

MULTI-MODE CAVITY DESIGN AND CHARACTERIZATION

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Abstract

We present the design and characterization of a multi-mode S/C-band cavity, operated at 2.8 GHz fundamental and 5.6 GHz harmonic. Superfish and COMSOL simulations were used to optimize the cavity's geometry with the goal of balancing various design parameters, such as Q -factor and cross-coupling. The results of bench tests of the fabricated cavity, including bead-pull, are presented.

INTRODUCTION

The concept of a dual frequency radiofrequency (RF) gun was proposed and developed for manipulating the bunch phase space and hence for attaining enhanced electron beam brightness [1–3]. More generally, multifrequency accelerator structures can perform a variety of functions, including energy spread dampening, bunching, and increased acceleration [4, 5]. Of particular interest are the following mixed-mode RF systems. Energy spread dampening (most often studied utilizing TM010 and TM012 modes) provides finer control over the energy distribution of the beam, crucial for experiments requiring precise control over particle energy. Positive net energy bunching (studied in this work utilizing TM010 and TM011 modes), enables more linear chirping of a beam for bunching of particles while also providing acceleration. Generally, utilizing multiple modes allows for tailoring the acceleration and manipulation of the particle beam specifically for a given objective or experimental requirement. While conceptually straightforward, such designs have not been widely realized and vetted in practice, because building and tuning such cavities poses significant challenges. In this paper, a successful multimode GHz-range cavity design and its basic characterization are presented.

CAVITY DESIGN

The fundamental mode represents the lowest-order transverse electromagnetic mode in a resonant cavity. For a cylindrical

cavity, the TM010 mode corresponds to the fundamental axial mode, where the electric field is aligned longitudinally and the magnetic field is in the transverse direction. For our cavity, the fundamental mode is at a resonant frequency of 2.81 GHz. This frequency is determined by the dimensions and geometry of the cavity. This mode was coupled using a magnetic loop coupler, which is positioned near the cavity wall, oriented such that the dot product of the loop's area, with the direction of the cavity mode's magnetic field, is non-zero. Loop couplers, generally, allow for the efficient transfer of RF power into the cavity, and the coupling can be changed by rotating the orientation of the loop with respect to the cavity's magnetic field.

The harmonic mode, exhibiting additional nodes and antinodes throughout the cavity, results in more complex electric and magnetic field distributions. The designed cavity support the second-harmonic TM011 mode resonates at 5.62 GHz, an integer multiple of the fundamental frequency. In contrast to the coupling mechanism of the fundamental mode, the harmonic mode is coupled via its electric field. An electric field probe, consisting of an isolated wire, is used to couple the mode. The coupling strength may be varied by changing the length of the antenna.

By coupling each mode to its own coupler, the amplitude and phase of each mode can be independently controlled. The specific locations of these couplers were chosen based on the relative magnitude of the fields of each mode. By placing each coupler at locations where its specific mode had a high field and the other mode had low field, the transmitted power between each coupler, or cross-coupling, is minimized.

Two tuners are used to tune the cavity such that the fundamental is at the desired frequency, and the harmonic is at an integer multiple of the fundamental frequency. One tuner changes the fundamental and harmonic modes' frequencies in opposite directions. Another tuner adjusts both the fundamental and harmonic modes' resonant frequencies in the same direction. A linear combination of the two tuners can then be used, therefore, to achieve both the desired frequency

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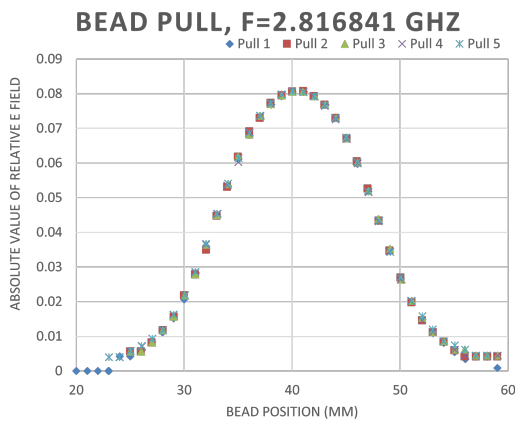


Figure 1: Five bead pulls were performed at 2.81 GHz using a 5mm diameter beam in 1 mm steps.

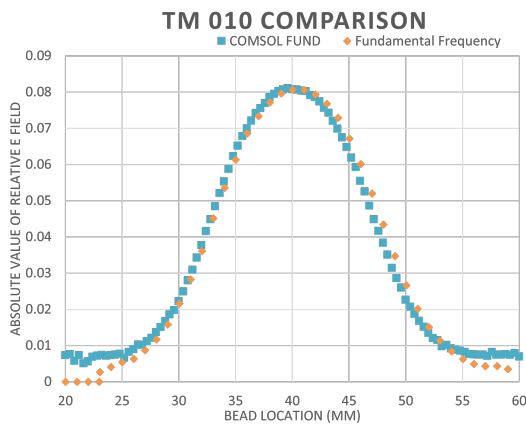


Figure 2: The results of the five fundamental mode bead pulls were averaged and compared to those obtained in COMSOL.

of the fundamental and exact integer harmonic frequency for the higher mode. Beyond that, inclusion of tuners allows both correction for manufacturing tolerances, and for operation at different duty factors and accelerating gradients.

CAVITY CHARACTERIZATION

Bead pulls were performed to confirm the desired modes within the cavity were being excited, and that their on-axis field profiles matched simulation. A 5-mm diameter metallic bead was pulled in 1 mm steps through the cavity 5 times for both the fundamental mode and its harmonic. The results can be seen in Figs. 1, 2 for the fundamental, and Figs. 3, 4 for the harmonic. These results were then averaged and compared to a similar bead pull done numerically using COMSOL. The results from COMSOL were scaled to match the same peak relative E -field measured. Comparison revealed a very good agreement between the simulated and fabricated cavity performances.

Preliminary measurements of Q_0 -factor for both the fundamental mode and the harmonic yielded numbers around 6,000. Additional refining is underway to gain experience with tuning the cavity.

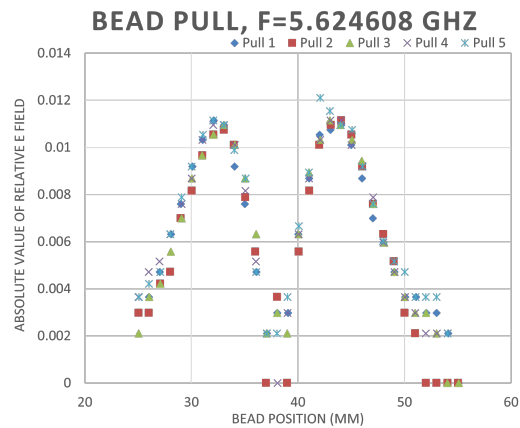


Figure 3: Five bead pulls were performed at 5.62 GHz using a 5mm diameter beam in 1 mm steps.

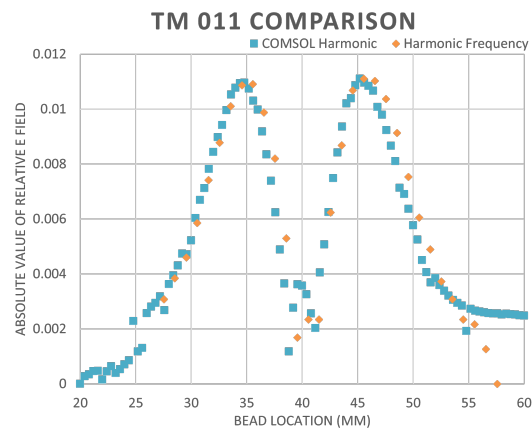


Figure 4: The results of the five harmonic bead pulls were averaged and compared to those obtained in COMSOL.

FUTURE WORK

As for future work, there are several tasks to be addressed. Firstly, there is a need to refine the couplers. This entails fine-tuning the coupler assemblies to optimize coupling strength and reliability. Secondly, conducting pulsed-mode measurements. Such measurements are valuable for understanding transient effects. Lastly, high-average-power testing with GHz transistor amplifiers is planned. This testing involves subjecting the amplifiers to high-power operation to assess their performance, reliability, and durability.

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