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OPERATION OF DIAMOND SUPERCONDUCTING RF CAVITIES

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Abstract

The Diamond Light Source (DLS) storage ring has been in operation using superconducting RF (SRF) cavities since 2007. Diamond has four superconducting cavity modules with two usually installed at any one time. The four cavities perform differently in many aspects such as reliable operating parameters and time in service, with the longest in continuous service for 7 years without failure and the shortest failing after only 8 months. All Diamond superconducting RF cavities suffered many fast vacuum trips in their early years, but after many years of efforts, the performance of the cavities have now been effectively managed by cavity voltage level control, weekly conditioning and partial warm-up during shut downs . We will discuss our experience with superconducting RF cavities and our future plan.

INTRODUCTION

The RF straight of Diamond storage ring is designed to allow three CESR type SRF cavities to be installed. In practice, only 2 cavities were in operation at the same time over the years. DLS has bought four cavities. For the moment, two cavities are in service, one is kept as spare and one is waiting for repair. A timeline of the four cavities installed in the three positions is shown in Fig. 1, with each cavity represented by a different colour. The stored beam current in the storage ring is also shown in the figure.

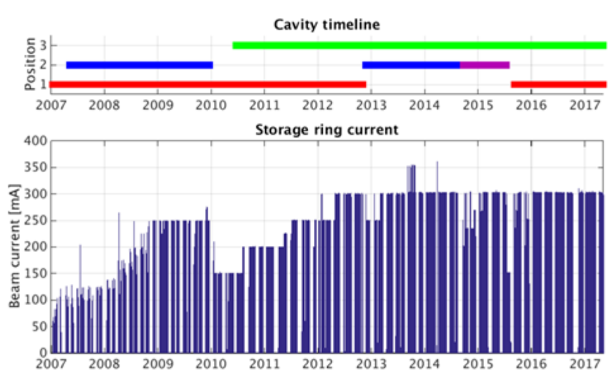

Figure 1: Cavity in service timeline and stored beam current.

The performance of the DLS SRF cavities varies hugely. It can be seen in Figure 1 that both cavity A (red) and cavity C (green) have been in operation for over 7 years while cavity D (purple) failed just 8 months after installation. Cavity B (blue) developed a leak in the indium seals during a cool-down after a warm-up to room temperature in 2014, but cavity C has survived many thermal cycles. The cavities suffered from fast vacuum trips in the early days of DLS. We have seen no cavity fast vacuum trips since September 2015 in our normal operating conditions but the avoidance of fast vacuum trips is the limiting factor of the cavity working voltage. General speaking, the performances of the cavities are not consistent with each cavity having a different safe operating voltage below which fast cavity trips do not occur.

CAVITY TRIPS

According to their signatures [1], cavity trips are mainly classified into fast vacuum trips, RF window vacuum trips, cavity quench, cavity arc and other trips. The fast vacuum trips and trips on RF window vacuum are two major types of cavity trip in DLS.

Fast Vacuum Trips and RF Window Vacuum Trips

During a fast vacuum trip, the cavity field collapses within several microseconds. A spike on the e- pickup in the waveguide near the coupling tongue can be observed before the trip. There are vacuum spikes on every gauge around the cavity. While in a trip on RF window vacuum, there is only vacuum spike on the pump-out box. The decay curve of the cavity field for a trip at the window is consistent with a high Q cavity.

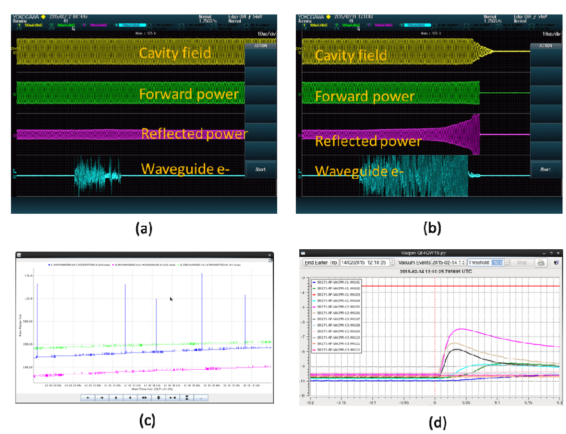

Figure 2: Activities on waveguide e- pickup and associated vacuum spikes.

Figure 2 shows the signals on cavity D waveguide e- pickup and vacuum gauges around the cavity. Figure 2 (a) shows an event on the waveguide e- pickup which didn't lead to a beam trip. Figure 2 (c) shows the vacuum signals of that day. There was only vacuum spike near the RF window. Every vacuum spike happened with a corresponding activity on the waveguide e- pickup at the same time. Figure 2 (b) shows an event on the waveguide elec-

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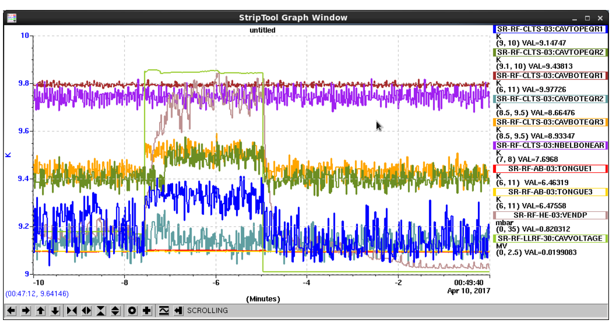
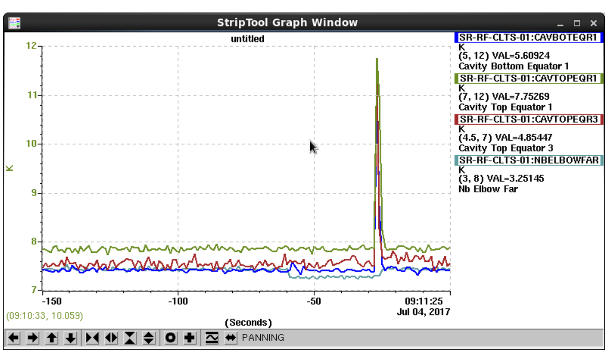
tron pickup which did lead to a beam trip. Figure 2 (d) is the vacuum post-mortem of this beam trip. The signal on waveguide e- pickup grew quickly and stayed strong before the cavity tripped. Vacuum spikes on the gauge near RF window (without tripping the cavity) were common to all our cavities. This confirmed our earlier speculation that the fast vacuum trip originated somewhere in the cold waveguide near the coupler tongue. The exact position is still not clear.

Cavity Quench and Heating on the Equator

Our cavities also will quench or suffer from heating on the cavity equator during continuous wave (CW) test when powered up to high voltage (normally 2.1 MV) after operation for a period. The heating on cavity C equator raised the temperature by about 0.2 K as shown in Figure 3 (a). The heating increased the helium gas flow which finally tripped the interlock. No vacuum spikes came with this kind of trip. A quench event saw a temperature rise from 4 K to several tens of Kelvin on the cavity equator as shown in Figure 3 (b). The event was normally accompanied by vacuum spikes inside the cavity and big fluctuation of helium bath pressure.



(a) Heating on cavity 3 equator



(b) Cavity 1 quench

Figure 3: Temperature rise on cavity equator.

Other Cavity Trips

Our cavities also suffer probe blips as we reported earlier [1]. The arc detectors contributed many false trips and they have been disabled since 2008. Other trips such as failures of water flow meters were mitigated by adaption of high performance devices.

CAVITY TRIP MANAGEMENT

Cavity trips used to contribute to 75% of total RF trips. 80% of the cavity trips were fast vacuum trips. Reduction of cavity voltage since initial operation has reduced the number of fast vacuum trips, but reliable operation at the cavity design voltage would be preferable. A lot of work was done to understand the trips and improve the situation. Field emission can be observed from as low as 1.2 MV. It grows almost exponentially after 1.5 MV. This indicates existence of dust particulates or other field emitters due to imperfections of manufacturing. The radiation level lowers after conditioning using high cavity voltage but will bounce back during the test after one week's operation.

The cold surface of CESR SRF cavity is over 3m^2 including Nb cavity, the cold helium gas cooled HEX, and LN2 cooled RBT/FBT transition and waveguide elbow. It has an estimated cryo-pumping speed of 600l/s. The SRF cavities become very efficient cryo-pumps. The RF straight has big 240 mm diameter beam pipes. The RF power is transferred through a 2 m long reduced height WR1800 waveguide after the RF window to the niobium part. Simulation confirmed that most of the gases generated due to the beam and RF field will be condensed onto the cavity surfaces. We believe the recurrence of the fast vacuum trips is caused by the change of surface conditions due to gas condensation on the cold surfaces.

Vacuum configuration was upgraded in 2010 to minimize the gas load to the cavities. Titanium Sublimation Pumps (TSP) pumps and NEG pumps were installed in the intermediate section to improve the pumping speed and capacity of hydrogen at low pressures. The pressures recorded in the RF Straight are now more than halved compared to pre-2010 levels.

Partial warm-up of the SRF cavities to 50K can be done during shutdowns to remove the accumulated gas. Pulse conditioning is done every week for the cavities. The effect of partial warm-up and conditioning on radiation levels can be seen in Figure 4.

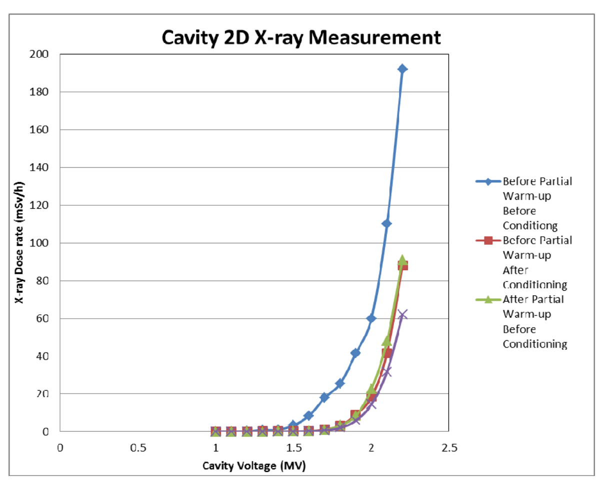


Figure 4: Effect of partial warm-up and conditioning.

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The fast vacuum trips limit reliable operating cavity voltage. The cavities will suffer repeated fast vacuum trips operating at 1.7 MV during low alpha mode operation while they work without trip at lower cavity voltages. Fast vacuum trip frequency changes with the length of service time. This can be seen in Figure 5. The cavity used to suffer more trips in their early days. With the two longest serving cavities in operation, we haven't seen fast vacuum trips since September 2015. Still caution is needed to manage the cavity carefully. The cavities need immediate attention when the fast vacuum trip starts. Otherwise the trip number will increase quickly.

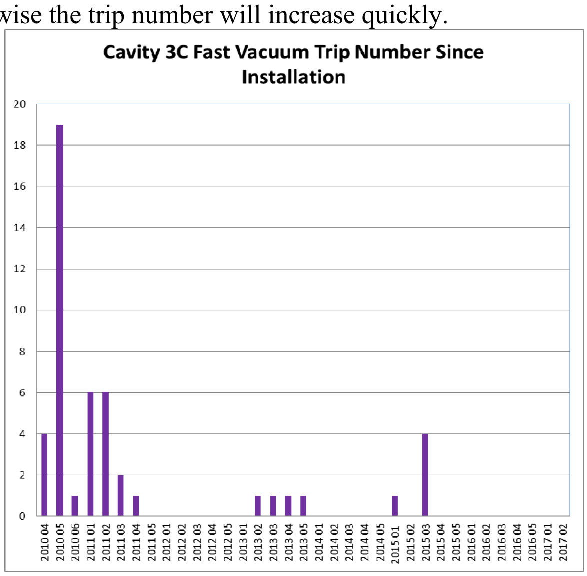

Figure 5: Cavity 3C fast vacuum trips.

The trips on RF window vacuum can be effectively managed by pulse conditioning with the cavity detuned. Occasionally beam conditioning was used to bring it to high power level. Probe blips are managed by lowering the gain of the LLRF control loop but this lead to reduced control accuracy of the LLRF.

CAVITY FAILURES

Our cavities suffered several disruptive failures in the past, which led to their removal from the storage ring. Cavity C suffered a leak of insulation vacuum when it was first installed. Cavity B developed a leak of cavity UHV due to overheating in 2010. It failed in 2014 due to a leak to cavity UHV during a cool-down after a warm-up to room temperature. Cavity D developed a leak on the RF window brazing in 2015.

Cavity failure has very serious implications for DLS operation. Up to two weeks are needed to replace a failed cavity with a spare one. This will often lead to loss of beam time. When a spare cavity is not available, this lead to reduced beam current and higher beam trip rate as the remaining cavity needs to work far from its reliable region. At this stage, our cavities need to be sent back to manufacture to be repaired. The repair will take a long time and is costly.

Cavity B was warmed up to temperature in a shutdown in August 2014. A leak developed from the helium can to cavity UHV when it was cooled down. The leak point was identified as the indium seal at niobium waveguide flange. The cavity failed at the indium seal on the FBT side after repair from the manufacture. It is now still with the manufacture.

We are now very cautious with the warmup of the cavities. Warm up to room temperature will not be done unless totally necessary, like when the cryogenic plant needs to be shut done for service. We are testing if we can keep the cavity cold even with the cryogenic plant shut down. With the cavities working smoothly, we have started testing reducing the frequency of partial warmups. There were no partial warmups in first six months of 2017 and no vacuum trips were recorded.

Cavity D suffered many fast vacuum trips from the start. The cavity voltage had to be reduced to 0.8 MV to avoid vacuum trips. This limited the beam life time to below 10 hours. It worked for some time before it couldn't hold enough RF power, which limited storage ring beam current .It failed during a conditioning intending to bring back its operating power level. The brazing material of ceramic-metal joint of the RF window was evaporated as shown in Figure 6. The RF window was replaced with a spare on site in a class 5 clean room of RAL Space. The cavity was subsequently tested to 2.1 MV inside our RF test facility.

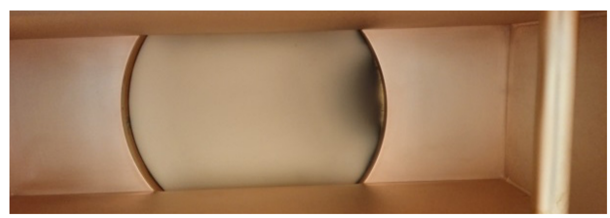

Figure 6: Cavity D damaged RF window.

To further reduce the risks of failures of SRF cavities, two normal conducting cavities [2] have been purchased and tested. They will be installed in the storage ring to reduce the voltage and power level of SRF cavities and amplifiers. This will hopefully improve the reliability and resilience of the RF systems of DLS.

SUMMARY

The performances of the DLS SRF cavities differ from each other. Many lessons have been learned after many years of operations. The hybrid operation of superconducting and normal conducting RF cavities will provide further redundancy for the DLS storage ring.

REFERENCES

[1] P. Gu *et al.*, "Reliability improvements of the Diamond superconducting cavities", in *Proc. 15th Int. Conf. on RF Superconductivity (SRF'11),* Chicago, USA, Jul. 2011, pp. 267-270.

[2] C. Christou *et al.*, "A hybrid superconducting/normal conducting RF system for the Diamond Light Source storage ring", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16),* Busan, Korea, May 2016, pp. 2950-29.