EXPERIENCE WITH DOROS BPMS FOR COUPLING MEASUREMENT AND CORRECTION

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Abstract

The Diode ORbit and OScillation System (DOROS) system is designed to provide accurate measurements of the beam position in the LHC. The oscillation part of the system, which is able to provide turn-by-turn data, is used to measure the transverse coupling. Since the system provides high resolution measurements for many turns only small excitation are needed to accurately measure the transverse coupling. In this article we present the performance of the system to measure coupling and compare it to the BPMs not equipped with this system.

INTRODUCTION

A good control of the transverse linear coupling is of great importance for the operation of the LHC. It is important for the tune feedback and has been linked to observed instabilities [1].

There are several different methods to measure the transverse coupling. One way is to try to push the horizontal and vertical tunes as close as possible. This is, however, rather time consuming and does not provide a way to calculate a correction of the coupling. Instead, different settings of the skew quadrupoles have to be tested in order to see which one reduces the distance between the tunes. Another method to measure linear coupling, which also provides information on the phase of the coupling and hence a way to find a correction, is from turn-by-turn data. The strength of the transverse coupling is related to the relative size between the main tune peak and the coupling peak, which appears in presence of coupling at the vertical tune in the horizontal spectra at the horizontal tune in the vertical spectra. A detailed explanation of the calculation can be found in [2] and recent improvements in the algorithm can be found [3].

The coupling measurements need high precision pickups or large excitation. The reason is that the coupling peak very easily is within the noise of the signal and hence the method to measure the coupling fails. In a machine like the LHC only very small excitation are allowed when high intensity beams are present and instead high precision pickups are needed to be able to measure the coupling accurately. The Diode ORbit and OScillation System (DOROS) system is able to provide accurate orbit and turn-by-turn data [4]. It is possible to install the DOROS electronics for the normal BPMs in the LHC. In this article we are focusing on the use of the DOROS system to measure transverse coupling and we compare the performance to that of the normal BPMs. We also make a small theoretical derivation on the relation between the $|C^-|$ and the relative amplitude of the tune and coupling peak for different tune splits. The $|C^-| = \Delta Q_{min}$ is defined as how close the horizontal and vertical tunes can approach each other. It is of interest to understand under which conditions it is possible to measure the coupling.

MEASURING TRANSVERSE COUPLING

In order to have precise reconstruction of the coupling it is necessary to have a good measurement of the phase and amplitude of the main tune peak and the coupling peak. In this paper we use the fact that the $f_{1001} >> f_{1010}$ in the LHC, where f_{1001} is the difference Resonance Driving Term (RDT) and f_{1010} is the sum RDT. This allow for the reconstruction of the coupling using the real turn-by-turn data without going to the complex variables.

In the following part we will derive how the $|C^-|$ relates to the relative strength of the tune and coupling peak. The horizontal spectrum (neglecting the mirror part) for a horizontal real spectrum with only betatron motion and coupling can be described by

$$\mathcal{F}\{x\} = A_{10}e^{i\psi_{10}}\delta(Q - Q_x) + A_{01}e^{i\psi_{01}}\delta(Q - Q_y) \qquad (1)$$

where

- x is the turn-by-turn data
- δ is 1 when $Q = Q_{x,y}$.
- $A_{10} = \cos(2f)\sqrt{2I_x}$.
- $A_{01} = \sin(2f)\sqrt{2I_y}$.
- ψ_{10} is the phase of the main peak and ψ_{01} is the phase of the coupling peak.
- $f_{1001} = f\ e^{iq}$.
- q is the difference between the phases in the horizontal and vertical plane.
- $2I_{x,y}$ and $\psi_{x,y}$ are the actions and the initial phases in the normal form coordinates respectively.

We can then write the relation

$$\frac{A_{01}}{A_{10}} = \tan(2f)\sqrt{\frac{2I_y}{2I_x}} \qquad (2)$$

It is possible to do the same thing for the vertical spectrum and normally that is desired in order to cancel out any dependency on the action and calibration. However, in this case

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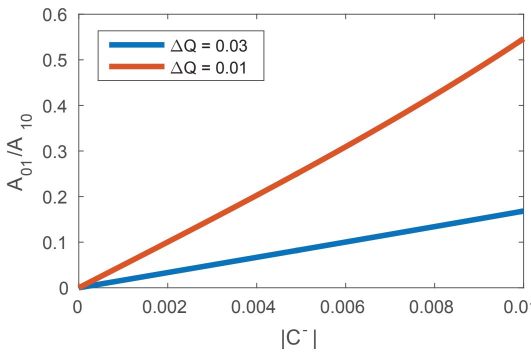

Figure 1: The ratio of the $\frac{A_{10}}{A_{01}}$ as a function of the $|C^{-}|$ for different tune splits.

we assume that $I_x = I_y$. Using that $|C^{-}| = 4\,\Delta\,Q\,|f_{1001}|$ we can rewrite Eq. (2) as

$$A_{01} = A_{10} \tan\left(\frac{|C^{-}|}{2\Delta Q}\right) \approx A_{10}\frac{|C^{-}|}{2\Delta Q} \qquad (3)$$

With this relation we can estimate the level of excitation needed to measure the coupling. The assumption that $I_x = I_y$ is rather realistic since we normally want a diagonal excitation to be able to obtain the horizontal and vertical spectrum at the same time. This is of importance in order to have a model and calibration independent measurement of the coupling [2]. In Fig. 1 the ratio of $\frac{A_{10}}{A_{01}}$ is plotted for injection tunes and collision tunes. This ratio can in cases when we do not observe the coupling peak enable us to put a upper limit on the $|C^{-}|$.

COMPARISON TO NORMAL BPMS

In 2015 we did a dedicated test to compare the DOROS system to the normal BPMs. The procedure was to first excite the beam with the AC-dipole at different amplitudes and to record the data with both the DOROS system and the normal BPM system. The AC-dipole is commonly used in optics measurements of the LHC but it is not used during fills for luminosity production. The beam was also excited with the ADTs [5] at different amplitudes and the data was recorded with both systems. The number of turns recorded with the AC-dipole was 6600 and for the ADTs 50k were recorded for the normal BPMs and more than 100k for the DOROS BPMs.

In Figs. 2 and 3 the comparison of the two spectra from a BPM equipped with and without the DOROS electronics is shown. It is clear from the plots that the noise level is order of magnitude smaller for the DOROS system.

Figures 4 and 5 show the spectra where the beam has been excited with the ADTs. We observe that the coupling peak is not even visible in Fig. 5 for the normal BPMs. In such a case it is normally not possible to get a measurement of the coupling.

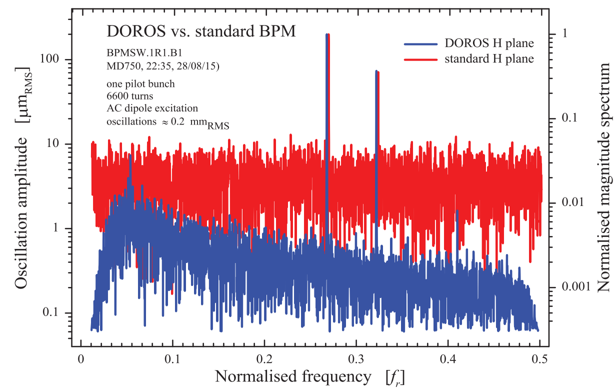

Figure 2: The horizontal frequency spectrum for BPMSW.1R1.B1 with the DOROS electronics (blue) and without (red) for a RMS excitation of 0.2 mm with the AC-dipole. The tune peak is normalized to 1 in the right hand scale and the left hand scale is in μm

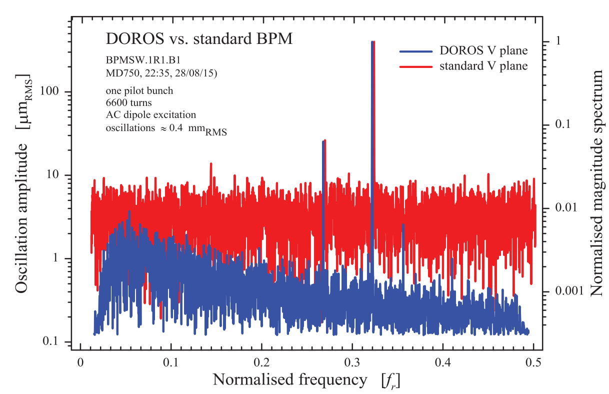

Figure 3: The vertical frequency spectrum for BPMSW.1R1.B1 with the DOROS electronics (blue) and without (red) for a RMS excitation of 0.4 mm with the AC-dipole. The tune peak is normalized to 1 in the right hand scale and the left hand scale is in μm.

COUPLING MEASUREMENTS WITH DOROS

In Fig. 6 the measured f_{1001} from the DOROS system is compared to the normal BPMs and in Fig. 7 the same comparison but zoomed in around the DOROS BPMs is shown. The two DOROS BPMs are located close to IP1 and are BPMSW.1R1 and BPMSW.1L1. The excitation, with the AC-dipole, for the measurements using normal BPMs was roughly 4 times higher than for the DOROS BPMs. This demonstrates that a smaller excitation is sufficient for a good measurement of the linear coupling when using the DOROS BPMs.

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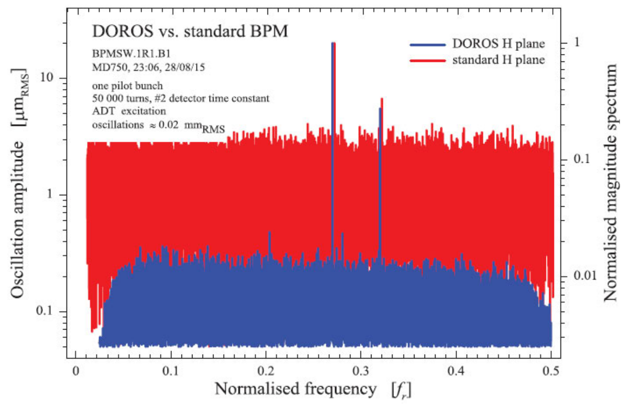

Figure 4: The horizontal frequency spectrum for BPMSW.1R1.B1 with the DOROS electronics (blue) and without (red) for a RMS excitation of 0.02 mm with the ADTs. The tune peak is normalized to 1 in the right hand scale and the left scale is in μm

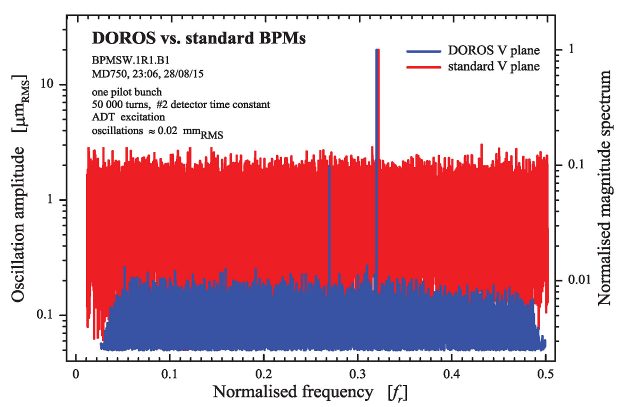

Figure 5: The vertical frequency spectrum for BPMSW.1R1.B1 with the DOROS electronics (blue) and without (red) for a RMS excitation of 0.02 mm with the ADTs. The tune peak is normalized to 1 in the right hand scale and the left hand scale is in μm.

The fact that the DOROS system is only measuring at a few locations is not a major concern since the local coupling sources are corrected during the commissioning and have shown to stay rather constant over the year.

CONCLUSION

The DOROS system showed an excellent performance during the MD. The system provides a good measurement of the transverse coupling with a small excitation, in this case with the AC-dipole. The required excitation amplitude will

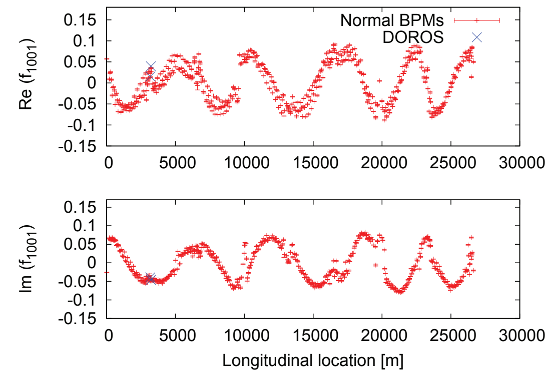

Figure 6: A comparison of the measured f_{1001} between the DOROS BPMs and the normal BPMs. The x-axis shows the distance to the injection point close to IP2.

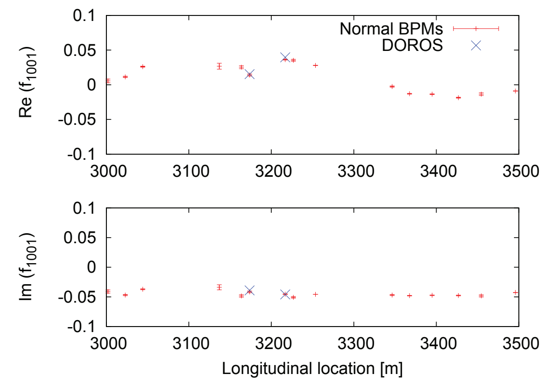

Figure 7: A comparison of the measured f_{1001} between the DOROS BPMs and the normal BPMs, zoomed around the location of the DOROS. The x-axis shows the distance to the injection point close to IP2.

depend on the intensity and other beam parameters, which influence the measurement. However, with a high quality turn-by-turn data it is even possible to envisage a feedback to control the coupling.

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