PROGRESS WITH THE DIAMOND LIGHT SOURCE RF UPGRADE

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Abstract

Failure of a superconducting cavity in the Diamond storage ring can lead to extended down-time because of the time required to remove the module from the ring, the inability to access the cavity without removal from the cryostat and the long time to repair of the module. To reduce the risk to storage ring operation, normal conducting cavities are being installed to support operation of the superconducting cavities. Two cavities will be introduced in 2017 and work is progressing with RF amplifiers, transmission lines and low-level RF as well as storage ring engineering and controls. A summary of progress so far is presented and the plan for installation and further RF upgrades is outlined.

SUPERCONDUCTING RF CAVITY PERFORMANCE AND RELIABILITY

Since operation for users at Diamond Light Source began in January 2007 the RF system has been responsible for approximately half of all beam trips. In the early years of operation the most frequent trip was the cavity “fast vacuum trip” in which a discharge in one of the two operational superconducting CESR-B cavities results in the collapse of field and loss of beam [1]. Figure 1 is a summary of beam trips per year, including 2017 to date, highlighting the number of RF and cavity trips.

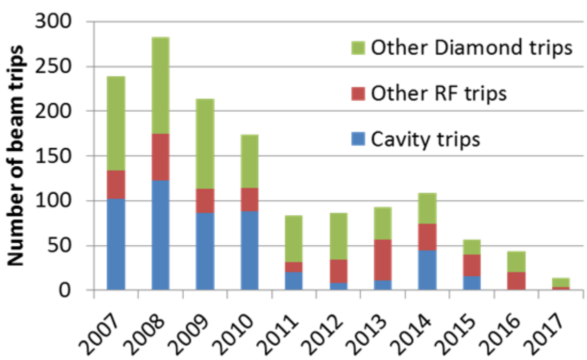

Figure 1: Summary of Diamond beam trips highlighting cavity and other RF faults.

Fast vacuum trips have been largely eliminated in Diamond by reducing cavity operating voltage and by regular cavity conditioning [2, 3], however the risk of a significant downtime arising from a cavity failure remains. There have been four cavity failures at Diamond, one during commissioning and three in regular operation. Three failures were vacuum leaks, and one was a window failure. Details of the cavity failures experienced at Diamond, together with the reliable operating voltages, V_{safe}, for each of the four cavities are given in Table 1. Each failure had a major impact on Diamond operation, with extended loss of beam time required to replace the failed module with one of the spares and then a slow and expensive repair required for the failed module.

Table 1: Cavity Failures

Cavity	Failure date	Detail	V_{safe}
A	none		1.1 MV
B	2009, 2014	UHV leak	1.2 MV
C	2006	Insulation vacuum leak	1.4 MV
D	2015	Window failure	0.8 MV

Introduction of one or more normal conducting cavities to the storage ring allows the voltage and power of the CESR-B cavities to be reduced further. In contrast to the CESR-B cavities, the normal conducting cavities can be repaired in-house. Use of two normal conducting cavities would allow 300 mA beam to be maintained with only one superconducting cavity.

NORMAL CONDUCTING CAVITIES

In February and March 2017 Diamond took delivery of two normal conducting cavities of the latest BESSY design [4]. A photograph of the cavity under construction at Research Instruments is shown in Fig. 2, showing three HOM dampers mounted radially around the resonant cavity together with the plunger tuner and input coupler. The pick-up coupler is mounted below the beam axis.

Figure 2: HOM-damped cavity under construction.

Table 2 shows the fundamental RF parameters of the two completed cavities.

Table 2: Cavity Parameters

Cavity	Parameter	Value
N1	$f_{nominal}$	499.64 MHz
	Tuning range	489.9 to 501.3 MHz
	Q_0	33000
N2	$f_{nominal}$	499.62 MHz
	Tuning range	499.0 to 501.4 MHz
	Q_0	32200

Input power to the cavity is limited to 120 kW by the 6 inch coaxial tee piece feeding the coupler. The cavities were both delivered with the input coupler configured for critical coupling in order to condition the cavity without beam with minimum reflected power, although the coupling will be adjusted to accommodate beam-loading in the ring.

The ceramic dome isolating the pick-up loop from the cavity has been problematic in other cavities of a similar design [5] and so these ceramics were treated with a titanium coating at ESRF before final assembly and delivery.

INCORPORATION OF NEW CAVITIES INTO THE STORAGE RING

After delivery to Diamond, the cavities were mounted on a girder trolley containing vacuum pumps and gauges on the tapers, and water cooling fittings for cavity HOM-absorbers and input coupler were attached. Temperature and flow interlock sensors were also added to the cavity and cooling pipes. The assembled trolleys will be installed upstream of insertion devices in straights immediately before and after the current RF straight, as pictured in Fig. 3.

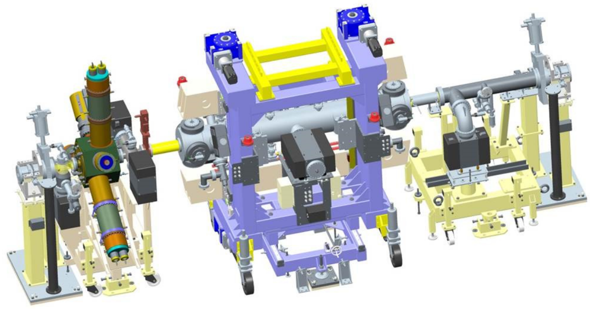

Figure 3: Cavity in straight with insertion device.

Positioning of the new cavities outside the RF straight reduces vulnerability of the RF cavities to a leak in the RF straight and protects the superconducting cavities from outgassing of the copper cavities in operation. A CST Microwave Studio study of the design indicates that leakage of RF from the new cavities should not affect the operation of the primary BPM at the start of the straight.

The three Diamond storage ring amplifiers each contain four IOTs combined in two stages to deliver up to 300 kW to each superconducting cavity [6]. Two amplifiers will remain unchanged after the installation of the normal conducting cavities, but the second combination stage of the third amplifier will not be used so that the amplifier can supply each of the two new cavities with up to 150 kW through new lengths of 9 inch coaxial line [2]. The first transmission line will use the pre-existing circulator and tunnel penetration and will run along the inner wall of the tunnel; the second will be installed on a platform outside the tunnel and use a new circulator and pass through a personnel labyrinth near the cavity. Initial operation will be limited to 120 kW by the 6 inch tee to the input coupler.

The new cavities will use a new digital LLRF system that has been developed in collaboration with Alba. This system has been successfully tested with a normal conducting cavity on the Diamond booster and is the subject of a companion paper at this conference [7].

CAVITY TEST AND CONDITIONING

The higher order mode spectrum of the new cavities has been measured. Figure 4 shows the transmission spectrum from 400 MHz to 1.8 GHz. This spectrum is consistent with that measured at BESSY [8] with the exception that the problematic high-impedance mode observed near 680 MHz at BESSY and Alba [9, 10] has been removed by the introduction of a fixed flange on the HOM dampers in the latest BESSY cavity design.

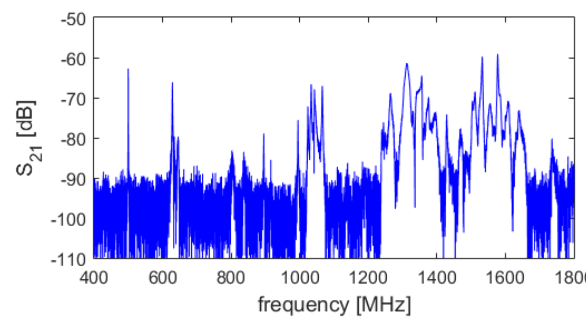

Figure 4: Measurement of HOMs in cavity N1.

The first of the two fully assembled cavities was baked out at Diamond in March-April for two weeks at 120°C. The pressure after the bake was measured to be in the mid 10^{-10} mbar range and the RGA scans shown in Fig. 5, taken during the final cool-down and after conclusion of the bake, are good, showing no evidence of leaks, minimal H_2O and no hydrocarbon contamination of the vacuum.

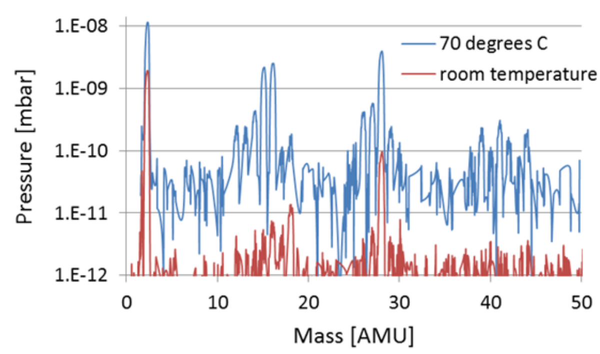

Figure 5: RGA traces during cool down following bake.

The first cavity and trolley was transferred to the Diamond RF test facility in April and is being prepared for imminent high power test and conditioning. The present status of the cavity is illustrated in Fig. 6, which shows the cavity wrapped in bake-out heater tapes and foil and coupled to the WR1800 waveguide from the high-power amplifier with a length of 9 inch coaxial line.

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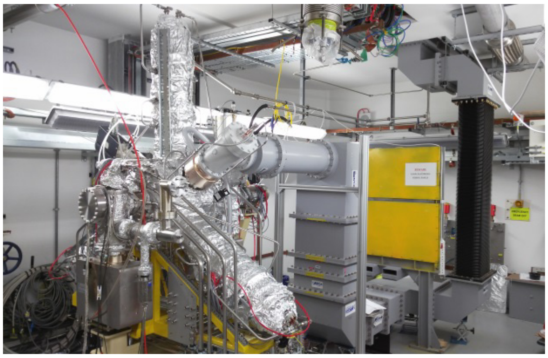

Figure 6: Cavity N1 installed in RF test facility for test and conditioning.

Conditioning is scheduled to continue through May and June with installation into the storage ring planned for the following machine shutdown.

OPERATIONAL PARAMETERS

Introduction of normal conducting cavities protects primarily against the inability to maintain storage ring operation in the event of failure of an operating superconducting cavity while the spares are under repair, and also contributes to reliability by reducing superconducting cavity operating voltage. Additionally, the extra cavities can reduce the power demand from each of the high power amplifiers to a level at which individual IOTs can be switched out when a fault is recorded, rather than turning off the high voltage power supply to all IOTs of an amplifier, as is the case now. The present arrangement protects the IOT but results in the loss of storage ring beam in the event of any IOT fault. Initial tests of drive power removal showed that beam can be retained in the storage ring when individual IOTs are switched off [2], and these have been followed by high-power tests of a 50 kV MOSFET switch installed in one of the Diamond amplifiers in line with the IOT, which show that individual IOTs may be switched in and out of circuit without interruption of power from the amplifier. Typical test results are shown in Fig. 7.

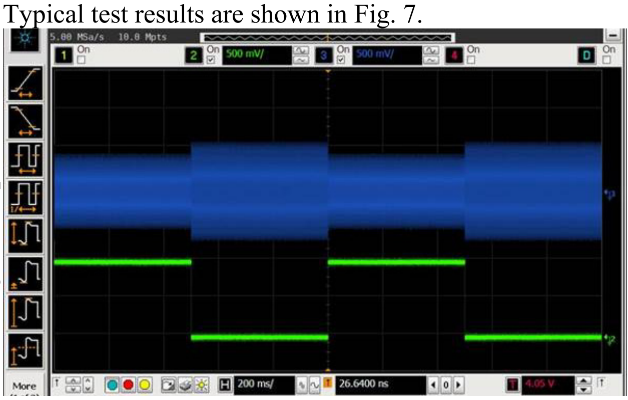

Figure 7: Dynamic switching of single IOT during high power operation showing amplifier power (blue) and MOSFET switch trigger (green).

Operational powers and voltages will become apparent after high-power cavity testing, but an idea of levels required to support 300 mA operation in Diamond can be gained from Table 3, which shows normal operation (two superconducting cavities and two normal conducting cavities), and operation with one superconducting cavity removed (leaving one superconducting cavity and two normal conducting cavities). IOT switching is possible with 140 kW to the superconducting cavity. The total voltage required for operation with one superconducting cavity and two normal conducting cavities will depend on beam lifetime.

Table 3: Illustrative Voltages and Powers for a Hybrid Normal and Superconducting RF System

Cavity configuration	Parameter	Value
Normal operation	V_{SC}	1.0 MV
	V_{NC}	0.3 MV
	P_{SC}	140 kW
	P_{NC}	110 kW
One failed SC cavity	V_{SC}	1.4 MV
	V_{NC}	0.4 MV
	P_{SC}	265 kW
	P_{NC}	120 kW

FURTHER RF UPGRADES

Several other projects are also underway at Diamond to improve machine reliability and performance. A second booster cavity will be installed in 2018 to provide RF redundancy in the booster ring. This will be powered by a 60 kW solid state amplifier, supplied by Ampegon, who are also building an 80 kW solid-state amplifier for the RF test facility, as the present RF test facility amplifier will be used for the two new HOM-damped cavities. Also, the digital LLRF system used for the new cavities will be further developed to replace the analogue systems presently used in the Diamond storage ring and booster. These projects will be fully reported at a later date.

SUMMARY

Two HOM-damped normal conducting cavities are being installed in Diamond to support operation of the superconducting cavities. They can be used to maintain beam in the event of the loss of a superconducting cavity and will enhance reliability by reducing operational voltage and power levels in the present RF systems. The cavities have been delivered to Diamond and testing is progressing with installation in the storage ring scheduled for later in 2017. Normal conducting cavity installation is the first of several RF upgrades at Diamond.

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