EM SIMULATIONS IN BEAM COUPLING IMPEDANCE STUDIES: SOME EXAMPLES OF APPLICATION

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Abstract

In the frame of the SPS upgrade an accurate impedance model is needed in order to predict the instability threshold and if necessary to start a campaign of impedance reduction. Analytical models, 3-D simulations and bench measurements are used to estimate the impedance contribution of the different devices along the machine. Special attention is devoted to the estimation of the impedance contribution of the kicker magnets that are suspected to be the most important impedance source in SPS. In particular a numerical study is carried out to analyze the effect of the serigraphy in the SPS extraction kicker. An important part of the devices simulations are the ferrite model. For this reason a numerical based method to measure the electromagnetic properties of the material has been developed to measure the ferrite properties. A simulation technique, in order to account for external cable is developed. The simulation results were benchmarked with analytical models and observations with beam. A numerical study was also performed to investigate the limits of the wire method for beam coupling impedance measurements.

INTRODUCTION

The aim of this paper is a description of the simulation studies performed in the frame of an improvement of the SPS impedance model. The simulations were performed mostly using the Wakefield solver of the 3-D commercial code CST Particle Studio.

SPS KICKER IMPEDANCE MODEL

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.

Simple models

In a very simple approximation an SPS ferrite loaded kicker can be modelled as two parallel plates of ferrite (see Fig. 1). For this simple geometrical model all the impedance terms (longitudinal, driving and detuning horizontal and vertical impedances) are calculated in [1, 2, 3]. Simulation results were found in very good agreement with the existing models [1, 2] and exactly predicted the detuning (also called quadrupolar) impedance of these devices [3]. The perfect agreement between analytical model and numerical simulations shown in [4] can be read as an important benchmark for the simulation code in the correct solution of electromagnetic problem involving dispersive materials such a ferrite.

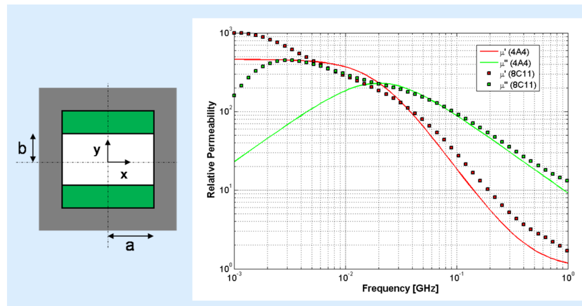

Figure 1: Tsutsui model on the left: ferrite in freen, PEC in gray and vacuum in white; complex permeability of the ferrite 4A4 and 8C11 on the right.

In the frame of an improvement of the kicker impedance model we performed a simulation study step by step to allow a good understanding of the different contributions to the kicker impedance. First, a device of finite length inserted in the vacuum tank and equipped with an inner conductor can support propagation of a quasi-TEM mode when interacting with the beam. The device behaves as a transmission line formed by the vacuum tank and the inner conductor which are continued on the external cables and closed on the appropriate circuit terminations. The TEM mode affects the impedance below a certain frequency (when the field penetration in the ferrite becomes comparable to the magnetic circuit length). This behaviour disappears as soon as we allow for 2-D geometries (infinite in the longitudinal direction) because the transverse TEM mode arises at the discontinuities which in this case are moved to infinity. In order to consider this aspect a circuit model was developed and benchmarked with CST 3-D simulations [5]. The good agreement between theoretical model and CST simulations is an ulterior proof of reliability of the code.

Realistic models

In order to approach a more realistic model other aspects have to be considered: the longitudinal segmentation (see Fig. 2), internal circuits, non ideal terminations etc. An important simulation effort was devoted to the estimation of the impedance contribution of the SPS extraction kickers. Due to heating issues the original design of these kickers was modified. Interleaved fingers were printed by serigraphy directly on the ferrite (see Fig. 3). At the moment among the 8 SPS extraction kickers (MKE) only one is still without serigraphy. Figure 4 shows the simulated longitudinal impedance for the MKE with and without serigraphy. As expected the effect of the serigraphy is a strong reduction of the real part of the longitudinal impedance. At the same time has to be noticed that the serigraphy introduces a resonance at 44 MHZ. This resonance (see Fig. 5) was studied in detail and recognized to be a quarter wavelength resonance on the silver fingers as shown in Figure 6. Neglecting the capacitive effect related to the finger width at the resonance frequency we obtain:

$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}(f)\mu_{eff}(f)}} = 0.78\,m \cong 4L_{finger}$$

where f is the frequency of the resonance, and μ_{eff} and ε_{eff} are calculated as the effective permeability and permittivity of the kicker magnet approximated as an equivalent microstrip [6] and L_{finger} is the finger length. The theoretical formula confirms that we have a quarter wave resonance in agreement with the CST simulations.

The impedance model of the SPS extraction kicker shown in Figure 4 can explain the beam induced heating observed in the machine [7].

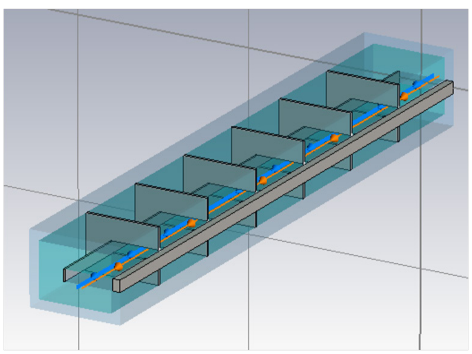

Figure 2: Simulation model of the SPS extraction kicker without serigraphy. The kicker is divided in 7 cells.

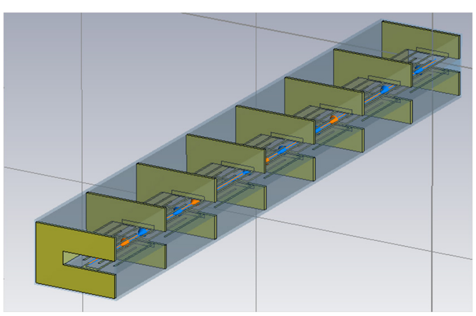

Figure 3: Simulation model of the SPS extraction kicker with serigraphy. The kicker is divided in 7 cells.

Ferrite model

The model for the ferrite permeability μ as a function of frequency f was obtained from a first order dispersion fit on measured data by the supplier. Most SPS kickers are made of Ferroxcube ferrite type 8C11. In order to verify the ferrite properties used in the impedance model a measurement setup was implemented [8]. The measured ferrite properties have been found in good agreement with the ferrite model used up to now (see Fig. 7).

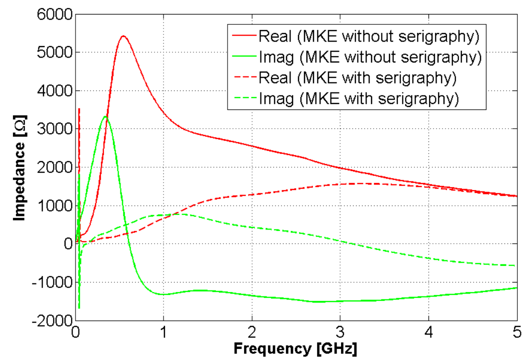

Figure 4: CST simulations of the longitudinal impedance for the SPS extraction kicker (MKE-L) with and without serigraphy

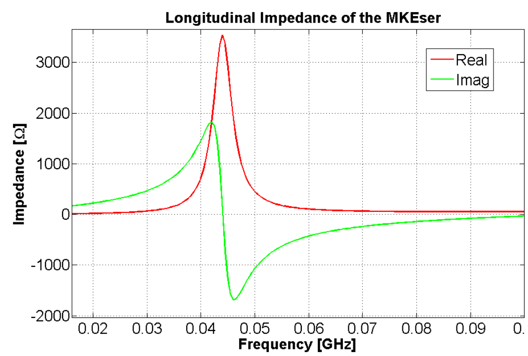

Figure 5: Zoom of the resonance due to the serigraphy

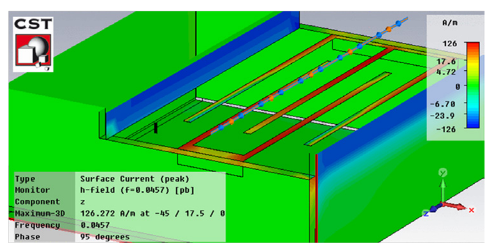

Figure 6: Surface current on the serigraphed fingers

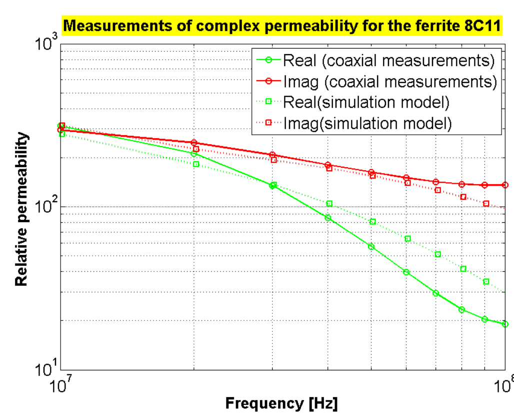

Figure 7: Measurements of complex permeability for the ferrite 8C11

Simulation of a kicker loaded by a coaxial cable

An open ended external cable (length *l*, propagation constant *k* and characteristic impedance Z_0) exhibits an impedance given by the usual formula coming from the transmission line theory $Z = -jZ_0 \cot(kl)$. Resorting to the expansion of the cotangent function as sum of polar singularities we may reproduce the cable behavior by a lumped constant element circuit. The circuit can be approximated by a finite number of RLC parallel cells connected in series where each cell accounts for a resonance

$$Z = \frac{1}{G_0 + j\omega C_0} + \sum_{n=1}^{\infty} \frac{1}{G_n + j\left[\omega C_n - (\omega L_n)^{-1}\right]}$$

Numerical investigation of bench measurements

Since many years the coaxial wire technique [9] is used to measure the beam coupling impedance of a device. Anyway the results obtained from wire measurements might be not entirely reliable because the stretched wire perturbs the EM boundary conditions, artificially introducing a TEM wave with a zero cut-off frequency among the solutions of the EM problem that will provide additional losses. For a better understanding of the limitations of the coaxial wire method, using the Transient Solver of CST Microwave Studio we performed numerical measurements, simulating the measurement setup. As example, we analyzed the case of an MKE-L with serigraphy. Difference with respect to the real setup could turn out from wire losses considered lossless in the model and from imperfect matching. In simulation the kicker is perfectly matched at both ends. Figure 8 shows a comparison of a CST Wakefield solver simulations and numerical measurements. The two curves are in good agreement for the broadband behaviour. Coherently to what expected by theory a reduction of Q and peak value for the low frequency resonance has been observed (see Fig. 9).

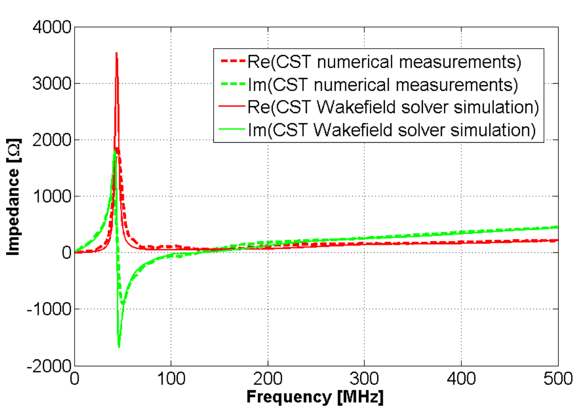

Figure 8: Longitudinal impedance of an MKE-L with serigraphy: comparing CST numerical measurements and Wakefield solver simulations.

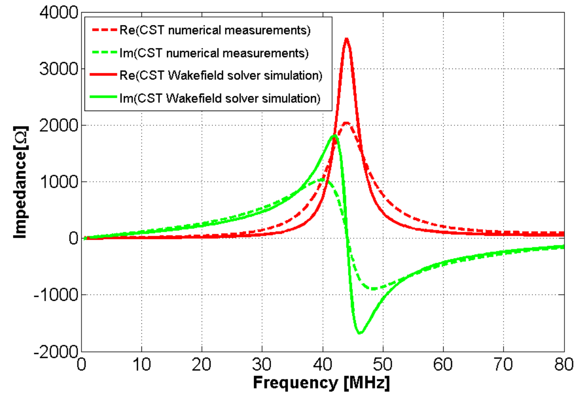

Figure 9: Low frequency behaviour of the longitudinal impedance for the MKE-L with serigraphy: comparing CST numerical measurements and Wakefield solver simulations.

CONCLUSIONS

Using the CST Wakefield Solver the SPS kicker impedance contribution has been estimated. The results were successfully benchmarked with analytical models [4, 5], and beam induced heating observations [7]. A numerical investigation of coaxial wire measurements has been presented as well.

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