

SIMULATIONS OF THE IMPEDANCE OF THE NEW PS WIRE SCANNER TANK

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Abstract

The CERN Proton Synchrotron (PS) is equipped with 4 Fast Wire Scanners (FWS). It was identified that the small aperture of the current wire scanner tank causes beam losses and a new tank design was needed. The interaction of the PS bunches with the beam coupling impedance of this new tank may lead to beam degradation and wire damage. This contribution presents impedance studies of the current PS tank as well as the new design in order to assess the need to modify the design and/or install lossy materials plates dedicated to damp higher order cavity modes and reduce the total power deposited by the beam in the tank.

INTRODUCTION

Beam losses on CERN PS high intensity cycles (CNGS, TOF) have been detected in the horizontal Fast Wire Scanners tanks. These losses were found to be due to the tank horizontal aperture restrictions [1]. In order to eliminate these aperture restrictions it was decided to design a new vacuum tank [2]. The new tanks will replace the existing tanks located in PS straight sections 54 (H), 64 (H), 65 (V), 85 (V). An additional fifth tank will be installed in straight section 68 to improve the diagnostics for the Multi-Turn Extraction (MTE) beam.

Following the damage caused to SPS wires by interaction with the higher order modes of the SPS wire scanner tank [3], it was important to check that the impedance of the new tank would not cause wire damage or beam degradation.

IMPORTING THE DESIGNS IN CST

The old and new wire scanner tank designs are presented in Fig. 1. Due to lack of adequate CATIA[4] import license, the new design was exported from an existing CATIA file into a STP file so that it could then be imported into HFSS [5] and exported as a SAT file that was imported into CST Studio [6]. The imported model should then be healed and simplified to remove unneeded mechanical features that increase considerably the number of mesh cells. This is a particularly critical step for the fork and the mechanical system of the wire scanner.

The current design was not imported from CATIA and was simplified to a box with inner dimensions (188mm*329mm*333mm). The connecting beam pipes for the new design were assumed to be round in the simulations, but it is important to note that the neighbouring magnet is very close to the tank, so that the transition to the elliptic beam pipe could also have an effect on the FWS impedance (see Fig. 2).

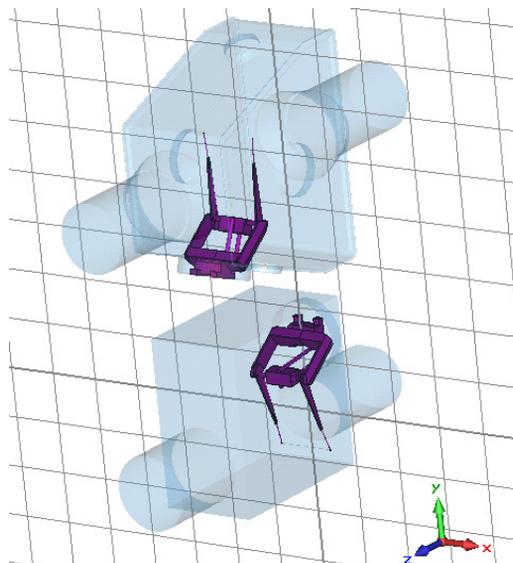


Figure 1: Comparison of a current wire scanner tank (bottom) and the new wire scanner tank (top) viewed with CST Studio. The two wire scan are in the IN position.



Figure 2: Integration of the current tank in PS section 54.

SIMULATIONS OF THE BARE TANK

CST Particle Studio simulations of the bare tank with connecting pipes were performed using an ultrarelativistic bunch with rms bunch length of 2 cm centered in the middle of the pipe, 2 million mesh cells, a wake length of approximately 20 m. The indirect testbeams wake integration method was used. The longitudinal impedance time domain simulation results are shown in Fig. 3. Resonant modes can be seen beyond frequencies of 0.8 GHz.

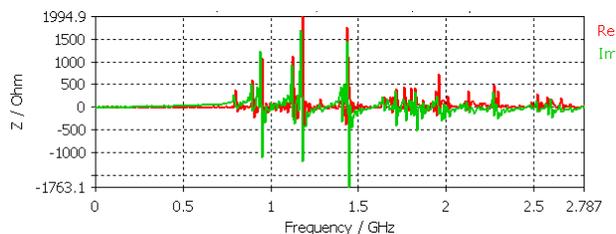


Figure 3: longitudinal impedance of the new design of the bare tank simulated with CST Particle Studio (real in red, imaginary in green).

Eigenmode simulations of the same geometry were performed with CST Microwave Studio to obtain the parameters of the resonant frequencies with the perturbation method (see Table 1). The shunt impedance R_s value was obtained using the LINAC convention (the Q factor is defined as $Q=2\pi fW/P$ with f the frequency, W the total stored energy and $P=V^2/R_s$ the dissipated power with V the voltage along the integration path). The power loss P_{loss} was obtained assuming that the mode frequency overlaps with one the beam harmonics, which is a conservative approach.

$$P_{loss} = \left(\frac{q}{t_b}\right)^2 R_s \exp\left(-\left(\frac{\omega\sigma_z}{c}\right)^2\right)$$

The parameters of the LHC nominal beam at ejection of the PS were used in the expected worst case scenario (nominal bunch charge after splitting $q = 18.4$ nC (1.15 e11 p/b), bunch spacing $t_b = 25$ ns smallest nominal RMS bunch length $\sigma_z = 30$ cm).

Table 1: Simulated parameters of the resonant modes of the new design for the bare tank.

| f | Q | $R_s (x,y=0)$ | R_s/Q | P_{loss} in W |
|----------|------|----------------|--------------|-----------------|
| 0.79 GHz | 5890 | 30 k Ω | 5 Ω | 3 10^{-7} |
| 0.90 GHz | 4730 | 24 k Ω | 5 Ω | 2 10^{-10} |
| 0.94 GHz | 6030 | 103 k Ω | 17 Ω | 4 10^{-11} |
| 1.11 GHz | 4930 | 92 k Ω | 2.8 Ω | 3 10^{-17} |
| 1.17 GHz | 6730 | 116 k Ω | 17 Ω | 3 10^{-19} |

The dissipated power is very small as the Gaussian bunch power spectrum is negligible beyond 0.4 GHz for the PS bunch at extraction.

SIMULATIONS WITH THE WIRE IN

CST Particle Studio simulations of the tank with connecting pipes and the wire and mechanical system in the IN position (see position in Fig. 1) were performed using an ultrarelativistic bunch with rms bunch length of 3 cm centered in the middle of the pipe, 2 million mesh cells and a wake length of approximately 20 m. The indirect testbeams wake integration method was used and it is important to note the mechanical system needed to be significantly simplified. The longitudinal impedance time domain simulation results are shown in Fig. 4. In this case resonant modes with lower frequencies are observed, in particular at $f=292$ MHz.

Eigenmode simulations enabled to obtain the parameters: $R_s=8.7$ k Ω and $Q=730$. The total power loss for this structure is then $P_{loss}=160$ W. It therefore appears that these low frequency resonant modes are generated by the shape of the wire scan system and the EM coupling with the shape of the tank affects their strength. In the frame of these simulations, the new tank design is increasing the power loss by a factor 5 compared to the old design.

05 Beam Dynamics and Electromagnetic Fields

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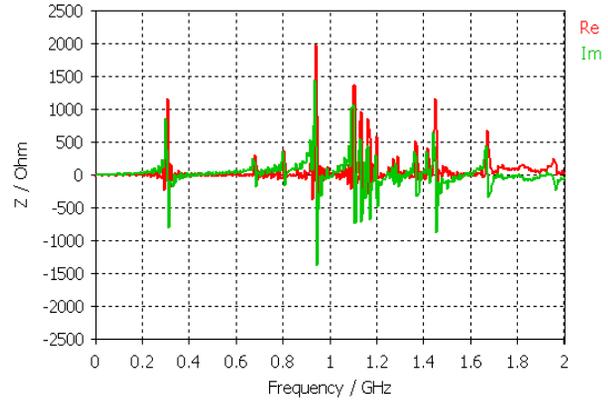


Figure 4: Longitudinal impedance of the new design of the tank simulated with CST Particle Studio (real in red, imaginary in green).

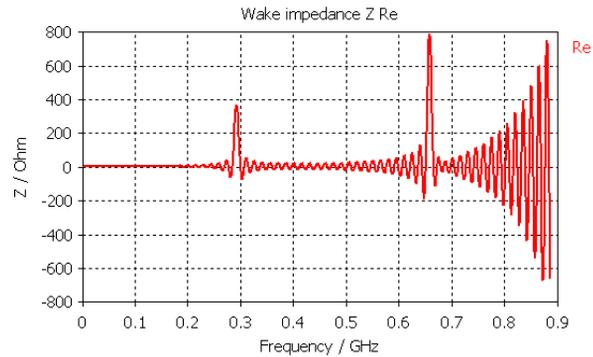


Figure 5: Real impedance simulation with the current design.

INCLUDING FERRITES TO DAMP THE 292 MHZ RESONANT MODE

As performed for instance in references [7, 8], damping of resonant modes can be performed by adding dispersive materials inside the structure. This can be understood with a simplified picture in which R_s and Q decrease with dispersive material, while only R_s enters in the power loss $R_s I^2$. For mechanical reasons, the only available spots for these ferrites are the top and bottom of the tank (referred to the orientation of the model in Fig. 6). The dispersive material should be placed at a location where the EM fields of the mode are strong but the image currents created by the beam are weak (i.e. far away and if possible shielded from the beam) to avoid increasing the resistive wall impedance of the device. Following the simulation showing the surface current of the $f=292$ MHz resonant mode (see Fig. 6), a potential location for two blocks of dispersive material could be found (see Fig. 7).

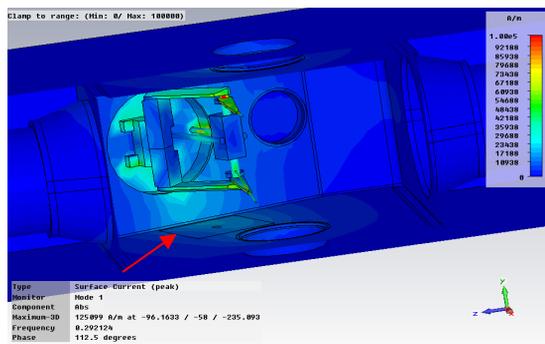


Figure 6: Current strength on the surface of the tank and wire scan system for the $f=292$ MHz mode obtained with the eigenmode solver. The proposed location of the dispersive material is the small square highlighted by the red arrow on the bottom of the tank, and its symmetric on the top of the tank.

This proposed location is not ideal as it is not so far from the beam and may induce additional image currents. An additional shielding metallic plate on top of the ferrite may then be needed. However, time domain and frequency domain simulations of the new design including two readily available 4S60 ferrite plates (see model in Fig. 7) were performed and showed a small increase in low frequency longitudinal impedance and a decrease in the resonance frequency, but also a significant decrease of the shunt impedance, Q factor and power loss with respect to the new design without ferrite, as seen on Fig. 8 and in Table 2.

Table 2: Parameters of the resonance modes for the new design without ferrite (from eigenmode simulations) and with ferrite (from time domain simulations).

| Wire | Ferrite? | frequency | Rs | Q | Ploss |
|------|----------|-----------|-----------------|------|-------|
| OUT | No | 264 MHz | 2.6 k Ω | 853 | 89 W |
| OUT | Yes | 256 MHz | 0.06 k Ω | 30 | 2 W |
| IN | No | 292 MHz | 43 k Ω | 1200 | 800 W |
| IN | Yes | 270 MHz | 0.26 k Ω | 21 | 8 W |

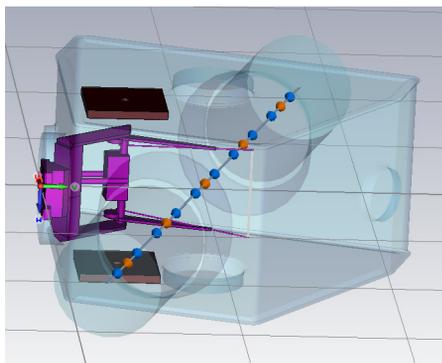


Figure 7: Model of the new design of the tank with 4S60 ferrite plates. Compared to the available plates, the modelled plates were larger (10 mm instead of 6mm).

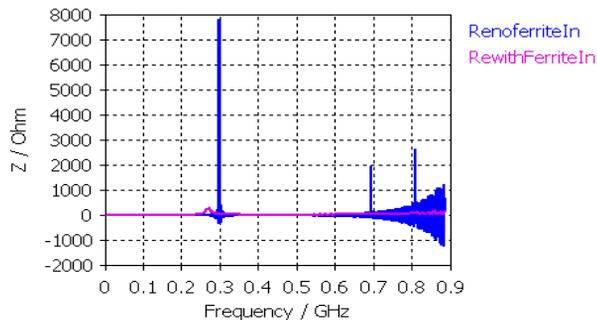


Figure 8: Comparison of the longitudinal impedance for the new design without ferrite (blue) and with ferrite (magenta).

Additional CST time domain simulations of the low frequency vertical (resp. horizontal) impedance with the beam displaced yielded around 1.3 k Ω /m (resp. 1.2 k Ω /m) with the wire IN and 0.9 k Ω /m (resp. 0.5 k Ω /m) with the wire OUT.

CONCLUSION

From these CST simulations, the new design for the PS wire scanner increases significantly the longitudinal impedance and the power losses compared to the current design, but this increase does not however appear huge and two ferrite plates could be installed to damp the resonant mode at 292 MHz at a later stage if operation requires it.

An RF measurement campaign with a tank on a bench is ongoing to check these simulation results.

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