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BEAM TRANSFER TO LHC WITH THE LOW γ-TRANSISTION SPS OPTICS

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Abstract

A new optics was introduced in the SPS for improving beam stability at high intensity. For transferring the beam to the LHC, the extraction bumps, extraction kickers and transfer lines needed to be adapted to the new optics. In particular, the transfer lines were re-matched and re-commissioned with the new optics. The first operational results are discussed for the SPS extraction, the transfer lines and the LHC injection. A detailed comparison is presented between the old and the new optics of the trajectories, dispersion, losses and other performance aspects.

INTRODUCTION

A low gamma-transition optics, Q20, was computed for the SPS with the aim of increasing instability thresholds [1] and therefore beam intensity for the machine operation as LHC injector. This new optics was successfully tested during dedicated machine development studies [2]. Owing to the fact that the new optics at the SPS extraction points, LSS6 (Beam 1) and LSS4 (Beam 2), differs from the old one, the extraction had to be redesigned and the transfer lines (TT60/TI2 and TT40/TI8 for LHC Beam 1 and 2 respectively) optics rematched. During the 2012 run, after the new extraction bumps and transfer line optics were commissioned, the new optics was implemented for routine operation [2].

RE-MATCHING OF THE TRANSFER LINES FOR THE Q20 OPTICS

The SPS to LHC transfer lines were rematched for the SPS Q20 optics. The steering into the transfer line was computed first and optics distortion due to extraction elements and orbit offsets in the quadrupoles were taken into account when matching.

Meeting the required conditions at the entrance of LHC, while keeping acceptable values for the Twiss functions, was not possible by using only the upstream quadrupole circuits in the initial matching sector between SPS and the regular TL arcs. For this reason also the downstream quadrupoles where the beam collimators are located, had to be used. The constraints that in the plane of collimation the value of the betatron function at the collimator must be not smaller than 15 m while the phase advance difference between consecutive collimators should be $60 + n \times 180$ degrees (3-phase collimation scheme) were preserved. Details about the new transfer lines optics are contained in [3].

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EXTRACTION SET-UP

The LSS6 and LSS4 extraction bumps are shown in figure 1 for the old Q26 optics and the new Q20 optics. A 4-coil extraction bump was chosen for TI8, the ratio between the kicks of the first two coils is optimized so to avoid the second peak of the orbit bump. This scheme could not be used for TI2 because of the TPS diluter and MST septum.

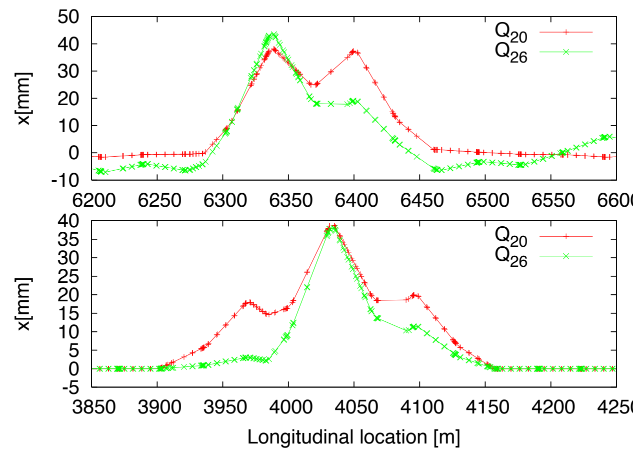

Figure 1: Extraction bumps for the Q26 (green) and Q20 (red) optics, TI2 (top) and TI8 (bottom). For TI2 a 3-coil extraction bump was used, while for TI8 a 4-coil extraction bump was preferred.

TRAJECTORY

During the commissioning of the Q20 optics, trajectory measurements were conducted for both optics. It was decided to correct the beam trajectories to the golden trajectories established during operation with the Q26 optics.

Figures 2 and 3 show the variation in TI2 and TI8, respectively. For both lines the differences are minimal, with an average deviation of around 0.4 mm. The peak difference of the trajectory is around 2 mm, located at the extraction from the SPS.

DISPERSION

TI8 dispersion was measured for both Q26 and Q20 optics, while measurements for TI2 were only conducted for Q20. Normalized dispersion beating for TI2 and TI8 are shown in figure 4 and in figure 5, respectively.

In TI8 the normalized dispersion beating appears to be similar for both optics in both planes. Conversely the TI2 dispersion beating in the horizontal plane is larger for Q26

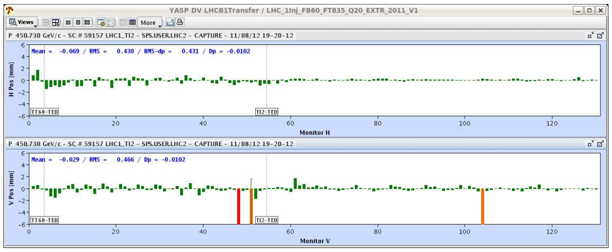

Figure 2: Trajectory for the TI2 transfer line. The top plot shows the difference between the horizontal trajectory measured with the Q20 optics and the golden trajectory. The bottom plot shows the same for the vertical plane.

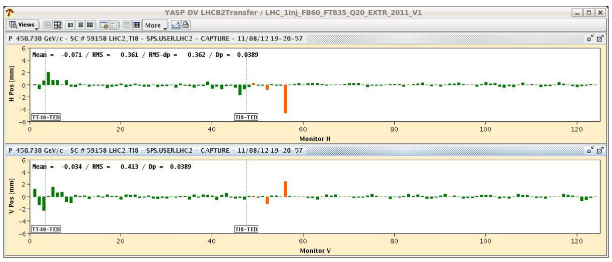

Figure 3: Trajectory for the TI8 transfer line. The top plot shows the difference between the horizontal trajectory measured with the Q20 optics and the golden trajectory. The bottom plot shows the same for the vertical plane.

than for Q20, while the opposite is true for the vertical dispersion beating. The Q26 TI2 dispersion measurement dates back to 2011, it could be questioned whether there is truly a difference between the two lines.

The dispersion beating was considered to be not an issue because in both lines it is of the same order of magnitude as for the Q26 TI8.

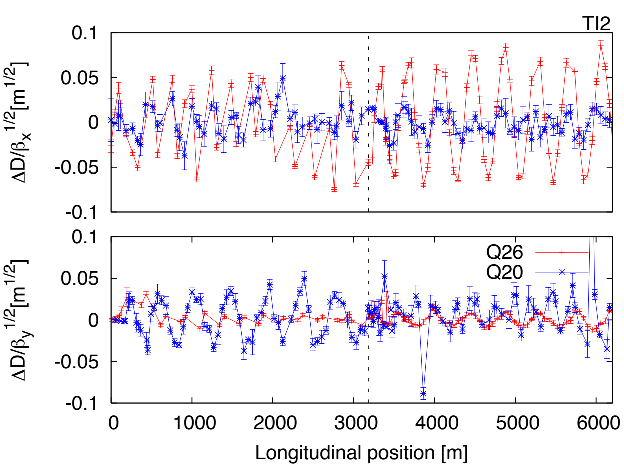

Figure 4: The top plot shows the TI2 horizontal normalized dispersion beat and bottom plot the vertical normalized dispersion beat, Q26 is shown in red and Q20 in blue. The dashed line shows where the beam is injected into the LHC.

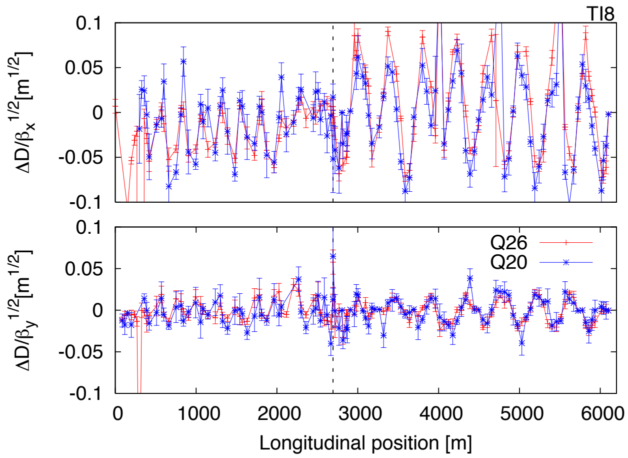

Figure 5: The top plot shows the TI8 horizontal normalized dispersion beat and bottom plot the vertical normalized dispersion beat, Q26 is shown in red and Q20 in blue. The dashed line shows where the beam is injected into the LHC.

Q20 OPTICS AND TCDI

Collimators (TCDI) are installed at the end of both TI2 and TI8 (in the matching sections) to intercept particles with large amplitude oscillations [4]. Each collimator is formed by two movable 1.2 m long carbon jaws. The TCDIs are organized in horizontal and vertical collimators, three per plane, which are spaced by about $60 + n \times 180$ degrees phase advance to provide a full phase space coverage. The jaws are set at $\pm 5\ \sigma$ from the beam axis to shield the mechanical aperture at the injection septum (MSI) and in the LHC injection region. The transfer lines had to be rematched to the new SPS optics when moving to Q20, [3]. The reference trajectories remained valid and negligible optics variations were expected at the TCDIs; the collimator settings were thus not modified. In reality, the change in the β-functions propagated until the TCDIs region determining, at two collimators (one per line), an half gap of 6.3 σ and as consequence a slight loss of protection. No tool was available to spot this kind of non-conformity and operation continued. Even if the machine was never in a real danger, this event raised a real concern about the possibility of having wrong settings and not being able to detect them. The possibility of automatically calculating the expected settings from the optics in use and comparing them with the applied settings is under development.

OPERATIONAL ASPECTS WITH Q20

The need for transfer line correction became more frequent and lengthly with the SPS Q20 optics (once/twice per week until the end of September, every 1-2 days in October and November). Transfer line stability studies were performed too try to understand the reason, the stability with the Q20 was comparable to the Q26. Results are presented in detail in [5].

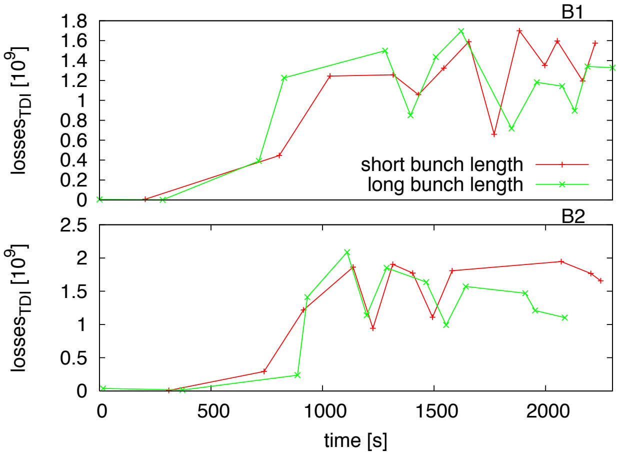

Figure 6: Capture losses on the LHC injection absorber (TDI) for beam 1 (top) and beam 2 (bottom). Two different cases were studied, beam was injected with short bunch length, green, and beam with long bunch length, red. There is no significant difference in the capture losses between a fill with short and long bunch lengths.

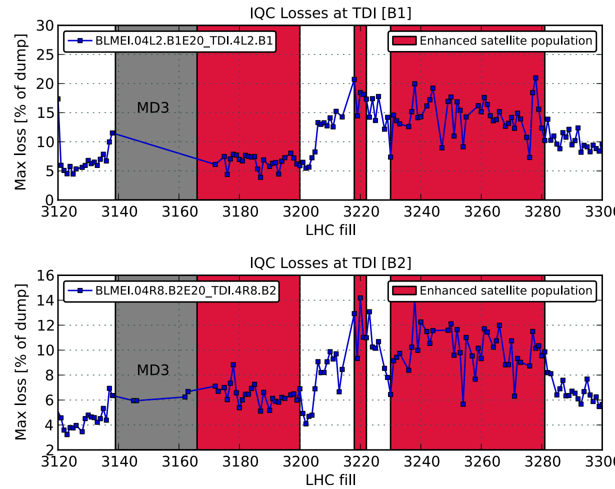

Figure 7: Maximum beam loss at injection (in % with respect to the BLM dump thresholds) at the TDI during operations with (highlighted in red) and without satellites enhancement are plotted for several fills for Beam 1 (top) and Beam 2 (bottom).

For the Q20, beam was injected with different bunch lengths to test whether large bunches led to increased losses. The captures losses during these injections were recorded and compared. Figure 6 shows the capture losses for beam with short bunch length (green) and beam with long bunch length (red). There is no significant difference in the capture losses between a fill with short and long bunch lengths. Capture losses observed for the Q20 are similar to the capture losses for the Q26.

The LHC was operated, for three short periods (Q20 optics), with an enhanced level of 25 ns satellites to produce collisions with the main bunches in ALICE. The injection losses at the TDI (longitudinal losses) doubled only during the last two runs with satellites (red zones in Figure 7). Moreover, for Beam 1, these losses remained higher than for the Q26 optics (before MD3), even after removing the satellites enhancement. Further elements (i.e. batch-by-batch blowup, injection cleaning, etc.) must have contributed to the increased rate of de-bunched and uncaptured beam but it was not possible to disentangle the different contributions and understand the reason for the observed degradation.

CONCLUSIONS AND OUTLOOK

The optics in the transfer lines and the extraction bumps were successfully rematched and deployed for the Q20 optics in the SPS. Significant time was spent on setting up the extraction region. During this set-up the trajectory was corrected to the golden orbit of the Q26. The peak trajectory difference was around 2 mm for both lines located at the extraction from the SPS. The rms trajectory difference is about 0.4 mm. Dispersion measurements were conducted in both lines and compared with the Q26. The results for both optics in TI8 are similar, for TI2 the Q20 measurements are significantly smaller than for the Q26 in the horizontal plane and the opposite in the vertical plane. As the reference trajectories remained unchanged and the actual optics variations at the collimators were overlooked, no time was allocated for recommissioning the collimator alignment. After some weeks of operation it was discovered that a loss of protection was present and the collimator position readjusted. Interlocks are going to be implemented to catch such mistakes in the future.

The Q20 optics has been successfully deployed in the transfer lines. The capture losses on the TCDI were comparable for both optics.

ACKNOWLEDGMENTS

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