CHARACTERIZATION OF THE ATLAS ROMAN POTS BEAM COUPLING IMPEDANCE AND MECHANICS

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Abstract

At the LHC, four Roman Pot (RP) type detectors will be installed on both sides of the ATLAS experiment with the aim of measuring elastic scattering at very small angles and determining the absolute luminosity at the interaction point. During dedicated LHC runs, the detectors will be positioned at about 1 mm from the nominal beam orbit. Numerical simulations and laboratory measurements were carried out to characterize the RP impact on the total LHC beam coupling impedance. The measurement results assess the effectiveness of RF-absorbing ferrite plates that have been mounted in convenient locations in order to damp high Q resonances of the RP structure. In addition, we review the RP mechanics emphasizing the accuracy and reproducibility of the positioning system.

INTRODUCTION

Roman Pot (RP) experiments consists of devices designed to host particle detectors with the possibility to approach locations very close to the circulating beam. At LHC, both sides of the ATLAS experiment will be equipped with RP detectors at about 240 m from the interaction point, with the aim of measuring elastic cross-sections and the collider luminosity [1]. The measurement and mechanical concept is shown in Fig. 1. An experimental unit will consist of 2 RP that will independently approach the beam from the bottom and the top, at the same location. Two units 4 m apart will be installed on each side, giving a total of 8 RP.

The mechanical design of a single RP is very similar to the one adopted for the TOTEM experiment [2] with few important differences reported in [1]. A 3D view of the RP unit outside (i.e. what will be seen by the beam) is shown in Fig. 2.

Due to the small distance from the beam during data taking and in order to guarantee accurate measurement results, two key issues in the RP operation are: i) the characterization of the beam-coupling impedance related to the wakefields induced by the beam on the surroundings ii) the accuracy and reproducibility of the positioning system.

BEAM COUPLING IMPEDANCE

The installation of the ATLAS RP units will contribute to the total LHC coupling impedance budget. The RP design must aim at minimizing the longitudinal and transverse impedances in order to avoid the generation of beam

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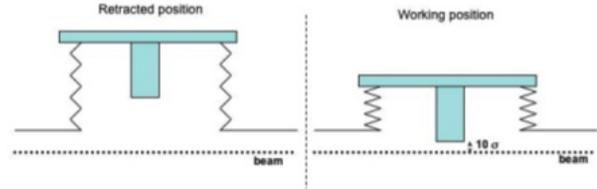* federico.roncarolo@cern.ch

Figure 1: Roman pot detector concept.

Figure 2: 3D view of a RP unit, side seen from the beam.

instabilities and power exchange between the particles and the RP walls. In general the impact of any accelerator element on the impedance is determined by:

- a resistive wall effect, enhanced as the beam approaches the surrounding materials and when low electrical conductivity materials are used;
- a geometrical effect, generated by any abrupt change of the beam pipe cross section and the presence of cavity-like structure (as for RP experiments).

In addition, transverse impedances are very much relates to single an multi-bunch instabilities while longitudinal impedances characterize the electromagnetic power exchange between the beam and the surroundings.

Transverse Resistive Wall Impedance

At the LHC the transverse resistive wall impedance will be dominated [3] by the collimator system and the contribution of the ATLAS RP positioned in data taking position at 1 mm from the beam was estimated 2 order of magnitude smaller over all the frequency band of interest. This

is explained by the limited portion of near-beam material (46 mm per unit) compared to the collimators (several meters) and the better conductivity of stainless steel (RP) with respect to graphite (collimators).

Longitudinal Geometric Impedance

The cavity-like nature of the RP devices can have a significant impact in terms of narrow-band resonances in the beam coupling impedance, in a frequency band of interest defined by the LHC beam spectrum. Here we present results of laboratory measurements and numerical simulation of the longitudinal impedance up to 3 GHz.

Both simulations and experiments are based on the well know coaxial wire method [4] which consists of a thin wire that is stretched inside the Device Under Test (DUT) along the reference beam trajectory and powered with an RF source. The simulated (or measured) scattering parameter S_21 of the resulting loaded transmission line, compared to the same quantity evaluated for a reference vessel (smooth beam pipe with same DUT initial diameter) allows determining the longitudinal impedance according to the well known 'log formula' $Z_L(\omega) = -2Z_c \ln[S_{21}^{DUT}(\omega)/S_{21}^{REF}(\omega)]$, where Z_c is the characteristic line impedance.

Numerical simulations (here performed with Ansoft HFSS [5]) are based on the finite element method. The volume meshing and related calculations can be memory and time intensive (in terms of accuracy and needed CPU time) for complicated or large geometries. In addition, simulating the real structure in terms of material properties and mechanical tolerances can be problematic.

On the other hand, laboratory measurements can be difficult to perform due non-ideal RF matching between the RF source and the DUT and other issues like wire alignment and sag.

The comparison between simulations and measurements in terms of $|S_{21}|$ is shown in Fig. 3. The agreement in terms of resonance frequencies and amplitude is better than 30 MHz and 5 dB respectively when looking at the 4 main modes from 1 to 3 GHz. Remanent differences are not surprising, given the simulation and measurement issues mentioned above. In addition, such an agreement validates the measurements results presented in the next paragraph. The measurements were performed for various RP operational settings, from a 'retracted' position at 36 mm from the wire to 'data taking' at 1 mm.

The same set of measurements were repeated after mounting on the pot walls a number of ferrite tiles. This is a commonly used method for absorbing the electromagnetic power associated to the high Q resonances with a high resistivity material.

The comparison between measurements before and after mounting the ferrite tiles is shown in Fig. 4, in terms of real and imaginary part of the longitudinal impedance $Z_L/n = Z_L/(f/f_0)$, where f_0 is the particles revolution frequency. The plots refer to a 'retracted' position, but sim-
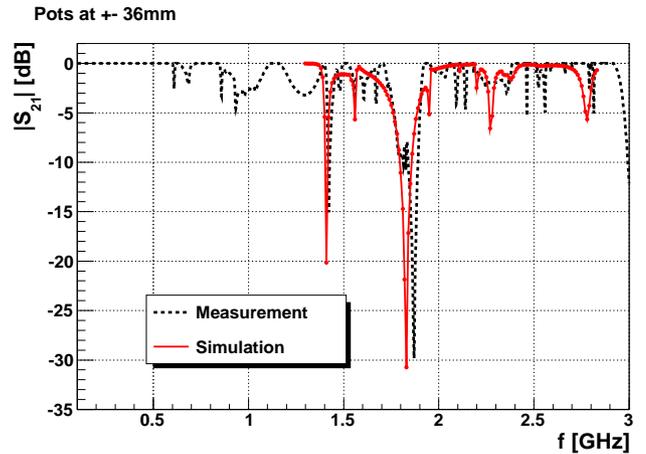
Pots at +- 36mm

Figure 3: Modulus of the transmission scattering parameter S_21 as measured and simulated with HFSS, for a RP retracted position at 36 mm from the wire (i.e. form the beam)

ilar results exist for pots close to the beam. In all studied cases, after installing the ferrite, the resonances Q factors are attenuated and the longitudinal impedance Z_L/n results below $10\,m\Omega$ at each considered frequency. This is considered a small effect w.r.t. the total LHC impedance.

MECHANICS AND POSITIONING SYSTEM

The RP unit will allow independent moving of the top and bottom pot to the nominal position via a high precision roller screw moved by a step motor. The pots are mounted on bellows that allow an excursion of 58 mm for the positioning around the circulating beam. The two bellows are part of the main vacuum chamber that is directly connected to one of the two LHC vacuum beam pipes. A compensation system [1] has been developed for balancing the forces acting on the pots, namely the pressure from the LHC primary vacuum and the gravity force due to the movable parts weight. Such a system allows a smooth operation of the motors by means of an over compensating force that allows to compensate the contrasting vacuum force, gravity and the residual torque of the motors, to achieve a moderate auto-retractive action.

For each unit, a very precise tuning of the movement in terms of relative position between the two pots and with respect to the beam will be insured by the overlap detectors inside the pots themselves. However, for a safe operation of the experiments and protection of the LHC, a reliable and reproducible system is required.

For this reason a series of tests in the laboratory are ongoing with a RP unit prototype assembled on a dummy LHC beam pipe. The system is equipped with the full motor system and a 10^{-4} vacuum in the main chamber is achievable.

The tests presented here aimed at assessing the position-
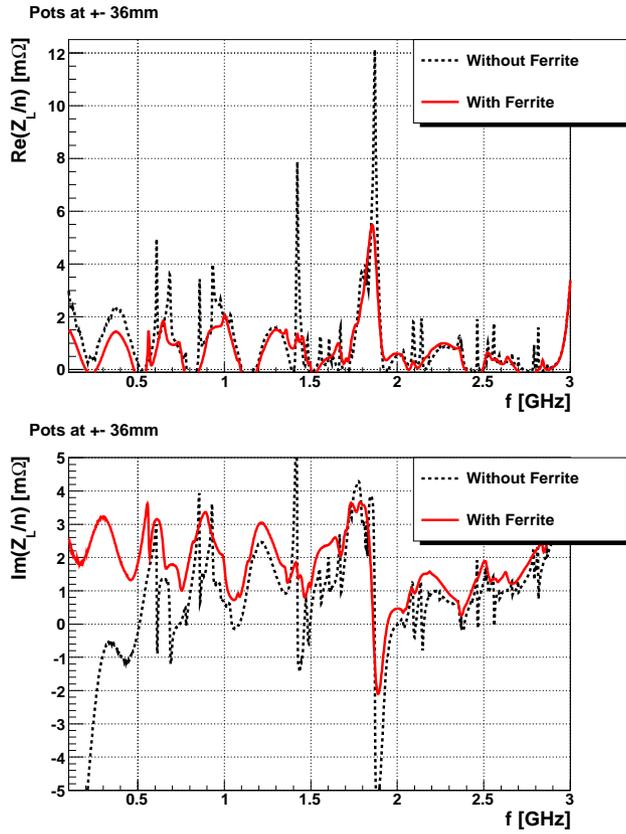
Pots at +- 36mm

Pots at +- 36mm

Figure 4: Real and imaginary part of the longitudinal impedance as measured for RP unit in retracted position, before and after mounting ferrite tiles.

Table 1: Reproducibility for top and bottom flanges. For convenience the value is in mm and the error in μm.

		No vacuum		Vacuum	
	Steps	y [mm]	σ_y [μm]	y [mm]	σ_y (μm)
Bottom	0	0.018	5	0.012	3
	500	2.478	8	2.461	17
	1000	4.939	1	4.908	2
Top	0	0.027	3	-0.045	8
	500	2.451	22	2.326	7
	1000	4.949	30	4.771	2

CONCLUSIONS

The ATLAS Roman Pot units that will be installed at about 240 m from the interaction point, must guarantee a safe operation with regard to the wake-field induced beam instabilities and the LHC machine protection. The added beam coupling impedance has been characterized in terms of transverse resistive wall impedance and longitudinal narrow band impedance. In both cases the results indicate relatively small values w.r.t. the total LHC budget. For the narrow band longitudinal impedance this is particularly true after mounting ferrite tiles, which have been added to the final RP design. Preliminary laboratory measurements exhibit an excellent reliability and reproducibility of the RP positioning system.

Acknowledgements

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ing reproducibility by using position sensors mounted on the top and bottom flanges, in locations where the reproducibility is expected to be worse than at the detectors level, mainly for mechanical play reasons.

Several measurements were performed, on the bottom and top flanges an the preliminary results are summarized in Table 1. Every time the pots position was readout at the "zero" position, 500 steps and 1000 steps (corresponding to an excursion of 5 mm), with and without vacuum. The error in columns 3 and 5 gives a measure of the reproducibility. The maximum error is for the top pot and is $\Delta = 30\ \mu$m. For the measurements at atmospheric pressure the reproducibility is better than $10\ \mu$m for the bottom pot. For the top pot it has a maximum value of $30\ \mu$m which is attributed to the uncertainty on the sensor angular position and to the out-of-tolerance roughness of the surface on which the sensor was fixed. The reproducibility obtained with vacuum in place results on average better for both pots. In this second set of measurements the absolute 'zero' position moved, due to the intervention of the compensation system mentioned above.