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Analysis and suppression of RF radiation from the PSI 590 MeV cyclotron Flat Top Cavity

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ABSTRACT

The Flat Top Cavity, located in the PSI HIPA Ring Cyclotron leaks RF power of several kilo Watts into the cyclotron's vacuum space causing several complications. A detailed electromagnetic model was created and simulations performed to analyze the mechanisms by which power is leaking out of the Flat Top Cavity. The tolerances needed to limit the leaked power in future iterations of the Flat Top cavity are reported. Comparison of the model to measurements are described as well as two potential methods to limit power leakage. These studies will have direct impact on future RF cavity designs for cyclotrons as power levels increase and higher RF fields are required.

1. Introduction

The Flat Top Cavity (FTC) in the PSI HIPA Ring Cyclotron [1] is one of the critical devices required to achieve a continuous 590 MeV, 2.2 mA proton beam. Operating on the 3rd harmonic, the fields have an effect of increasing the longitudinal acceptance of the machine. The addition of a slight slope to the voltage confines the beam, reduces the longitudinal emittance growth and compensates for space–charge effects [2].

The PSI Ring cyclotron, Fig. 1, has been upgraded from 100 μA to 2.2 mA over 41 years. However the Ring can only achieve 1.1 mA without the FTC. The FTC, which up until January 2015 had not been moved in 35 years, is one of the oldest components in the system. It is also the piece of hardware preventing the machine reaching higher currents.

The FTC's limitation is a complex problem. The power being inserted into the cavity causes deformation, due to heating, which results in detuning. The existing hydraulic tuning systems have reached their limitations as well as the RF amplifier and coaxial line, and thus the cavity can not achieve higher voltages. Additionally, a portion of the RF power is leaking out of the cavity and igniting a plasma in the cyclotron vacuum space [3].

This paper reports on a finite element model that illustrates the mechanism by which the RF power is leaking out of the cavity and methods to suppress the leakage. Though the treatment below is specific to the PSI Flat Top Cavity, the same physics and phenomenon are relevant in other high power cyclotrons, such as the Daedalus [4] and TAMU SFC [5] cyclotrons, that use large aperture RF cavities that accommodate several tens of orbits. Below is a description of the models and the experimental data used to understand the cavity's operation. We also establish parameters that must be adhered to for future iterations of the FTC.

2. RF models

For RF cavities, symmetry is sought to reduce variation in field profiles and to reduce higher order modes. In the case of the FTC, there is also a direct correspondence between asymmetry and the amount of power leaked out of the cavity. The position of the “lips”, shown in gold in Fig. 2, is the most influential feature in the entire cavity with regards to voltage gain, frequency, peak electric field, and power leakage. Due to the variations throughout the cavity, a parametric study was performed to determine the positioning tolerances on the lips and walls.

A detailed model was made from the 3D CAD drawings (shown in Fig. 3). The empty space within the 3D cavity was extracted. The significant features to note are: the different size and shape for each of the two apertures leading out of the cavity to the sector magnets, the entire vacuum chamber between the cavity, and the Sector Magnet 7 (SM7), and lastly an Aquadag [6] thin film coating

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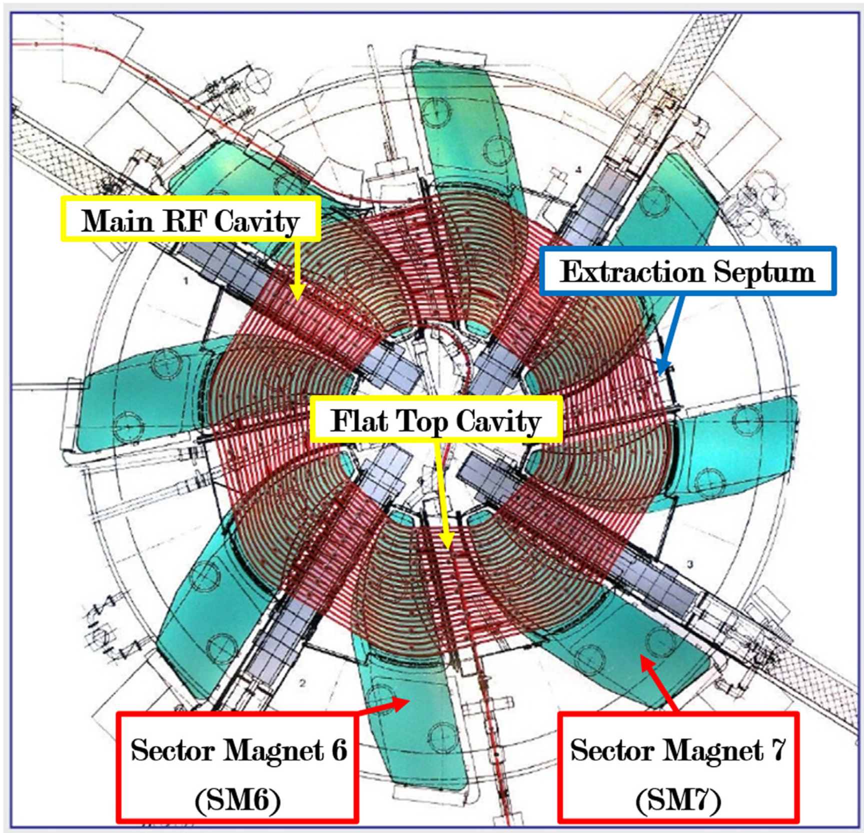

Fig. 1. Image shows a schematic of the PSI Ring Cyclotron highlighting the Flat Top Cavity and the two sector magnets that flank it. The dark red line shows the beam path through the cyclotron, including the injection which is located between Sector Magnet 6 (SM6) and Sector Magnet 7 (SM7) and passing though the Flat Top Cavity. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

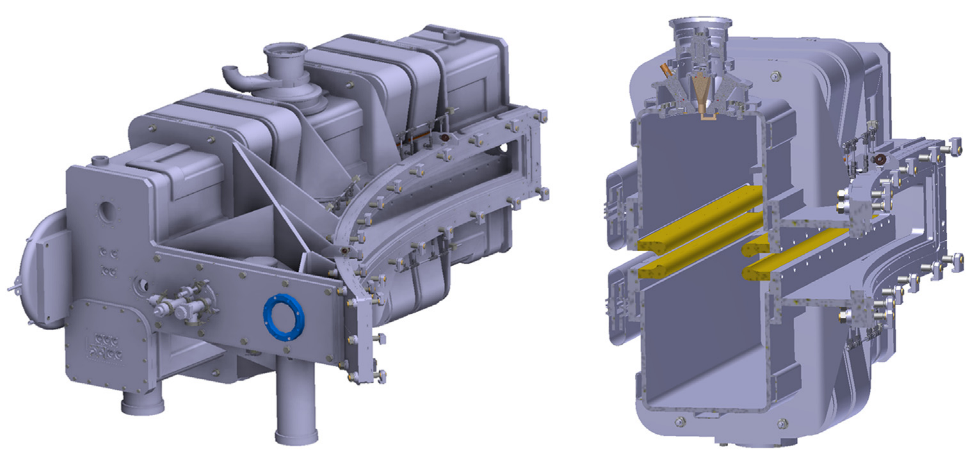

Fig. 2. *Left*: The 3D CAD model of the Flat Top Cavity. *Right*: A cross section of the cavity is presented highlighting the lips in gold. The lips' locations are critical to reduce leaking power. Additionally the coupler is shown in copper.

was placed on the corresponding surfaces which altered the surface resistance.

The resulting model has an un-loaded quality factor of 29 406 at 30 °C compared to the measured value of the cavity at 28,287 ± 58. Q_0 takes into account the power that is leaked out of the cavity. The Q_0 of the modeled cavity at operation temperature is 28,111 from the temperature dependent resistances used for the aluminum and Aquadag coated aluminum. The aluminum used was EN AW-1050A aluminum and an estimated 25 μm thickness was assumed for the Aquadag coating on the aluminum. The model is close to the measured value but is most likely higher due to the exact thicknesses of the Aquadag being estimated and other unknowns from 35 year of operation.

Using laser interferometry, the cavity's inner surface was mapped to a 7–8 ppm accuracy in distance between the surface and the tracker. The general dimensions were confirmed but irregularities also appeared. For example, the lips were not vertically aligned on their respective sides, but were aligned horizontally. On each side, a difference of 1–2 mm occurred between the top and bottom lips. This was initially thought to be rather inconsequential as 2 mm difference in a cavity that is 2.7 m long is rather trivial. However this was found to be an incorrect assumption.