STUDY OF COLLECTIVE BEAM INSTABILITIES FOR THE MAX IV 3 GeV RING

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Abstract

The present paper reports on a systematic simulation study made on the collective beam instability in the MAX IV 3 GeV ring. We study both single and multibunch instabilities in the longitudinal plane. Specifically, we focus on the microwave instabilities which are considered to be particularly dangerous for MAX IV, in view of its small effective radius of aperture ($b_{eff} < 11mm$), the high intensity (500 mA) and the low emittance (0.24 nm.rad) nature of the circulating beam. Single and multibunch tracking are performed using wake fields that were numerically obtained using GdfidL for the ensemble of the vacuum components. A special effort was made to include dynamically the effect of harmonic cavities that lengthen the bunch and introduce Landau damping, whose details are described in the companion paper [1] . The study aims to confirm the effectiveness of storing long bunches in the 100 MHz RF system, where tune spreads are further increased by the harmonic cavities, in order to fight against collective instabilities.

INTRODUCTION

MAX IV will be the next-generation synchrotron radiation source scheduled to start operations in mid 2016. The new accelerator complex will include two storage rings and a linac-based short-pulse facility. The main light source of MAX IV will be a 528 m low emittance storage ring operated at 3 GeV producing hard X-ray radiation. The RF system will consist of 6 active 100 MHz cavities and three passive higher harmonic cavities (HC) operating at 300 MHz. The main purpose of the higher harmonic cavities is to increase the bunch length from natural 40 ps up to 195 ps and damp longitudinal instabilities [2].

Possible collective effects for the MAX IV 3 GeV ring were studied on a pre-manufacturing stage to guarantee beam stability during the operation. Studies include the three following steps:

- The longitudinal geometric impedance was obtained using GdfidL [3, 4] which performs wake potential calculations and can treat 3D objects using extremely fine meshing. In order to save time, all the computations were done on the SOLEIL computer cluster as parallel processed tasks.
- The total longitudinal impedance output data was decomposed to a number of resonators, purely resistive and inductive components.
- The obtained parameters of the resonators, i.e. shunt impedance, Q-value and resonance frequency, were used as an input to the particle tracking code *mbtrack* [5] as one of the factors contributing to the possible rise of instabilities.

IMPEDANCE BUDGET

Longitudinal Impedance

The MAX IV 3 GeV ring vacuum chamber was divided in 23 different components occurring in the 20 cells around the ring. This ring model has apertures of about 11 mm and no insertion device low gap chambers or tapers were yet included. All walls in GdfidL computations are treated as perfectly conducting and the output impedance is purely geometrical. The wall resistivity can be included in the particle tracking code as an optional effect. In the GdfidL computations a 4 mm long bunch was used to excite the field in a structure. Corresponding wake potentials were calculated up to 8 meters and Fourier transformed to obtain the impedance up to 30 GHz. Though the bunch length of 195 ps corresponds to a spectral width of 0.8 GHz, we also investigate the high frequency region, which becomes important as soon as the density modulation occurs in the electron distribution. The frequency content of the geometric longitudinal impedance is presented in Fig. 1.

The main contributor to the total longitudinal impedance at frequencies below 5 GHz are the RF cavities and above are flanges and BPMs.

Impedance Decomposition

The impedance data has to be further processed in order to find the corresponding wake functions required for the macroparticle tracking. One way to deduce a Green's function directly from the wake potential is to decrease the length of the passing bunch. This method, however, results in a significant increase of the computation time. We followed a different approach and fitted the numerically calculated impedance to a number of resonators, also adding a purely inductive and resistive components [6]. This has the advantage, that the analytically Fourier transformed resonator wake fields are guaranteed to have the right physical properties. With the help of those Green's functions, the wake voltage of any electron distribution can be calculated.

The fitted resonators are shown in Fig. 2. The four narrow resonators are from BPMs and flanges, the broad resonator at around 1 GHz arises from the cavities and the other two broad resonators are originated as a sum of other

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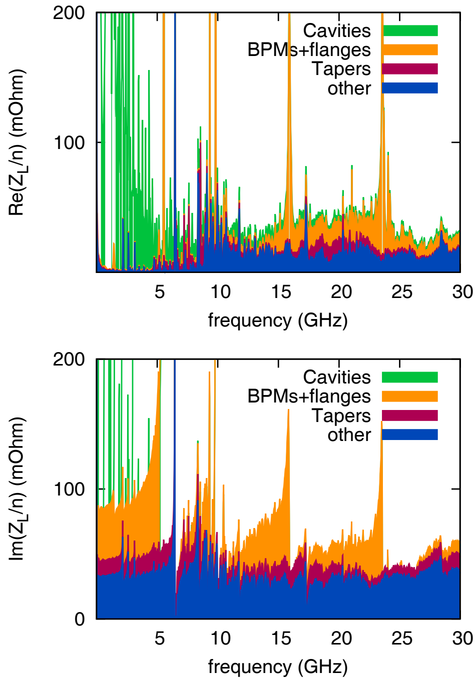

Figure 1: Frequency content of the MAX IV 3 GeV ring longitudinal geometric impedance. The four largest contributors are distinguished. Top: real part. Bottom: imaginary part

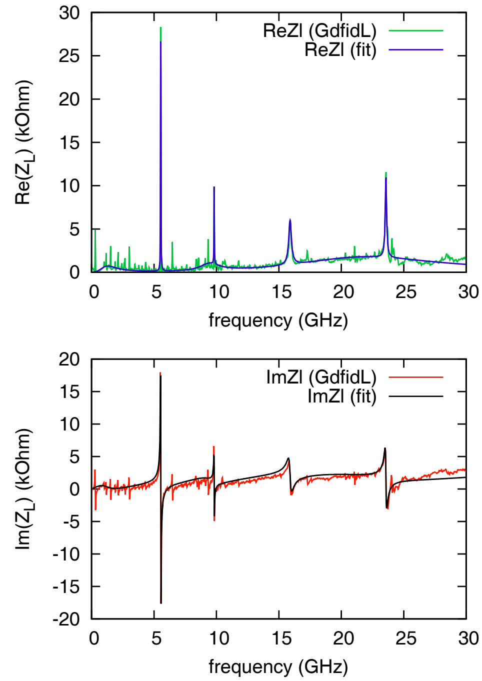

Figure 2: Longitudinal impedance fit to resonators. Top: real part. Bottom: imaginary part.

vacuum chamber components. In total it required 7 resonators, a resistive offset of 12 Ω and an inductive term of 100 Ω/GHz to resemble the impedance data well. To describe the data above 25 GHz an additional resonator would be needed. But, since it evidently extends beyond the available frequency range, it was ignored.

INSTABILITY SIMULATION

Single Bunch Calculations

The single bunch longitudinal instabilities were investigated using the *mbtrack* code. The particle tracking was performed considering the effect of the geometric impedance (7 resonators and the resistive and inductive term obtained from the impedance decomposition), quantum excitation and radiation damping effects. The additional potential of the HC, providing Landau damping, was excluded. As we concentrate on investigating possible negative effects caused by the geometry of the vacuum chamber, the option of the resistive wall impedance was switched off during the simulations.

The analysis of the energy spread evolution for different combinations of resonators determined two of them, at 5.54 GHz (referred to as "resonator 2") and 20.07 GHz (referred to as "resonator 6"), which are causing instabilities for currents per bunch below 10 mA. Resonators 2 and 6 cause energy spread growths starting at 9 mA and 5 mA respectively. The MAX IV design current per bunch is 2.84 mA.

From the frequency content of the MAX IV 3 GeV ring we can see that the resonator number 6 arises from BPMs and flanges. Fig.3 shows the change in bunch length and energy spread evolution when excluding resonator number 6 from the tracking input.

In the presence of all resonators the energy spread growth is observed at 3.5 mA and in the absence of resonator number 6, the beam stays stable up to 9.5 mA current per bunch.

The effect of the BPMs and flanges on the beam stability in the MAX IV 3 GeV ring needs further investigations.

Multi Bunch Calculations

As described for the single bunch studies, we used the *mbtrack* code to extend our simulation to multibunch effects. The main difference is the accounting for the planned passive harmonic cavities which shall elongate the bunches and damp instabilities. The implementation of this new feature in the simulation code is described in detail in another contribution [1].

The runs discussed here simulate the beam filling process for a uniform filling pattern, where every 50,000 turns the beam current is increased by 10 mA (corresponding to 0.57 mA bunch current). Figure 4 shows the bunch length σ_τ under the influence of the increasing induced field in the HC due to the current rise with and without the impact of the geometric ring impedance: in the first case, the σ_τ spread amongst the bunches increases significantly above 550 mA as the error bars show. Adding the ring impedance effect, an additional bunch lengthening takes place as expected.

ISBN 978-3-95450-122-9

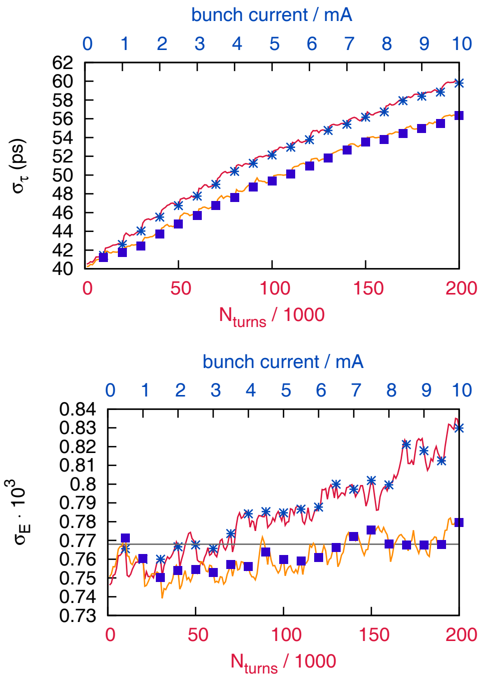

Figure 3: Top: Bunch length evolution with current. Bottom: Energy spread evolution with current. Red: all resonators included. Orange: resonator number 6 excluded. Markers indicate a current increase by 0.5mA after tracking for 10000 turns. The gray line indicates the natural energy spread of $7.69 \cdot 10^{-4}$.

As displayed in Fig. 5, no instability occurs up to the planned operating beam current of 500 mA. Starting at 600 mA, a clear energy spread increase appears even without the geometric impedance effect, which is probably due to the overstretched bunches since the present passive HC is optimized for the nominal beam current. Including the ring impedance, a σ_E increase starts already at about 550 mA but disappears again between 600 mA and 650 mA.

SUMMARY AND OUTLOOK

The longitudinal impedance budget was determined and its impact tested with single- and multibunch runs of macroparticle tracking. No energy spread blow-up was observed in the planned operating current range. An increase at higher currents can potentially be avoided with a HC tuning optimized for high currents.

In the future we will extend these studies by investigations of the effect of wall resistivity within the bunch and as a long range multi-bunch effect. The impedance modeling will be extended to both transverse planes to study transverse instabilities as well.

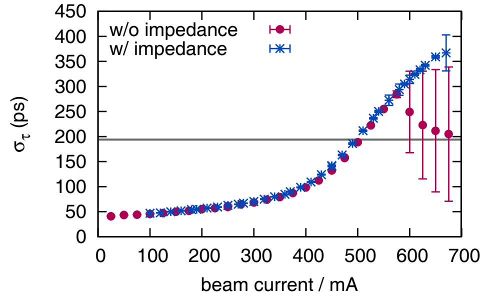

Figure 4: Bunch length evolution with current: The HC potential as well as the geometric impedance lengthen the bunches. The gray line indicates the nominal value of 195 ps at 500 mA

ACKNOWLEDGMENT

The authors want to acknowledge the excellent work of Thomas Günzel (ALBA), who prepared a large number of GdfidL computations and launched first investigation in the longitudinal plane.

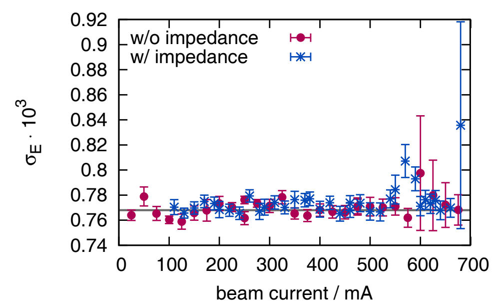

Figure 5: Energy spread evolution with current: Due to the geometric impedance, a clear increase occurs at 550 mA, which is above the planned operating current of 500 mA. The gray line indicates the natural energy spread.

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