A HYBRID SUPERCONDUCTING/NORMAL CONDUCTING RF SYSTEM FOR THE DIAMOND LIGHT SOURCE STORAGE RING

C. Christou, A. G. Day, P. Gu, N. Hammond, J. Kay, M. Maddock, P. Marten, S. A. Pande, A. Rankin and D. Spink, Diamond Light Source, Oxfordshire, UK

Abstract

300 mA beam in the Diamond Light Source storage ring is presently maintained by two 500 MHz superconducting (SC) CESR-B cavities. Cavity reliability is acceptable at voltages up to 1.4 MV per cavity but falls off rapidly above. Installation of extra cavities would reduce the voltage demand on the current cavities and also the operating power level of the amplifiers, with commensurate improvement in reliability. Furthermore, two recent SC cavity failures have resulted in machine down-time and reduced-current operation, and repair has proven to be prolonged and expensive. It is therefore planned to install two normal conducting (NC) cavities into the ring to support operation of the SC cavities and to act as a safeguard against any future SC cavity failures. Details are presented in this paper of plans and progress towards the installation of the hybrid RF system.

SUPERCONDUCTING RF RELIABILITY

Diamond Light Source has been providing beam for users since January 2007. For most of this time, the RF straight, which can accommodate up to three SC cavities, has been equipped with two operational cavities, with up to two cavities available as spares. A timeline of the four cavities in the three available positions is shown in Fig. 1, with each cavity represented by a different colour.

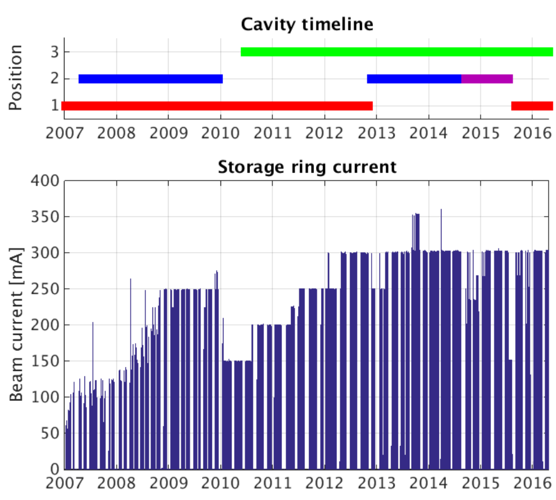

Figure 1: Storage ring current (below) and cavity arrangement in the RF straight (above).

Figure 1 also shows the beam current in the storage ring, illustrating the vulnerability of operation to cavity failure, for example failures of the second cavity, shown in blue in the figure, in 2010 and 2014 resulted in reduced beam current for extended periods, and window damage to the fourth cavity (purple) in 2015 required a reduction in operating current until the first (red) cavity was reinstalled at the start of the following run.

The early days of RF operation at Diamond were plagued by cavity "fast vacuum trips" [1] in which a discharge at the cavity results in the collapse of field and loss of beam. Study of the phenomenon is ongoing [2], but the problem has been effectively managed by weekly cavity conditioning and by reducing cavity voltage over the years to a level at which the problem does not occur, as can be seen in Fig. 2.

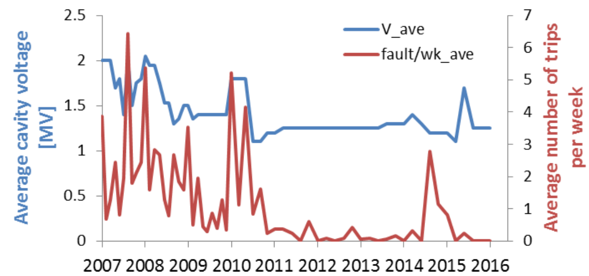

Figure 2: Average cavity operating voltage (blue) and frequency of cavity fast vacuum trips (red).

There are two periods of poor performance in Fig. 2: when a single cavity had to be run at high voltage in 2010, and when the conservative voltage of the new cavity introduced in 2014 proved to be insufficient to eliminate the trips and had to be lowered further. In general, there exists an operating voltage, independent of power, below which the cavities are unconditionally stable to fast vacuum trips; this level lies between 0.8 MV and 1.4 MV for each cavity. The RF voltage limitation impacted machine lifetime in 2015, although 300 mA beam was maintained by top-up operation.

Diamond's cryogenic system has been very reliable to date and there have been no extended beam-time losses such as those reported at other facilities [3]. Reliability has been maintained by close management of the helium plant and regular servicing of the components. A full service, however, requires a warm-up of the cavities, risking failure of indium seals during the thermal cycle.

Vacuum leaks in the past have made it necessary to ship the cavities to the manufacturer for repair. This can be a lengthy process and extremely expensive, and so the 2015 window failure was repaired on site in a satellite assembly cleanroom made available by RAL Space. A photo of the repair in progress is shown in Fig. 3.

Availability of a cleanroom on site enables a faster repair of simple faults, but the slow and expensive turn-around for more complex repairs and the loss of beam-time while the cryostat is warmed up before interventions remains. The lack of a suitable location for a cryostat outside the RF straight also makes the risk of a total loss

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of RF through a vacuum event in the RF straight a real possibility [4]. These issues have led to the decision to introduce NC cavities into the storage ring to support RF operation.

Figure 3: Cavity window change in cleanroom.

INCORPORATION OF NORMAL-CONDUCTING CAVITIES

The cavities selected for the storage ring are the EU HOM-damped cavities of the BESSY design [5], which are also installed at ALBA [6]. A drawing is presented in Fig. 4, showing the 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. Tuners and couplers are of a similar design to those that have operated reliably for many years in the Diamond booster [7].

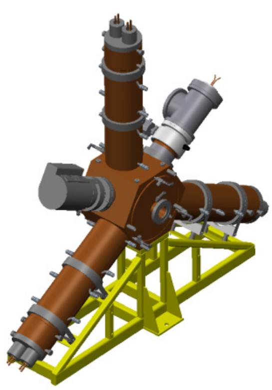

Figure 4: EU HOM-damped cavity.

The operating frequency is designed to be 499.654 MHz ± 200 kHz, shunt impedance > 3.1 MΩ and Q_0 > 27000, allowing operation up to 0.7 MV per cavity with a dissipated wall power of 80 kW. The ability of the present girder water supply to provide sufficient cooling to the cavities has been verified. The coupler is designed to operate up to 150 kW CW as significant beam loading is anticipated.

The flange-to-flange insertion length of the cavity is 50 cm, which allows it to be placed in the same straight as any standard in-vacuum undulator away from the RF straight. This mitigates the risk of loss of all RF as a result of an RF straight vacuum event, and protects the SC cavity from outgassing of the copper cavity in operation. It is planned to install two cavities in the ring, one in the straight before the SC cavities and one in the straight after, both upstream of pre-existing insertion devices. The straight layout is shown in Fig. 5. The selection of adjacent straights simplifies the routing of the transmission line and minimises impact on PSS zones for conditioning and operation.

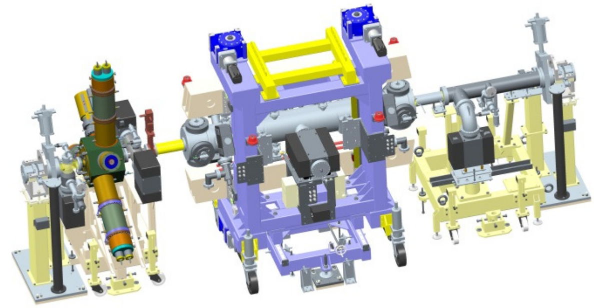

Figure 5: Cavity in straight with insertion device.

AMPLIFIER MODIFICATIONS

Diamond currently has three high power amplifiers generating up to 300 kW each by the combination of four IOTs in the waveguide combiner system shown in Fig. 6 [8]. The two SC and two NC cavities will be independently powered by the three amplifiers and so the output of one amplifier must be split. To minimise costs and allow a quick change of amplifier should a change of configuration of the RF straight be necessary, the combination system will not be dismantled, instead the two phase shifters *S1* and *S2* in Fig. 6 will be de-phased to send power from one IOT pair through the *output* channel and the remainder through the final *combiner reject* channel.

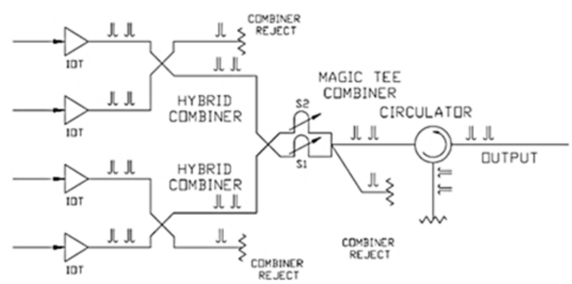

Figure 6: IOT combination scheme.

Figure 7 shows the isolation of the two output channels with a phase difference of 90° between *S1* and *S2*. Turning off one IOT reduces one output by 75% and leaves the other output unchanged. VNA measurements indicate that -50 dB isolation should be possible with exact de-phasing.

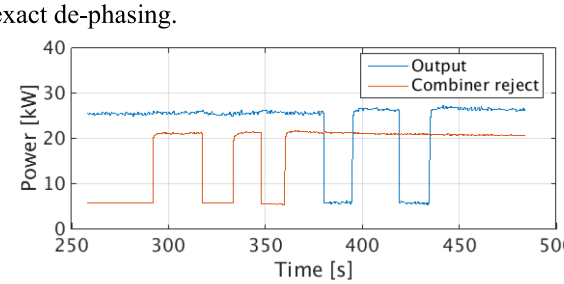

Figure 7: Power steps of output and reject channels.

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The total power loss from the storage ring with a full complement of insertion devices is around 450 kW: this allows operation with seven of eight IOTs connected with the present two operational cavities and amplifiers as long as *S1* and *S2* are suitably phased in one amplifier. The phase shifters are however mechanically driven and are unable to react quickly enough to prevent beam loss and so no IOT redundancy is possible with the present arrangement of eight live IOTs. Furthermore, in order to protect the IOTs from damage in a fault state, any tube fault causes the HVPS voltage to be dumped, shutting down the entire amplifier. Introduction of extra cavities can address the first issue by reducing the power demand on the four-IOT amplifiers below 170 kW, and trials are underway of a fast-acting 50 kV MOSFET switch in line with each IOT to isolate individual IOTs locally in the event of a fault. Preservation of beam at 250 mA when one IOT is removed has been demonstrated: Figure 8 shows IOT powers and orbit disturbance during the test.

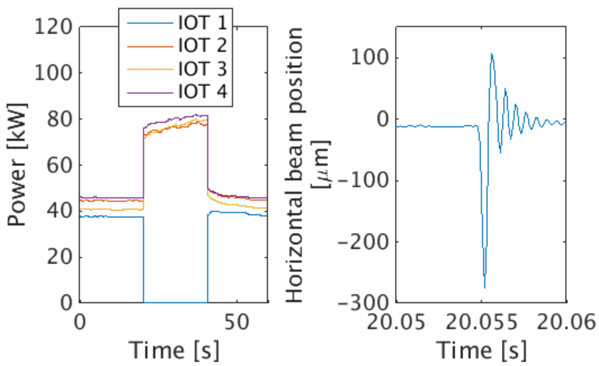

Figure 8: Reaction of remaining IOTs to the loss of power from one IOT (left) and the effect on stored beam (right).

LOW LEVEL RF

The new cavities will require their own low-level RF controls and so a collaboration has begun with ALBA to develop a new digital LLRF system closely based on their existing system [9]. A modified ALBA system will be tested on the Diamond booster in autumn 2016 and then if successful will be modified further for use with both NC and SC cavities. The new systems will initially provide the same functionality as the present analogue LLRF, but the digital nature of the design will allow further functionality to be added over time, such as recognition and management of "probe blip" events [1], individual IOT control, enhanced event diagnosis, cavity co-operation and the development of automatic start-up and conditioning routines.

COMMISSIONING PLANS

Cavity delivery is scheduled for early 2017. On receipt the cavities will be tested in Diamond's RF Test Facility and will be installed into the storage ring one at a time over the course of the year. There is some flexibility in the exact operating parameters, but the aim is to operate at conservative voltages and powers to ensure reliable operation. Figure 9 shows a typical scenario, with 1.0 MV on both SC cavities and 0.3 MV on both NC cavities. This configuration maximises reliability and has plenty of power and voltage in hand for further ring developments and non-standard modes of operation.

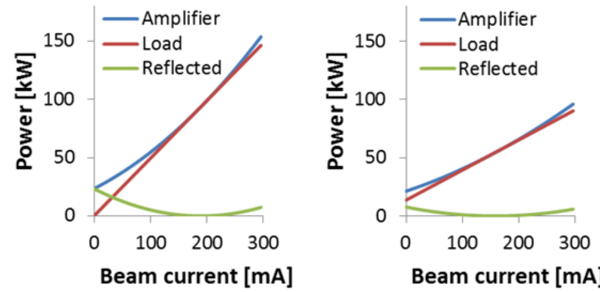

Figure 9: SC (left) and NC (right) power requirements.

The HOM-damped cavity design minimises the increase in ring impedance, but nevertheless further cavities, whether NC or SC will increase machine impedance and so a longitudinal feedback kicker is in development to combat longitudinal instabilities [10].

SUMMARY

Reliability of Diamond's RF has improved significantly since the start of user operation, but the risk of significant down-time in the event of a cryogenic cavity failure is recognised. As mitigation against this possibility, two normal conducting cavities will be installed in the storage ring in 2017 to enable low voltage and low power RF operation. The impact of the extra cavities on the present installation has been described and commissioning requirements and details have been outlined.

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