ASSESSMENT OF BEAM IMPEDANCE FOR THE CERN PS-BOOSTER WIRE SCANNER

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Abstract

It is well known that performance of accelerators critically depends on the interaction of high intensity beams with the surrounding structures. As a result of these beam interactions, it is required at CERN to characterize the beam coupling impedance of each new machine element that is to be installed in the accelerator ring. In the framework of the LIU (LHC Injectors Upgrade) project, a new design of rotational wire scanner to be used in the PS Booster is currently under development. As an intermediate step, the prototype of this wire scanner was evaluated with respect to its longitudinal beam coupling impedance. Depending on the performance of this machine element, it is planned to replace existing wire scanners in other machines at CERN (e.g. PS-Booster, PS and SPS) with very similar designs. This paper presents the simulations and describes the measurement methods used for benchmarking electromagnetic simulations performed for the impedance evaluation of the LIU wire scanner for the PS-Booster. Additionally, the device was fitted with an RF feed-through in order to monitor and attenuate certain undesired modes supported by this structure.

INTRODUCTION

Wire scanners (WS) are electro-mechanical devices to measure the transverse beam density profile in a particle accelerator by means of passing a thin wire through the beam. The interaction with the beam generates a cascade of secondary particles which are detected, or if the wire consists of electrically conducting material, secondary emission electrons are measured as current on the wire. In the framework of the the LIU (LHC Injectors Upgrade) project [1], new wire scanner designs are under development with the aim to increase the performance of the currently available devices [2]. These next generation of rotational wire scanners at CERN requires the wire to scan at speeds of 20 m/s and with a position measurement accuracy on the order of 1 μm [3]. Using a new WS that was designed for the Super Proton Synchotron (SPS) as a starting point, a re-optimized version was derived with its prototype deployed to the Proton Synchrotron-Booster (PSB) [4]. If the new design performs according to expectation and does not show detrimental impact on beam stability, the deployment plan for the long shut-down 2 (LS2) foresees the installation of 17 new devices in the LHC injectors. Table 1 shows a detailed breakdown of the LS2 baseline for the new and existing WS [5].

This paper describes the evaluation of the longitudinal beam coupling impedance of the new WS design and the RF-measurements for benchmarking the simulation model. Further details about RF-measurements and EM-simulations are shown in [6].

Table 1: Number of new wire scanners planned for installation in the LHC injectors during LS2 (New WS in) and how many existing WS will be removed (Old WS removed).

Machine	New WS in	Old WS removed
PSB	8	0
PS	5	5
SPS	4	4[1]

RF-MEASUREMENT AND EM SIMULATION

Figure 1 shows the 3D CAD model of the new PSB wire scanner. A capacitive rod coupler with an N-connector at the air-side and a ceramic feed-through was considered in the design in order to allow power extraction from the structure and observation of beam induced signals during operation. Three different types of RF-measurements, along with the corresponding simulations, were performed with metal flanges closing the beam pipe. First, two RF-probes were inserted axially and transmission S-parameter (S_{21}) were acquired to identify resonant modes. This is the so-called probe-to-probe measurement set-up, which is shown

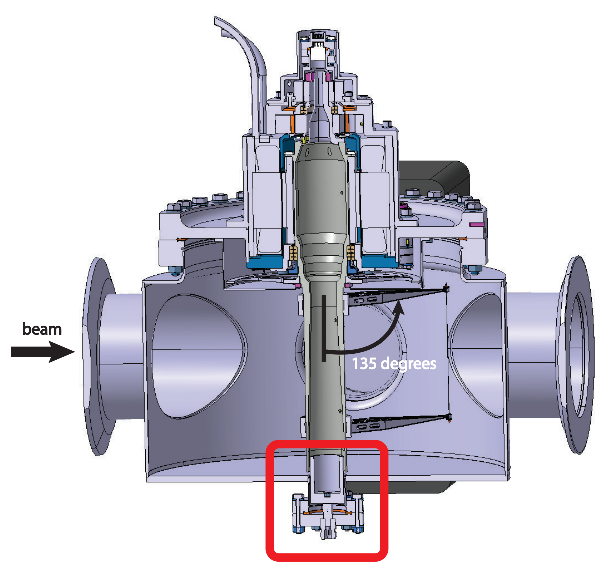

Figure 1: 3D CAD model of the PSB wire scanner in cross-sectional view. The fork is positioned in a 135 degrees rotation angle with respect to the so-called parking position (0 degrees) and the capacitive rod coupler and air-side N-connector are highlighted with a red frame.

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[1] There are two linear WS installed in the SPS which may be removed too.

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in Fig. 2. The WS model was simplified since not all details are necessary to sufficiently describe the EM-behavior of the structure and also to reduce simulation time. Second,

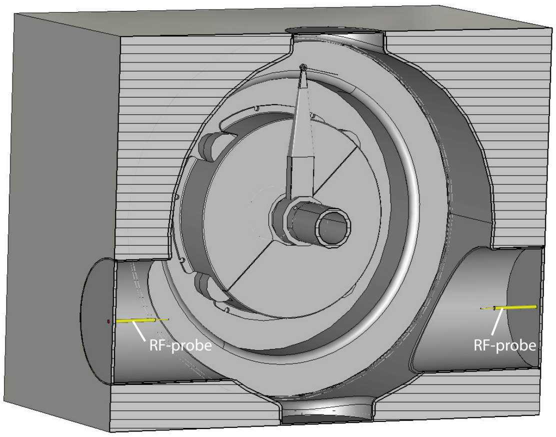

Figure 2: CST EM simulation model for S-parameter calculation of the probe-to-probe measurement. Note the axial position of the RF-probes and that the tip of the probe couples only to electric fields with non-zero field component at the axis.

a transmission measurement from an RF-probe to the capacitive rod coupler was performed in order to estimate the coupling to EM-fields inside the structure which in turn gives hints how much RF-power may be extracted. The excitation of the structure with two different sources (probe-to-probe and probe-to-rod coupler) also permits different field patterns inside the geometry. Third, the two ends of the wire which is running through the fork, shaft and a feed-through to the outside of the structure were connected to a hybrid junction (MACOM H-9-N; nominal bandwidth 2 to 2000 MHz) [7] which allows measurement of the relative coupling of electric and magnetic fields from the probe to the wire (see schematic in Fig. 3). This information is of great importance since it could identify possible heating mechanisms in the wire which could lead to the destruction of the wire during operation. Beam energy loss that resulted in wire heating and destruction was observed for existing rotational scanners at CERN [8]. Thus for the next generation WS, it is vital to identify possible heating sources already during the development phase.

Note that for the RF-measurements the WS was equipped with a 150 µm diameter beryllium-copper wire instead of a 30 µm thin carbon wire which will be used later for operation.

RF-MEASUREMENT AND EM SIMULATION RESULTS

Figure 4 shows the result of simulated S-parameter measurement (Fig. 2) with the probe-to-probe set-up in comparison to the transmission measurement of the same set-up and probe-to-feed-through. Frequencies, found by eigenmode simulations are shown in addition as vertical lines. It

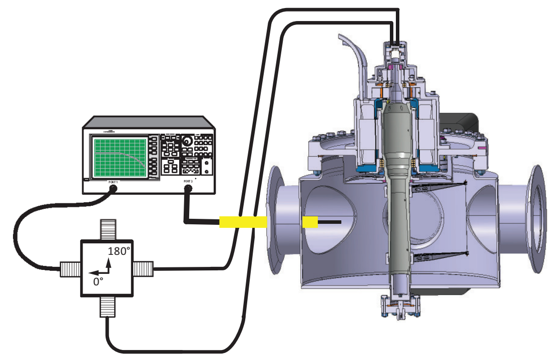

Figure 3: Schematic of the transmission measurement from RF-probe to the wire using a hybrid junction to deduce sum (coupling to E-field; 0 degrees output) and difference (coupling to H-field; 180 degrees output at the hybrid). Only the E-field coupling measurement is shown. Note that the N-connector at the feed-through and the 180 degrees output of the hybrid were terminated with 50 Ω during this measurement and the beam pipe opening was closed with a second probe (not shown) inserted and terminated with 50 Ω as well.

can be seen that with the probes only, the lowest frequency mode cannot be excited, however it is unveiled by using the feed-through as pick-up for the transmission measurement.

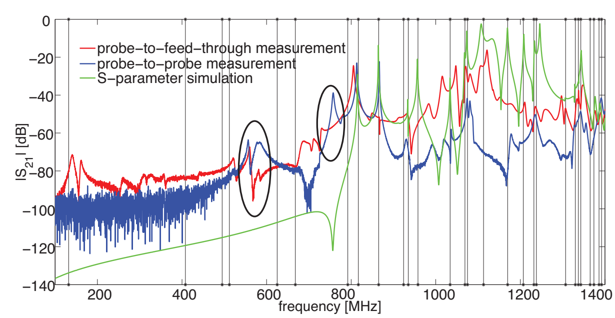

Figure 4: Comparison between simulated measurement and probe-to-probe as well as probe-to-feed-through measurement for a 0 degrees rotation angle of the wire. The vertical black lines indicate the frequencies found by the CST [9] eigenmode solver and the oval frames enclose probe modes which occur as an artifact of the measurement.

The results of the transmission measurements from RF-probe to the wire (Fig. 3) are shown in Fig. 5 and give the relative contribution of the electric and magnetic coupling. For instance, the resonant mode at 876 MHz couples about 30 times more power to the structure magnetically than electrically. The resonant mode is highlighted by the black arrow.

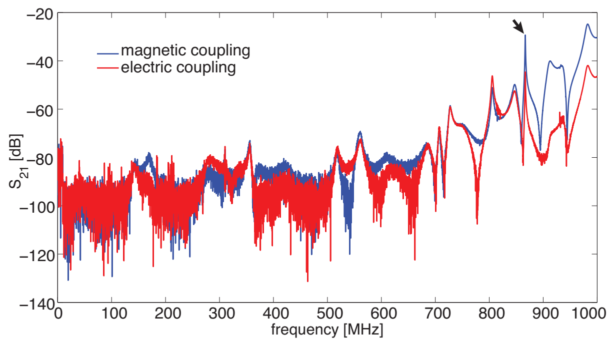

Figure 5: Probe-to-wire measurement results to quantify the relative electric and magnetic coupling of the EM-modes.

Figure 6 shows the comparison between the simulated longitudinal coupling impedance (top) and the probe-to-probe transmission measurement (bottom) for 0 and 45 degrees wire rotation angle. Note that not all modes change their frequency as a function of the wire rotation angle such as the mode at 130 and 810 MHz, respectively. This is also reproduced by EM-simulations, hence the results are in very good agreement with the measurements.

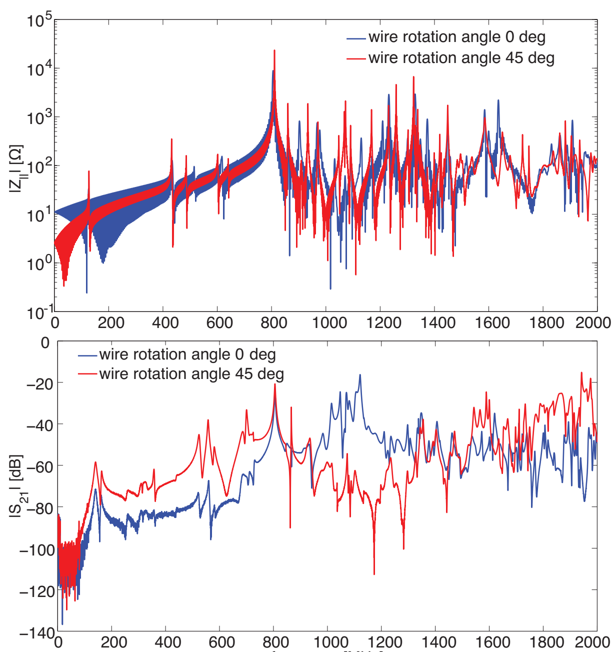

Figure 6: Wakefield simulation (top) and probe-to-feed-through transmission measurement results (bottom) for the wire rotation angles of 0 and 45 degrees respectively.

CONCLUSION

The new wire scanner design for the PS-Booster was evaluated by means of RF-measurements and EM-simulations. From the simulated longitudinal beam coupling impedance, the expected contribution to the overall impedance budget of the PS-Booster is not large, since the resonant modes are located about 1 to 2 orders of magnitude higher in frequency compared to the beam spectrum. The same is valid for beam induced heating in the device where the evaluated power loss in the device is about 1 μW. Furthermore, the simulation results were confirmed by RF-measurements. Concerning microwave instabilities, a more detailed beam dynamics evaluation would be necessary but cannot be provided at the moment since the currently existing model for longitudinal beam impedance of the machine does not cover the considered frequency range. Beam dynamics models for the PSB and PS that cover also high frequency ranges are currently under development at CERN. It should be mentioned that due to the very similar designs of the new wire scanner for other accelerators at CERN, detailed EM-studies are necessary especially for beam induced heating since the modes identified in this work indicate strong coupling at frequencies around 800 MHz.

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