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MULTIPACTING ANALYSIS OF THE QUADRIPOLAR RESONATOR (QPR) AT HZB

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Abstract

Multipacting (MP) is a resonating electron discharge, often plaguing radio-frequency (RF) structures, produced by the synchronization of emitted electrons with the RF fields and the electron multiplication at the impact point with the surface structure. The electron multiplication can take place only if the secondary emission yield (SEY, i.e. the number of electrons emitted due to the impact of one incoming electron), is higher than 1. The SEY value depends strongly on the material and the surface contamination. Multipacting simulations are crucial in high frequency (HF) vacuum structures to localize and potentially improve the geometry. In this work, multipacting simulations were carried out on the geometry of the Quadrupole Resonator (QPR) in operation at HZB using the Spark 3D module in Microwave Studio suite (CST). These simulations helped to understand a particular behavior observed during the QPR tests, and furthermore made it possible to suggest enhancement ways in order to limit this phenomenon and facilitate its operation.

INTRODUCTION

The Quadrupole resonator at HZB is a device developed measure the surface resistance of superconducting samples. It is based on a design from CERN [1]. The structure of the quadrupole resonator is based on the theory of transmission lines. Four rods are connected to each other with a pair of loops. The magnetic field is maximum at both ends of the resonator. The sample is at the bottom of the loop where the magnetic field is maximum (see Fig. 1). The fundamental operating frequency is 427 MHz, other harmonics can be excited such as 868 MHz and 1310 MHz. The measurement of the surface resistance is done by a calorimetric method. As all RF structures, the phenomenon of multipacting can exist and potentially hinder the operation at several field levels.

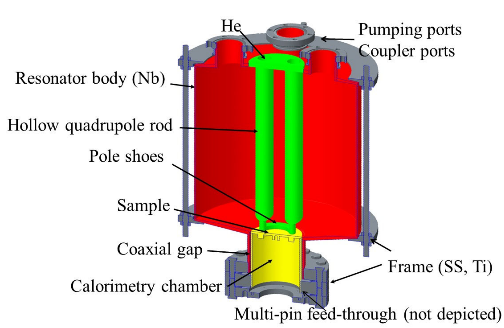

Figure 1: Schematic view of the QPR, taken from [2].

Multipacting is a resonant secondary electron emission phenomenon that is generated in an RF structure (see Fig. 2). When a primary electron collides with the surface after an RF or multiple period, secondary electrons reemitted by the surface could be accelerated again and so on at each period. Some conditions are necessary for multipacting to develop [3]: A synchronization between the RF period and the electron trajectory is given by the RF field distribution and thus the geometry and the electronic multiplication can only take place if the secondary emission yield (SEY), depending on the material and its surface, is greater than 1.

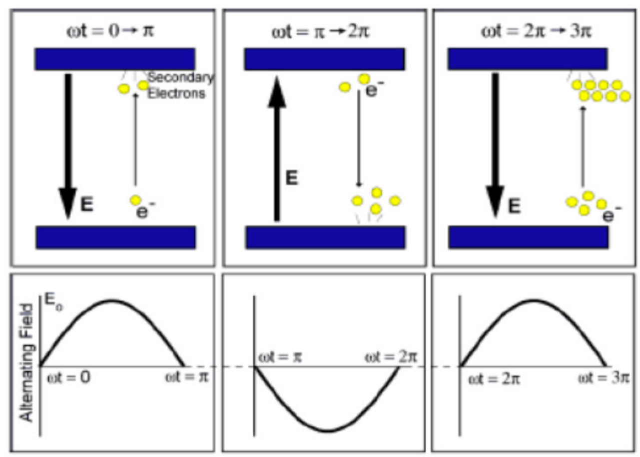

Figure 2: Multipacting phenomenon.

The collision of the electrons with the RF surface produces important heating. As the measurement of the surface resistance in the QPR is done by the calorimetric method, anomalous heating triggered by multipacting can bias the measurement of the surface resistance.

So as to ensure a reliable measurement of the surface re-sistance, multipacting simulation is necessary.

SIMULATION RESULTS

The multipacting simulations were done with SPARK3D module included in CST Microwave Studio [4]. At the beginning of the simulation, primary electrons are generated all over the surface. Trajectories of secondary electrons are tracked over several RF periods. The main input parameters for SPARK3D are:

- Frequency and electromagnetic field distribution are imported from CST.
- RF power level.
- Electron parameters: Initial electron number, simulation time (related to period number) and secondary emission coefficient (SEY) curve of niobium (Fig. 3).

SPARK3D allows to identify multipacting region. The simulations are done on three QPR regions; around coupler, rods and on the coaxial line (see Fig. 4).

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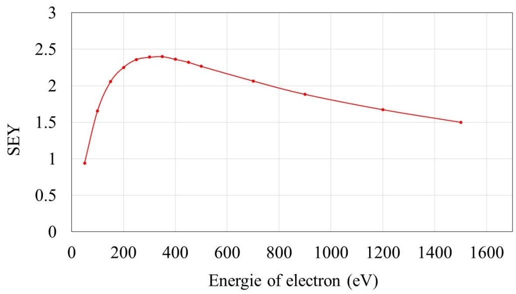

Figure 3: Niobium SEY as function as energy of electron.

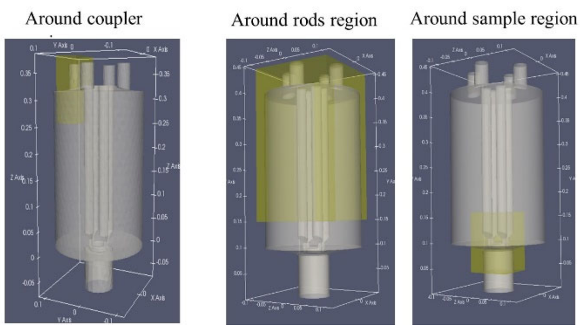

Figure 4: the studied geometry of quadrupole resonator and the green parts represent the regions studied separately.

The number of initial electrons simulated are 20000 and simulation time is set to 20 RF periods. The main output parameter is the final number of electron. Indeed, if the final number is greater than the initial number, or if the ratio $e_{final}/e_{initial} > 1$, multipacting is occurring and can be directly localized.

For the first mode, the ratio $e_{final}/e_{initial}$ is greater than 1 for low magnetic fields between 1 and 3 mT indicating the presence of multipacting (see Fig. 5). This was confirmed by HZB team. They observed RF power fluctuations at around 5 m typically attributed to multipacting (see Fig. 6).

The good agreement between observations and simulations validates the model and simulations and the complete study of multipacting of quadrupole resonator for the three operating modes can be carried out.

The simulations were performed by region in order to determine the multipacting region. The curves in Figs. 7 and 8 show the evolution of the ratio $e_{final}/e_{initial}$ as a function of the maximum magnetic field in the quadrupole resonator for the region around the coupler and around the rod. This ratio is lower than 1 whatever the magnetic field value. No multipacting is identified in the coupler and the rod regions for the three operating frequencies.

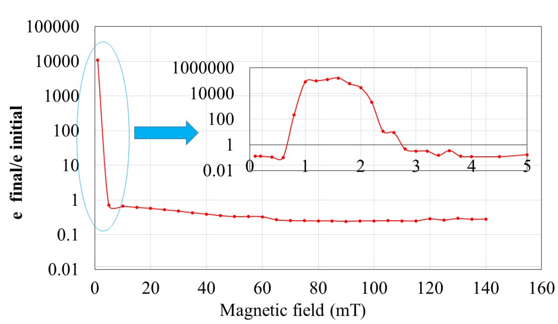

Figure 5: final electron number/ initial electron number as function of the peak magnetic field for mode 1.

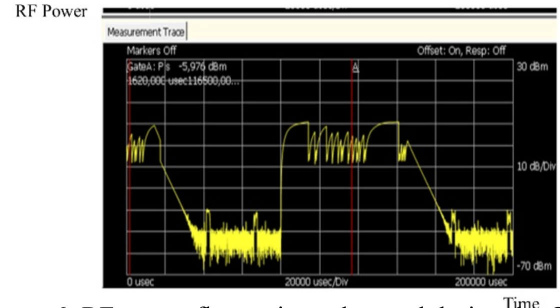

Figure 6: RF power fluctuations observed during the QPR test at a magnetic field of 5 mT.

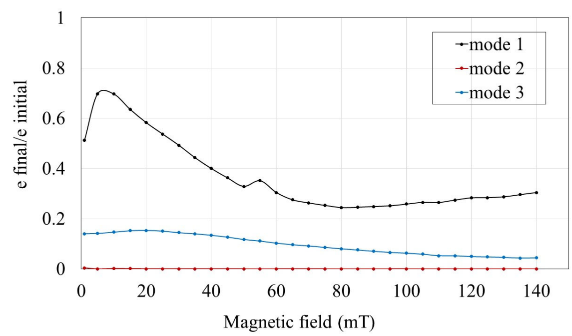

Figure 7: The ratio of final electron to initial electron as a function of the maximum magnetic field around the rods for the three modes of operation.

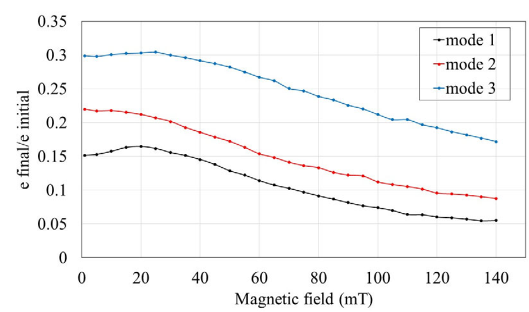

Figure 8: The ratio of final electron/initial electron as a function of the maximum magnetic field around the coupler for the three modes.

The multipacting study was then performed around the sample on the coaxial line (Fig. 4). The results are plotted in Fig. 9 for the three modes of operation of the quadrupole

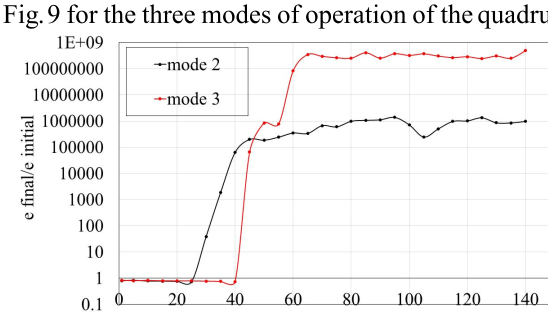

Figure 9: The ratio of final electron/initial electron as a function of the maximum magnetic field around the sample for the modes 2 and 3.

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quadrupole resonator. Multipacting is occurring for magnetic field values greater than 20 mT for mode 2 and 40mT for mode 3 (see Fig. 9).

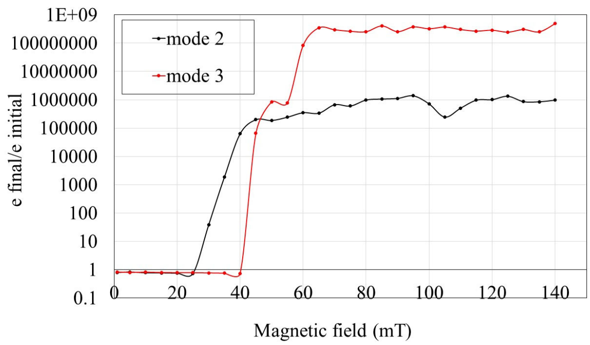

Figure 9: The ratio of final electron/initial electron as a function of the maximum magnetic field around the sample for the modes 2 and 3.

Figure 10 shows the location of the multipacting. It is distributed all around the sample, in the coaxial zone. This can generate anomalous heating of the sample during the tests and thus lead to an overestimation of the surface resistance of the sample. In order to guarantee a reliable measurement for modes 2 and 3 at magnetic fields above 20 mT, it is imperative to resolve this problem.

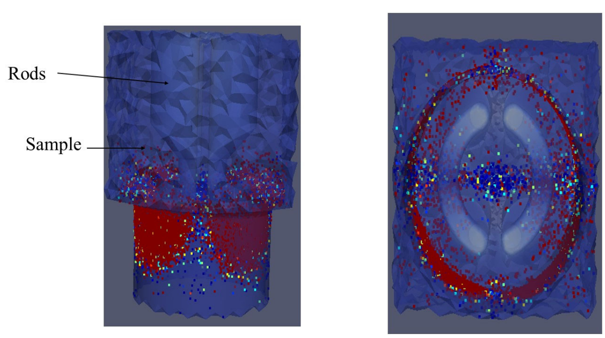

Figure 10: Localization of multipacting (red areas).

DISCUSSION

The multipacting phenomenon is very problematic for the operation of a test system such as a QPR. Indeed, the multipacting for modes 2 and 3 is localized on the sides of the sample which can cause a significant heating because it is cooled by conduction. This thermal contribution is added to the heating created by the thermal dissipation of the electromagnetic wave on the top of the sample. Therefore, this can induce important uncertainties on the evaluation of the surface resistance of the sample. In order to effectively reduce the multipacting phenomenon, several solutions can be considered:

Modifying the geometry: the modification of the resonator appears to be complicated but the geometry of the sample would be easier to implement. The influence of the gap of the coaxial zone on the multipacting conditions have been studied. We can see in Fig. 11, that a reduction to 1 mm would completely cancel the multipacting for mode 2. The multipacting for mode 3 stays the same. This could be attenuated by decreasing even more the coaxial gap, but the technical feasibility becomes very complex.

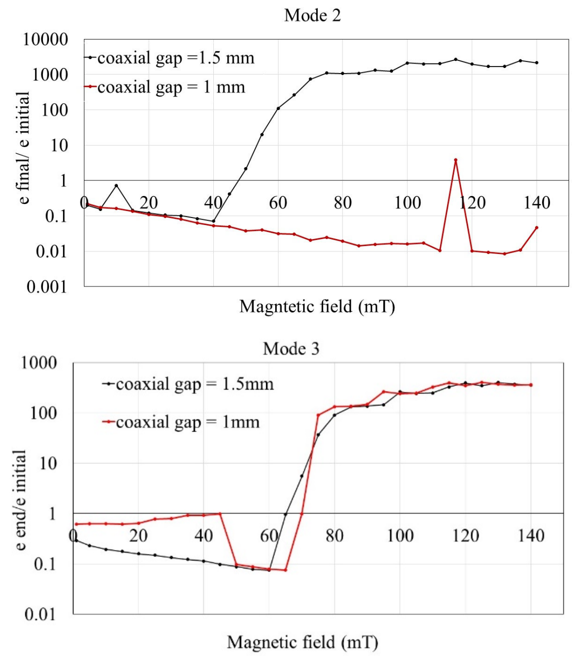

Figure 11: The ratio of final electron/initial electron as a function of the maximum magnetic field around the sample for the second and third modes at different coaxial gap values.

Modifying the SEY coefficient: the SEY can be modified by depositing a material with a low SEY coefficient such as TiN. The realization of such a deposit is not possible on the resonator as it could significantly impact the superconducting properties. It would be possible to realize such a thin film deposition on the sides of the sample as RF currents are sufficiently low.

CONCLUSION

In this paper the multipacting study of quadrupole resonator in operation at HZB have been done using SPARK3D module from CST Microwave Studio. These numerical simulations helped in the understanding of multipacting phenomenon in the quadrupole resonator. The simulation predictions are in agreement with experimental observations during the operation of mode 1. The presence of multipacting was observed for mode 2 and 3 at high magnetic field. A solution has been proposed to mitigate the multipacting and to allow surface resistance measurement above 20 mT for modes 2 and 3.

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