A POSSIBLE UPGRADE FOR THE SRS RF SYSTEM

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Abstract

The world's first dedicated source for synchrotron radiation, the Synchrotron Radiation Source (SRS) at Daresbury, UK is now 20 years old. During its operational lifetime, the control and stability of the electron and photon beams have been significantly improved, to ensure continued reliable operation, in order to necessitate various lattice and insertion device (ID) upgrades [1][2]. The SRS currently utilises four 500MHz accelerating cavities, which can provide a maximum of 2.1MV accelerating voltage, equating to ~300mA of stored beam current at 2GeV. To operate the SRS at this beam current level routinely for users, would undoubtedly be very difficult due to cavity induced beam instabilities. As a possible way of upgrading the SRS to operate at these beam current levels and beyond, it is proposed to replace the existing SRS RF cavities with two new higher order mode (HOM) damped cavities. This would enable beam currents up to 1Ampere to be stored both reliably and with a higher degree of stability. The availability of two additional straight sections would then offer the possibility of introducing two high field MPW devices. This paper details the new cavity design, highlighting the associated RF system modifications that would become necessary.

1 INTRODUCTION

Multi-bunch instability limits have been previously observed on the SRS and have so far been avoided by careful adjustment of the cavity temperatures to sustain normal operations [3]. In order to reliably achieve beam currents >250mA on the SRS, experience has shown that the cavity temperature stability is critical and the temperature range over which control of the multibunch instabilities is maintained, is severely restricted the larger the stored beam currents.

The total RF power (P_T) required on an accelerator is derived from:

$$P_T = P_C + P_b + P_P \qquad 1$$

P_C is the cavity power necessary to accelerate the beam and is evaluated from; $P_C = (U_o q)^2 / 2R_s$, where q is the overvoltage factor, U_o is the energy loss/turn (KeV/turn) and R_s is the cavity shunt impedance (MΩ). P_b is the beam power required to replace the energy lost to synchrotron radiation and is derived from $P_b = U_o I_b$, where I_b is the stored beam current. P_P is the power required to overcome any parasitic losses and from practical measurements on the SRS, equates to ~10kW at 250mA. Table 1 shows that for the 321keV energy loss per turn on the SRS, if the existing RF cavities are employed, 475kW of RF power would be required to achieve 1Ampere. This would necessitate an overvoltage change from q=3.75 to q=5.5, for system stability reasons, which could be accommodated in the existing cavity feeder design.

Table 1. RF Power Needed for Existing SRS Cavities.

RF Power Components (kW)							
250mA (q=3.75)				1A (q=5.5)			
P_C	P_b	P_P	$\mathbf{P_T}$	P_C	P_b	P_P	$\mathbf{P_T}$
51	80.2	10	**141.2**	112.5	321	40	**475**

The total RF power figures quoted in Table 1 are for a critically matched RF system, whereby all cavities are resistively tuned, this however is not easily achieved on the SRS as its energy is ramped and the beam loading in the cavities can vary dramatically under these conditions. Therefore the cavities are normally inductively detuned to avoid Robinson instability and consequently more RF power is required to account for the additional reflected power. This can amount to 2-3kW of additional RF power required per cavity (at 250mA), which means that the total RF power P_T at 1A would rise to ~ 490kW.

As a way of overcoming the multibunch instabilities and also improving RF power transfer efficiency, a replacement of the existing RF cavities with a new, higher efficiency accelerating structure has been investigated. This new optimised cavity design could inherently damp the HOM impedances whilst also enabling a larger RF input power; large enough to necessitate a requirement for only two cavities instead of the original compliment of four. This would then release a further two ID straights, for installation of devices which would benefit from the increased photon flux available.

2 THE NEW RF CAVITY DESIGN

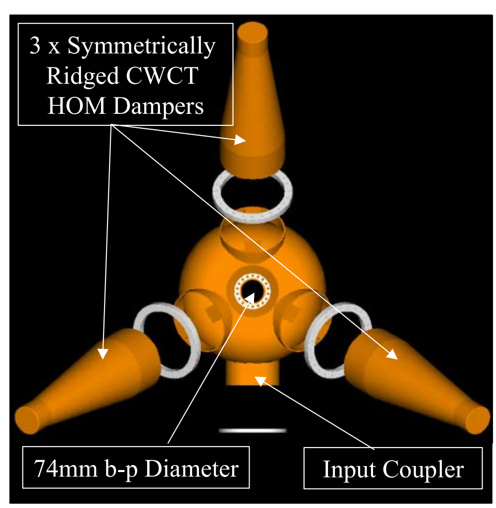

Figure 1. Spherical EU Cavity Design Assembly.

As part of an EU collaborative team, Daresbury Laboratory has already led the design of a spherical, re-entrant cavity, operating at 500MHz, which incorporates 3 equispaced ridged waveguide tapers, with a circular waveguide to coaxial transition (CWCT) to couple out the HOM power to external HOM loads. Figure 1 shows a layout for the spherical EU cavity design incorporating the 3 CWCT damping waveguides along with a longitudinally offset, aperture input coupler, which also provides additional narrowband HOM damping.

This cavity design employs a 74mm beam-pipe diameter to primarily enhance the fundamental mode shunt impedance with an R_s=4.7MΩ, a consequence of which is to also enhance the HOM shunt impedances. The magnitude of these limiting impedance characteristics, calculated using MAFIA [4] are discussed in more detail elsewhere [5]. They do however highlight excellent HOM damping characteristics, when compared to the current generation of normal conducting, HOM damped cavities, such as those employed on the PEP-II [6] and DAΦNE [7] accelerators.

Table 2. SRS Machine Parameters

Parameter	Symbol	Value
RF Frequency (MHz)	f_{RF}	499.7
Energy (GeV)	E	2
Revolution Frequency (MHz)	f_{rev}	3.123
Synchrotron Tune	Q_s	0.01748
Momentum Compaction	α	0.0288
Longitudinal Damping Time (ms)	τ_s	1.988
Transverse Damping Time x,y (ms)	$\tau_{x,y}$	4.2,4.0
Beta x,y (m)	$\beta_{x,y}$	5.85,1.93
Number of Cavities	n_{cav}	4

For the SRS machine parameters as shown in Table 2, longitudinal (Equation 2) and transverse (Equation 3) multibunch instability beam current thresholds have been computed for this EU cavity design of Figure 1 and predict thresholds of: $I_{th}^{//}$=473mA and $I_{th}^{\perp}$=553mA respectively.

$$\text{Longitudinal, } I_{th}^{//} = \frac{2EQ_s}{\alpha\tau_s R_{HOM}^{//} f_{HOM}^{//} n_{cav}} \qquad 2$$

$$\text{Transverse, } I_{th}^{\perp} = \frac{2E}{\beta_{x,y}\tau_{x,y} R_{HOM}^{\perp} n_{cav} f_{rev}} \qquad 3$$

The figure of merit for longitudinal instability performance for a particular cavity solution, from Equation 2 is the maximum impedance-frequency product in the bandwidth below beam-pipe cut-off (f_c^{TM01}=3.1GHz) and above CWCT cut-off (f_c^{CWCT}=650MHz) frequencies. The corresponding limitation for the transverse plane is purely the maximum transverse HOM impedance as there is no inverse frequency dependence (see Equation 3). The HOM damping for this cavity design is such that for beam currents up to 500mA operation on the SRS, this would be a viable cavity solution. For 1A operation however, its HOM damping characteristics require some improvement, to avoid the potential for mutlibunch instabilities.

An adaptation of the EU cavity design has therefore been performed to try and improve the cavity HOM damping characteristics. Figure 2 illustrates the spherical EU cavity geometry and the associated modifications that have been implemented.

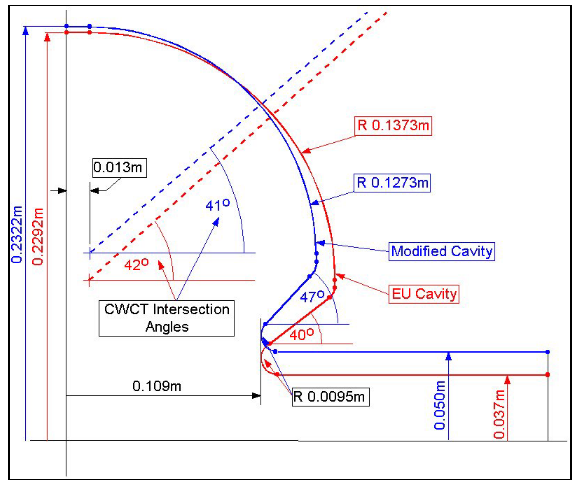

Figure 2. EU Cavity and Modified Cavity Geometries.

By relaxing the beam-pipe dimension from 74mm diameter for the EU cavity design, to 100mm diameter and re-correcting for 500MHz operating frequency, a reduction in the longitudinal AND transverse HOM impedances are observed (see Figure 3).

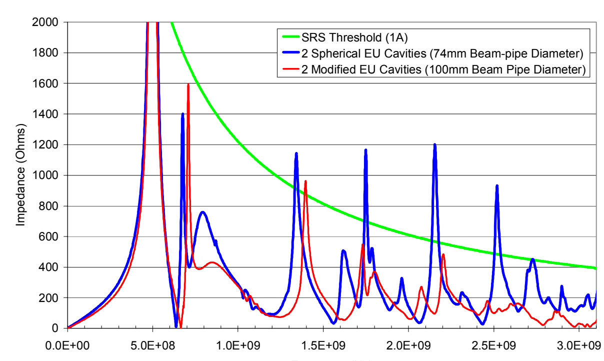

Figure 3. Cavity Longitudinal HOM Spectrum.

This can be seen by evaluation of the HOM impedance spectra for the two cavity geometries and comparing with the machine impedance at which, the HOM growth rates equal the machine damping times. This effectively defines the point at which the onset of multibunch instabilities occurs. Figure 3 shows the longitudinal impedance spectrum of the spherical EU cavity with a 74mm beam-pipe and that of a modified design incorporating a 100mm beam-pipe, compared with these is the impedance threshold for the SRS at 1A.

The technique employed for the characterisation of such HOM damped structures has been detailed elsewhere and uses a MAFIA time-domain excitation technique to compute the longitudinal and transverse wakefield responses, which are Fast Fourier Transformed (FFT) and normalised by the gaussian bunch excitation signal [8].

The HOM performance figures of merit for the two geometry options are shown in Table 3 along with the corresponding beam current thresholds predicted when two of each cavity type are applied on the SRS.

Table 3. Beam Current Thresholds.

	EU Cavity (74mm b-p)	Modified (100mm b-p)
Max $R^{//}_{HOM} f^{//}_{HOM}$ (Hz.Ω)	1.29e12	6.72e11
Long. Threshold $I^{//}_{th}$ (mA)	**473**	**908**
Max $R^{\perp}_{HOM}$ (kΩ/m)	46.9	20.7
Trans. Threshold $I^{\perp}_{th}$ (mA)	**553**	**1250**

The improvement in the longitudinal performance is clear, an almost doubling of the predicted beam current threshold limit from $I^{//}_{th}$=473 to 908mA. The increased beam pipe dimension has also benefited the transverse HOM impedances significantly as shown in Figure 3, with a beam current threshold improvement from $I^{\perp}_{th}$=553 to 1250mA.

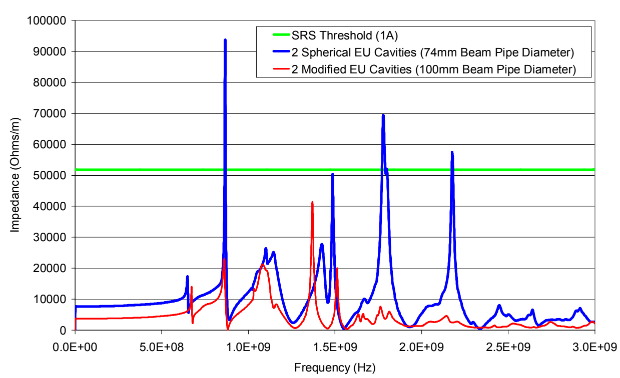

Figure 3. Cavity Transverse HOM Spectrum.

The accelerating efficiency or fundamental mode shunt impedance has been estimated for this modified cavity geometry as R_s=4.3MΩ. This equates to a 9% reduction in R_s compared to the original EU cavity design of 4.7MΩ. Although more RF power would be required to generate the necessary accelerating voltage, the increased HOM damping for this modified cavity design more than compensates for its marginally reduced efficiency, plus the fact that it is already 20% more efficient than the current non-HOM damped SRS cavities.

3 CAVITY APPLICATION ON THE SRS

This new cavity design would be capable of providing an acceleration voltage of 850kV/cell. If two cavities were employed in the SRS, requiring a momentum aperture voltage of 1.2 MV, the power required to generate this voltage would be 84kW.

Table 4. RF Requirements For New RF Cavities.

Modified Cavity RF Power at 1A (q=3.75)			
P_C	P_B	P_P	$\mathbf{P_T}$
84	321	40	**430**

The new configuration of only 2 cavities could either be fed by a single 500kW klystron via a single Magic-Tee and isolation transformer, or else by 2 x 250kW klystrons each cavity being fed by a single klystron. The latter option is a more cost-effective solution on the SRS, as 2 x 250kW klystrons are already available as part of a "hot" standby amplifier system, should the operational klystron fail [9].

4 CONCLUSIONS

A possible upgrade of the SRS RF system to enable beam currents approaching 1A to be more reliably achieved with a higher degree of stability has been identified. A new HOM damped cavity has been designed, adapting the already excellent performance of a cavity developed by Daresbury Laboratory as part of an EU collaboration. The predicted performance of this new cavity design suggests that stable longitudinal and transverse operation could be expected on the SRS approaching this 1A upgrade goal.

5 REFERENCES

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