Linear coupling dependence on intensity and a next step towards a feedback (MD1850)


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Summary

Transverse coupling has proven to be an important variable to control beam dynamics and performance in the LHC. In this report, we present the first measurement of transverse coupling vs beam intensity. The analysis shows no dependency within the experimental uncertainties. This study was made possible with the new implementation of an AC-dipole-like excitation using the ADT. It provides the functionality to excite a single bunch in a train. The demonstration of this functionality is also an important step towards creating an automatic coupling correction tool for the LHC.

Transverse coupling has been observed to vary with time at injection. In this report, a quantitative measurement of the coupling as a function of time after ramp-down is presented. Turn-by-turn data was also acquired to compare the performance of the new DOROS system to the standard BPMs.

Contents

1 Introduction 2

2 Coupling Decay 2

3 Linear transverse coupling vs Intensity 4

3.1 First fill (100 min - 170 min) 4

3.2 Second Fill (290 min - 320 min) 4

3.2.1 Results 7

4 DOROS BPMs 7

5 Conclusion and outlook 10
1 Introduction

High level of transverse coupling has been linked to collective instabilities, and it has been shown to reduce the dynamic aperture \cite{1, 2}. The main source of coupling is the skew quadrupolar fields generated by, for instance, a rotation in a normal quadrupolar magnet, feed-down from sextupoles or magnetic field errors in the main dipoles. In this MD we investigated another potential source of coupling, linked to the beam intensity. Furthermore, we probed how coupling varies with time at injection.

The high intensity beam used in this MD prevents the use of the AC-dipole to excite the beam. Instead, the ADT can be safely used to this aim. The ADT has recently been equipped with the functionality to excite an individual bunch adiabatically in a similar manner as the AC-dipole \cite{3, 4}.

The DOROS system provides high resolution turn-by-turn data \cite{5, 6}. During the MD we acquired data which is compared to the normal BPM system.

2 Coupling Decay

It has been observed in operation of the LHC that coupling drifts at injection \cite{7}. This is surprising since there is no prediction of an $a_2$ decay. The source of this decay is currently unknown, but it will be investigated in the near future.

The measurement of the coupling decay was performed on Beam 2 which was left untouched except for small tune corrections. The Landau octupoles were kept at zero and the chromaticity was kept low. When the beam emittance was increased, a new bunch was injected. The beam was excited with the AC-dipole and the increase of the $|C^-|$ is shown in Fig. 1.

3 Linear transverse coupling vs Intensity

The beam intensity as a function of time is shown in Fig. 2. The following list describes the change in configuration and parameters for Beam 1 during the MD. The fractional tunes were set to $Q_x = 0.270$ and $Q_y = 0.295$ throughout the MD. The tunes were obtained from the BBQ system \cite{8}. The time line of the experiment is given below.

1. 0 min - 100 min, Setting up the machine, testing the ADT-AC-dipole and taking turn-by-turn data with the DOROS system.

2. 100 min - 170 min Adjusted the $Q'_x$ and $Q'_y$ to 10 units, the MO were powered to MO = 18 m$^{-4}$. 5 trains were injected between each ADT-AC dipole measurement. In the end of the fill the MOs were lowered to 9 m$^{-4}$ and chromaticity was set to 5.

3. 200 min - 250 min Measuring a pilot bunch and cross-checking the ADT results with the established method using the AC-dipole.

4. 260 min - 280 min Beam dumped after 3 trains, because of an RF trip of 5B1 of module M2B1. $Q'_x$ and $Q'_y$ were at 5 units.
Figure 1: The measured transverse coupling in Beam 2 as a function of time since ramp-down.
5. **290 min - 320 min** The $Q'_x$ and $Q'_y$ were increased back to 10 since we at this point did not understand why the beam was dumped. The octupoles were still at 9m$^{-4}$. After 14 trains the beam was dumped due to losses at injection.

6. **330 min** Beam dumped at first injection due to losses. This was later confirmed to be due to tails coming from SPS.

### 3.1 First fill (100 min - 170 min)

In the first fill $Q'_x$ and $Q'_y$ were set to 10 units and the MO were powered to 18 m$^{-4}$. Five trains were injected between each measurement. In the end of the fill MO were lowered to 9 m$^{-4}$ and chromaticity was set to 5 in order to improve the tune signal. The horizontal tune and intensity values as a function of time are shown in Fig. 3. We can clearly observe that the tune signal is noisy and that the tune shifts with intensity. In this case, there was no compensation for the Laslett tune shift.

In Beam 2 we observed a coupling decay of about $C^{-} = 10^{-3}$ between 100-170 min since ramp-down. As we can not exclude the possibility that this effect is present also for Beam 1, this data was not analyzed for the impact of intensity on coupling.

### 3.2 Second Fill (290 min - 320 min)

For the second fill the Laslett tune compensation was switched on and the octupoles were set at MO = 9m$^{-4}$. The lowering of the octupoles was performed in order to improve the tune resolution. However, the tune resolution was still far from ideal, as seen in Figs. 4 and 5.
Figure 3: The blue line shows the horizontal tune and the red line shows the beam intensity for the first fill.

Figure 4: The blue and red lines show the horizontal tune and the beam intensity, respectively.
Figure 5: The blue and red lines show the vertical tune and the beam intensity, respectively.
Figure 6: The blue lines shows the horizontal tune after removing outliers and applying a running average. The red line shows the beam intensity.

After filtering outliers and performing a running average, we obtain a clearer tune signal as seen in Figs. 6 and 7. We observe also a small drift of the horizontal tune while the vertical one seems to be more constant.

3.2.1 Results

The calculation of $|C^-|$ is based on the $f_{1001}$ measured by the ADT AC-dipole [9, 10, 11]. The $f_{1001}$ is not invariant under tune changes and in order to calculate $|C^-|$ the fractional tune split is needed. Since there is a forced oscillation, the reconstruction of the unperturbed $f_{1001}$ is also dependent on the distance between the natural and the driven tunes. This means that the tune precision is very important for an accurate measurement of $|C^-|$. This is also the main source of the error bars of the coupling measurements. The coupling as a function of intensity is shown in Fig. 8. Within the error bars of the measurement it is not possible to observe a trend.

4 DOROS BPMs

The DOROS system provides high resolution, turn-by-turn data. The beam was excited while the oscillations were recorded both with the standard BPM system and with the DOROS BPMs. A powerful method to improve resolution is to remove the noise which is uncorrelated between different BPMs. A method to perform this cleaning is the singular value decomposition (SVD) [12]. In Fig. 9 a comparison of the normal BPM, with and without SVD cleaning, and the DOROS BPM is shown. The displayed signals are all from the same BPM and excitation. We observe that, even after the SVD cleaning of the standard BPMs, the DOROS system performs significantly better.
Figure 7: The blue lines shows the vertical tune after removing outliers and applying a running average. The red line shows the beam intensity.

Figure 8: The transverse coupling as a function of total beam intensity.
Figure 9: A comparison of the turn-by-turn resolution of BPMSW.1L1 equipped with the DOROS system compared to the signal obtained from the normal BPM system, with and without SVD-cleaning.
5 Conclusion and outlook

The previously observed coupling decay at injection was measured for Beam 2. The coupling was observed to change until about 200 min since ramp-down. The mechanism responsible for this decay is still to be understood.

The coupling as a function of intensity was measured for the first time in the LHC. We were not able to measure any changes of $|C^-|$ within the experimental uncertainty. This measurement was possible due to the recent implementation of an AC-dipole like excitation with the ADT. This implementation and successful test is an important step towards an automatic coupling corrections for high intensity beams.

Furthermore, we recorded turn-by-turn data with the DOROS system for a nominal bunch for the first time. The DOROS system showed a significantly better resolution than the standard BPM system.

References


