Numerical Study of the Tuning, Pressure Sensitivity and Lorentz Force Detuning of SRF Crab Cavities

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Abstract

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. The LHC machine consists on a 27 km circumference tunnel that accelerates and collides proton beams and heavy ions. The High Luminosity LHC (HL-LHC) is a project aiming to upgrade the LHC collider by achieving instantaneous luminosities a factor of five larger than the nominal LHC luminosity. One of the key devices of the HL-LHC project are Superconducting Radio-Frequency (SRF) Crab Cavities. The crab cavities are RF components designed in such a way that the electromagnetic force is perpendicular to the motion of the particle beam crossing them. Therefore, when operated at the adequate frequency, the cavities would tilt the proton bunches, maximizing their overlap at the collision points. Two crab cavity concepts have been developed: the Double Quarter Wave (DQW) and the RF Dipole (RFD). Currently, two DQW crab cavity prototypes have been successfully fabricated and tested with the beam in the Super Proton Synchrotron (SPS) at CERN in May 2018, whereas the prototyping stage of the RFD cavities is currently ongoing. For an adequate operation, the crab cavities are designed to deflect the particle bunch at a specific resonant frequency. A tuning system, consisting in slightly modifying the shape of the cavity is used to correct possible deviations from the fundamental frequency of the cavity. In addition, among the different design constraints of the RF cavities, Pressure Sensitivity (PS) and Lorentz Force Detuning (LFD) represent two paramount parameters. PS analyses the variation of the fundamental frequency of the cavity when subjected to pressure fluctuations of the superfluid helium bath which surrounds the cavity, whereas LFD accounts for the shift on the cavity frequency due to the RF electromagnetic forces acting on its walls.

The aim of the present study is twofold. Firstly, COMSOL numerical results were successfully validated against experimental results obtained from the tuning of the DQW cavity prototype. To do so, the Electromagnetic Waves (frequency domain), Solid Mechanics and Moving mesh interfaces available in COMSOL Multiphysics® were used. Making use of these modules, the fundamental frequency of the cavity was calculated before and after elastically deforming the tuning region of the cavity (and its mesh). The expertise gained during this experimental validation was subsequently used as a support for the design of the RFD cavity. PS and LFD analyses made use of the same philosophy and COMSOL modules as the tuning analysis. The PS study evaluates the variation of the cavity fundamental frequency when a constant pressure deforms the cavity walls. Nevertheless, the computation of the LFD implies a slightly more complex procedure. For LFD, the calculation of the electromagnetic pressure on the cavity walls needs to be scaled up to the cavity deflecting nominal voltage, which makes use of the integration of the

kicking voltage on the particle bunch along the cavity axis. All these calculations were integrally carried out using COMSOL Multiphysics® and reflected the huge capabilities of this software to precisely calculate key parameters on the design of RF superconducting cavities.

Figures used in the abstract

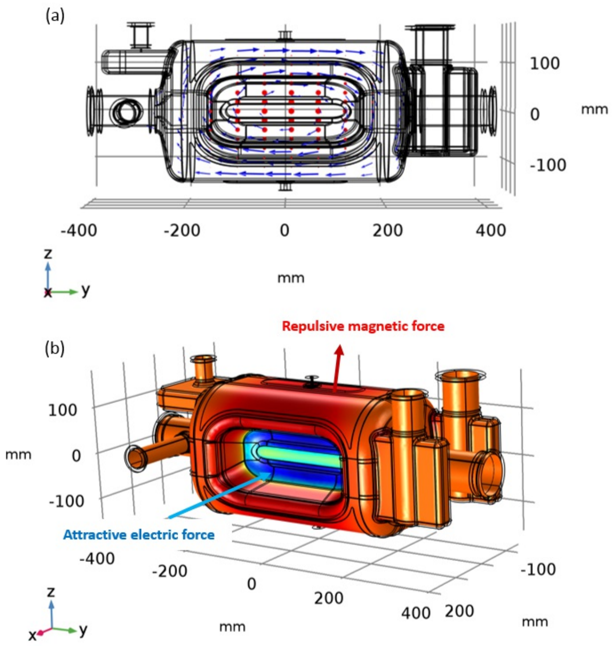

Figure 1: (a) Magnetic (blue) and electric (red, pointing in the negative x direction, towards the paper) field vectors for the fundamental mode of the RFD superconducting cavity. (b) Electromagnetic pressure on the cavity interior walls for the RF fundamental frequency, used for Lorentz force detuning calculations.