FUNDAMENTAL DAMPER POWER CALCULATION OF THE 56MHZ SRF CAVITY FOR RHIC *

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Abstract

At each injection period during RHIC's operation, the beam's frequency sweeps across a wide range, and some of its harmonics will cross the frequency of the 56MHz SRF cavity. To avoid excitation of the cavity at these times, we designed a fundamental damper for the quarter-wave resonator to damp the cavity heavily. The power extracted by the fundamental damper should correspond to the power handling ability of the system at all stages. In this paper, we discuss the power output from the fundamental damper when it is fully extracted, inserted, and any intermediate point.

INTRODUCTION

A Fundamental Damper (FD) will greatly reduce the cavity's Q factor to ~300 during the acceleration phase of the beam. However, when the beam is at store and the FD is removed, the cavity is excited by both the yellow and the blue beams at $2\times0.3A$ to attain the required 2MV voltage across its gap [1]. The cavity then is operated to increase the luminosity of the RHIC experiments. Table 1 lists the parameters of the FD.

Table 1: Fundamental Damper Parameters.

Parameters	Value [cm]
loop length	7.7
loop height	7.7
loop width	4.0
distance of FD center to end of cavity	20
distance between loop top and the cavity (fully inserted)	1.1

Figure 1 shows the configuration of the FD fully inserted into the 56MHz SRF cavity; this complete insertion is defined as the start location (0cm) of FD simulation, an assumption we make throughout this paper.

The power consumed by the cavity while maintaining the beam's energy and its orbit is compensated by the 28MHz accelerating cavities in the storage ring.

The power dissipation of the external load is dynamic with respect to the position of the FD during its extraction. As a function of the external Q and the EM field in the cavity, the power should peak with the FD at a certain vertical location. Our calculation of the power extracted is detailed in the following sections.

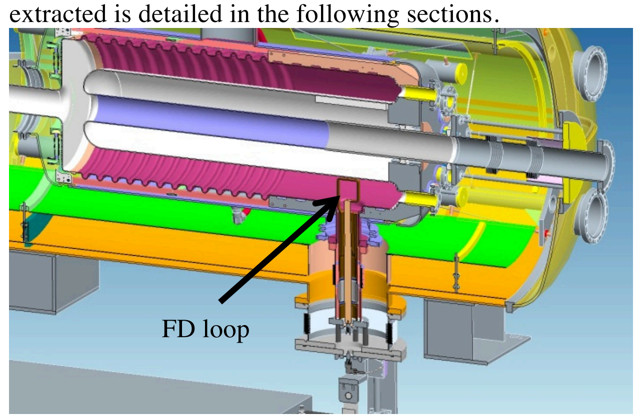

Figure 1: Cross section of 56MHz cavity with the Fundamental Damper fully inserted.

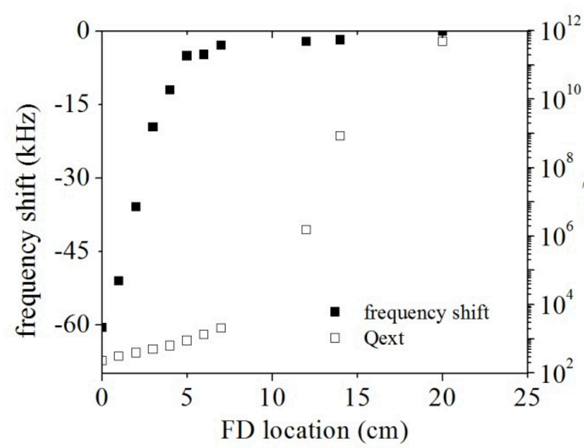

Figure 2: 1. Solid squares: Frequency shift versus the various insertion locations of the FD. 2. Open squares: External Q of the FD port versus the various insertion locations of the FD.

Figure 2 plots the frequency change in the cavity, and the external Q against the changes in position of the FD. The location of the FD is selected carefully such that the frequency will approach the designed working point from the lower side only [2]. The loaded Q of the cavity is 223 when the FD is fully inserted.

The simulation was carried out with Microwave Studio 2010 [3].

CALCULATIONS AND SIMULATIONS

For design purposes, the voltage across the inner and outer conductor of the 56MHz cavity should be evaluated at all stages of moving the FD in the cavity.

*Work supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE.
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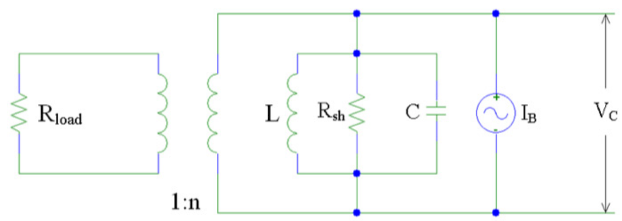

Figure 3: Circuit diagram representing the 56MHz cavity with the FD inserted.

Figure 3 is a lumped circuit model representing the cavity with only the FD inserted.

For simplification, we removed the transformer and replaced the resistance load by a transformed load of R_{sh}/β [Figure 4].

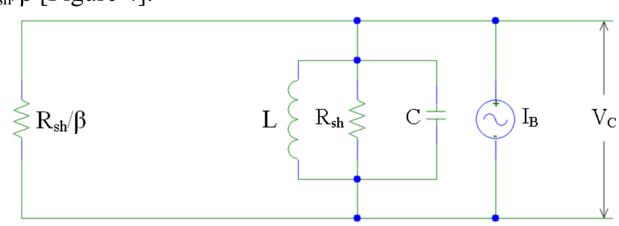

Figure 4: Simplified circuit diagram representing the cavity with the FD inserted.

The coupling factor β in the simplified circuit is

$$\beta = \frac{P_e}{P_c} = \frac{Q_0}{Q_e} \tag{1}$$

For a bare cavity

$$\frac{R_{sh}}{Q_0} = 2\sqrt{\frac{L}{C}} \tag{2}$$

where Rsh/Q can be obtained from the MWS simulation. By definition in the accelerator form, Rsh/Q is 80Ohm for the 56MHz cavity. Together with the equation for the cavity resonance frequency $\omega_0 = 1/\sqrt{LC}$, we can calculate the value for the inductor in the circuit to be 113nH.

The loaded cavity impedance is

$$Z_c = \frac{\beta + 1}{R_{sh}} + j\left(\omega C - \frac{1}{\omega L}\right) \tag{3}$$

Inserting in Equation (1) and (2), we can rewrite the impedance as

$$Z_c = \frac{\omega_0 L}{\frac{1}{2}Q_L^{-1} - j\Delta} \tag{4}$$

with $\Delta = 2\frac{\omega-\omega_0}{\omega}$ describes the detuning of the cavity. ω_0 is the cavity resonance frequency, and ω is the frequency of the beam's harmonic. Q_L is the loaded Q of the cavity.

Then, the beam induced voltage on the cavity would be

$$V_C = \frac{Z_C(2I_B)}{\sqrt{2}}$$

with I_B being the beam current. For the RHIC, I_B would be 2×0.3A, contributed by both the yellow and blue ring.

The energy in the cavity E_C is distributed in the LC loop, therefore

$$\begin{aligned} E_C &= \frac{1}{2} C V_C^* V_C \\ &= \frac{1}{4} I_B^2 C \frac{\omega_0^2 L^2}{\frac{1}{4} Q_L^{-2} + \Delta^2} \\ &= \frac{L I_B^2}{Q_L^{-2} + 4\Delta^2} \end{aligned}$$

At any moment, this equation gives the cavity's stored energy with respect to the loaded Q. It also takes into account the detuning of the cavity. .

With our particular design of the tuning plate in the front of the 56MHz cavity, the maximum frequency shift can be as high as 23kHz. Applying the full measure of detuning, with a Q_L of 223, the cavity's stored energy is 1.9mJ, i.e., small enough to dampen the cavity to a level that does not affect the beam.

Figure **5** shows the dependence of stored energy on the location of the FD during extraction. At all FD positions, the tuning plate provides 23kHz detuning to the cavity.

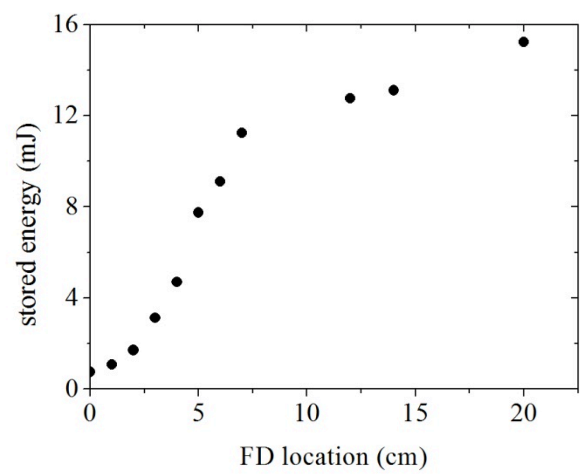

Figure 5: Stored energy in the cavity versus various locations of the FD during extraction, with 23kHz of detuning from the tuning plate.

The power extracted from the cavity is dissipated into the transformed external load R_{sh}/β. The power then is determined from Equation (4) as

$$\begin{aligned} P_{extract} &= \frac{Z_C^* Z_C I_B^2}{R_{sh}/\beta} \\ &= \frac{2\omega_0 L I_B^2}{Q_e(Q_L^{-2} + 4\Delta^2)} \end{aligned} \tag{5}$$

As a consequence of the change in the extracted power, the voltage across the inner and outer conductor of the

FD, V_{load}, varies as the loop changes its vertical position. This voltage for a 50Ω external load is

$$|V_{load}|^2 = P_{extract}R_{load} = 50\Omega \frac{2\omega_0 L I_B^2}{Q_e(Q_L^{-2} + 4\Delta^2)} \tag{6}$$

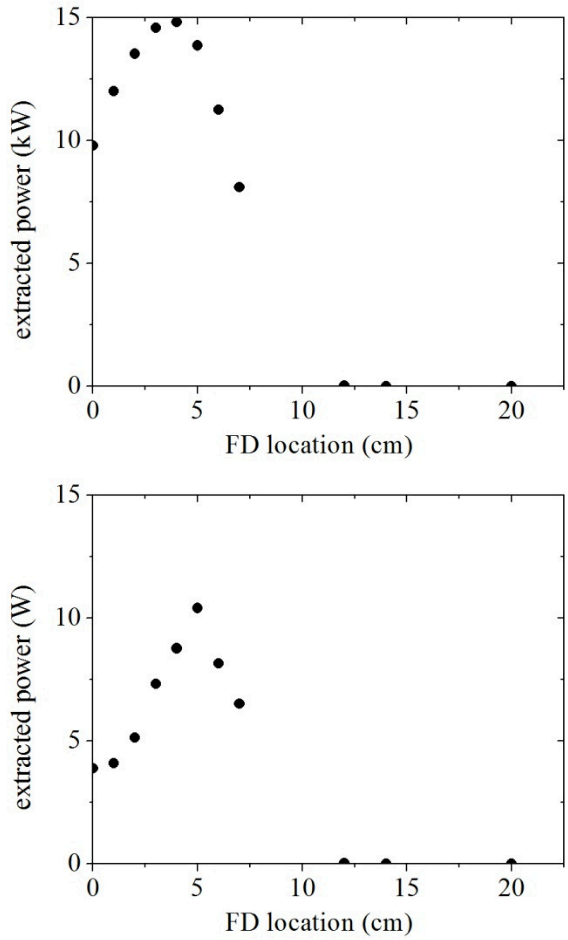

Figure 6: Upper: Extracted power to the external load of the FD system versus various locations of the FD. Top: Only 23kHz detuning from the tuning plate; Bottom: Both 23kHz detuning and the frequency shift due to the FD.

The power that will be dumped in the external load varies as the location of the FD changes during extraction. Figure 6 illustrates the power value in relation to the location of the FD.

With both the detuning of the tuning plate and the frequency shift due to inserting the FD, we found that the extracted power peaks at 10.4kW when the FD is withdrawn by 5cm from its fully inserted position.

Figure 7 shows the voltage across the FD's inner and outer conductors. The voltage V_{load} does not exceed 860V, thereby assuring a peak current of 17A through the circuit.

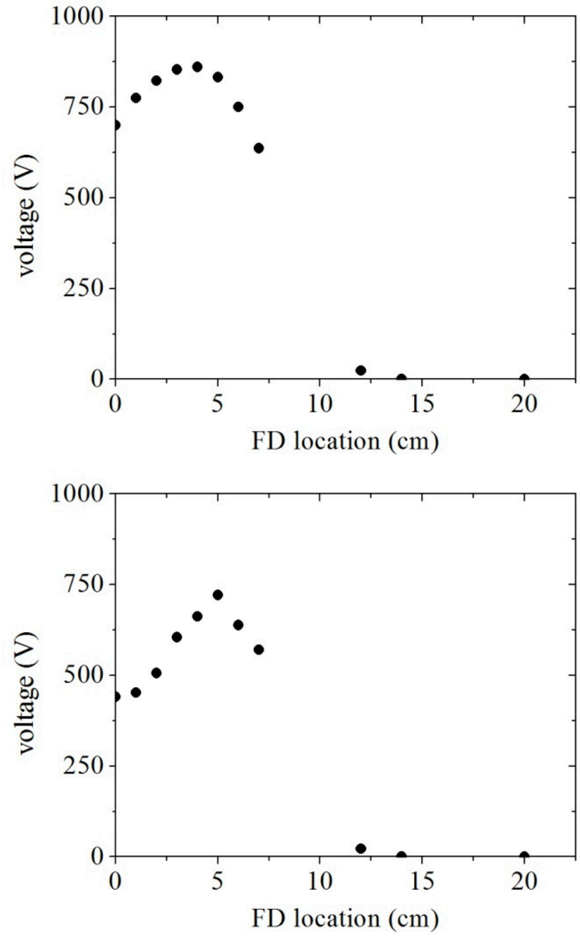

Figure 7: Voltage across the inner and the outer conductor of the FD plotted against various FD locations. Top: Only 23kHz detuning from the tuning plate. Bottom: Both 23kHz detuning and the frequency shift due to the FD.

CONCLUSION

The current FD design for the 56MHz SRF cavity for RHIC delivers significant power to the external load during its extraction. The power peaks at 10.4kW and, correspondingly, the voltage between the inner and outer conductors peaks at 860V correspondingly. We realized this peak power and voltage when we withdrew the FD by 5cm from its fully inserted position.

REFERENCES

[1] I. Ben-Zvi, *Superconducting Storage Cavity for RHIC*, Tech. Rep. 337 (Brookhaven National Laboratory, Upton, NY 11973 USA, 2004).

[2] E. Choi, H. Hahn, Tech. Rep. 314 (Brookhaven National Laboratory, Upton, NY 11973 USA, 2004).

[3] CST Microwave Studio Suite 2010.