SIMULATION OF CAVITY CONDITIONING FOR THE DIAMOND SCRF CAVITY

S. A. Pande[†1], C. Christou, P. Gu, Diamond Light Source Ltd., OX11 0DE Didcot, UK
[1]also at Lancaster University, LA1 4YW Lancaster, UK

Abstract

Diamond SCRF cavities are pulse conditioned every week in order to keep them operating reliably. During conditioning, the cavities are detuned in order to sweep the standing wave through the waveguide. To match these cavities at lower voltage (typically < 1.4 MV) and at higher power, 3 stub tuners are used in the waveguide feed. Simulations with CST studio reveal that a strong SW field exists between the RF window and the matching posts. As the cavity is detuned the electric field maximum passes through the window causing heating of the ceramic. Temperature measurements with thermal camera reveal that the temperature of the window increases to maximum when the cavity is detuned towards higher frequency. Based on the simulation results and the measurements, it was decided to reduce the conditioning voltage. The simulation and measurement results are summarised.

INTRODUCTION

For reliable operation, the Diamond SCRF cavities are operated at relatively lower voltage, typically between 0.8 MV and 1.4 MV. During normal operation at 300 mA, the total power to be supplied by the RF system is in excess of 450 kW. With some amount of reflected power, each cavity has to supply in excess of 225 kW. These cavities have fixed coupling with $Q_{ext} \sim 2.3e+05$. The operation at lower voltage necessitates the use of 3 stub tuners to lower the Q_{ext} to push the matching condition towards higher power. This results in a strong Standing Wave (SW) between the post / stub and the cavity. At present, Cavity-1 and Cavity-3 are operating with Q_{ext} values of 1.1e+05 and 1.4e+05 respectively.

Initially, the cavities were pulse conditioned at 2.5 MV every week on Machine Development (MD) day to maintain their reliable operation. During conditioning, more than 99.9% power is reflected leading to a pure SW in the coupling waveguide. To condition the coupling waveguide, the cavity is detuned by ±70° to sweep the SW across it. The Pump Out Box (POB), which is a section of the coupling waveguide equipped with vacuum pump out arrangement and connects the window assembly to the cavity through the rest of the coupling waveguide. While conditioning, occasionally pressure spikes are observed on POB gauges which are typically conditioned out in few minutes especially on detuning of the cavity. However the background pressures in the POB always increase on detuning to +ve side on Cavity-1 and –ve side on Cavity-3. There is no change (or marginal decrease) in the pressure on detuning to the opposite side.
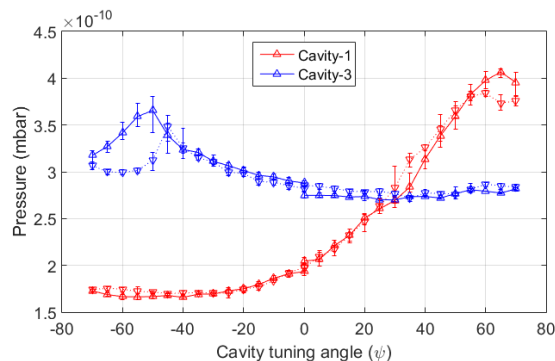
† shivaji.pande@diamond.ac.uk.

Figure 1: POB pressure vs detuning angle.

Figure 1 shows the POB pressures versus cavity tuning angle during one of such conditioning sessions at 2.3 MV. The continuous lines with upward pointing triangles show the POB pressure while going away from resonance and the dotted lines with downward pointing triangles show pressure while coming towards resonance. It can be seen that the effect is more pronounced in case of Cavity-1. The increase in the background pressure is observed irrespective of whether the pressure spikes are present or not. The occasional occurrence of the fast pressure spikes indicate some electronic (vacuum) activity inside the coupling waveguide. Whereas the increase in the background pressure points towards a thermal effect. In order to investigate the effect of detuning on the Standing Wave (SW) field pattern in the coupling waveguide and the window assembly, CST Studio [1] simulations were performed. The window temperatures were measured with the help of a thermal camera with and without the stub insertion while changing the cavity tuning angle.

EM SIMULATIONS

Figure 2 shows the CST model for the Diamond CSER cavity. The cavity is simulated with the Frequency Domain solver of CST Studio considering all the parts as lossy materials. To simulate the behaviour of the cavity during conditioning, the conductivity of the cavity with the beam tubes and a section of the coupling waveguide (shown in green colour in Fig. 2) is changed to a value which gives Q_0 = 6e+08 (the measured value). Following three cases have been considered:

- Cavity with uniform waveguide – No window and no 3 stub tuner.
- Cavity with RF window alone (No 3 stub tuner).
- Cavity with RF window and 3 stub tuner.

Once the resonant frequency (ω_0 or f_0) is determined,

the field distributions at different tuning angles (ψ) can be obtained with the help of following relation.
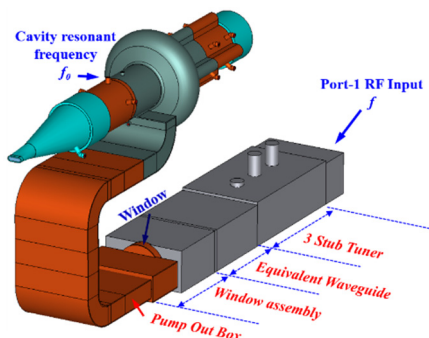
$$\tan(\psi) = -2Q_L \frac{(f - f_0)}{f_0}$$

Figure 2: CST Model of Diamond CESR Cavity.

The frequency samples are computed at frequencies $f > f_0$ for negative tuning angles and at $f < f_0$ for positive tuning angles as shown in Fig. 3 below.
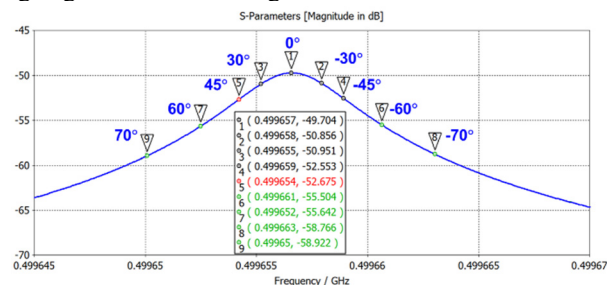

Figure 3: Frequency samples for different tuning angles.

RESULTS

In first case the cavity is simulated with a uniform waveguide i.e. with no RF window and no stub tuner. Figure 4 shows the electric field along the axis of the waveguide starting from cavity side. The high field at x=0 is the cavity field at the beginning of the coupling waveguide. The field is normalised for cavity voltage, Vc = 2.5 MV in all the cases.
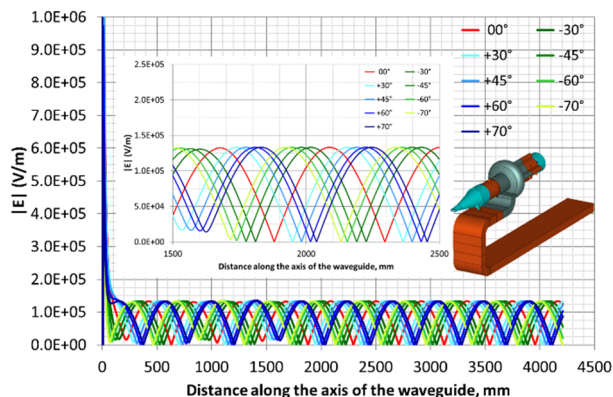

Figure 4: Electric field along the waveguide axis for uniform waveguide case.

Figure 5 shows the electric field along the waveguide axis for the cavity simulated with window but no 3-stub tuner. Figure 6 shows the case for the cavity with the window and one stub inserted. It can be seen from Fig.4
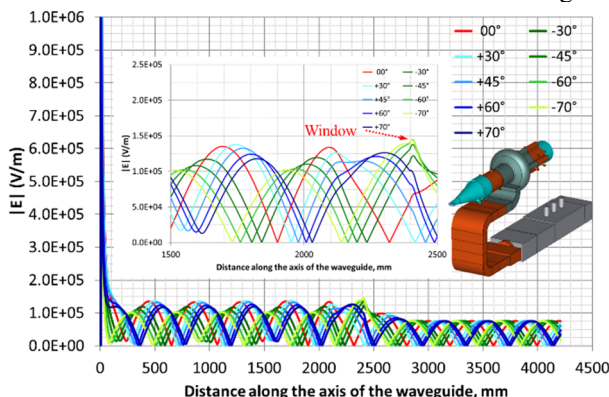

Figure 5: Electric field along the waveguide axis for cavity with window but stub tuner.
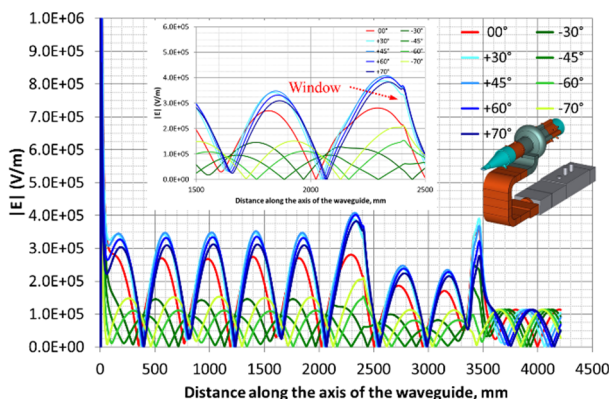

Figure 6: Electric field along the waveguide axis for cavity with window and the stub inserted.

Table 1: Qext for Different Cavity Configurations and Power Required for Vc = 2.5 MV

Configuration	Qext	Power (kW)
Uniform waveguide	1.86e+05	94
With RF window	2.35e+05	75
With window & Stub	1.10e+05	160

that the field minima / maxima move symmetrically about the resonance ($\psi = 0$) across the waveguide length for the cavity with no window or stub. Whereas Fig. 5 shows that the field minima are closely spaced when $\psi > 0$ and widely spaced when $\psi < 0$. Additionally, the field maxima are reduced for $\psi < 0$ as compared to those for the $\psi > 0$ case. The window assembly introduces a step in the coupling waveguide on the vacuum side [2]. The reflected wave from the cavity reflects back at this step and combines in phase for positive tuning angles and out of phase for negative tuning angles. The stub introduces much stronger reflections and redefines the SW pattern. This difference between the maxima on negative and positive detuning is seen more prominently from Fig. 6. The field

enhancement near the window is due to the presence of the matching posts. The Qext values and the power required (pulsed) to generate the conditioning voltage of 2.5 MV are listed in Table 1 for the cases studied.

Figure 7 shows the electric field in the window assembly for cavity with no stub (top) at ψ = -45° on the left and at ψ = 45° on the right and the same is shown for the case with one stub on the bottom. It can be seen that the electric field maximum falls near the window for ψ = 45° when the stub is inserted.
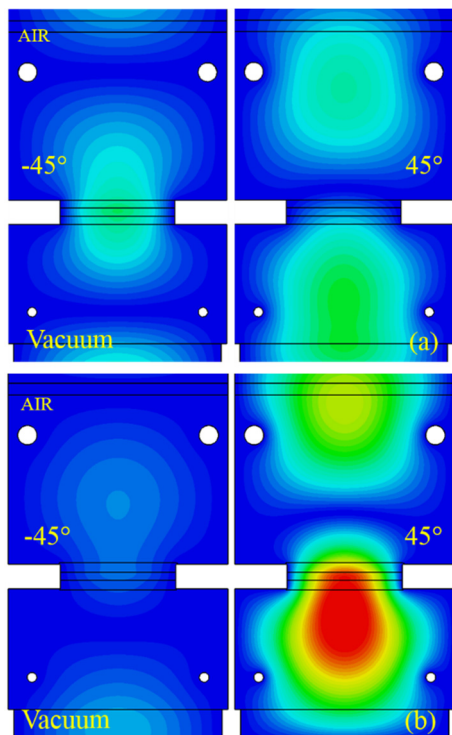

Figure 7: Electric field in the window assembly (a) No stub and (b) with stub.

TEMPERATURE MEASUREMENTS

The temperature of the RF window was measured while looking at the window from air side during conditioning at 2.5 MV and 10% duty factor (10/100 ms pulses). The pictures (1) and (2) in Fig. 8 were taken for ψ = -50° and 50° respectively when the stub was fully withdrawn and pictures (3) and (4) with the stub fully inserted for ψ = -50° and 50° respectively.

Figure 9 shows window temperature measured during conditioning for two cases, no stub shown by blue curve and with stub case shown by red curve. Comparing the red curve with the red curve in Fig. 1, it can be seen that the rise in background pressure correlates to the measured window temperature. The marginal drop in POB pressure about ψ= -40° is consistent with minimum temperature measured on the RF window.
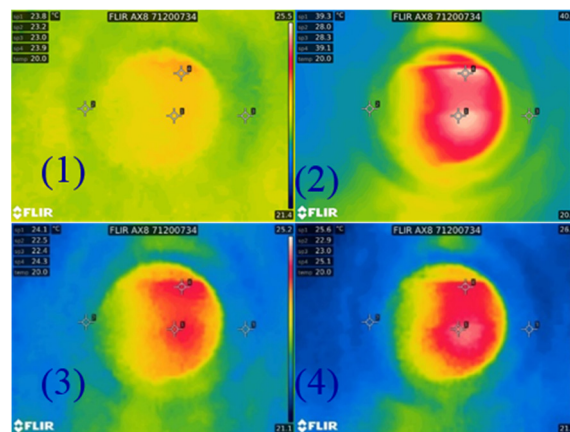

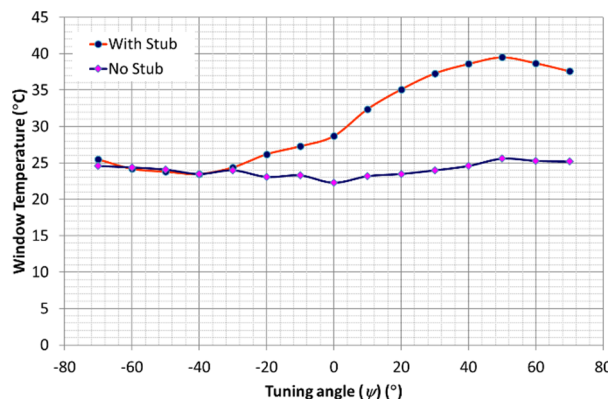Figure 8: Thermal camera images - (1) for the cavity tuning angle.

Figure 9: Measured window temperature during conditioning, blue curve - No stub case, red curve - with stub.

SUMMARY

The CST simulation results show that the SW maximum passes through RF window for positive tuning angles which is supported by the measured temperature of the window. Thus it can be concluded that the observed rise in the background pressure in the POB is due to the heating of the RF window. It can be seen from Table 1 that the power needed for conditioning with stubs is almost twice of that needed for conditioning without the stubs. Based on these studies it was decided to reduce the conditioning voltage from 2.5 MV to 2.3 MV in order to reduce the risk of window failure due excessive heating or breakdown.

REFERENCES

[1] CST Studio Suite, CST AG, https://www.cst.com
[2] S. A Pande et al., "Modifications to the Pump Out Box to Lower the Qext of Diamond SCRF Cavities", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 2251-2253, DOI:10.18429/JACoW-IPAC2016-WEPMB060