## P.5: Development of a 3D computer code to study space charge induced multipacting current saturation in superconducting RF elliptic cavities

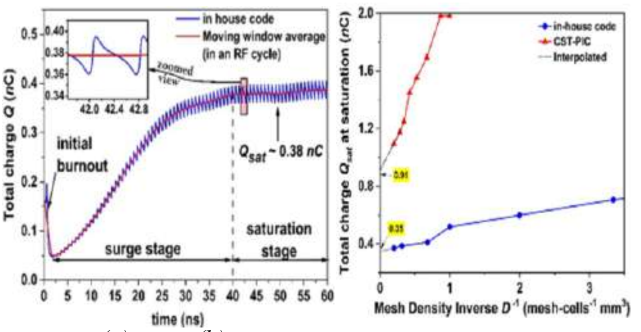
Design and development of superconducting elliptic RF cavities at RRCAT have progressed significantly in recent years. Several cavities have achieved the design accelerating gradients during the powering experiments conducted at the Vertical Test Stand (VTS). During VTS tests, it is sometimes observed that at a particular accelerating gradient, even when additional RF power is supplied, the gradient does not increase further. At this point, the quality factor drops significantly, along with observation of increased x-ray emission. This condition occurs due to multipacting, where the cavity surface produces a large number of secondary electrons whose motion between successive surface impacts is resonant with oscillation of RF field. The multipacting electrons repeatedly strike the cavity surface, resulting in exponential growth in the electron population. The electrons absorb a large amount of RF energy form the cavity, and deposit it as heat, thereby creating local hotspots on the cavity surface, which often lead to quench. Since multipacting is detrimental to cavity operation, it should preferably be mitigated at the RF design stage itself, by suitably modifying the cavity geometry.

To gain deeper insight into this phenomenon in superconducting elliptic cavities, dedicated computer code is needed. Traditionally, in numerical simulations of multipacting, multiple seed electrons are initialized within the cavity and tracked for several RF cycles. When the seed electrons strike the cavity surface, new secondary electrons are emitted according to the secondary emission model used in the simulation code. After a few initial RF cycles, if the electron population grows exponentially over successive cycles, multipacting is considered to be present. In the absence of multipacting, the electron population decays. These simulations are repeated over a range of accelerating gradients to identify multipacting prone gradient ranges. However, the typical analysis does not account for realistic scenario experienced by multipacting electrons, such as electrostatic repulsion among multipacting electrons (space charge effects) and RF loading induced by the multipacting current. These effects lead to saturation of multipacting charge after an initial growth. In order to assess the severity of multipacting, it is important to evaluate the saturated multipacting charge.

In this work, we focused on the less-explored problem of space charge induced saturation of multipacting, by including space charge in an in-house developed 3D code. This code computes the electrostatic repulsion within the multipacting bunch by solving Poisson's equation using a finite-difference method. To advance particles in the 3D space, the code employs an RK4 particle pusher. The code includes boundary effects, which are important in our case because multipacting trajectories lie very close to the cavity surface (~1 mm), as shown in Figure P.5.1. For improved accuracy, the code uses a smooth cavity boundary representation instead of a staircase approximation. The developed code was used for multipacting simulations following a rigorous mesh optimization study. The time evolution of multipacting charge at 12 MV/m is shown in Figure P.5.2(a). The results show that the number of particles increases exponentially at the beginning because the electron population is small and mutual repulsion among them is weak. As the population increases, space charge repulsion becomes stronger, leading to many particles getting pushed out of synchronization and lost. Eventually, a saturated state is reached where particle loss per RF cycle equals the number of particles generated in the secondary emission process. The in-house code was benchmarked against CST-PIC, as shown in Figure P.5.2(b), and demonstrated better convergence. The developed code was subsequently used to estimate the saturated multipacting current over a range of accelerating gradients.


(a) (b)

*Fig. P.5.1: (a) 3D view of the single cell of the $\beta_g$= , 650 MHz elliptic cavity, and (b) a sample particle trajectory corresponding to the 2-point 1st order multipacting shown on a 2D plane in the elliptic cavity.*




(a) (b)

*Fig. P.5.2: (a) Saturation of multipacting charge due to space charge effects at the gradient of 12 MV/m. (b) Comparison of the results from the in-house developed code and results from CST-PIC.*

Development of this code improves our physical understanding of multipacting and strengthens our efforts toward developing indigenous computational tools as a reliable alternative to imported commercial software.

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