RELIABILITY IMPROVEMENTS OF THE DIAMOND SUPERCONDUCTING CAVITIES

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Abstract

For successful operation of superconducting cavities in light sources, high reliability and minimal beam losses are essential. Diamond started operation with users in January 2007 and since then, the Diamond storage ring superconducting cavities have been the largest single contributor to unplanned beam trips. We have dedicated extensive effort to improve our data acquisition, numerical modelling and fault analysis to improve our understanding of the main causes of the trips and how to prevent trips or reduce their frequency. In the past seven months, the performance of the cavities has improved significantly. We present here our analysis of some of the trips and their underlying causes and discuss improvements carried out.

INTRODUCTION

The Diamond storage ring (SR) RF system [1] consists of two high power, 300 kW IOT based amplifiers each connected to a 500 MHz Cornell-type superconducting single cell cavity. A third system is available for testing and as a future upgrade. Since the start of operation with users in Jan 2007, the operation of the RF systems is becoming more and more demanding as the beam current is increased and more insertion devices are installed. In all the beam trips at Diamond, around half of trips have been due to the RF systems of which 75% have been cavity trips. Analysis of cavity trips is of vital importance to improve the performance of RF system and Diamond as a whole. A systematic data acquisition system was set up to capture important signals including RF signals, vacuum signals, radiation signals etc [1]. To understand the mechanism behind the trips, extensive particle-in-Cell (PIC) numerical simulations were performed [2]. After various experiments, a set of measures, including pulse conditioning, cavity partial warm up, regular TSP pump firing, is found to be effective to be operation of SRF cavities. The performance of cavities has improved significantly.

CAVITY DIAGNOSTICS SYSTEM

The cavity diagnostics system include a Libera beam position processor configured to record RF amplitude and phase signals, a fast vacuum recorder and a National Instrument PXI data acquisition system. A detailed description can be found in [1]. Recently, radiation monitors have been installed to observe radiation from the SRF modules during RF conditioning and beam operation. The data acquired from the variety of the different signals combined with the results of the beam position monitors, can serve to identify the cause of the beam trip. When it is an RF trip, it provides information regarding the signals immediately before and after the trip and accurate time stamping allows the sequence of events to be investigated.

CLASSIFICATION OF CAVITY TRIPS

The cavity trips can be classified according to their signatures. They may be classified into fast cavity vacuum trips, trips on the RF window, cavity quench, cavity arc and other trips. The most common and important cavity trips in Diamond are fast vacuum trips. During such a trip, the cavity field collapses within a few microseconds and there are vacuum spikes on all the gauges around the cavity. 80% of the cavity trips are due to this kind of trip. The second type is a trip on the RF window. Vacuum spikes are only seen on the pump-out box and the cavity field decays normally. The Diamond SR cavities also suffer from probe problems. High amplitude spurious signals were observed on many probes. These spurious signals can confuse the LLRF leading to subsequent reaction which may cause a beam trip. We have also experienced trips caused by peripheral devices such as water flow meters, insulation vacuum and the N2 heater.

FAST CAVITY VACUUM TRIPS

Fast vacuum trips were observed as early as the commissioning of CESR SRF cavities at Cornell. It has also been observed in many other labs. The trip rate is found to be increasing with time and eventually they limited maximum cavity voltage and RF power through the coupler. This is the most dangerous trip to the long term stable operation. Sometimes cavity voltage and input RF power have to be lowered to keep the system working.

The vacuum post-mortem is shown in Figure 1. From the vacuum post-mortem, it can be observed that there are vacuum spikes on every gauge around the cavity which tripped. Gas can travel to and beyond the other cavity. Gas can't travel through the cold waveguide bend into the waveguide of the other cavity.

The RF signals captured by NI PXI data acquisition system is shown in Figure 2. The cavity field collapsed within 4.8μs.

There is always a spike on the e- pickup before the trip. During conditioning, probe blips together with X-ray spikes were observed.

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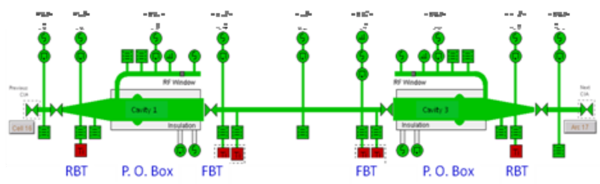
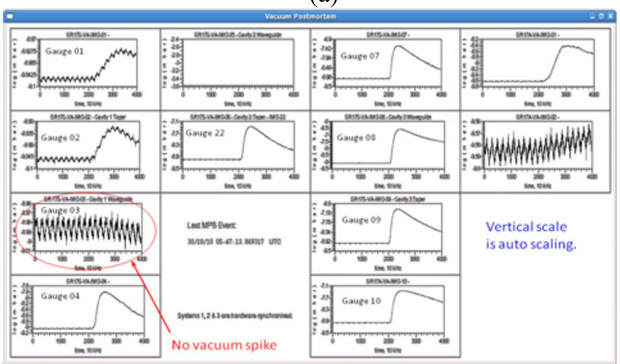


(a)



(b)

Figure 1: (a) Vacuum setup in RF straight. (b) Vacuum post-mortem of fast vacuum trip.

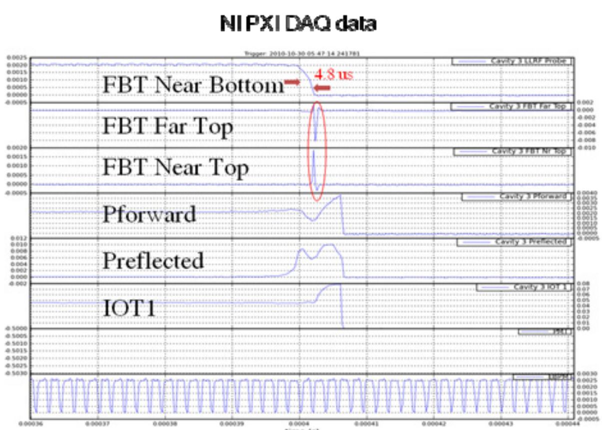


Figure 2: RF post-mortem of fast vacuum trip.

In Diamond, we also observe that after one week of operation with beam, the cavities will trip at the same level (For example, cavity 3 will trip at 1.9 MV). During pulse conditioning out-gassing spikes can be observed at this level inside the cavity. Radiation spikes are found to accompany the pressure spike. After pulse conditioning the cavity can be powered to above this level without problem.

The fact that such a kind of trip happens after a significant time interval and the trip rate increases with operational time suggests that there is an accumulative effect. It is well known that layers of gas will accumulate on the SRF cavity surface due to cryo-pumping [3]. It is also very well known that condensed gas can activate field emission. Processed field emission sites may come alive again after gas molecules accumulate on the surface. Processed multipactor bands may also recur due to increased SEY caused by condensed gas. It is reasonable to credit this kind of trip to gas evolution on the surface of SRF cavities. It is essential to keep the gas desorbtion from the bulk at a minimum to reduce the gas absorption onto the surface. There may additionally be a critical threshold to stay below.

Recently specific upgrades have been implemented to keep the accumulation of gas collecting on the cavity surfaces at a minimum. Titanium Sublimation Pumps (TSP) pumps have been installed in the intermediate section as they have high pump speeds but importantly they retain a high pump speed for hydrogen at low pressures unlike standard ion pumps. The TSP pumps are fired every week during machine development time to reactivate the surfaces and to retain high pump speeds. Due to the success of the TSP pumps, it is now planned to add NEG pumps to the installation due to their high pump capacities. The pressures recorded in the RF Straight have halved after repeated firing of TSP pumps. The vacuum improvement can be seen in Table 1 which has listed all the gauge readings along the RF straight before and after TSP firings. As a complete thermal cycle takes more than 2 weeks, there isn't much opportunity to do a complete warm up to ambient temperature. Instead, the cavity was partially warmed up to 30K during recent shut downs and will also be done after 4 weeks operation. This can release part of the gas condensed on the cavity surface. Hydrogen peak up to1.8×10^{-5} mbar was observed during the partial warm ups.

Table 1: Improvement of Vacuum with beam after TSP Firing, Unit: mbar

Pump No.	Before TSP firing	After TSP Firing
1	9×10^{-10}	7.1×10^{-10}
2	1.0×10^{-9}	5.8×10^{-10}
3	1.2×10^{-9}	6.9×10^{-10}
4	1.0×10^{-9}	3.5×10^{-10}
22	1.1×10^{-9}	6.3×10^{-10}
7	9.8×10^{-10}	3.6×10^{-10}
8	9.1×10^{-10}	6×10^{-10}
9	1.1×10^{-9}	6.6×10^{-10}
10	1.2×10^{-9}	9.1×10^{-10}

The cavities are pulse conditioned during MD time every week. The cavities were conditioned using 1-10ms/100ms pulse up to 2.5MV peak cavity voltage. The cavity is pulse conditioned for several days after the partial warm up during shut down time.

The trip rate decreased significantly with all the measures working together. The MTBF (Mean Time between Failure) increased steadily and greatly since November 2010 as shown in Figure 3.

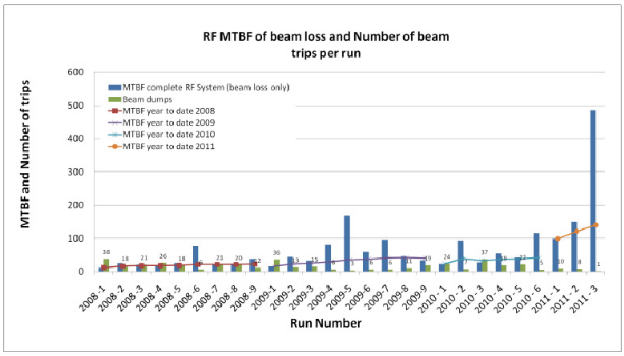


Figure 3: RF MTBF and number of beam trips per run.

X-RAY MEASUREMENTS

A series of X-ray measurements have been done after the X-ray sensors were installed. X-ray intensity starts at around 1.6 MV without beam and increases exponentially as the field is increased. At cavity voltage greater than 2.4 MV the x-ray count can reach several Sv/hr. X-ray intensity increases linearly with beam current. The change rate increases with the cavity voltage as shown in Figure 4. But the X-ray intensity doesn't increase with the RF input power under the same cavity voltage.

X-ray spikes were found to accompany the out gassing spikes during conditioning. After pulse conditioning, the X-ray spikes disappeared. The X-ray level also dropped a lot as shown in Figure 5.

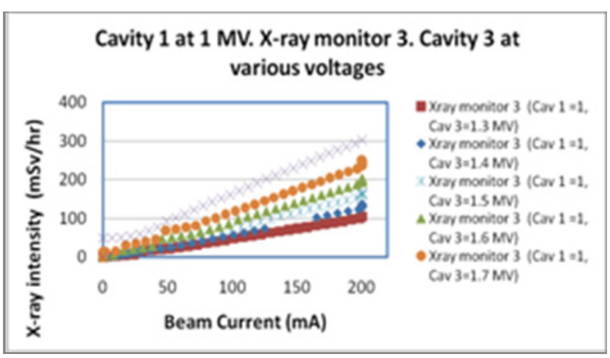
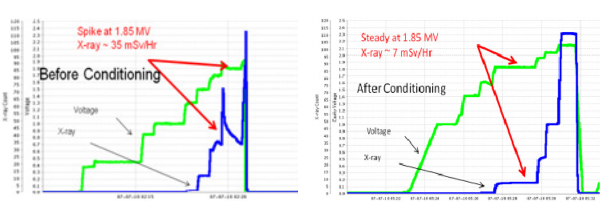


Figure 4: X-ray intensity increases with beam current.



(a) (b)

Figure 5: X-ray spikes (blue) (a) during conditioning, (b) after conditioning.

TRIPS ON RF WINDOW

The vacuum post-mortem is shown in Figure 6. It can be seen that there is only out gassing on the pump-out box. The RF post-mortem is shown in Figure 7. The decay curve of the cavity field is consistent with a high Q cavity.

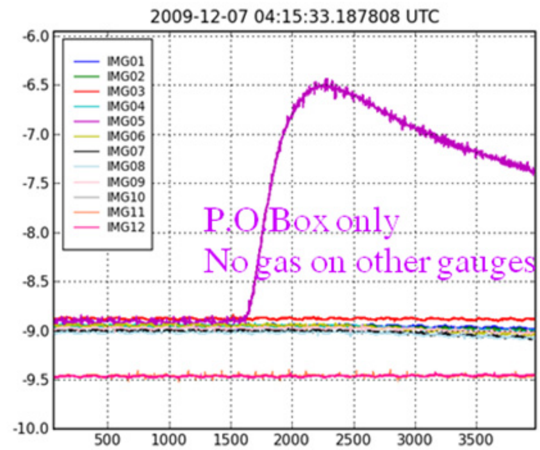


Figure 6: Vacuum Post-mortem of RF Window Trip.

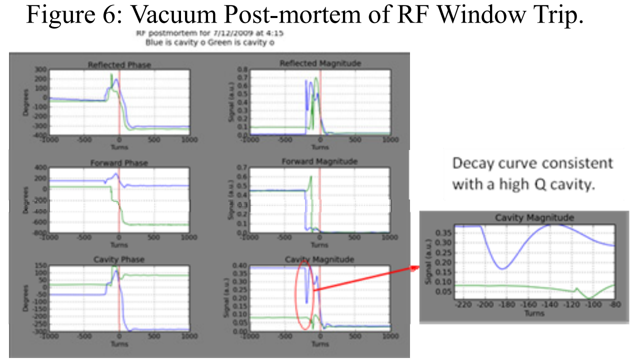


Figure 7: RF post-mortem of RF window trip.

The source of the gas may come from the ceramic window, condensed gas on the cold waveguide or the defective copper plating on the waveguide surface. Copper plating was found to be peeled in some places during repair work of our cavity 2 as shown in Figure 8.

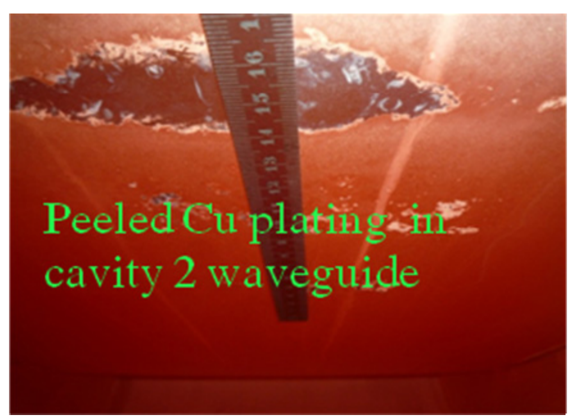


Figure 8: Peeled Cu plating on the inside surface of cavity 2 waveguide.

Pulse conditioning with the cavity off resonance is done every week. The detune angle of the cavity is scanned to find out-gassing in the pump-out box.

Beam conditioning was used in the early commissioning stage. The multipactor edges were very sharp with heavy out-gasings on the pump out box. A very small beam current step down to 0.2mA was needed to precisely locate the edge. The cavity voltage and beam current were scanned to condition out all the bands in the working range. After conditioning, we are able to inject up to 260 mA beam and 260 kW in single cavity operation.

The RF window was also baked to 120°C every time a cavity is warmed up.

With all these efforts, this kind of trip is very seldom encountered now in Diamond.

PROBE BLIPS

Two of the Diamond SR cavities suffer from blips on the RF probes as shown in Figure 9. It has very high amplitude. These blips may be due to electrons picked up by the probes. Figure 10 shows the RF post-mortem of one of the trips. The cavity signal was lost for 2 µs after which the signal returns but the amplifier has already tripped on reflected power. The probe blips happen with and without beam and they don't always trip the beam.

Figure 9: Probe blips on spare pickup.

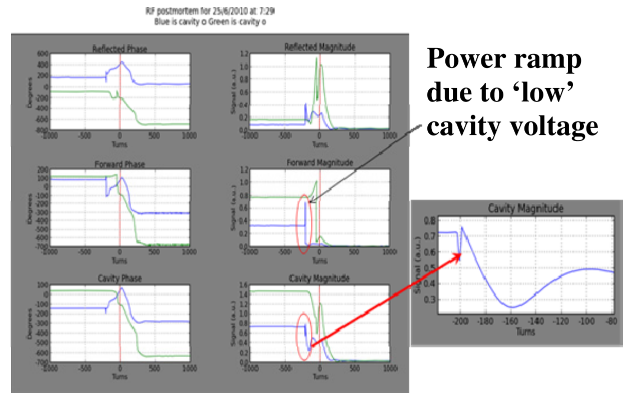


Figure 10: RF post-mortem of probe blip trip.

We used DC block, band pass filter and bias T to try to filter out the probe blips. Signals can be improved but the blips can't be eliminated by the filtering. This kind of trip was stopped by lowering the gain of LLRF. A lower gain means a slower ramp rate of the drive power. The risk of a trip on reflected power was reduced.

SUMMARY

The long term reliability of DLS SRF cavities has been improved significantly after a lot of effort. This improvement will help to improve the performance of Diamond.

REFERENCES

[1] M. Jensen et al., "Operational Experience of Diamond's Superconducting Cavities", SRF2009, p. 228.

[2] S. Pande, "Multipactor Studies for Diamond Storage Ring Cavities", these proceedings.

[3] R. L. Geng, "Condensation/Adsorption and Evacuation of Residual Gases in The SRF System for the CESR Luminosity Upgrade", PAC 99, p. 983.