CHARACTERIZATION OF SHIELDING FOR THE CERN-SPS VACUUM FLANGES WITH RESPECT TO BEAM COUPLING IMPEDANCE

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Abstract

Longitudinal multi-bunch instabilities in the CERN-SPS pose a serious limitation for future beam intensities required for high luminosity LHC. Hence, an impedance model for the SPS accelerator was developed from which one group of vacuum flanges could be identified as being a major culprit for these instabilities. These flanges support high impedance modes and their impact on beam stability was traced to a longitudinal mode at about 1.4 GHz. For improvement of multi-bunch stability threshold, this group of flanges will be shielded as part of an impedance reduction campaign. We describe the evaluation of different impedance shielding designs proposed to reduce the longitudinal beam coupling impedance of this group of vacuum flanges in the SPS. EM-field simulations were performed to identify remaining resonances in these vacuum flanges with impedance shield prototypes installed, and the simulation models were benchmarked with RF-measurements. Depending on the performance and other parameters, the most suitable shield design will be selected, built and installed. As a first step, the installation of one shielding design in some positions in the SPS is planned for the beginning of 2017.

INTRODUCTION

The LHC will undergo a major upgrade to increase the integrated luminosity by a factor of ten compared to the original design value. This new configuration is referred to as High Luminosity LHC (HL-LHC) and demands also an upgrade of the LHC injector chain. This LHC Injectors Upgrade (LIU) project [1] aims to reliably deliver the high-intensity beams required for HL-LHC. However, there are still intensity limitations which restrict the maximum intensity below the targeted $2.6{\times}10^{11}$ ppb (twice the nominal bunch intensity) in the CERN Super Proton Synchrotron (SPS). Analysis of longitudinal instabilities observed in beam measurements, and the current longitudinal beam coupling impedance model of the SPS [2] have unveiled the main contributors to the resistive impedance which are: vacuum flanges, the 200 MHz cavities an their HOMs, to name but a few. The main contributors to the broad-band impedance are the kicker magnets and again the 200 MHz cavities [3]. Various upgrades are planned and were launched by the LIU project to overcome intensity limitations in the SPS such as e-cloud effect, beam loading in the 200 MHz system and longitudinal instabilities. An impedance reduction campaign for a specific type of vacuum flanges (VF) [3,4] is in progress since they were found to be one of the main impedance sources responsible for longitudinal multi-bunch instabilities [1,5]. The contribution of different types of vacuum chambers to the longitudinal beam coupling impedance was already studied as early as in 1973 [6]. In this contribution, we concentrate on the comparison of different shielding designs for the flange interconnection combination of MBA and QF that are currently being discussed. Additionally, a strategy is presented to obtain a robust solution that provides impedance reduction for this type of vacuum flange.

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DESIGNS FOR VF IMPEDANCE SHIELDINGS

Impedance Shields

There were various VF impedance shielding designs suggested, which were then narrowed down to the three designs presented here. These are the so-called braided shield, the double-tube shield and the retro-fitted shield. The latter was derived from the pumping port shield design that was developed during the year 2000 impedance reduction campaign [7,8]. The main goal of the present shielding design is to reduce the R/Q value of the 1.4 GHz resonant impedance.

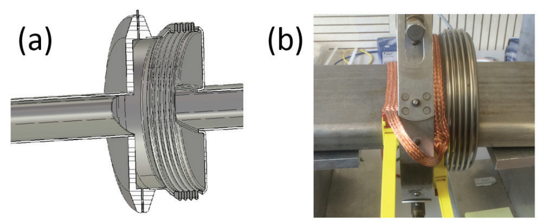

Figure 1: SPS vacuum flange. (a) Model of a QF/MBA flange without impedance shield, (b) Image of a QF/MBA flange installation in the SPS (with soft-clamp installed).

Figure 1 (a) shows the model of an unshielded QF/MBA flange with bellows, and (b) shows an image of this type of vacuum flange in the SPS machine. The three proposed designs are shown in Fig. 2: double-tube shielding (a), retro-fitted shielding (b), and braided shielding (c). All the shields have the gap opening between the two flange sides, which can be minimized by introducing a filling plate on the non-flexible side (i.e., side without bellows). The filling plate is highlighted in green in the image of the VF with the retro-fitted shield. All three impedance shields have to provide a transition from a near rectangular MBA beam pipe to a near elliptical QF beam pipe (see Fig. 3). The main difference between these shield designs are mechanically implemented to provide a proper RF-contact. The double-tube shield (a) has extendable, convoluted RF-contact fingers that are fixed on both sites where they are touching the two inserted pieces of beam pipe, so that an electromagnetic continuation of the beam pipe is provided. Due to the convolution height, these extendable RF-contact fingers can be installed only on

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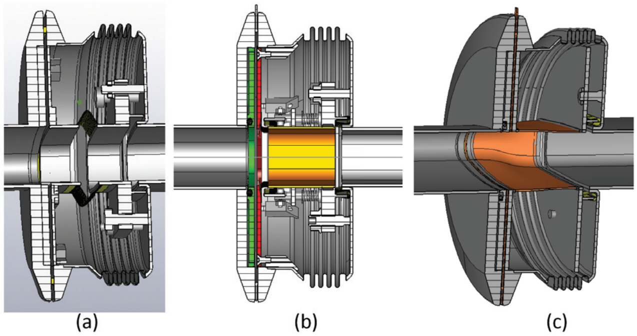

Figure 2: Vacuum flange with 4-convolution bellows for QF/MBA interface with double-tube shield (a), retro-fitted shield (b), braided shield (c).

the upper and lower parts of the shield, whereas the sides remain uncovered. The retro-fitted shielding (b) employs a moveable part by means of a spring that pushes RF-contact fingers against the fixation plate (red color in FIG. 2 (b)). Also for the retro-fitted solution, the RF-contact fingers only cover the upper and lower parts of the shield, leaving the sides open. Note that these spring-driven RF-contact fingers are mechanically posing the intrinsic risk of partially malfunctioning by losing contact with the fixation plate, hence providing a partial shielding effect only. It will be shown later by means of RF-measurements that a partial loss of contact is introducing lower frequency resonances in the structure. Finally, the braided shield consists of a bundle of wires woven into a metal braid. This idea was originally introduced by [9] and has been studied for the SPS vacuum flanges. Similarly to the double-tube shield, the braided shielding part is connected to the fixation plates on both sides of the VF and has no moveable parts. The flexibility of the braid allows a change of shape and in this way smoothly connects the two different cross-sections of MBA and QF beam pipe. It also covers the entire cross-section, including the sides.

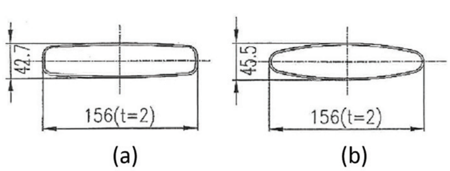

Figure 3: SPS vacuum chambers of the main bending magnet (MBA, (a)) and the quadrupole magnet (QF, (b)). Dimensions are shown in mm.

Gasket Gap Filler

Amongst the SPS VFs, a certain portion is enamelled to ensure electrical insulation of the VFs, e.g. to avoid the propagation of eddy currents induced on the beam pipe. These enamelled VFs are usually placed next to quadrupole magnets and are part of the SPS grounding scheme. The requirement of keeping the two flange halves electrically separated means a further complication for the impedance shield design, as it would mean that after installation of the impedance shields, a very flat cavity (of pill-box type with r=89 mm and h=2 mm) remains. It was shown from simulations that this pill-box type cavity omits the full suppression of the undesired resonance at about 1.4 GHz. As can be seen in Fig. 5, a shift of this resonance by about 150 MHz together with a reduction in Q-value takes place, however, no full suppression is possible. The question of whether

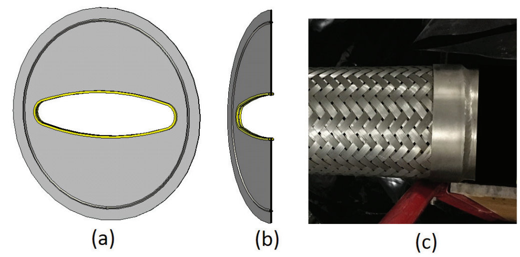

Figure 4: Re-designed gasket that closes the pill-box shaped gasket gap in front (a) and cross-sectional view (b). Woven wire structure of stainless steel for braided shield (c).

insulating flanges are necessary at those positions was therefore addressed by a specific test in which more than 100 enamelled flanges were short-circuited [10] by temporarily installed copper braids (so-called soft-clamps) on the outside of the flanges (see Fig. 1 (b)). First runs with beam and with short-circuited VFs were successful, however, not all beams could be tested due to other issues in the machine. Hence, the final decision whether or not these enamelled VF are needed is still pending. It is, however, currently assumed that impedance shields which are electrically contacting the two VF halves can be installed without detrimental effects. Therefore, we intend to close the remaining pill-box at the gasket level, e.g. by means of a gasket re-design (see Fig. 4 (a) and (b)) that fills the gap and leaves an aperture opening in beam pipe shape. RF-contact fingers around the beam-pipe opening are introduced to provide electrical continuity.

SIMULATIONS

All shielding geometries were modelled from layout drawings and their electromagnetic behaviour was evaluated using HFSS [11] and CST [12] EM simulation software. The evaluation of the beam coupling impedances is obtained from the CST wakefield solver. Figure 5 shows the simulation results of replacing the standard gasket gap with the re-designed gasket in case of the double-tube shield design. As can be seen from the calculated longitudinal impedance, implementing the double-tube shield and the closing of the gasket gap successfully suppresses all resonances for frequencies below 3.5 GHz. It can also be seen that without the gasket-gap filler the resonance at about 1.65 GHz is dampened but does not vanish, even with the impedance shield in place. This 1.65 GHz resonance can only be suppressed if the remaining pill-box shaped cavity at the gasket level is closed. Figure 5 shows a comparison of the performance of the different shielding designs with repect to their lon-

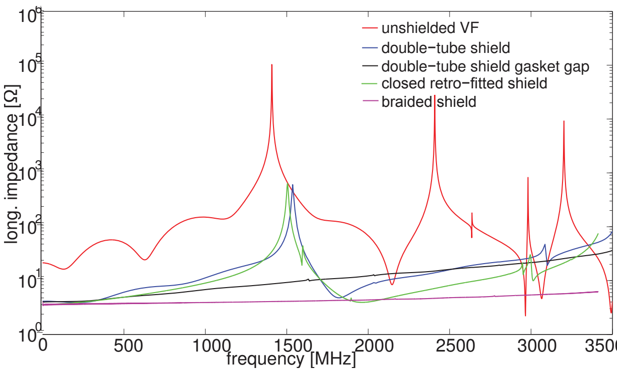

Figure 5: Comparison of simulation results for the longitudinal impedance of SPS vacuum flange connecting QF/MBA beam pipes for the unshielded case (red), vacuum flange equipped with double-tube shielding and gap filler (blue), and additional gasket gap closing (black), the retro-fitted shield (green) and the braided shield (violett). The closing of the gasket gap effectively suppresses the resonance seen at about 1.4 GHz/ 1.65 GHz.

gitudinal coupling impedances. As can be seen from the traces, all shielding designs give a considerable reduction of longitudinal impedance, when compared to the unshielded case. Further, very little difference can be seen between the double-tube shield and the retro-fitted shield (compare green and blue traces in Fig. 5). As already mentioned, a shift of the resonance at 1.45 GHz to values at about 1.5 GHz/ 1.65 GHz takes place for all shield designs (only results for double-tube shield and retro-fitted shield designs are shown), which can be suppressed by using the re-designed gasket introduced in the section above. Best performance in view of longitudinal beam coupling impedance is obtained with the braided shield design together with the re-designed gasket to close the gasket gap. Note that for all designs, the gap on the fixed side of the VF was closed (see Fig. 2, (center), filling plate highlighted in green).

MEASUREMENTS

The VF shield designs have to be compatible with variations in the alignment of adjacent vacuum chambers in the transverse and longitudinal plane. At the position of the bellows, the expected maximal longitudinal variation is ±4 mm and ±1 mm for the transverse plane. RF-measurements were performed on a special set-up that allows to compress and extend the flange assembly with bellows in a reproducible fashion. Furthermore, the case for imperfect contact of the RF-fingers of the retro-fitted shield prototype was simulated by using Kapton tape as a spacer. Figure 6 summarizes the wire measurement results for the bellows in nominal position with and without proper contact of the RF-finger. The latter was also evaluated at the expected extreme longitudinal positions ±4 mm. As can be clearly seen, the remaining resonance at about 1.65 GHz is apparent due to the gasket gap of about 2 mm (blue). Furthermore, the poor RF-contact of the RF-finger introduces significant resonances below

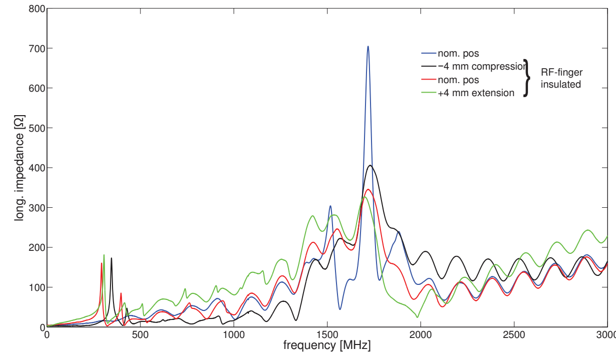

Figure 6: Wire measurement results of the retro-fitted shield prototype for nominal, extended (green) and compressed bellows (black) position as well as with (blue) and without insulated RF-fingers (red).

500 MHz [10] and vary as expected with extension or compression of the bellows.

CONCLUSION

In this contribution, we have evaluated different shielding designs proposed to reduce the contribution of one type of SPS vacuum flanges to the longitudinal coupling impedance of the machine. Of the three different shielding designs presented, the so-called braided shield gives the best performance but also the other two designs reduce the resonant impedance significantly. However, all shielding designs are carried out with a filler on the fixed part of the vacuum flange and require a re-designed gasket for optimal performance. One shielding design is using moveable RF-connecting fingers whereas for the other two designs, no moveable parts are used. It could be shown from RF-measurements that in the case of erratic contact of the moveable RF-fingers, undesired low resonance frequencies are introduced in the structure. We therefore conclude that special attention needs to be paid to avoid erratic contact in case moveable parts are present in the shielding design.

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[11] HFSS, ANSYS High Frequency Electromagnetic Field Simulation Program, Canonsburg, USA `http://www.ansys.com/products/electronics/ansys-hfss`

[12] CST Studio Suite 2016, CST AG, Darmstadt, Germany, `http://www.cst.com`