IMPEDANCE SIMULATIONS AND MEASUREMENTS FOR ThomX STORAGE RING*

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Abstract

ThomX is a compact Compton Backscattering Source (CBS) which is being built at LAL, Orsay, France. ThomX ring has a short circumference of 18 m and a design energy of 50 MeV. Due to the low energy of the beam and in order to avoid beam degradation it is important to evaluate the ring components impedance. A CST Particle Studio impedance simulation of the different components of the ring (BPM, bellows, optical chamber, etc.) is under way. It will be followed by a bench measurement of the longitudinal and transverse impedance using the coaxial wire method. This paper will detail the preliminary results of the ThomX storage ring impedance simulations and the measurement principle we will use.

INTRODUCTION

ThomX is a low energy Compton Backscattering Source (CBS) demonstrator which is being built at LAL, Orsay, France. A 50 MeV electron beam is produced from a warm linac and is injected into a 18 m storage ring, then it collides with a laser beam at each turn in order to produce 10^{13} photons per second in the hard X rays range (50 to 90 keV) [1]. After 20 ms the beam is too degraded by collective effects, intrabeam scattering (IBS) and Compton interaction so it is extracted and dumped while a new one is injected. Due to the short storage time, the electron dynamics is not damped and the beam stability becomes a crucial matter. To achieve ThomX expected performances it will be important to know and to minimize the possible sources of beam instability and degradation. An important source of longitudinal and transverse instability may be the beam coupling impedance of the storage ring elements. As the beam is 1.5 mm long at the injection it is necessary to consider the impedance up to high frequencies which is challenging both in simulations and measurements. Simulations are done using CST Particle Studio [2] wakefield solver up to 50 GHz for both transverse and longitudinal one. A measurement bench is currently being assembled to study longitudinal, transverse dipolar and transverse quadrupolar impedances up to 9 GHz. This paper will detail the preliminary results of impedance simulations for ThomX Beam Position Monitor (BPM) and the future measurements.

SIMULATION RESULTS

Wakefield simulations are performed with the wakefield solver of CST Particle Studio [2]. Figure 1 shows the simplified geometry of a 4 button BPM (BPM4) where the beam is represented by the blue line, the orange line being the integration line where the wakefield is computed, at the center of the BPM4 in this case. The stainless steel structure is represented in light blue, the molybdenum buttons are in dark blue and the alumina insulator is in red. The stainless steel and the molybdenum are modelled as lossy metals whereas the alumina is modelled as ‘normal’ material. Lumped ports of 50 Ω labelled 1 to 4 are used to model the output coax cables of the BPM and to prevent unwanted reflections at the end of the structure.

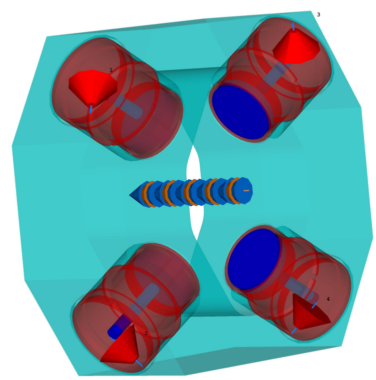

Figure 1: Simulation model of ThomX 4 button BPM in CST Particle Studio.

The beam has a Gaussian longitudinal distribution of standard deviation $\sigma_z = 2\,mm$ and is modelled using the transmission line injection scheme. Special care have been taken to improve the mesh quality and to check that the results do not change with the mesh. First simulations were done using the *direct* solver in which the wakefield is directly integrated along the specified path. Then in a second time the *indirect interfaces* solver was used, for which the integration path is direct for cavity-like structures and indirect for pipe-like structures. This second solver is supposed to be more accurate and benchmark test for the ‘step-out’ structure seemed to confirm that. A ‘step-out’ transition is a structure composed of two round pipes of different radius, the beam is exiting the small pipe of radius a to enter the bigger pipe of radius b. The expected high-frequency impedance for a ‘step-out’ transition is $Z_{out} \approx \frac{Z_0}{\pi} \ln\left(\frac{b}{a}\right)$ with Z_0 the vacuum impedance. Figure 2 shows that the *indirect interfaces* solver gives the correct impedance for a ‘step-out’ whereas the *direct* solver gives a non-constant impedance at high frequency.

Figure 3 shows the real part of the impedance for the BPM4 for both solvers up to 30 GHz. The peak at 6.5 GHz is the main coupling mode of the BPM4 with higher order modes (HOM) around 13 GHz, 20 GHz and 26 GHz. One of the main difference between the two solver results is that

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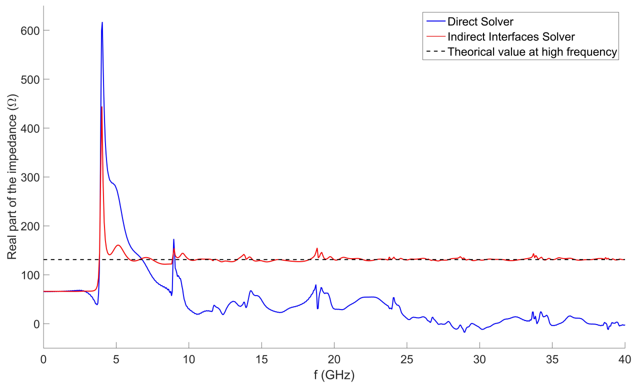

Figure 2: Real part of the impedance for the *direct* solver in blue and for the *indirect interfaces* solver in red versus frequency (preliminary results). The theoretical value for this case, $b = 3a$, is shown in dotted black line, $Z_{out} \approx 131\,\Omega$. Simulations done for the 'step-out' transition using CST Particle Studio 2016.

the amplitude of the 6.5 GHz peak is much higher for the *direct* solver impedance spectrum. The second difference is that the high frequency part of the *direct* solver is negative. The negative peaks shown in the *direct* solver impedance spectrum mostly have the same amplitude and frequency. Figure 4 shows the imaginary part of the impedance for both solvers. The spectrum amplitude is globally larger for the *direct* solver as for the real part of the impedance. The sign change between the two solvers is also observed for frequencies bigger than 8 GHz.

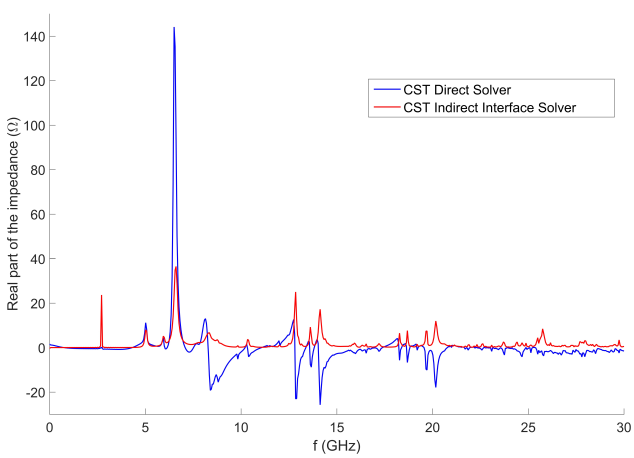

Figure 3: Real part of the impedance for the *direct* solver in blue and for the *indirect interfaces* solver in red versus frequency (preliminary results). Simulations done for the BPM4 using CST Particle Studio 2016 with 12 millions meshcells for the *direct* solver and 15 millions for the *indirect interfaces* solver.

IMPEDANCE MEASUREMENTS

The impedance effects will be included in the electron beam dynamics simulations to quantify and prevent instabilities. To be able to minimize error sources during the comparison between the simulated and measured beam dynamics, it is important to have a way to check the simulations validity. In order to do that we will soon start impedance measurements up to 9 GHz to cross check the simulation result in this frequency range. Impedance measurements will be performed using the classical coaxial wire method for the longitudinal part [3]. This method use the fact that electromagnetic field produced by an ultrarelativistic beam is close to the one produced by a TEM transmission line. It is then possible to measure the impedance using a network analyser matched to the TEM transmission line created by device under test (DUT) and the wire inserted inside the DUT. The transverse dipolar and quadripolar impedance will be obtained by wire scans measurements and two wire measurements [4].

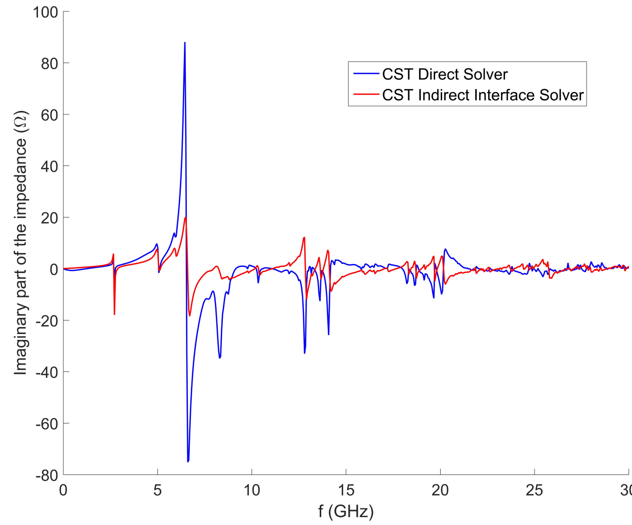

Figure 4: Imaginary part of the impedance for the *direct* solver in blue and for the *indirect interfaces* solver in red versus frequency (preliminary results). Simulations done for the BPM4 using CST Particle Studio 2016 with 12 millions meshcells for the *direct* solver and 15 millions for the *indirect interfaces* solver.

$$Z = -2Z_L \ln\left(S_{21}\right)\left(1 + \mathrm{j}c\frac{\ln S_{21}}{4\pi L f}\right) \tag{1}$$

Equation (1) is the improved log formula for the wire measurement [5], with Z_L the line impedance of the transmission line created by the device under test (DUT) and the wire, $S_{21} = \frac{S_{21,\mathrm{DUT}}}{S_{21,\mathrm{REF}}}$ the ratio of the DUT forward transmission parameter to a reference forward transmission parameter, c the speed of light, L the length of the DUT and f the frequency. Using Eq. (1) and simulation results it is possible to estimate the transmission signal $S_{21,\mathrm{DUT}}$ that should be measured by the network analyser as it is shown in Fig. 5. Figure 6 shows the impedance measurement bench being built at LAL (Orsay, France). The first impedance measurements will start in the coming months on ThomX prototypes of BPM, pumping ports, bellows, ...

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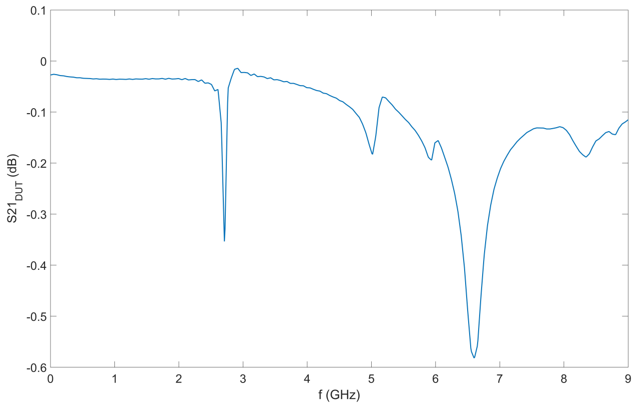

Figure 5: Transmission signal $S_{21,\mathrm{DUT}}$ expected for the longitudinal impedance measurement for the BPM4 using simulations results from CST PS with the *indirect interface* solver and improved log formula, Eq. (1). Inputs are : $Z_L = 300\,\Omega$ and $S_{21,\mathrm{REF}}$ obtained from CST MWS simulations.

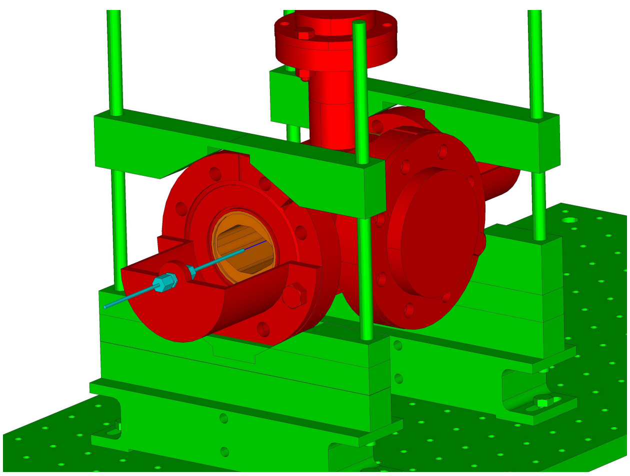

Figure 6: Mechanical drawing of the impedance measurement bench with wire in dark blue, DUT in orange, flanges and boxes in red, electronics in light blue and mechanical support in green.

CONCLUSION

Preliminary results of impedance simulations are presented for ThomX BPM. The comparison between the *direct* solver and the *indirect interfaces* solver shows that there is amplitude difference and a sign change at high frequency between the two solvers. Future impedance measurements using the coaxial wire method are presented and will be useful to cross-check simulations.

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