BETΑ* MEASUREMENT IN THE LHC BASED ON K-MODULATION

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Abstract

Accurate knowledge of the collision point optics is crucial to equalize the luminosities at the different experiments. K-modulation was successfully applied at several accelerators for measuring the lattice beta functions. In the LHC, it was proposed as an alternative method to compute the beta* at the collision points. Results of beta* measurements in the LHC based on the K-modulation technique are presented with comparisons to nominal segment-by-segment method.

INTRODUCTION

Measuring the β* via a modulation of the nearest quadrupoles to the IP is probably the least invasive and most accurate technique. A change in the integrated strength of a quadrupole ΔK yields a change in the tunes ΔQx,y that can be unambiguously used to determine the average βx,y functions at the quadrupole, see e.g. [1],

$$β_{x,y} = \pm \frac{2}{ΔK} \left( \cot(2πQ_{x,y}) \left(1 - \cos(2πΔQ_{x,y})\right) + \sin(2πΔQ_{x,y}) \right) ≈ ±4π\frac{ΔQ_{x,y}}{ΔKL},$$ (1)

where the ± sign refers to the horizontal and vertical planes, respectively. The approximation displayed to the right of Eq. (1) is applicable for 2πΔQx,y ≪ 1 and Qx,y far away from the integer and the half-integer. This technique was successfully applied in the interaction regions of LEP [2]. Hadron colliders typically operate with Qx very close to Qy. In this case a good correction of coupling is required prior to measurements with quadrupole strength modulation. The practical application of this algorithm in the LHC consists in measuring the tune response from the left, Qx,yL, and the right, Qx,yR, quadrupoles to the IP and determining β* via a polynomial function of the form

$$β^*_x(ΔQ_{x,y}^L, ΔQ_{x,y}^R) = \sum_{i+j<3} \sum_{i,j=0}^{i+j<3} a_{ij}(ΔQ_{x,y}^L)^i(ΔQ_{x,y}^R)^j$$ (2)

where the coefficients aij have been precomputed with simulations. A similar polynomial expression is used for the waist location. Error propagation from the tune measurement is straight forward for these polynomials. The next sections report on the K-modulation measurements at β*=1.5 and 90 m.

β*=1.5 M

An illustration of the computation of the coefficients aij for the case with β*=1.5 m is shown in Fig. 1. The effect of the quadratic terms are clearly visible. The quality of the fit can be regarded as perfect with a $χ^2 < 10^{-6}$.

An illustration of the tune measurement during the K-modulation process is shown in Fig. 2. The tune data is noisy with spurious peaks around the tunes in the Fourier spectra. Appropriate cuts in the tune histograms can be used to partially remove the spurious peaks during the quadrupole current plateaus. Figure 3 illustrates the cleaning process with a typical histogram of the horizontal tune. Figure 4 shows a histogram of the achieved tune resolution for all the K-modulation measurements during 2011.

Table 1 shows the measured β* after the optics corrections. The maximum relative deviation between model and
Figure 3: Illustration of a typical histogram of the tune measurement during about one minute without quadrupole changes. Clear spurious tunes measurements are observed requiring cleaning.

Figure 4: Tune resolution histogram for the 2011 K-modulation measurements after filtering the spurious data.

Figure 5: Illustration of the absence of hysteresis effects showing identical tune measurements after 1 hour of K-modulation.

Figure 6: IP5 vertical $\beta^*$ versus tune-shifts from a change of $\Delta K = 4 \times 10^{-5}$ m$^{-2}$ in the left and right Q1 quadrupoles. The nominal lattice has $\beta^*$=90 m and random errors around the ring are considered.

measured $\beta^*$ is about 6%. Typically, resolutions between 3% and 5% are achieved. The luminosity imbalance from these measurements is $(4 \pm 4)$%, compatible with zero and consistent with the luminosity measurements.

To assess the effect of hysteresis the same modulation was applied to Q1 right of IP5 after one hour of K-modulation measurements. Figure 5 shows no hysteresis effects.

$\beta^*$=90 M

TOTEM [3] and ALFA [4] request the best possible control and knowledge of the optics in the IR. Dedicated Machine Development (MD) time has been devoted to measure and commission the optics with $\beta^*$=90 m. Prior to the experiment the tune response of the Q1 quadrupoles is studied for small variations in $\beta^*$. Figure 6 shows the IP5 $\beta^*_y$ versus tune-shifts from a change of $\Delta K = 4 \times 10^{-5}$ m$^{-2}$ in the left and right Q1 quadrupoles for an ensemble of machines with different optics errors. This allows for the computation of the $a_{ij}$ coefficients of Eq. 2. Opposite to the $\beta^*$=1.5 m case, a very linear behavior is observed.

During the 1st MD [5] the AC dipole was used to measure the $\beta$ function around the accelerator. This served to compute the correction for the 2nd MD. This correction is stored in two knobs.
Figure 7: Beta-beating for Beam 1 as measured and as expected from the computed correction.

Figure 8: K-modulation in IR1 and IR5 Q1 quadrupoles for $\beta^*=90$ m.

Table 2: $\beta^*$ Measurements with K-modulation at $\beta^*=90$ m

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REFERENCES