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MULTIPACTOR STUDY IN THE COUPLER REGION OF THE DIAMOND SCRF CAVITIES

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Abstract

The Diamond storage ring operates with two CESR-B type Superconducting RF cavities. The cavities suffer from trips with a sudden loss of accelerating field if operated above a certain voltage. Consequently the cavities are operated between 0.8 and 1.4 MV for better reliability. These cavities are iris coupled and have fixed Qext. At these lower operating voltages, the optimum condition for beam loading is satisfied at powers around 100 kW. For operation at 300 mA with two cavities, the power needed per system exceeds 200 kW. Consequently, 3 stub tuners are used to lower the Qext to move the optimum condition close to 200kW. Additionally, the difference in the height of the coupling waveguide on the cavity and that of the vacuum side waveguide on the window assembly results in a step transition. This step results in a standing wave between the cavity and window even at matched operation. The 3 stub tuner further modifies this standing wave. Numerical simulation reveals that the standing wave field from the cavity penetrates into the coupling waveguide increasing the probability of multipactor in this region. The results of multipactor simulations with CST Studio are discussed.

INTRODUCTION

The Diamond cavities suffer from fast vacuum trips if operated above a threshold voltage which lies between 0.8 to 1.4 MV [1]. A very sharp rise in pressure is recorded on the beam pipe gauges and also in the Pump Out Box (POB), which is a small section of the reduced height waveguide equipped with the ports for vacuum pumping connecting the RF window. For some of the trips, the pressure rise occurs only in the POB. Typically the cavity field collapses in few µs, a fraction of the cavity filling time appropriate for the Q_{ext} of the cavity. A fast data acquisition system based on NI PXI-5105 has been installed in the RF Hall to study the nature of these trips.

Figure 1 shows layout of the RF straight with cavities in positions 2 and 3. The numbers in blue show the gauge numbers. The gauge numbers 01, 21, 04, 06, 07, 09 and 10 are mounted on the beam pipe whereas gauge numbers 05 and 08 are mounted on the POBs of cavity-2 and cavity-3 respectively. Figure 2 shows the CST [2] model of the Diamond CESR Cavity with the RBT (Round Beam Tube) taper, the coupling waveguide, the RF window, the rest of the waveguide WR1800 and the 3-stub tuner. |The HOM loads are shown as cyan cylinders. Note the locations of various pickups. The HF pickup which has highest coupling is used for frequency and voltage control of the cavity. The WaveGuide e$^-$ (referred to as WGe$^-$ in the following) pickup is located just under the coupling tongue, (a specially shaped iris) to pick any electronic activity in this region. There are 2 HOM pickups located on the RBT and 4 on the FBT thermal transitions on the cavity. However, there are extra pickups included in the model to make the structure symmetric to reduce the size of the model. A pair of very weakly coupled pickups is located on the taper as shown.

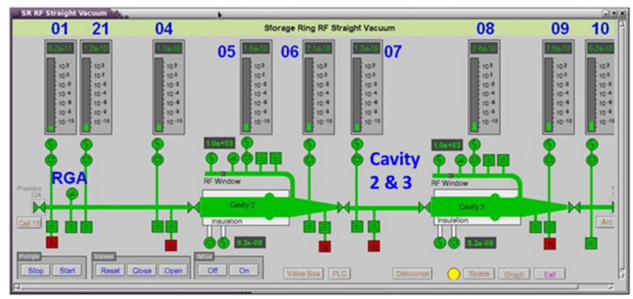

Figure 1: Layout of the RF straight with cavity 2 and 3 in place. The numbers in blue show the vacuum gauge numbers starting from cavity 1 (not shown) side.

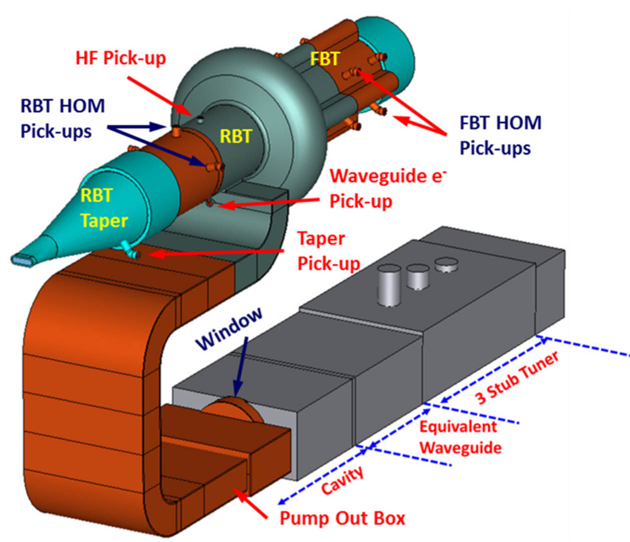

Figure 2: CST model of the Diamond CESR cavity with RBT taper, the coupling waveguide and different pickups.

The data recorded on the NI TDMS system shows the cavity field collapses typically in few µs, which is a fraction of the cavity filling time corresponding to the Q_{ext} of the cavity. These trips are characterised by a sharp signal recorded on the WGe$^-$ pickup. Figure 3 shows the signals recorded during such a fast trip on Cavity-3. The plot on the right shows from top, the Cavity-3 LLRF probe, FBT

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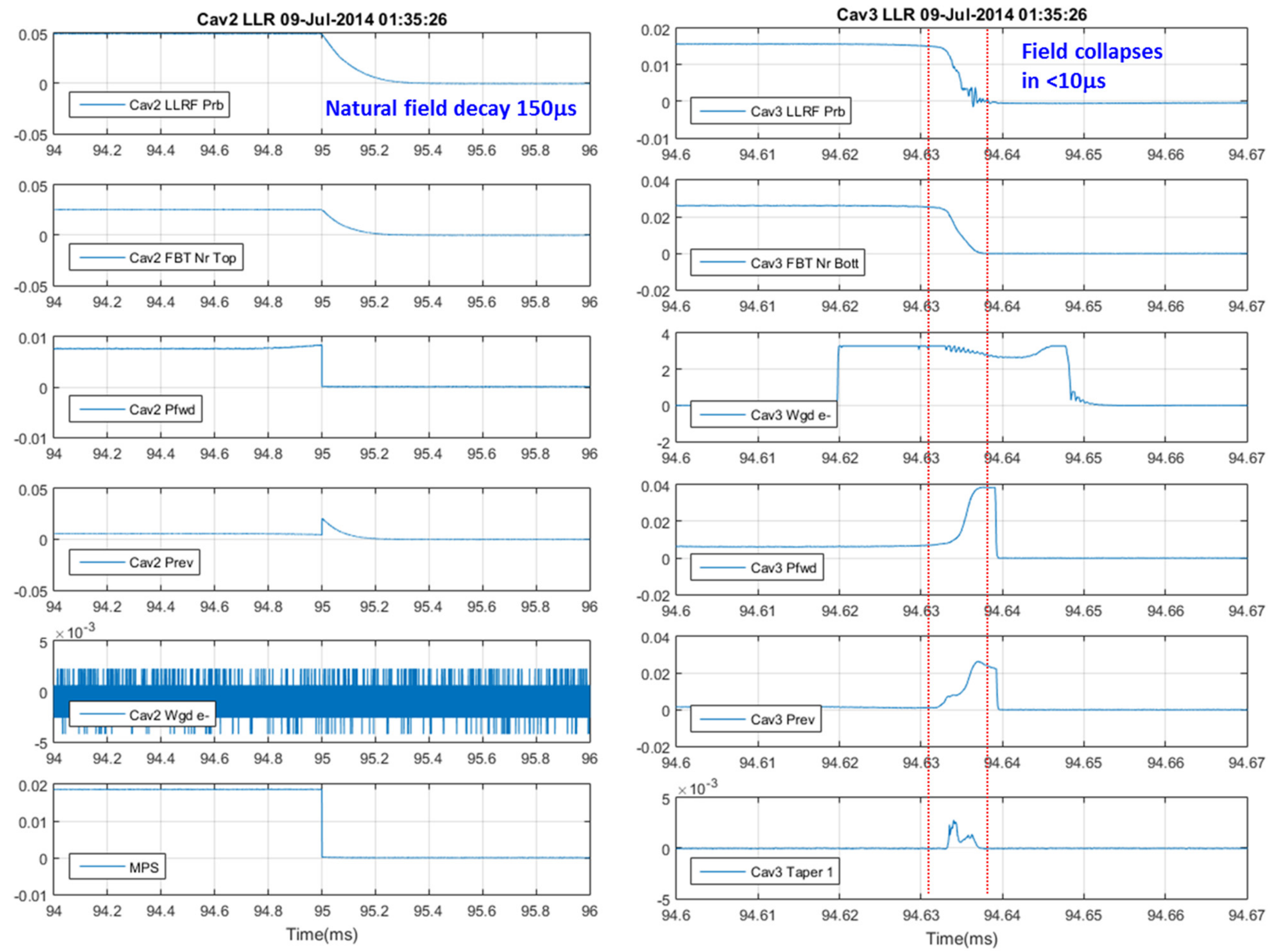

Figure 3: Signals recorded on NI TDM System on during a fast trip on Cavity-3. Plots on the right from top show the signals recorded on LLRF probe, FBT Near bottom, waveguide e$^-$, P_{for}, P_{ref} and Cavity-3 taper pickup. Plots on the left show the respective signals from Cavity-2. The last curve on the left is the MPS signal (see text for further details).

Near Bottom, WGe$^-$, P_{for}, P_{ref}, and the Taper pickup. The top two curves show that the cavity field collapses in <10 µs and a signal appears on the WGe$^-$ pickup >10µs before and sustains for >10µs after the field collapse in the cavity. The WGe$^-$ signal is clipped in the figure. It can be seen that the P_{for} and P_{ref} (curve 4 and 5) vanish before the signal on WGe$^-$ drops. Coincident with the field collapse, a spike appears on the taper pickup. It should be mentioned here that the taper pickup falls after Cavity-3 HOM loads and so is very weakly coupled (< -150 dB). This makes it difficult for the EM fields from the cavity to reach at the location of the pickup. The Plot on the left shows the probe signals from Cavity-2 on a different time scale. After Cavity-3 is tripped on reflected power with fast pressure rise in RBT taper, beam orbit breaches the interlock level and the MPS (Machine Protection System) trips the amplifier 2 and the cavity-2 field decays naturally as seen from first two plots (from top) on the left. Investigation of similar fast trips on cavity-2 show a similar spike on Cavity-3 taper pickup. Occasional spikes on Cavity-3 FBT pickups coincident with the field collapse in cavity-2 are also observed. It is worth mentioning here that the normal beam dump or beam trip due to any other reason do not show such spikes on any of the pickups.

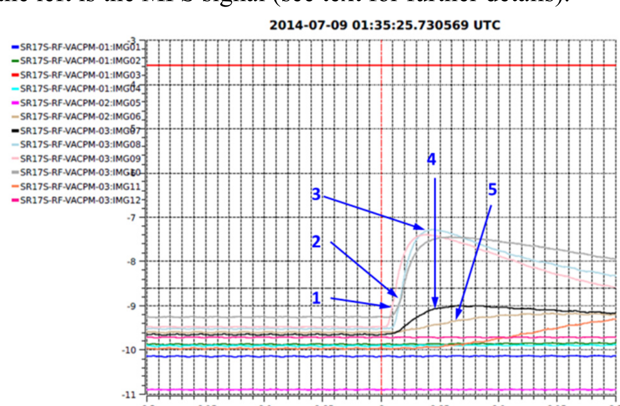

Figure 4: The vacuum post-mortem after Cavity-3 trip. The numbers in blue indicate the order in which the pressure rise is recorded on the gauges.

The frequency of such fast vacuum trips increases in Low-α mode of operation where the bunch length is much smaller and the cavity voltage is 1.7 MV, which is higher than that during the normal multi-bunch run.

Figure 4 shows the vacuum post-mortem for the same trip described above. The numbers in blue indicate the order in which the pressure rise is recorded on various

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gauges. The pressure rise is first recorded on gauge 09 (see Fig. 1 for gauge nomenclature) which is on Cavity-3 taper followed by gauges 10 and 08 which are on the vacuum chamber and Cavity-3 POB and then on gauges 07 and 06 which are on the beam pipe.

A sharp spike on the taper pickup just after or during the field collapse and the rise in pressure first recorded on the gauge mounted on the taper points towards some electronic activity in the cavity and the beam pipe region. The taper is the first component which the electrons moving parallel to the cavity axis will encounter.

The strong signal on the WGe^{-} pickup suggests a strong discharge / electron activity in its vicinity. The measured signal is in excess of 3 V at the NI TDMS system which is located in the RF Hall several tens of meters from the cavity. The measured attenuation of the cable between the cavity and the NI System is 14.5 dB indicating >5W power being deposited at the cavity end. Figure 5 shows the electric field in the DLS Cavity and part of the coupling waveguide computed with CST Studio FD solver for matched condition [2]. The Standing Wave (SW) field from the cavity penetrates into the coupling waveguide. Also a SW exists in the coupling waveguide even for the fully matched condition due to the step in the waveguide cross-section after connecting the RF window [3]. Multipacting (MP) in the coupler region could be one of the possible forms of discharge / phenomenon responsible for the observed signal on the e- pickup.

The Diamond cavities are equipped with the arc detector on the vacuum side of the RF window. However he arcs very rarely observed on the window. According to reference [4], in the pressure range of operation of the DLS cavities, the existence of multipactor is most likely. The other form of discharge e.g. the multipactor plasma or the RF gas discharge are observed in higher pressure region. It is also mentioned that at pressures below 2x10^{-6} mbar, the intensity of the light is very low.

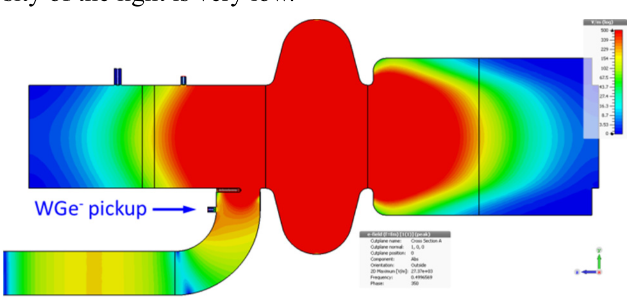

Figure 5: Electric field (Abs) in the cavity and the coupling waveguide for matched condition, Pin = 0.5W rms. The field maximum is clamped at 500V/M to highlight the field in the waveguide.

MULTIPACTING SIMULATIONS

The representative steady state fields for different operating conditions are obtained by CST Studio Frequency Domain (FD) solver considering the wall losses and the full geometry including the full coupling waveguide, the window assembly, the waveguide WR1800 (reduced to fraction of $\lambda_g/2$) and the 3 stub tuner. The following operating conditions are considered for these simulations.

a. A matched cavity without the stub tuner corresponding to Qext = 2.35e+05
b. Low-α case where the cavities are operated with no stubs corresponding to Qext = 2.35e+05 but with almost full reflection owing to lower beam current and
c. Under-coupled operation with reflection beyond the optimum condition with Qext ~1.3e+05.

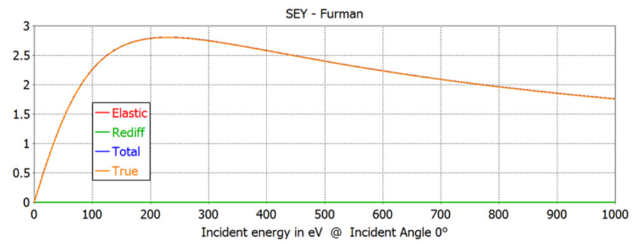

Figure 6: SEY of material Niobium Wet Treatment.

The built-in material in CST Studio 'SEE Niobium Wet Treatment' with Secondary Electron Yield (SEY) as shown in Fig. 6 is chosen for the flowing study.

Results and Discussion

Matched Cavity The steady state fields for matched condition without the 3 stub tuner are used. The multipacting simulations are carried out to saturation [5] using CST PIC solver with space charge. Figure 7 shows the number of particles vs time for cavity voltage (Vc) varied from 0.9 to 2.2 MV. As the required number of particles to achieve saturation increases with voltage, the number of primary electrons is increased to 86520 to save the simulation time for Vc > 1.4 MV whereas <20000 primaries are used for Vc ≤ 1.2 MV. The picture in the inset shows the CST model with the cuboidal volume (dark blue) under the coupling tongue in where the primary electrons are released over one RF period with the macro-particle ratio of 100000 fixed for all the cases studied.

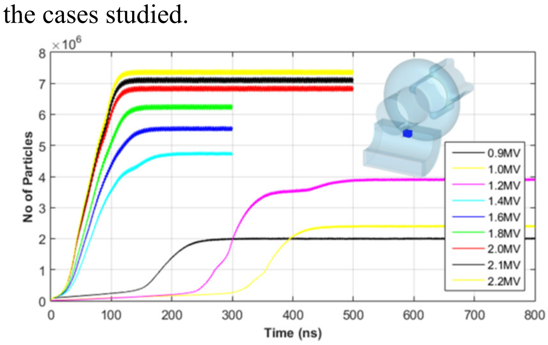

Figure 7: Number of particles vs time for VC = 0.9 to 2.2 MV for matched case. Different numbers of initial primary electrons are used in for voltage 1.0 and 1.2 MV.

The signal recorded on the WGe^{-} pickup as the MP develops is shown in Fig. 8. The signal strength increases as the impact energy and current of the secondary electrons increases with Vc. Figure 9 shows the multipactor through the RF cycle. In a fully developed discharge, high energy electrons enter the beam tube (RBT) through the coupling iris in the first half of the rf cycle and enter into to the wave-

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guide in the second half. The electrons entering the RBT gain more energy, accelerate away from the cavity and exit through the RBT. Tracking simulations suggest that the electrons entering the RBT always fly out of the RBT for voltage up to 3 MV. If such a discharge occurs in Cavity-2, the electrons can enter Cavity-3 where they can be further accelerated and encounter the taper on Cavity-3. The fraction of the electrons entering the waveguide sweep across the waveguide bend wall and part of it strikes the WGe pickup. Electrons with enough energy travel down and strike the opposite wall of the Nb waveguide bend. The MP can progress further down the waveguide and to the window region

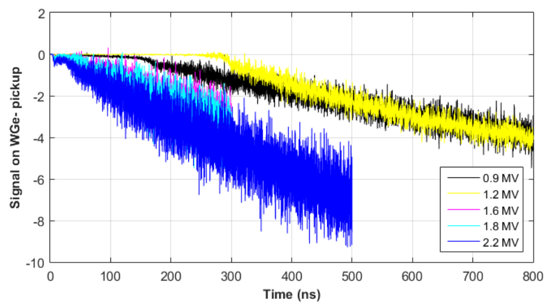

Figure 8: Signals recorded on waveguide e- pickup.

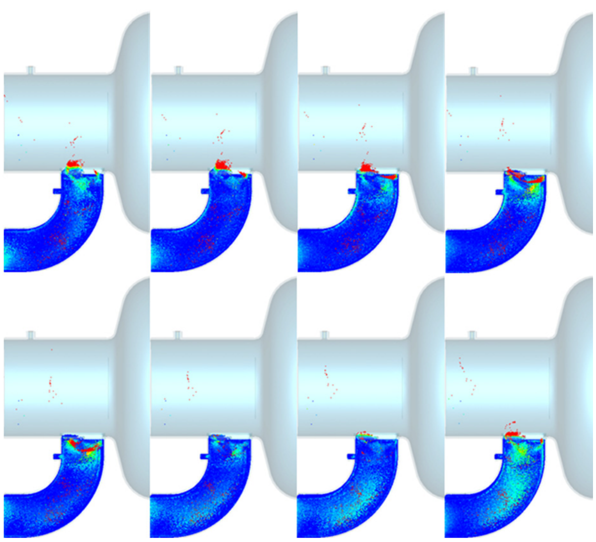
Figure 9: Multipacting electrons through the RF cycle. The electrons entering the cavity always fly away from the cavity through the RBT.

Over-coupled (**Low-α**) In this mode of operation the bunch length is much smaller than that during a normal run, the beam current is <20 mA and the cavities are operated at higher voltage, usually at 1.7 MV. The number of particles vs time for VC = 1.3 to 1.9 MV are shown in Fig. 10. Comparing with Fig. 7 the number of particles to reach saturation is almost half for similar voltage. This is due to the over-coupled operation of the cavity with same Q_{ext} as in the matched case but with almost full reflection where much less power is required to establish the same voltage.

Under-coupled As mentioned earlier, for routine operation the cavities are operated under-coupled with reflection at voltage <1.4 MV with Q_{ext} lowered with the help of 3-stub

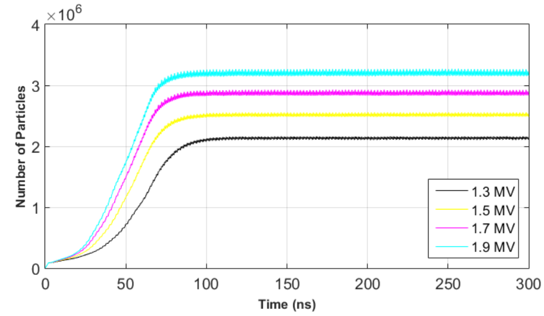

Figure 10: Number of particles vs time for VC = 1.3 to 1.9 MV for the over-coupled case.

tuners. Figure 11 shows the number of particles vs time for Vc = 1.0 to 1.4 MV for Cavity-2 with Q_{ext} = 1.3e+05. The corresponding forward power ranges from 96 to 187 kW.

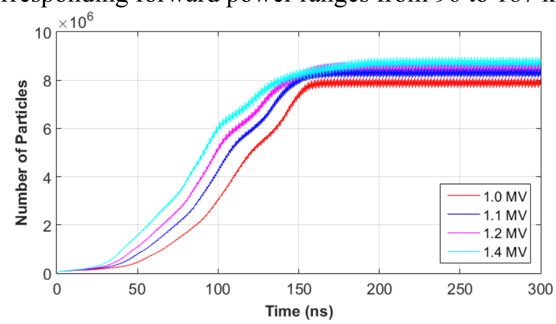

Figure 11: Number of particle vs time for VC = 1.0 to 1.4 MV for the over-coupled case.

SUMMARY

A fully developed multipacting discharge can produce a signal on the WGe- pickup. The electrons from the discharge enter the RBT and get accelerated away from cavity irrespective of operating mode, matched over-coupled or under-coupled. The appearance of signal on WGe- pickup several tens of µs before the collapse of the field in the cavity suggest that the discharge builds sufficiently over time. The observed signal on the taper pickup coincident with the field collapse could be the secondary effect of the discharge. The high energy electrons impinging on the RBT and the taper wall lead to gas desorption and subsequent ionisation due to strong RF field in the cavity. The ionised gas and electrons absorb the whole energy making the field to collapse. The electrons exit the cavity with high energy strike the taper to produce the observed spike on the taper pickup.

REFERENCES

[1] C. Christou *et al.*, “A hybrid superconducting/normal conducting RF system for the Diamond Light Source storage ring”, in *Proc. IPAC’16*, Busan, Korea, May 2016, paper WEPOW047.
[2] CST Studio Suite, CST AG, https://www.cst.com
[3] S. A. Pande and C. Christou, “Optimisation of window position on Diamond SCRF cavities”, in *Proc. IPAC’14*, Dresden, Germany, June 2014, paper WEPRI049.
[4] F. Honn *et al.*, “The transition of a multipactor to a low-pressure gas discharge”, *Phys. Plasmas* 4 (4), April 1997.
[5] S. Riyopoulos, “Multipactor saturation due to space-charge-induced debunching”, *Phys. Plasmas* 4 (5), May 1997.