ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAF063

IDENTIFICATION OF IMPERFECTIONS IN IMPEDANCE SHIELDS ON THE SPS-QF FLANGES VIA NON-INTRUSIVE MEASUREMENTS

A. Farricker*, P. Kramer, B. Popovic, E. Sunar[1], C. Vollinger, M. Wendt
CERN, Geneva, Switzerland
[1]also at Bogazici University, Istanbul, Turkey

Abstract

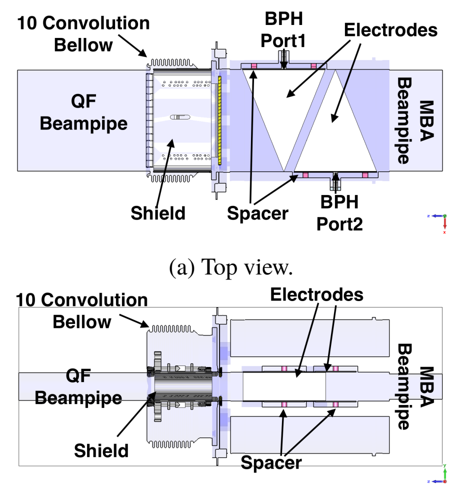
In order to achieve the beam intensities required in the LHC the highest quality beam possible has to be supplied by the injector chain. The Super Proton Synchrotron (SPS) at CERN is the last accelerator in the injector chain of the LHC. One factor that is currently known to limit the intensity of the beam for injection to the LHC, is the longitudinal beam-coupling impedance in the SPS. One known source of multi-bunch instability is the pumping ports and campaigns to mechanically shield this source were completed in the year 2000. However, today it cannot be excluded that some of these shields may have partial or indeed full failures. Since these flanges are next to a QF magnet and are in most cases connected to a BPH (Beam Position Monitor Horizontal), it is possible to carry out via the BPH an in-situ measurement of the effectiveness of the shields. In this paper we present a methodology as well as measurement results taken with this non-intrusive in-situ method. From measurements, it is possible to identify if the flanges are without any impedance shield, equipped with either a fully functioning shield or a shield exhibiting non-ideal properties.

INTRODUCTION

One of the major limitations in achieving the intensities required for the operation of the LHC in the high luminosity era is the beam quality supplied by the injector chain [1]. A known limitation to this is the multi-bunch instability caused by longitudinal beam-coupling impedance due to pumping port and similar cavity-like structures in the Super Proton Synchrotron (SPS) [2,3]. In order to mitigate this instability several shielding campaigns have been carried out most notably in year 2000 [4]. One resonance at 1.3 GHz in flanges between the beam pipes of the bending magnets (MBA-type) and the focusing quadrupole (QF-type) at the location of the BPH was identified and subsequently a number of these were shielded. A flange of this type with a shield installed is illustrated in Fig. 1.

There are currently 104 of this type of flange located at the BPH–QF junction of which 67 have shields installed and two which have no associated ten-convolution bellow. There is currently no straightforward method to confirm which BPHs have shields and which may have shields with less than ideal contacts reducing their effectiveness.

The methods which have been employed in the past for this type of investigation include opening up the flange or using x-rays. Neither of these is efficient for control checks



(a) Top view.

(b) Side view.

Figure 1: 3D Geometry of BPH in CST MWS.

of all locations and additional vacuum or radiation issues are raised. Therefore the method presented in this paper has significant benefits as it is carried out using a minimal amount of equipment and coaxial ports on existing equipment.

TEST MEASUREMENTS

The purpose of the shields is to mitigate the cavity-like resonances at frequencies of 1.3 GHz and 1.6 GHz caused by having a circular bellow neighboured by elliptical beam pipes [4,5] and it is the effectiveness of these shields which we would like to test. The effectiveness of the shield and the feasibility of using the coaxial ports of the BPH to probe the shielding of the bellow has been demonstrated using a test stand with two measurement setups shown schematically in Fig. 2.

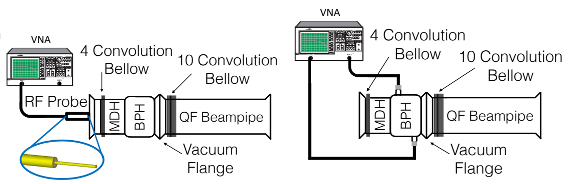
It was found that by measuring in transmission across the BPH it is not possible to directly measure the changes caused by the presence of the shield at these two specific frequencies.

However by measuring in reflection using a probe reaching into the bellow (which is only possible in the lab) as shown in Fig. 2 it is possible to detect a weak resonance at 1.3 GHz. Several traces were taken having the BPH closer or further away from the magnet effectively changing the amount of contact and by using kapton tape to remove the contact of the shield to the BPH altogether. The effects of this on the resonance at 1.3 GHz are shown in Fig. 3. It is evident, that by reducing the effectiveness of the shield the resonance becomes stronger. This also illustrates that the shield is able

* aaron.farricker@cern.ch

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAF063

to reduce the strength of the resonance and hence reduce the beam-coupling impedance as intended.



(a) Probe measurement. (b) Transmission measurement.

Figure 2: Test measurement setup in the laboratory.

As it is not possible to use a probe to measure the effectiveness of the shield in the SPS and we are unable to directly measure the 1.3 GHz resonance in transmission through the coaxial ports we had to find another indicator in the scattering parameters. To achieve this, sweeps from 1 MHz to 4.5 GHz taken for the different shielding cases were carefully analysed to identify regions with differences. At approximately 3.7 GHz a significant deviation between the cases with and without a shield was identified, this behaviour—in both amplitude and phase—is shown in Fig. 4. It is also possible to identify this feature in reflection at both ports, however in transmission the signal is cleaner and is therefore preferred in this analysis.

As this measurement is performed at a frequency which is above the beampipe cut-off frequency it is possible that this may be a feature of the measurement setup caused by reflections from the flanged ends. To determine if this is the case the flange covers at the ends were removed to create an open boundary. The difference between the two signals was measured and found to be negligible. This is a strong indication that the signal measured at 3.7 GHz is from the interplay between the BPH–Bellow system and is independent of the surrounding objects. It is hence a good indicator for evaluating the effectiveness of the shield.

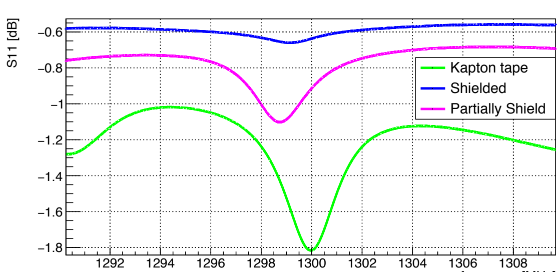
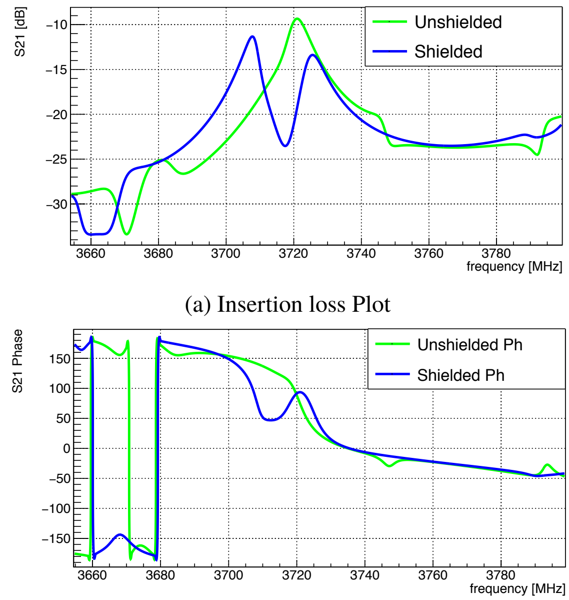


Figure 3: Probe measurements at 1.3 GHz for the cases of unshielded, shielded and partially shielded flanges shown in green, blue and pink respectively.

IN-SITU MEASUREMENTS

During the limited time available during the 2017 Year End Technical Stop (YETS) as many of these flanges as possible were measured in the tunnel by disconnecting the coaxial lines attached to the BPH and connecting a VNA. Sweeps of the transmission properties were performed in the range of 1 MHz to 4.5 GHz using 8001 points and an IF bandwidth of 1 kHz. In total 70 BPHs were measured with several missed out as they were close to areas of high activation such as the beam dumps and septa.



(a) Insertion loss Plot

(b) Phase Plot

Figure 4: Insertion loss of unshielded and shielded data taken from laboratory. Green and blue lines are unshielded and shielded data traces respectively.

Within the group of BPHs that were measured we expect to see two clear subgroups; one which is shielded well and one which is unshielded. In addition, it is anticipated that a third group which lies somewhere in between the main classifications will be present where a shield has only a partial contact resulting in reduced performance.

In Fig. 5 examples are shown of the traces taken in-situ within the SPS tunnel during the YETS. An example of a shield which is listed as unshielded (Fig. 5a), shielded (Fig. 5b) and one which is listed as shielded but appears to have a reduced effectiveness (Fig. 5c).

In these examples we can be confident that the BPH shown in Fig. 5a is unshielded as there is no record of a shield being installed and we have good agreement between the lab measurement and the data. In the case of the shielded BPH shown in Fig. 5b the shield should be good as it was installed during the YETS in the weeks prior to the measurements being performed. For the case in which a supposedly shielded BPH differs significantly from the expected behaviour and tends towards that expected of an unshielded BPH we believe that the RF contact of the shield to the BPH may be inhibited in contrast to the ideal case.

A summary of the number of shielded and unshielded BPHs that are expected compared to what is observed with this measurement technique is given in Table 1.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAF063

Table 1: Summary of Results

Status	Expected	Measured
Shielded	47	28
Unshielded	23	14
Unclassified	N/A	24
Bad Traces	N/A	4

The ultimate goal of this method is to identify the main cases where there is clearly no shield installed from that where a shield is present. Out of the 70 BPHs measured there are expected to be 23 which are unshielded. With this method we were easily able to identify 14 of these, in five cases a classification was impossible due to significant variations in the traces and in the final four cases we misidentified the unshielded BPH. This misidentification could be due to the sensitivity of the high frequencies to geometric errors or there is a finite chance of a shield which was installed but not documented.

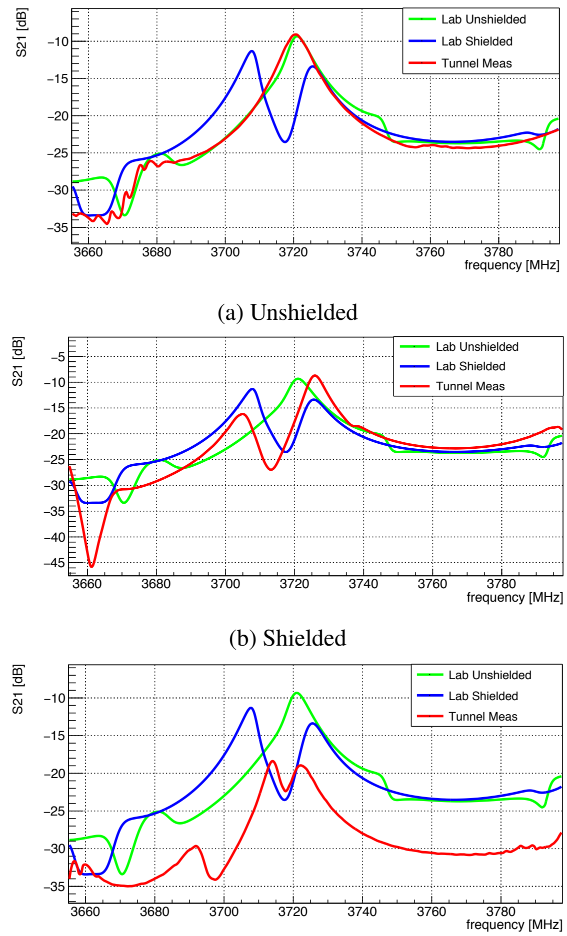
Out of the 47 BPHs that are expected to be shielded we were able to clearly identify 28 that were consistent with the laboratory measurements. The other 19 cases were either unclear or appeared to be consistent with the unshielded laboratory measurement which suggests a partial or full loss of RF contact. In particular, four of these were identified as completely unshielded using the laboratory measurement as a baseline. These four cases are the ones which need to be investigated further at the earliest opportunity as we now have a strong indication that there is a chance the shields have been rendered ineffective and could be contributing to the current instability threshold of the beam.

SUMMARY

In this paper it was shown that the shields installed in the BPH–QF flanges are effective at shielding the 1.3 GHz resonance through the use of a probe in reflection. It was also shown that measurements using the BPH coaxial ports as probes to measure this resonance directly is not possible. However, it was found that the shielding of this resonance can be inferred from features in the transmission measurements at higher frequencies (≈3.7 GHz).

This methodology of using the BPH was then applied to 70 of the BPHs in the tunnel of the SPS where the feature at 3.7 GHz was used to classify if a BPH was shielded, unshielded or potentially poorly contacted. We were able to identify a large fraction of the unshielded cases as expected from installation records and a large number of those which were shielded. There are five unshielded BPH that we could not identify due to large variations in the traces. However four BPHs which should be shielded were classified as being unshielded and 28 fell somewhere between the two cases which suggests that the RF contact may not be as good as required to give adequate shielding.

This sub-group is made up of the shields which require further investigation during the Long Shutdown Two (LS2) in 2019-2020 when the SPS is being upgraded in the scope of the LIU Project [1]. In particular the four BPHs which were classified as unshielded when records indicate a shield has been installed in their locations require looking into at the earliest available opportunity.



(a) Unshielded

(b) Shielded

(c) Partially Shielded

Figure 5: Three examples of the different cases from the tunnel measurements. Green, blue and red lines are unshielded, shielded and partially shielded data traces respectively.

Furthermore, this family of shields is also installed in over 1,200 locations where there are similar bellows/pumping ports which exhibit cavity-like behaviour. This measurements suggests that it is possible that some fraction of these may also exhibit nonconformities which may be contributing to the machine impedance. Indeed the need to move the main dipoles during installation creates an additional step that could result in further nonconformities compared to those identified here.

ACKNOWLEDGEMENTS

We would like to thank F. Caspers for his help with the test measurements.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAF063

REFERENCES

[1] J. Coupard *et al.*, “LHC Injectors Upgrade TDR”, CERN-ACC-2014-0337.

[2] T. Bohl, T. P. R. Linnecar, and E. Shaposhnikova, “Measuring the Resonance Structure of Accelerator Impedance with Single Bunches”, *Phys. Rev. Lett.*, vol.78, no.16, pp.3109–3112, Apr. 1997.

[3] E. Shaposhnikova, T. Bohl and T. Linnecar, “Results from the Impedance Reduction in the CERN SPS”, in AIP Conference Proceedings 2002, 642:1, 62–64.

[4] P. Collier *et al.*, “Reducing the SPS Machine Impedance”, in *Proc. EPAC 2002*, pp. 1458–1460, Paris, France, June 2002.

[5] E. Shaposhnikova *et al.*, "Identification of High-Frequency Resoant Impedance in the CERN SPS", in *Proc. IPAC 2015*, Dresden, Germany, TUPME029.