ELECTROMAGNETIC SIMULATIONS OF SIMPLE MODELS OF FERRITE LOADED KICKERS

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Abstract

The kickers are major contributors to the CERN SPS beam coupling impedance. As such, they may represent a limitation to increasing the SPS bunch current in the frame of an intensity upgrade of the LHC. In this paper, CST Particle Studio time domain electromagnetic simulations are performed to obtain the longitudinal and transverse impedances/wake potentials of simplified models of ferrite loaded kickers. The simulation results have been successfully compared with some existing analytical expressions. In the transverse plane, the dipolar and quadrupolar contributions to the wake potentials have been estimated from the results of these simulations. For some cases, simulations have also been benchmarked against measurements on PS kickers. It turns out that the large simulated quadrupolar contributions of these kickers could explain both the negative total (dipolar + quadrupolar) horizontal impedance observed in bench measurements and the positive horizontal tune shift measured with the SPS beam.

INTRODUCTION

A kicker is a special type of magnet designed to abruptly deflect the beam off its previous trajectory, for instance to extract the beam to a transfer line or to a beam dump. Among all the SPS elements, the kickers are suspected to contribute to a significant amount of the transverse impedance of the SPS [1]. Up to now, to obtain the impedance of the SPS kickers we have used the Zotter/Métral model [2], [3] for a cylindrical beam pipe made of ferrite applying the Yokoya form factors [4] to transform into a flat chamber. However, the Yokoya factors were obtained under the assumption that the beam is ultra-relativistic, the beam pipe is longitudinally uniform, and the skin depth is much smaller than both the dimensions of the beam pipe and the thickness of the material [4]. In our case the third hypothesis is not true and it could be expected that the Yokoya factors are not valid. In order to refine the model for the kickers, H. Tsutsui derived a field matching theory to obtain the longitudinal [5] and transverse dipolar [6] impedance of a geometrical model with the metal electrode plates described in Fig. 1 for an ultrarelativistic beam.

It would be interesting to be able to use this impedance formalism to generate transverse wake functions that could be imported into HEADTAIL [7]. In his paper [6], H. Tsutsui only derived the transverse dipolar impedances. However, it would be good to have also the quadrupolar part, as it is expected to dominate the dipolar part and thus produce a negative total part of the impedance and therefore a positive horizontal tune shift [8]. We have derived the quadrupolar impedance [9] from the source and electromagnetic fields obtained for the calculation of the longitudinal impedance in Ref. [5].

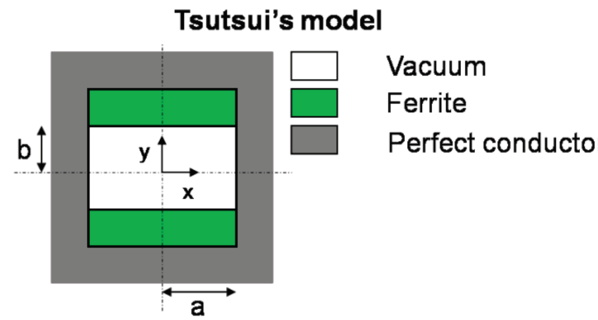

Figure 1: Geometric models for theoretical impedance calculations. H. Tsutsui derived a formalism to obtain the impedance of a model that accounts for perfect conducting plates on both sides of the ferrite plates. The beam travels perpendicularly to the drawing.

ELECTROMAGNETIC SIMULATIONS

We have performed CST Particle Studio simulations of simple 3D models of kickers [10]. Here we describe the benchmark of the simulated impedance of Tsutsui's kicker geometrical model and the available theoretical computations.

Simulation Setup

The model for the ferrite permeability μ as a function of frequency f was obtained from a first order dispersion fit on measured data up to 1.8 GHz [3]. The ferrite used for these measurements was of type 4A4 made by Philips Components (now Ferroxcube). Most SPS kickers are however made of Ferroxcube ferrite type 8C11. In spite of this difference, recent studies [11] underline that the beam coupling impedance models obtained for kicker type structures made of ferrites 4A4 and 8C11 are actually very similar.

The geometrical model described by H. Tsutsui was already shown in Fig. 1. The boundary conditions are set to electric around the ferrite except on the beam entrance and exit planes, for which the boundary condition is set to an absorbing Perfect Matching Layer. An average of 5 millions hexahedral mesh cells was used for the simulations (around 1.3 mm between 2 consecutive mesh points). Four simulations per kicker were performed to obtain the dipolar and quadrupolar transverse wake potentials [12]. This procedure is illustrated in Fig. 2.

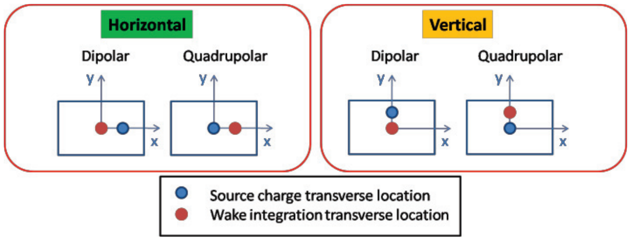

Figure 2: Procedure to obtain the dipolar and quadrupolar transverse wake potentials from 3D time domain simulations with a simulated beam.

Simulation results: Comparison with Theory and Measurements

As an example, the simulated transverse wake potentials for a model of MKE kicker (MKE.61651) are presented in Fig. 3. The impedance derived from these simulated wake potentials with a DFT can be compared to the theoretical impedance obtained by H. Tsutsui for the dipolar contribution, and the new theoretical formulae for the quadrupolar impedance [9] from Tsutsui's formalism (see Fig. 4).

The simulation results have also been benchmarked against measurements on PS kickers (see Fig. 5). We can measure the transverse generalized impedances using the coaxial wire method [13]. We measure the longitudinal impedance placing the wire at different transverse positions. The longitudinal impedance can then be approximated by the following formula when there is top/bottom and left/right symmetry [14]:

$$Z_l(f) = Z_{l,0}(f) + Z_{l,1x}(f)x_0^2 + Z_{l,1y}(f)y_0^2$$

where x_0 and y_0 are the transverse offsets of the wire from the centre of the chamber and then:

$$Z_x^{generalized} = Z_x^{dipolar} + Z_x^{quadrupolar} = \frac{Z_{l,1x}(f)}{\omega / c}$$

$$Z_y^{generalized} = Z_y^{dipolar} + Z_y^{quadrupolar} = \frac{Z_{l,1y}(f)}{\omega / c}$$

Therefore we expect a parabolic behavior of the longitudinal impedance with the wire position. The transverse impedance is obtained using a parabolic fit including also the linear term $y=a+bx+cx^2$ in order to take into account also the uncertainty on the longitudinal impedance with the wire in the center. Since the theoretical predictions are perfectly superimposed to the simulation results, we can compare measurements with either theory or simulations. Figure 5 shows a good agreement between measurements and theory for longitudinal and horizontal impedance, while a significant discrepancy is to be noticed for the vertical impedance.

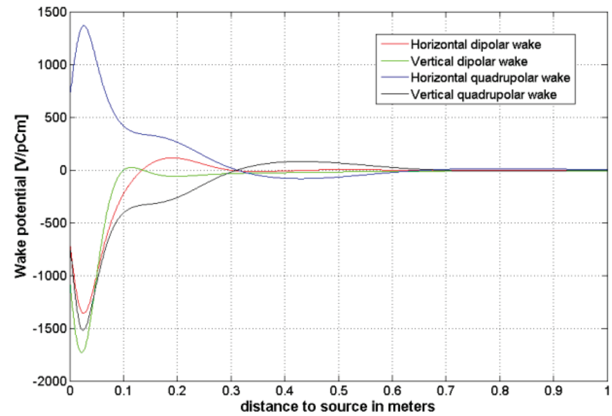

Figure 3: Simulated transverse wake potentials.

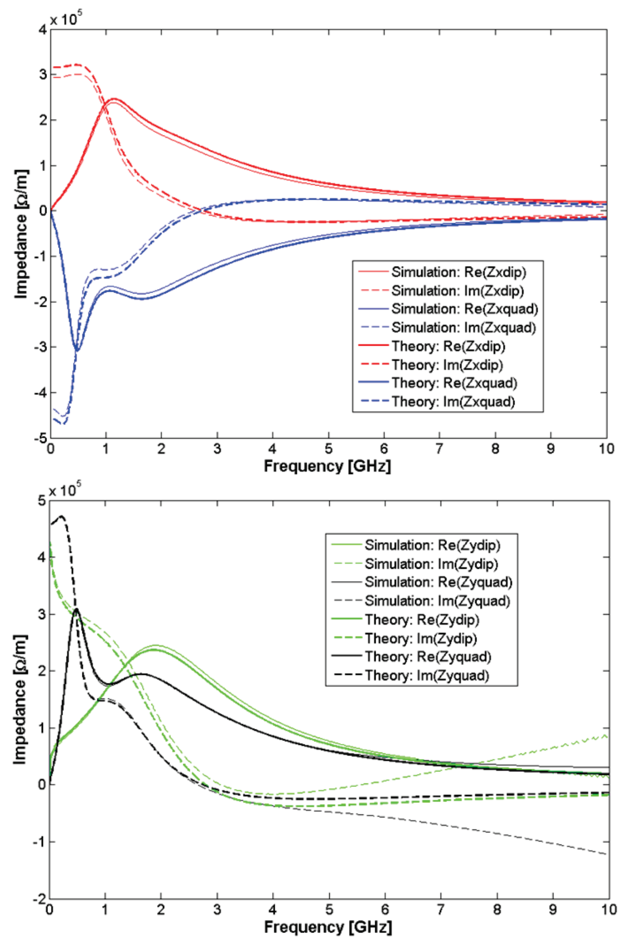

Figure 4: Comparison between theoretical and simulated horizontal (top) and vertical (bottom) dipolar and quadrupolar impedances for Tsutsui's kicker geometry model. The theoretical predictions and simulations show similar behaviour up to 4 GHz, frequency at which the theory and simulations start to differ significantly (more than 10%), in particular the imaginary vertical contributions. New simulations seem to be able to solve this problem [15].

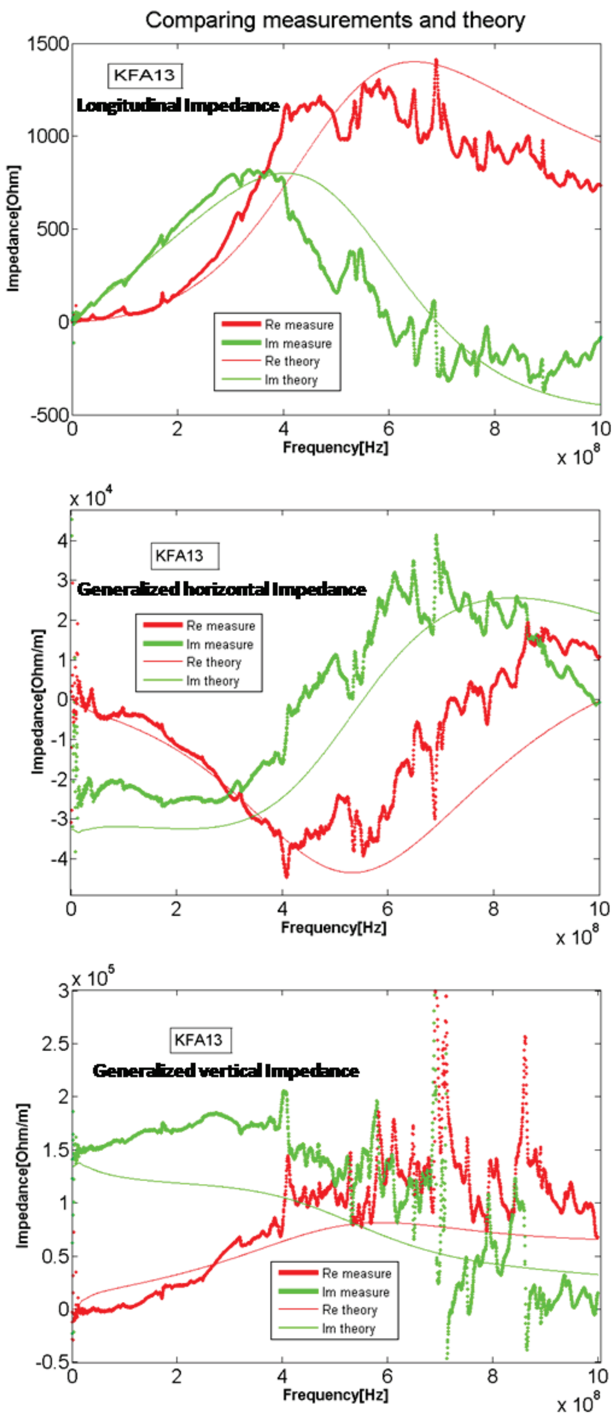

Figure 5: Longitudinal and transverse impedance: comparing theoretical and measured results for a PS kicker from 0 to 1 GHz.

CONCLUSION

We successfully benchmarked CST time domain simulations for the simple model of kicker proposed by Tsutsui with the dipolar and quadrupolar theory based on Tsutsui's formalism.

Simulations and theory of the quadrupolar impedance explain both the negative total (dipolar + quadrupolar) horizontal impedance observed in bench measurements and the positive tune shift, as observed in the measurements with beam in the SPS. In fact, summing the dipolar and quadrupolar imaginary contributions in the horizontal plane yields a large negative horizontal impedance at low frequency, which could explain the positive tune shift observed in the SPS in the horizontal plane.

We compared the theory and EM simulations with RF impedance measurements with one wire for a PS kicker. The behavior is somewhat similar, but some observed differences may suggest that many effects are not accounted for in the simple model of kicker used for theory and simulations.

REFERENCES

[1] E. Métral et al, "CERN SPS Impedance in 2007", Proc. EPAC'08 Genoa, Italy, 2007.
[2] B. Zotter, "New Results on the Impedance of Resistive Metal Walls of Finite Thickness", RN-AB-2005-043, 2005.
[3] E. Métral, "Transverse resistive-Wall impedance from very low to very high frequencies", CERN-AB-2005-084, 2005.
[4] K. Yokoya, "Resistive Wall Impedance of Beam Pipes of General Cross Section", Number 41. Part. Acc., 1993.
[5] H. Tsutsui, Some Simplified Models of Ferrite Kicker Magnet for Calculation of Longitudinal Coupling Impedance", CERN-SL-2000-004 AP, 2000.
[6] H. Tsutsui, "Transverse Coupling Impedance of a Simplified Ferrite Kicker Magnet Model", LHC Project Note 234, 2000.
[7] G. Rumolo and F. Zimmermann, "Practical user guide for HEADTAIL", SL-Note-2002- 036-AP, 2002.
[8] E. Métral, "SPS Impedance Budget Follow-up", Presented at the CERN SPS Impedance Meeting, 18/07/2008, 18 July 2008.
[9] B. Salvant et al, "Quadrupolar Transverse Impedance of Simple Models of Kickers", these proceedings.
[10] C. Zannini et al, "Simulations of the SPS kickers with CST Particle Studio", Presented at the CERN SPS Impedance Meeting, 27 August 2009.
[11] C. Zannini et al, "Electromagnetic Simulations of Simple Models of Ferrite Loaded Kickers", CERN-BE-Note-2010-006, 2010.
[12] C. Zannini et al, "Simulation of dipolar and quadrupolar wakes with CST Particle Studio", Presented at the CST European User Group Meeting, 21 April 2010.
[13] V.G. Vaccaro, "Coupling Impedance Measurements: an improved wire method", INFN/TC-94/023, 1994.
[14] E. Métral et al, "Kicker Impedance Measurements For The Future Multiturn Extraction Of The Cern Proton Synchrotron", CERN-AB-2006-051, 2006.
[15] C. Zannini et al, "Simulations of simplified model of kickers in a large range of frequency", Presented at the CERN SPS Impedance Meeting, 4 May 2010.