ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRI053

TRANSVERSE INSTABILITIES IN THE MAX IV 3 GeV RING

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Abstract

Collective effects in MAX IV 3 GeV storage ring are strongly enhanced by the combination of low emittance, high current and small effective aperture. Three passive harmonic cavities (HC) are introduced to lengthen the bunches, by which beam stabilization is anticipated via decoupling to high frequency wakes, along with Landau damping. The role of the transverse impedance budget of the MAX IV 3 GeV storage ring as a source of collective beam instabilities was determined. With the help of the macroparticle multibunch tracking code *mbtrack* that directly uses the former as input, we studied the influence of geometric and resistive wall impedance in both transverse planes, as well as that of chromaticity shifting. A fully dynamic treatment of the passive harmonic cavities developed for this study allowed us to evaluate their effectiveness under varying beam conditions.

INTRODUCTION

The MAX IV facility, presently under construction in Lund(Sweden), includes two storage rings (1.5 and 3 GeV) and a short pulse facility, driven by a 3 GeV linac. Both storage rings are injected at the full energy and operated at 500 mA current top-up regime (2.84 mA per bunch). The 3 GeV ring is an ambitious project which combines low emittance (0.24 nm.rad) with a high beam current in a considerably small effective aperture ($b_{eff} < 11$ mm). Such machine parameters lead to the need of long bunches, which are provided by three passive HCs (300 MHz) additional to the 100 MHz RF system.

In this paper we focus on the MAX IV 3 GeV ring transverse impedance and instabilities, both single- and multibunch. The following section describes the calculation and processing of the transverse geometric impedance budget. No low-gap insertion device (ID) chambers and surrounding tapers are included in these calculations. Next, we present the results of the particle tracking with *mbtrack* code [1,2]. The single-bunch tracking explores the effects from the wall resistivity and HC in combination with shifting the chromaticity. The multi-bunch tracking evaluates instabilities induced by the presence of the long-range resistive wall wake in the ring with and without the low-gap ID chambers. A special emphasis is put on the study of HC impact on the beam stability.

TRANSVERSE IMPEDANCE

The transverse impedance of the MAX IV 3 GeV ring components is obtained using GdfidL [3]. A 4 mm long test bunch at 1 mm offset from the beam pipe center was used to calculate wake potential up to 8 meters, which is then transformed to impedance up to 30 GHz. This determination of the geometric ring impedance ignores the resistivity of the walls but the used tracking code includes the effect of the smooth resistive pipe.

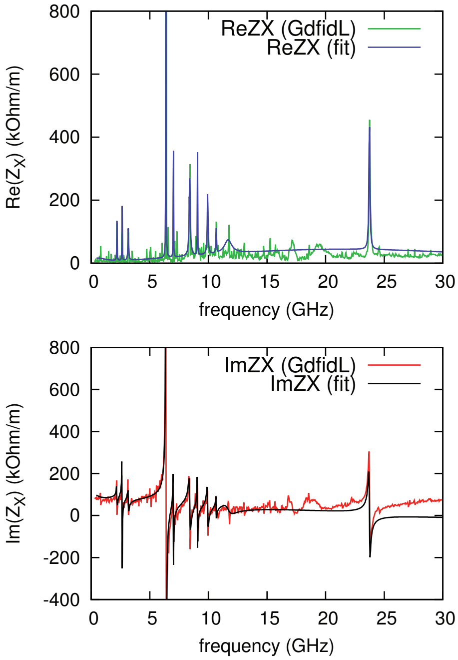

Figure 1: Horizontal resonators fitted to the impedance numerically obtained in GdfidL: real (top), imag (bottom). No wall resistivity assumed.

Following the impedance decomposition procedure presented in [4], we have fitted the horizontal and vertical impedance to several resonators. The result of the fit is shown in Fig. 1 for the horizontal plane and Fig. 2 for the vertical.

In the horizontal plane a total of 13 and in the vertical plane a total of 12 resonators were necessary to achieve a good agreement. Similar to the treatment of the longitudinal impedance data [4] no resonators with a resonance frequency above 25 GHz were considered. A proper fit above this frequency would require an extension of the GdfidL calculations above 30 GHz. As a result of using the 195 ps long bunches, the overlap of the corresponding bunch spectrum with such high frequencies is considered to be small. Similar to the longitudinal plane, a strong contributor in both transverse planes is a narrow resonance at 6.38 GHz which is excited in the flanges surrounding the BPMs.

To estimate the goodness of the impedance fit we reconstructed the wake potential corresponding to the 4 mm test bunch and compared it to the potential calculated directly in GdfidL. The two showed adequate match up to the dis-

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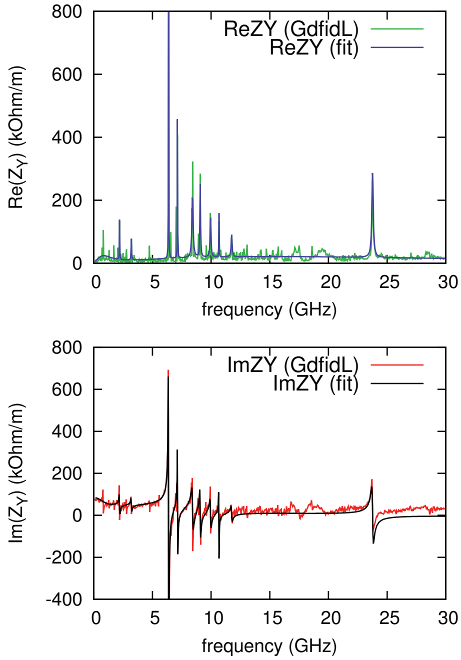

Figure 2: Vertical resonators fitted to the impedance numerically obtained in GdfidL: real (top), imag (bottom). No wall resistivity assumed.

tance of 1 m, whereas at greater distances the discrepancy gradually increases.

Shunt impedances, quality factors and resonance frequencies of the fitted resonators are the required input parameters for the tracking code, where they are used to retrieve the corresponding total Green's function.

INSTABILITY SIMULATION

Single-bunch

In the study of single-bunch transverse instabilities the tracking was performed in horizontal and vertical plane independently. The effects of quantum excitation and radiation damping were accounted for in all performed simulations. To evaluate the threshold current of instability we analyzed the transverse beam size evolution during the current ramp: the instability was identified by a drastic increase of the beam size σ and the calculations were done both with and without the effect of the resistive wall. As the more critical case, the results for the vertical plane are shown in Fig. 3.

In presence of the wall resistivity a significant decrease of the threshold current down to $I_{th} \approx 6$ mA per bunch is observed, which is twice smaller than if we assume perfectly conducting walls.

In order to gain insight in the interplay of effects with chromaticity shifting, we studied several scenarios for both transverse planes: in presence of the geometric impedance and wall resistivity with or without the longitudinal impedance; with and without the impact of an active HC which ensures optimal bunch lengthening and Landau damping. Similar to results above, the tracking with the current ramp was done at different values of the chromaticity and the thresholds of instability were determined. The results are presented in Fig. 4, where the vertical gray line indicates the design chromaticity $\xi = +1.0$ in both planes.

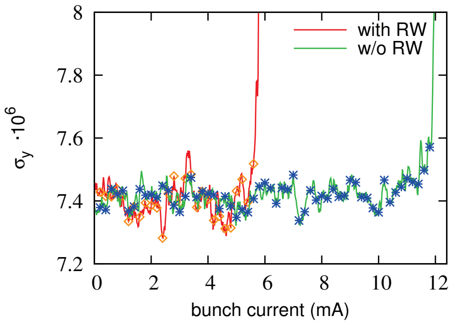

Figure 3: Vertical beam blowup at zero chromaticity: only geometrical impedance (green, asterix), geometrical with resistive wall (orange, diamonds). Markers indicate a current increase every 10,000 turns by 0.2 mA.

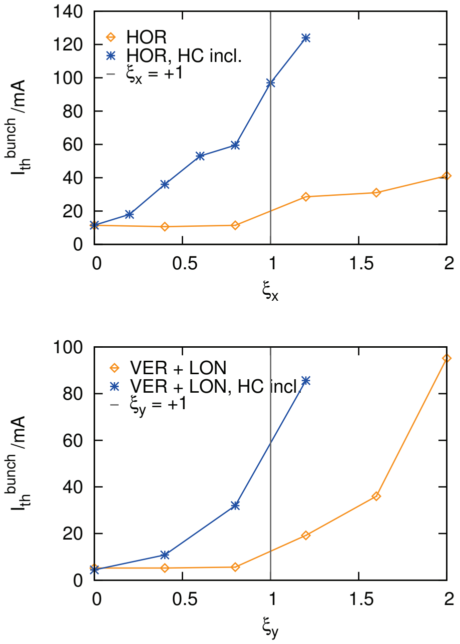

Figure 4: Threshold current trend depending on chromaticity: w/o HC (yellow,diamonds), with HC (blue, asterix). Horizontal plane (top), vertical plane (bottom).

At $\xi = 0$ HC does not effect the instability onset whereas at nominal chromaticity it increases the threshold by the factor of five. The design operation current per bunch is 2.8 mA which is orders of magnitude smaller than obtained single-bunch instability thresholds.

Multi-bunch

Multi-bunch simulations focus on two effects: the passive HC, loaded by the entire beam and the longliving transverse resistive wall (RW) wake. While the effect of the HC can be deduced from updating the voltage from the previous step with the impact of the passing charge [5], the calculation of the RW wake voltage needs the whole history of charge distribution over the time the field is lasting. For the MAX IV parameters, we found the field persistent for 90 turns. We regard the effect of the internal bunch structure negligible and store only the position of the center of mass over this number of turn.

mbtrack uses an effective beam pipe radius b_{eff} which is the result from a weighted average over the ring circumference taking cross section changes, the changing beta function and changing materials along the circumference into account. To minimize the runtime we used the active HC module again to find the start of the instability and cross checked afterwards this result with the passive HC.

We defined the onset of the instability where the averaged single particle emittance is growing with turns. Just before the instability we could observe a first but constant increase of this emittance, as displayed in Fig. 5.

Tests revealed that the RW instability takes up to 15,000 turns of tracking to build up. To speed up this process, we divided the beam pipe radius by two for 50 turns and increase it to normal afterwards. This triggers the instability without changing the threshold current. We observed that an additional geometric impedance in the same plane increased the threshold while the longitudinal one did not effect it.

First of all, we evaluated the thresholds of the bare ring without low-gap ID chambers. Without chromaticity, the instability starts at a ring current of 40 mA in the vertical plane, no matter which harmonic cavity setting was used. With the nominal chromaticity $\xi = +1.0$ and active HC the threshold current increased to 950 mA (Fig. 5) for the vertical and 3500 mA for the horizontal plane.

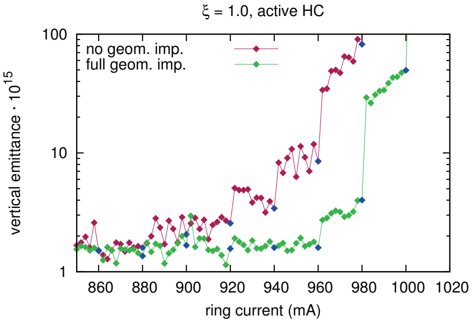

Figure 5: Vertical emittance under the influence of the RW wake, with and without geometric ring impedance. The ring current is increased every 10,000 turns by 20 mA (blue markers).

Since the the resistive wall effect scales with $b_{eff}^3 \cdot I$, the thresholds for a lattice with IDs could be found by scaling the above retrieved currents. For a scenario including the first five IDs slated for installation in the 3 GeV ring, the vertical threshold comes down to 380 mA. An increase of chromaticity to $\xi = +1.2$ restores the capability of running with more than 500 mA.

The tests with the passive HC revealed a critical point during beam filling around 40 mA for all chromaticities. To overcome this problem in the MAX IV 3 GeV ring it is possible to use the available reserve of shunt impedance, which is much greater than the one needed to get the maximum lengthening at 500 mA. Thus, one can find a setting of tuning angles of cavities providing reasonable bunch lengthening at lower currents. A further increase of chromaticity, a feedback system or an active powering of the HC may be considered as another possibility to ensure a stable operation.

CONCLUSION AND OUTLOOK

Transverse impedance of the MAX IV 3 GeV ring was determined, thus, completing the total impedance budget of the machine with the exception of IDs.

The tracking code *mbtrack* was completed with the treatment of short-/long-range RW and active/passive HC. It showed reasonable and consistent results and established itself to be a good tool to perform studies of collective effects under different beam conditions.

The results of the tracking showed that the use of HC in combination with chromaticity of +1.0 shifts the thresholds of single-bunch instabilities to values significantly higher than the operation current. However, the multi-bunch studies showed that the precise tuning of cavities is needed to overcome the instabilities occurring during the filling process. Considering the resistive wall wake exited in five low-gap ID chambers we determined that the shift to chromaticity higher than the design value is necessary to have a stable machine operation. As there is still a margin in achievable chromaticity value this change can be easily implemented.

In future this study will focus on the contribution of the IDs to the geometric impedance and it's effect on the beam stability in all three planes.

The threshold increase caused by the geometric impedance shown in Fig. 5 suggests that a head-tail damping takes place. The investigation of the internal bunch structures, revealing the nature of arising instabilities, is the next major step in this study.

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