Superconducting Accelerating Cavity Pressure Sensitivity Analysis

J. Rodnizki, Z. Horvits, Y. Ben Aliz, A. Grin, L. Weissman

Soreq NRC, Yavne 81800, Israel

INTRODUCTION

The SARAF Prototype Superconducting Module (PSM) Houses six 176 MHz Half Wave Resonators (HWR) and three Super Conducting (SC) 6T solenoids(1). The PSM accelerates protons and deuterons from 1.5 MeV/u to 4 and 5 MeV(2). The HWRs are highly sensitive to the coolant liquid Helium pressure fluctuations which might limit the available current to 1-2 mA depending on the output energy. Since new 4 kW amplifiers were installed at SARAF(3), reducing the cavity sensitivity may enable SARAF to increase the available current towards 4 mA beams.

To analyze the effect of the HWR eigen mode frequency sensitivity to helium pressure the following formula is used(4):

$$P_g = \frac{V_c^2}{R_{sh}} \cdot \frac{(1+\beta)^2}{4\beta} \cdot \frac{1}{\cos^2\varphi}\left\{\left[\cos\theta + \frac{I_b R_{sh}}{V_c(1+\beta)}\cos^2\varphi\right]^2 + \left[\sin\theta + \frac{I_b R_{sh}}{V_c(1+\beta)}\cos\varphi\sin\varphi\right]^2\right\}$$

where P_g is the power required to excite the cavity, V_c is the cavity voltage, R_{sh} is thecavity shunt impedance, β is the cavity coupling constant, I_b is the beam current, and θ is the relative phase angle between the point of maximum acceleration of the cavity RF and the center of the beam bunch being accelerated, and φ is the cavity detuning angle
(microphonics).

The effect of the detuning angle φ due to microphonics including the sensitivity to helium pressure Δf_{pk-pk}, $\varphi = \tan^{-1}(\Delta f_{pk-pk}/(f_0/Q_{load}))$, is given in fig. 1 for a set of cavity parameters of the PSM HWR as measured in SARAF and simulated by CST MWS(5): $Q_0 = 5*10^8$, V_c=850kV, I_b= 4mA, R_{sh}/Q_0= 163, $\beta = Q_0/Q_{ext}$ and a synchronous phase $\theta = -20^o$.

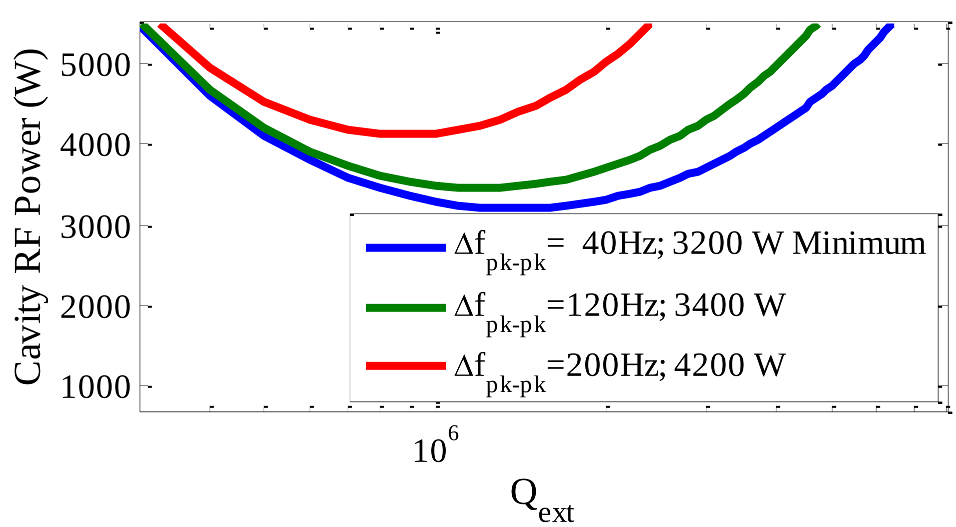


Figure 1. The required cavity RF power for 40, 120 and 200 Hz peak-to-peak microphonics detuning amplitudes, including helium pressure fluctuations.

The SARAF HWRs are extremely sensitive to LHe pressure fluctuations. Detuning signal is dominated by the Helium pressure drift. Detuning sometimes exceeds +/-200 Hz (~ +/-2 BW). The cavity FWHM is evaluated by: $2\Delta\omega = \omega_0 / Q_{load} = 130 Hz$. The measured sensitivity to helium pressure is 60 Hz/mBar as shown in figure 2[6].

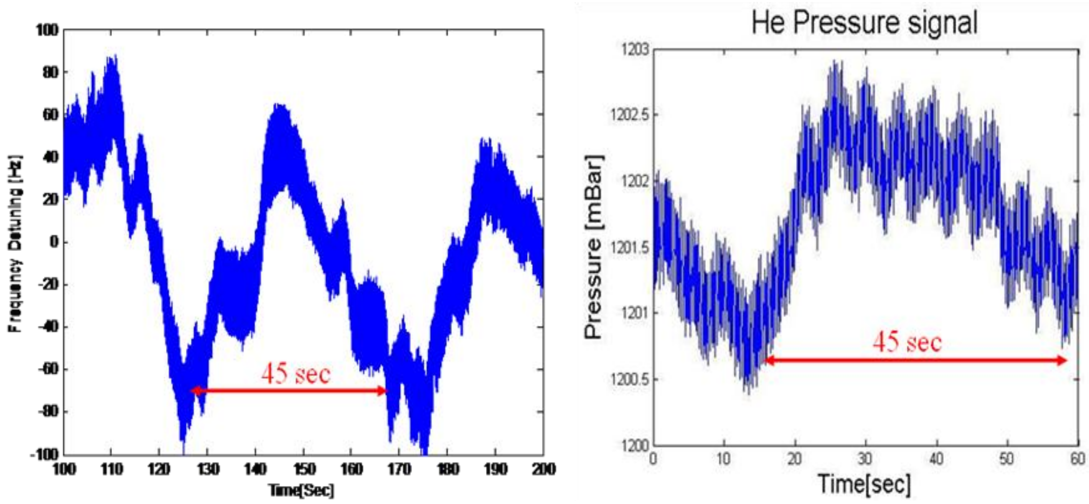


Figure 2. HWR Microphonics measurements (taken from [6]).

ANALYSIS

The high cavity sensitivity is due to the cavity asymmetric radial structure in the vicinity of the beam line. The flat shape of the cavity along the beam line in the area of the high electric field (fig. 3) generates the high sensitivity of the Eigen mode frequency to helium pressure.

The evaluation of the cavity Eigen mode frequency sensitivity to helium pressure fluctuation is based on the following:

The radiation pressure on the cavity surface due to EM fields is evaluated by [7]:

$$P = \frac{1}{4}(-\varepsilon_0 E^2 - \mu_0 H^2)$$

The Eigen mode frequency deviation due to helium hydrostatic pressure HWR cavity surface deformation is evaluated by [7]:

$$\frac{\Delta\omega}{\omega} = \frac{\Delta U}{U} = \frac{1}{4U}\int_{\Delta V}\left(\varepsilon_0 E^2 - \mu_0 H^2\right)dV = \frac{1}{4U}\int_S \left(\varepsilon_0 E^2 - \mu_0 H^2\right)\delta_{norm} ds$$

The HWR EM fields as simulated with the CST MWS. The fields as shown in fig. 3 demonstrate high electric fields in the vicinity of the flat shape of the external conductor around the beam line. In this region the external conductor deformation due to helium hydrostatic pressure gain the maximal value as shown in figure 4. The cavity evaluated sensitivity is in full consistent with the HWR measured values (60Hz/mBar). The found cavity sensitivity values are:

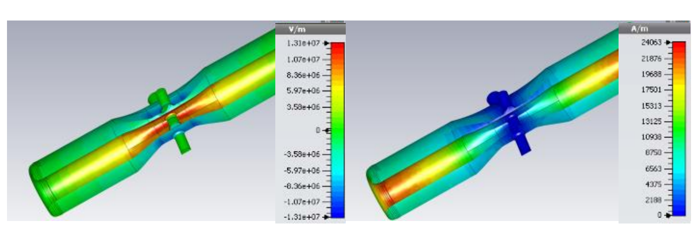


Figure 3. HWR E (left) and H (right) fields.

$$\frac{\partial f}{\partial P} = -60.6\frac{Hz}{mBar}$$

$$P = 10 mBar \Rightarrow$$

$$\delta_{normbeamline} = -0.7\mu$$

$$\delta_{normmax} = -0.98\mu$$

$$\sigma_{\max} = 0.56 MPa$$

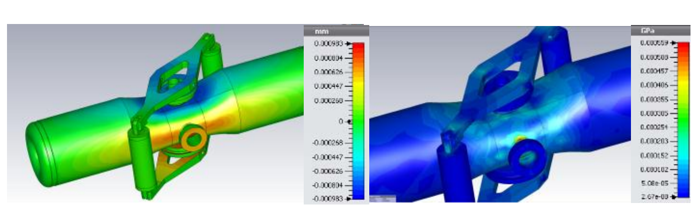
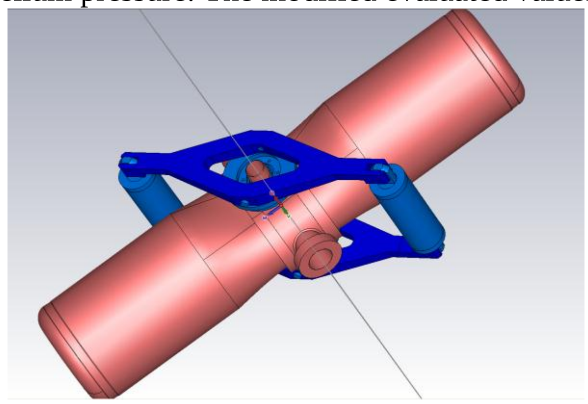


Figure 4. The normal deformation and the stress due to hydrostatic helium pressure.

Increasing the rigidity of the tuning fog and adding ribs at the vicinity of the beam line (fig. 5) may reduce the sensitivity of the HWR to helium pressure: The modified evaluated values are:



$$\frac{\partial f}{\partial P} = -21\frac{Hz}{mBar}$$
$$P = 10mBar \Rightarrow$$
$$\delta_{normbeamline} = -0.15\mu$$
$$\delta_{norm\max} = -0.38\mu$$
$$\sigma_{\max} = 0.34Mpa$$

Figure 5. A double thick fog with enforced ribs at the cavity neck.

The tuning system operation effect due to helium pressure is demonstrated in fig. 6 for 200 μm tension displacement, both sides both step motor and piezo and 1.2 bar He pressure. This simulation may be used to explore the stresses on the cavity due to cool down and warm up procedure as used in SARAF. The found sensitivity values for the original cavity and tuning system are:

$$P = 1.2Bar$$
$$\delta_{piezo\,step\,motor\,both\,sides} = 200\mu \Rightarrow$$

$$\delta_{normbeamline} = 39\mu$$
$$\delta_{norm\max} = 39\mu$$
$$\sigma_{\max} = 62.4MPa$$
$$\Delta f = -5.302kHz$$

Table 1summarizes the three simulations scaled to 1.2 Bar.

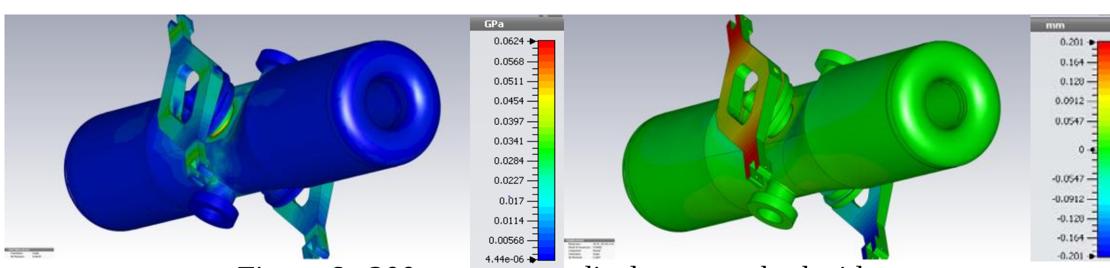


Figure 6. 200 μm tension displacement, both sides both step motor and piezo and 1.2 bar He pressure

Table 1. The three simulated cases scaled to 1.2 Bar

Simulated Case	Δf (kHz)	$\sigma_{\max}$ (MPa)	δ_{beam} (μ)	$\delta_{\max}$ (μ)
Original cavity	-73	67	84	120
Rigid cavity and fog	-25	41	18	46
Original cavity + 200μ tuning tension excitation	-5.3	62	39	39

CONCLUSIONS

The measured sensitivity of the cavity was evaluated and it is full consistent with the measured values. It was explored that the tuning system (the fog structure) has a significant contribution to the cavity sensitivity. By using ribs or by modifying the rigidity of the fog we may reduce the HWR sensitivity. During cool down and warming up we have to analyze the stresses on the HWR to avoid plastic deformation to the HWR since the Niobium yield is an order of magnitude lower in room temperature.

REFERENCES

1. M. Pekeler et al., DEVELOPMENT OF A SUPERCONDUCTING RF MODULE FOR ACCELERATION OF PROTONS AND DEUTERONS AT VERY LOW ENERGY, Proceedings of LINAC2006, Knoxville, Tennessee USA, 2006.
2. D. Berkovits et al., OPERATIONAL EXPERIENCE AND FUTURE GOALS OF THE SARAF PROTON / DEUTERON LINAC, Proceedings of LINAC2012, Tel-Aviv, Israel,
3. I. Fishman, I. Gertz, B. Kaizer, D. Har-Even, HIGH POWER AMPLIFIER SYSTEMS FOR SARAF PHASE II, LINAC2012 Tel Aviv, Israel, 2012.
4. M. P. Kelly et al, “Microphonics in the ATLAS Upgrade Cryomodule, Proc. of the 14th International SRF Conference, Berlin, Germany, 2009.
5. CST STUDIO SUITE Version 2013 http://www.cst.com.
6. A. Perry et al., SARAF SUPERCONDUCTING MODULE COMMISSIONING STATUS, Proc. of the 14th SRF Conference, Berlin, Germany, 2009.
7. H.Gassot, MECHANICAL STABILITY OF THE RF SUPERCONDUCTING CAVITIES, Proceedings of EPAC 2002, Paris, France.