in defocusing magnet.

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