COLLIMATOR IMPEDANCE MEASUREMENTS IN THE LHC

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Abstract

The collimation system of the LHC is one of the largest impedance contributors of the machine, in particular for its imaginary part. To evaluate the collimator impedance and its evolution with integrated luminosity, several measurement campaigns were performed along the year 2012, in which collimator jaws were moved back-and-forth leading to significant tune shifts for a nominal intensity bunch in the machine. These observations are compared to the results from HEADTAIL simulations with the impedance model in its current state of development.

INTRODUCTION

The LHC impedance model [1] currently includes the resistive-wall impedance of the 43 collimators (some being in carbon material), of the copper-coated beam screens covering 86% of the ring, and of the copper vacuum pipe for the remaining 14%, together with a broad band impedance model to account for most of the smooth transitions around the ring [2]. In this model the impedance of the LHC at top energy is dominated by the resistive-wall impedance of the collimators. This is visible in Figs. 1 and 2 where we show the relative contributions from the resistive-wall impedance of various collimator families, to the total dipolar vertical impedance. Similar plots would have been obtained for the horizontal impedance. Among the collimator families, the primary (TCP) and secondary (TCSG) collimators made of carbon material (CFC) are clearly dominant.

To assess the part of the impedance due to collimators and check the accuracy of the model for them, several measurement campaigns were carried on. The idea was to measure tune shifts observed upon moving several collimators in and out relative to the beam center. Several such experiments were already performed in 2010 [3] and 2011 [4], and compared [5] to the impedance model plugged in the simulation code HEADTAIL [6]. In 2012 some additional experiments (also called MD below, for Machine Development) were performed [7–9], the idea being to check for a possible evolution of the impedance with time in order to identify possible radiation damage to the jaw materials. We present here a description of the experiments, followed by the available results on CFC collimators in IR7 (interaction region around point 7 in the LHC ring) and a comparison with the current impedance model plugged in HEADTAIL simulations.

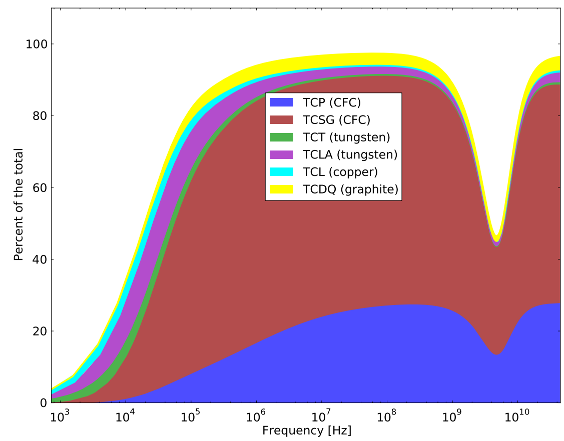

Figure 1: Contributions (in percent) of various collimator families to the total vertical dipolar impedance (real part) at 4 TeV (squeezed optics) with typical 2012 collimator settings [10]. The main jaw material is indicated between parentheses (CFC stands for carbon fiber-reinforced carbon). TCP, TCSG and TCT are respectively primary, secondary and tertiary collimators, TCL are physics debris absorbers, TCLA are absorbers of particles scattered at the other collimators and TCDQ are dump protection collimators [11].

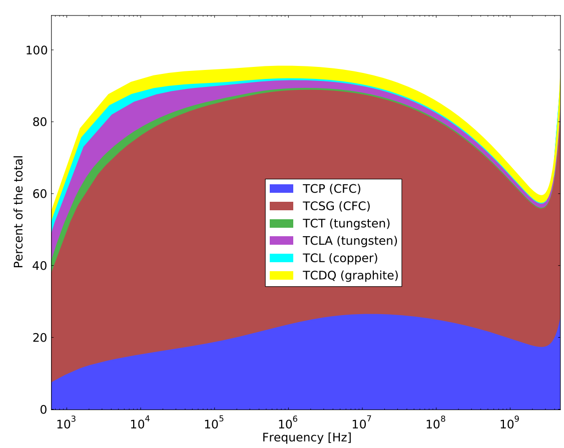

Figure 2: Contributions (in percent) of various collimator families to the total vertical dipolar impedance (imaginary part) at 4 TeV (squeezed optics) with typical 2012 collimator settings [10]. See Fig. 1 for the acronyms definitions.

DESCRIPTION OF THE EXPERIMENTS

In 2012 the tune shifts measurements were done with a single bunch close to nominal intensity ($\sim 10^{11}$ protons

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per bunch) in both rings of the machine. The bunches positions around the rings were chosen such that the two beams (called B1 and B2 in the rest of the paper) were not colliding. The collimators of both rings were moved simultaneously, at 4 TeV and with squeezed optics ($\beta^* = 0.6$ m in interactions points 1 and 5), with both the abort gap cleaner and the tune feedback switched off. Secondary collimators in IR7, then primaries in IR7, were moved back and forth. The chromaticity was kept at low values (Q' between 1 and 5), and the effect of the transverse feedback (called ADT in the rest) was tested on the secondary collimators movement. In Fig. 3 we show the spectrum amplitude vs time for beam 1 in vertical from the BBQ position data, together with the movement of a secondary collimator, during the full measurement sequence on June 24th, 2012 [7]. The effect of switching off the ADT (around 4:25) is well visible in this plot: it clearly reduces the noise level especially around the main tune line. Most importantly, the frequency change of the spectrum lines of highest amplitude (so of the tune) when the collimator is put in and out relative to the beam center, is also visible. An exemple of tune measurement when the collimators move can then be seen in Fig. 4 in the case of beam 2 vertical when the secondary collimators in IR7 were moved together several times back and forth from 5.1 to 9σ (σ being calculated with the nominal emittance of 3.5 mm.mrad, at 4 TeV). Similar plots were obtained with the primaries moving from 4.2 to 6.2σ, as well as for the other beam and the other plane. Finally we could get an almost complete set of tune shifts measurements from the June 2012 MD. Unfortunately, due to unknown reasons the BBQ data was much more noisy during the November 2012 MD [8] so that the tune shift of only one configuration, and with a higher error bar, could be found for this experiment.

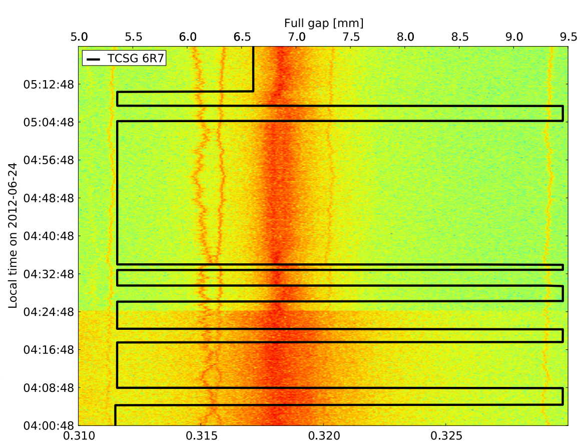

Figure 3: BBQ spectrum vs time for beam 1 in vertical (from an FFT performed on a sliding window) together with the gap of one of the secondary collimators moved during the MD of June 2012. The color indicates the amplitude of the spectrum lines. Note that primary collimators were moved as well (separately from the secondaries) but this is not indicated in the plot.

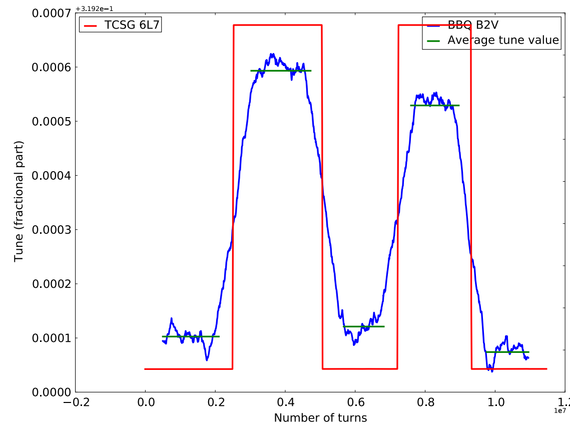

Figure 4: Tune vs. time when the TCSG in IR7 are moving, with transverse damper on, during the MD of June 2012. One of the TCSG gap (twice the half gap, which varies between 5.1 and 9σ) is also shown (in mm units).

RESULTS AND COMPARISON WITH THE LHC IMPEDANCE MODEL

In Fig. 5 we plot the tune shifts slopes (i.e. the tune shifts normalized by the bunch intensity) in units of $10^{-3}/(10^{11}$ protons per bunch). Note that all the TCSG (respectively TCP) in IR7 were moved together for each measurement point, leading to a different tune shift in each plane, hence the labels of the plot. Results are mainly from the June 2012 measurements, but one result for the primary collimators from the November 2012 experiment is also given (with a higher error bar due to the noise in the data mentioned in the previous section). As could be inferred from Fig. 2, secondary collimators are responsible for a higher tune shift than the primaries.

We compare in Fig. 6 the measured tune shifts during the June 2012 experiment (which gives the most reliable and complete collimator tune shifts measurements to date) and the one that we can obtain from HEADTAIL simulations with the LHC impedance model (actually, only the resistive-wall impedance of the collimators is used). Measured beam and machine parameters such as chromaticity, bunch length and intensity vary between the various measurements but are all taken into account in the simulations, as well as the half-gaps of the collimators. Results are presented in terms of discrepancy factor between the measured tune shift and the simulated ones. One gets an average factor 2 discrepancy, which can be considered as relatively good given the complexity of the 27 km LHC machine. Possible explanations of this discrepancy are the yet unaccounted-for change in geometric impedance with half-gaps, or a possible deviation of the CFC resistivity from the value of 5 $\mu\Omega$.m measured initially on the collimator jaws [12, 13], due possibly to material degradation upon irradiation. While the former hypothesis is under study, we try to check here the latter hypothesis by showing the evolution of these discrepancy factors since 2010 (data ex-

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tracted from Ref. [5]). This is shown in Fig. 7, where no general trend can be clearly identified in the evolution of the discrepancy factor, at least with respect to the error bars. Still, the data remains relatively scarce such that definite conclusions cannot be drawn.

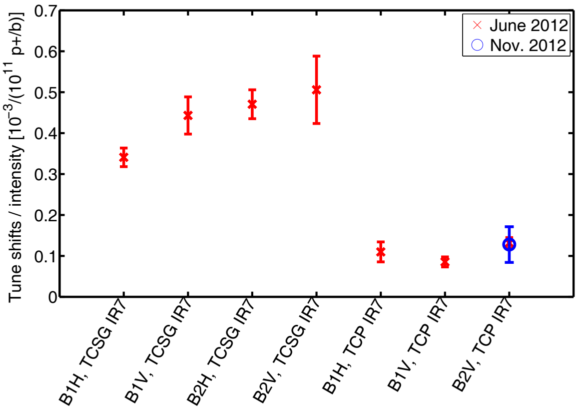

Figure 5: Tune slopes for various collimators families, from the 2012 measurements (ADT off, $-0.5 < Q' < 7$).

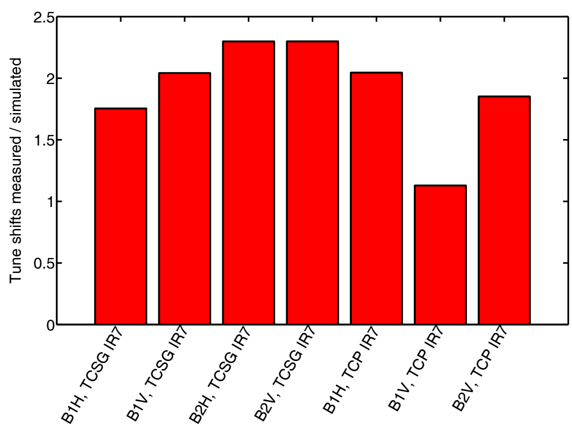

Figure 6: Discrepancy factor between the measured (in June 2012) and simulated tune shifts, for various collimators families (ADT off, $1 < Q' < 5$).

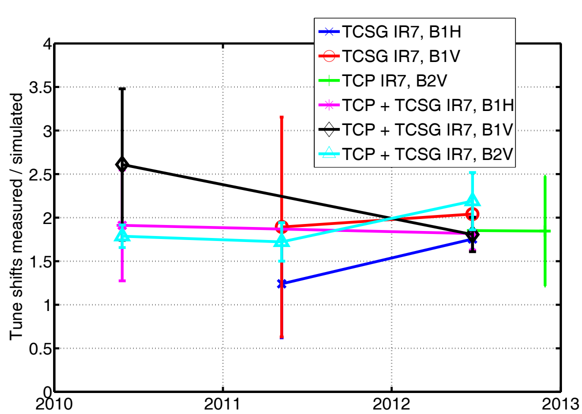

Figure 7: Evolution of the discrepancy factor between the measured and simulated tune shifts from mid-2010 till the end of 2012, for various collimators families (ADT off).

CONCLUSION

A relatively complete set of tune shifts measurements vs collimator half gaps is now available for the LHC for low chromaticity values (Q' between 1 and 5), giving a first hint of the impedance of the machine. Discrepancy with respect to the LHC impedance model (in particular the resistive-wall impedance of the collimators) and HEADTAIL simulations is around a factor 2 and seems to have remained approximately constant since 2010. Therefore one cannot a priori explain the discrepancy between measurements and simulations with a radiation damage possibly creating a change of resistivity of the collimator jaws and consequently of the resistive-wall impedance.

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