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FEM ANALYSIS OF BEAM-COUPLING IMPEDANCE AND RF CONTACTS CRITICALITY OF THE LHC UA9 PIEZO GONIOMETER

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Abstract

The UA9 piezo-goniometer has been designed to guarantee micro-radians-accuracy angular positioning of a silicon crystal for a crystal collimation experiment in the LHC, and to minimize the impact on the LHC beam-coupling impedance. This paper presents a Finite Element Method (FEM) study of the device, in both parking and operational positions, to evaluate its impact on the LHC impedance budget. In addition, the shielding contribution of the RF gaskets has been carefully evaluated, with the objective to assess the consequences for operation in case of their failure. A final word is drawn on the overall device impedance criticality.

INTRODUCTION

The UA9 experiment at CERN aims at collimating a beam of particles with the use of bent crystals [1]-[2]. Such crystals have to be positioned next to the beam with an angular accuracy of 1 micro-radian [3]. The LHC UA9 piezo goniometer has been designed for this purpose.

Given the strict impedance constraints in LHC [4] impedance simulations and measurements are part of the procedure to approve and finalize a device installation. For the UA9 goniometer, these have been carried out in parking position (i.e. when the crystal is hidden to the beam and a masking cylinder shields the beam pipe, as in Figure 1) and operational position (i.e. when the crystal is next to the beam, a condition which is foreseen to happen just for low-intensity beams, Figure 1).

This paper gives an outline of the impedance numerical assessment of the UA9 goniometer for both parking and operational position.

FEM SIMULATIONS

The code used for the impedance simulations is CST, in particular Particle Studio and Microwave Studio [5].

Parking Position and RF Contacts Criticality

In parking position (Fig. 1), a cylinder physically closes the beam pipe to reduce the overall impedance (toroidal RF contacts guarantee electrical continuity), introducing very little discontinuity. The equivalent goniometer structure in parking position is depicted in Fig. 2. It is evident that the perturbation to the pipe walls is determined just by 2 small parasitic cavities (0.5 mm length and 2.5 mm depth). The structure has been simulated using symmetries and with lossy metal background (Steel 316LN).

In this situation, the simulated impedance is very small (Fig. 3 – wakefield solver), as however expected. On the longitudinal plane, the only contribution on the real part is given by a small (< 1 Ohm) peak at about 2.88 GHz (above the beam pipe cut-off frequency). On the transverse plane, the impedance is negligible. Table 1 lists the impedance simulation results in parking position.

Since the values are significantly small (compared to the overall LHC impedance budget), the UA9 goniometer in parking position is not considered a concern from the impedance viewpoint.

A study has been performed also simulating a total failure in the RF contacts, to check if their design is critical (they are the only element which assures continuity to the wall currents). In this particular case, eliminating the toroidal RF contacts from the device geometry, the beam chamber will be in direct communication with the surrounding cavities, where the motorization and actuation systems are placed. The equivalent structure is depicted in Fig. 2. The simulations (Fig. 4) show that lower-frequency peaks (i.e. less than 1 GHz), associated to resonances inside these cavities, start appearing both on the longitudinal and transverse planes. Even if such peaks are not extremely important (their

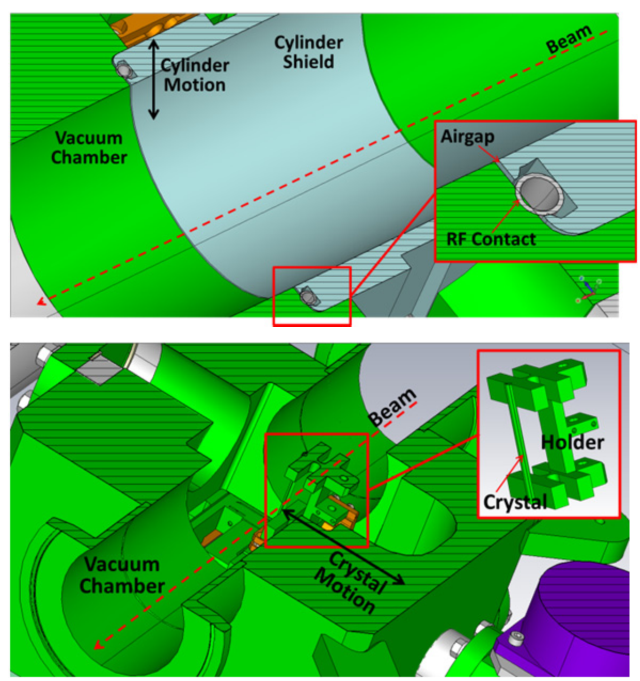

Figure 1: (Top) Longitudinal section of the UA9 goniometer in parking position (masking cylinder is in place), with zoom on the RF contact area. (Bottom) Longitudinal section of the UA9 goniometer in operational position (masking cylinder completely out) with zoom on the crystal holder area.

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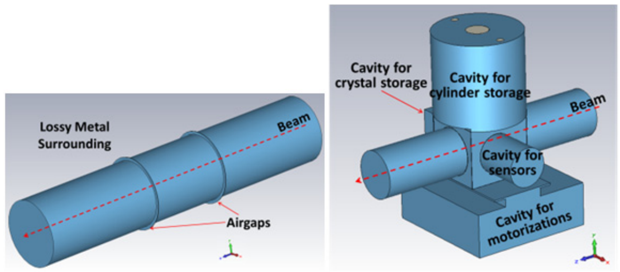

Figure 2: (Left) Equivalent structure of UA9 goniometer in parking position. (Right) Equivalent structure in case of total failure of RF contacts

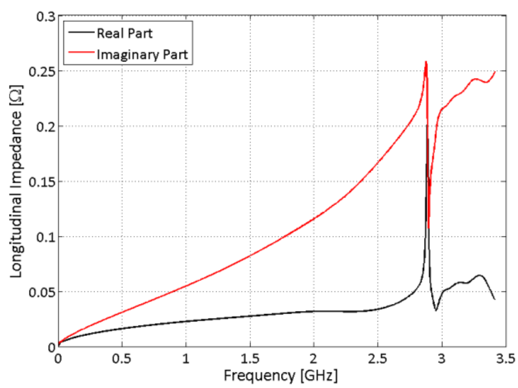

Figure 3: Longitudinal impedance simulations of the UA9 goniometer in parking position.

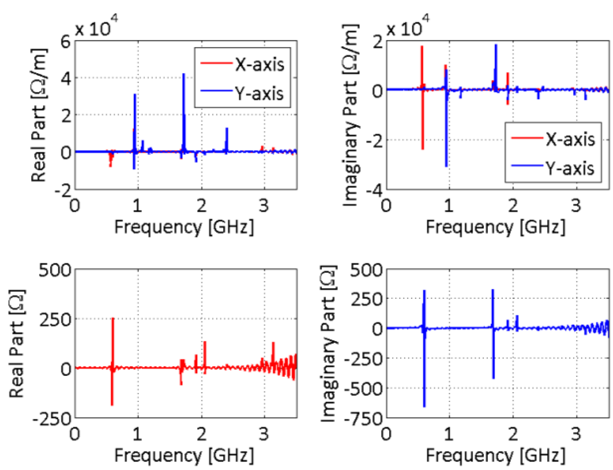

Figure 4: Real and imaginary parts of (Top) transverse and (Bottom) longitudinal impedance of the goniometer with complete failure of RF contacts.

magnitude has been counterchecked with eigenmode simulations, being under the beam pipe cut-off frequency), this result translates in a design recommendation on the strength and reliability of the RF contacts. However, this result also demonstrates the effectiveness of the design solution with the masking cylinder for decreasing the overall impact of the device impedance, which otherwise would have been much more concerning.

Table 1: Impedance Contribution in Parking Position

Parameter	Value
Z/n [Ω]	$6 \cdot 10^{-7}$
Max trans. impedance (real) [Ω/m]	50
Max transv. impedance (imag.) [Ω/m]	100

Operational Position

In operational position, the crystal is aligned within its designed angle and placed next to the beam (Fig. 1 – the distance beam-crystal is 1 mm, which corresponds to the worst-case situation). In this case, the geometry of the problem is much more complicated. For the FEM analysis, the study of the entire geometry proved to be impossible, due to convergence problems caused by the excessively detailed structure.

The study has been then concentrated on two steps:

1. Analysis of the effect of the crystal and its holder.
2. Analysis of the surrounding cavities.

The FEM geometries are in Fig. 5. For case 2, eigenmode simulations have been performed, since wakefield simulations did not show convergence. To allow proper comparison, eigenmode simulations have been performed for case 1 as well. For each resulting mode, the shunt impedance has been calculated, as well as the transverse impedance (applying the Panofsky-Wenzel theorem). The impedance spectrum has been reconstructed by superposing the resonances and applying a Lorentzian fit, knowing the peak value, the Q value and the frequency of each resonance.

For the case 1, the electromagnetic properties of the crystal (made of polycrystalline silicon) have been taken into account. The results on the longitudinal and transverse planes are in Fig. 6. It is interesting to notice that the resonance at about 1.64 GHz on the longitudinal plane is due to the crystal holder. The crystal itself does not introduce significant contributions to the impedance, even if it is closer to the beam (Fig. 5). On the transverse plane (Y-axis), a sharp peak appears at 1.02 GHz, due to the top-down symmetry braking.

For case 2, since in this situation the beam pipe is completely open to the surrounding cavities (rather than being connected to them with thin slits, as in Fig. 2), the structure has been more comprehensively detailed (Fig. 5). The results are depicted in Fig. 7. As for the case of RF contacts failure, many low-frequency peaks appear, both on longitudinal and transverse planes, due to resonances in the surrounding cavities. In this case though, the amplitudes of such resonances are significantly bigger.

EXPERIMENTAL CONSIDERATIONS

In this section, some considerations on experimental measurements, which have been performed on the UA9 goniometer and will be discussed in detail in a future

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work, are proposed. In fact, the measurements have been conducted using the wire method [6] and with fixed antennas. In parking position, no modes were observed, except for the waveguide modes due to the metallic

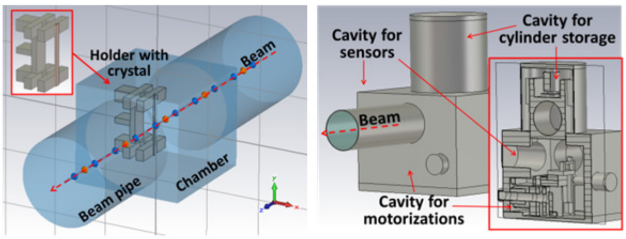

Figure 5: (Left) Equivalent structure of UA9 goniometer in operational position considering just the crystal, the holder and the main chamber. (Right) Equivalent structure in operational position considering all surrounding cavities.

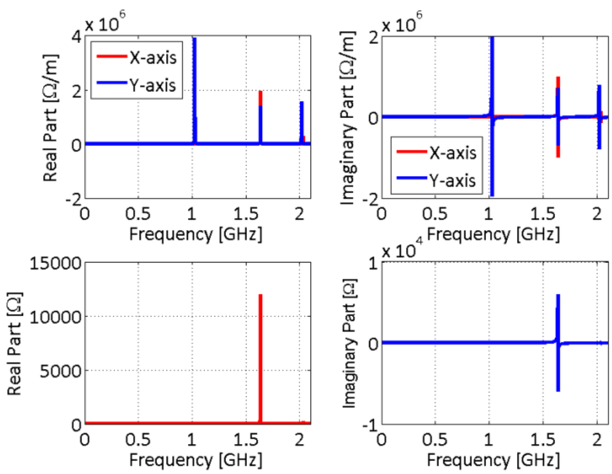

Figure 6: Real and imaginary parts of (Top) transverse and (Bottom) longitudinal impedance of the goniometer in operational position, considering just the crystal and the holder, for two different beam-crystal distances.

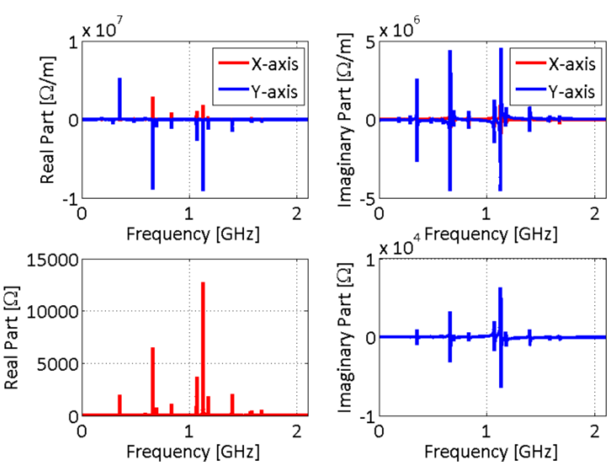

Figure 7: Real and imaginary parts of (Top) transverse and (Bottom) longitudinal impedance of the goniometer in operational position, considering just the surrounding cavities.

enclosures of the device under test (DUT). The amplitude of the simulated mode at 2.88 GHz (Figure 3) is too small (in addition to being above cut-off) to be successfully observed.

Following the simulation results presented in the previous sections, an RF contact test has been performed, to check the repeatability of the contacts with iterated movements of the cylinder. The results had a very good repeatability, showing an actual robustness of the RF contacts.

Even if in absence of the crystal, measurements have been done with the cylinder retracted. Low-frequency peaks were observed in this case too. The agreement with the simulations is still under evaluation.

CONCLUSIONS AND OUTLOOK

The impact of the impedance of the LHC/UA9 goniometer has been assessed in this paper through numerical simulations using CST Studio Suite. The device has been studied both in its parking position (explicitly conceived to minimize the impedance) and in operational position. The impedance in parking position has proved to be insignificant. The RF contact criticality study has highlighted low-frequency peaks which translate into a necessity of having good robustness. In operational position, low-frequency peaks are also observed in both planes, leading to a much more important impedance contribution.

Overall, the device impedance contribution in parking position (the condition of functioning during usual beam intensity) is not of concern.

Finally, some considerations on measurements are also drawn, pointing out the expected blandness of the impedance contribution in parking position and demonstrating a good RF contacts repeatability.

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