ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRI060

IMPEDANCE STUDIES FOR THE PS FINEMET® LOADED LONGITUDINAL DAMPER

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Abstract

The impedance of the Finemet® loaded longitudinal damper cavity, installed in the CERN Proton Synchrotron straight section 02 during the Long Shutdown 2013-2014, has been evaluated [1]. Time domain simulations with CST Particle Studio have been performed in order to get the longitudinal and transverse impedance of the device and make a comparison with the longitudinal impedance that was measured for a single cell prototype.

INTRODUCTION

In the framework of the LHC Injectors Upgrade (LIU) [2] a new damper cavity has been designed to operate as longitudinal kicker of the feedback system to damp coupled-bunch instabilities in the CERN Proton Synchrotron (PS). Before the installation of the new damper, during the Long Shutdown (LS1) 2013-2014, the coupled-bunch feedback was provided by two dedicated 10 MHz cavities operating as longitudinal kickers. The design of the new damper, driven by a solid state amplifier, is based on the wideband frequency characteristics of Finemet® magnetic alloy [3]. An accurate impedance study of the new elements to be installed has been requested in order to determine the contribution to the current longitudinal and transverse impedance budget of the machine, to exclude the excitation of trapped modes due to the interaction between the beam and the cavity, to assess the impact on the stability of the beam, and to explore the electromagnetic characteristics of Finemet® .

LONGITUDINAL IMPEDANCE CALCULATION

The Finemet® loaded longitudinal damper has been initially modelled in CST [4] Particle Studio as a single cell cavity. This model consists of a beamline section with an alumina gap of 3 mm and two Finemet® rings of 165 mm radius and 25 mm thickness, enclosed into a metallic squared tank. Finemet® has been put in contact with the tank of the cavity through two support copper disks. Such a cavity system forms two $\lambda/4$ resonators excited in counter-phase [5]. The single cell model used for impedance simulations is shown in Fig. 1. Finemet® dispersive parameters have been defined in CST importing μ_1 and μ_2 measured data. CST offers the possibility of defining and automatically fitting a specific magnetic material dispersion curve from uploaded data: several different magnetic dispersion fit models can be chosen, but in this case a general N-th order has been selected. The relative permittivity of Finemet® has then been set to $\epsilon_r = 25$. A comparison between the Finemet® measured and fitted μ' and μ'' parameters is shown in Fig. 2. For CST Particle Studio 2012 simulations, the bunch length was chosen in order to obtain a good resolution in the desired frequency range, while the length of the wake has been fixed long enough to obtain impedance peaks with saturated amplitude. An r.m.s. bunch length of 50 cm has been considered. The wake potential has been evaluated through the Indirect Test Beam integration method using a wake length of 600 m. Perfect electric conductor (PEC) has been defined on all the surface as boundary condition, except on the plane perpendicular to the beam axis, which has been defined open due to the beam pipe aperture. Azimuthal symmetry has been used to reduce by a factor 4 the number of mesh cells. The main parameters of the simulation are summarized in Table 1.

In the low frequency range of the longitudinal impedance one can identify the first accelerating mode of the cavity; the real part of the longitudinal impedance is about 350 Ω at a frequency of 4 MHz. Results from simulations have been compared to the longitudinal impedance obtained with bench measurements for a single cell prototype. Measurements and simulations show a good agreement: the small discrepancies can be due to some inaccuracies in the fitting of dispersive parameters performed by CST Particle Studio. Comparison between measured and simulated longitudinal impedance is shown in Fig. 3.

Furthermore, the strong damping effect of Finemet can be observed from simulations: no excitation of parasitic or trapped modes has been detected.

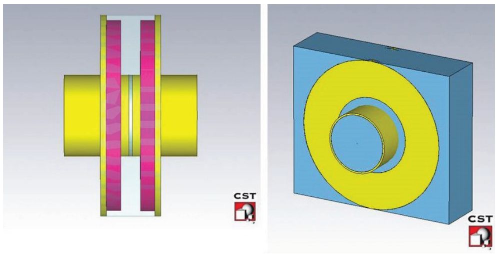

Figure 1: CST model of the one cell prototype of the Finemet® loaded longitudinal damper.

Once we were confident that the single cell was well modelled, the impedance of the whole longitudinal damper, made of six Finemet® loaded cells, has been investigated (Fig. 4). The model has been obtained repeating six times the single cell model, thus avoiding all the issues related to import a complex drawing from a mechanical CAD. The model does not include transitions between the circular pipe of the cavity and the elliptical pipe of the PS: no changes on the impedance

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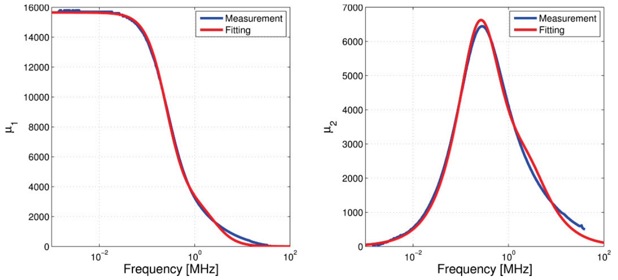

Figure 2: Comparison between Finemet® measured and fitted dispersive parameters μ_1 and μ_2.

Table 1: Main parameters of CST Particle Studio simulations for the single cell Finemet® loaded longitudinal damper.

Bunch length (r.m.s.)	50 cm
Wake length	600 m
Frequency max	200 MHz
Number of mesh cells	112.860 hexahedral
Method of field integration	Indirect Test Beam

have been predicted because of the tapers, thanks to the large bunch length circulating in the PS (26 cm-12 m) [6]. The main parameters of the simulation are summarized in Table 2. The simulated longitudinal impedance for the six-cells damper is shown in Fig. 5. The first accelerating mode of the cavity is clearly visible from the longitudinal impedance. PS bunches circulating in the center of the cavity can excite a longitudinal impedance, the real part of which has a maximum of about 2 kΩ at 4 MHz. Parasitic or trapped modes have not been detected.

Table 2: Main parameters of CST Particle Studio simulations for the six cells loaded longitudinal damper.

Bunch length (r.m.s.)	50 cm
Wake length	600 m
Frequency max	345 MHz
Number of mesh cells	3,000,816 hexahedral
Method of field integration	Indirect Test Beam

Connection Lines Effect on the Impedance

The longitudinal impedance seen by a beam circulating inside the damper is defined not only by the cavity impedance, but also by the effects of the amplifier output impedance and the connection transmission lines. The longitudinal impedance of the single cell prototype connected to the amplifiers through 4 ns cables has been measured, and is shown in Fig. 6. This response shows a broadening and a further reduction in the longitudinal impedance with respect to Fig. 3. By comparing the results with and without the effects of the power amplifier and the transmission lines, the contribution of the damper to the total impedance budget discussed in [7] and [8] allows to conclude that the damper can be safely installed in the PS ring. An additional reduction of the cell impedance will be provided by means of a one-turn feedback loop.

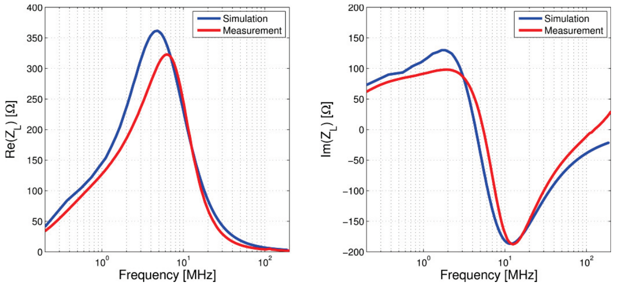

Figure 3: Comparison between longitudinal impedance simulation and measurements for the single cell damper.

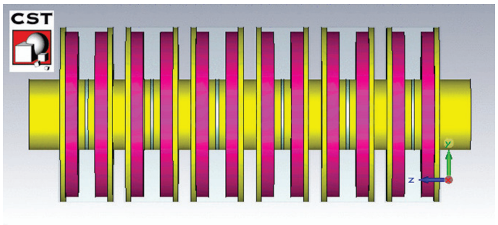

Figure 4: CST model of the six cells Finemet® loaded longitudinal damper.

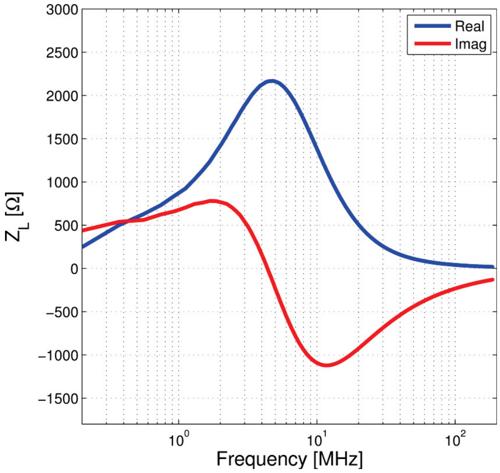

Figure 5: Longitudinal impedance of the six cells damper.

TRANSVERSE IMPEDANCE CALCULATION

Transverse dipolar impedance can be evaluated with CST Particle Studio shifting the beam in the transverse direction and performing the integration of the field along the axis of the cavity. The dipolar component is then obtained by dividing the simulated transverse wake potential by this displacement. Being the structure symmetric it is sufficient to compute the dipolar impedance shifting the beam in only one transverse direction. For this simulation XZ symmetry has been used, allowing a factor two of reduction in the number of mesh cells. Simulations have been performed both for the single cell and for the six cells models, considering different

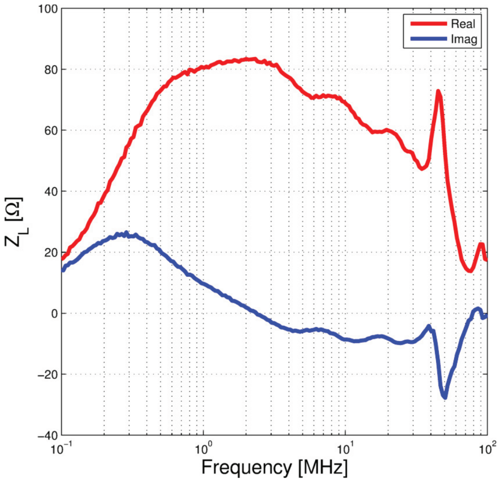

Figure 6: Measured longitudinal impedance of the single cell as seen by the beam when going through one gap connected to the amplifiers with 4 ns cables.

shifts of the beam from the center to verify linearity. The main parameters are summarized in Table 3. Simulation results confirm that the first accelerating mode of the cavity does not have a transverse component. Figure 7 shows that a parasitic mode at the frequency of 400 MHz is now excited giving a dipolar impedance. The absence of excitation of this mode in the longitudinal impedance is probably due to the TE-like configuration of the field. Due to the strong damping effect of Finemet® , the 400 MHz mode appears very broad and shifted at lower frequency with respect to the expected eigenmode resonating in the structure (450 MHz). The dipolar impedance curve in Fig. 7 is superimposed to the sum of all PS kickers transverse impedance (sum of dipolar and quadrupolar components), in order to compare the mode with the major contributor of transverse impedance in the PS. Since the transverse impedance of the damper is predicted to be negligible with respect to the total impedance of the kickers [8], no issue is expected after the installation.

Table 3: Main parameters of CST Particle Studio transverse simulations for the six cells longitudinal damper.

Bunch length (r.m.s.)	200 cm
Wake length	800 m
Frequency max	511 MHz
Number of mesh cells	3,000,816 hexahedral
Method of field integration	Indirect Test Beam

CONCLUSIONS

In this work we presented the results of impedance simulations and measurements of the new PS longitudinal damper, installed in straight section 02 during LS1. The objective of the studies was to evaluate the impedance of the damper modelled as a Finemet® loaded cavity, under realistic assumptions of bunch length. Simulations with CST Particle

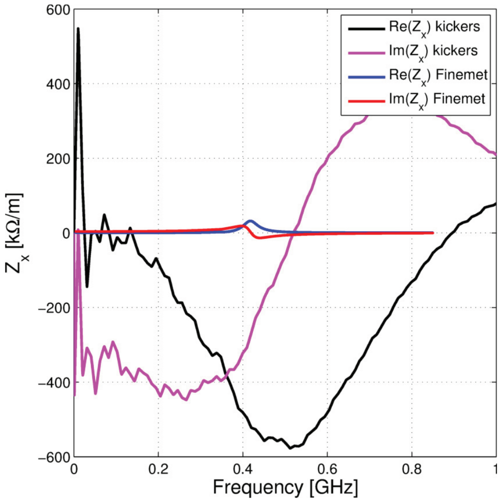

Figure 7: Comparison between the dipolar impedance of the longitudinal damper and the sum of the horizontal impedances of the PS kickers.

Studio confirmed that the longitudinal impedance observed with measurements can be excited by bunches circulating in the PS. For the six cells model, PS bunches circulating in the center of the damper can excite a longitudinal impedance, the real part of which has a maximum of 2 kΩ at 4 MHz. This mode does not seem to have any transverse component. The transverse impedance shows a parasitic resonant mode around 400 MHz, strongly damped by Finemet® . We predict that the installation of the damper does not introduce any detrimental effect due to beam coupling impedance.

ACKNOWLEDGEMENTS

The authors acknowledge H. Damerau, S. Gilardoni, K. Hasegawa, N. Chritin and the CERN impedance team for useful discussions.

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