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ESS HIGH-BETA CAVITY TEST PREPARATIONS AT DARESBURY LABORATORY

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Abstract

Science and Technology Facility Council (STFC) is responsible for supplying, and testing 88 high-beta elliptical SRF cavities, as part of the UK In Kind Contribution (IKC) to the European Spallation Source (ESS). The high-beta=0.86, cavities have been designed by CEA- Saclay and are a five cell Niobium cavity operating at 704.42 MHz. They are required to provide an accelerating gradient of 19.9 MV/m at an unloaded Q of 5×10^9. Preparations are underway to upgrade the cryogenic and RF facilities at Daresbury laboratory prior to the arrival of the first cavities. As part of these arrangements, a niobium coaxial resonator has been manufactured, to validate the test facility. The design considerations, for the coaxial resonator are presented, along with preliminary results. The RF measurement system to perform the cavity conditioning and testing is also presented.

INTRODUCTION

As part of the UK IKC to the ESS project [1], STFC are undertaking the procurement, qualification, testing, and delivery to CEA Saclay. The latter, for the cryomodule integration of 88 high-beta dressed cavities. These cavities are five cell superconducting Niobium cavities operating at 704.42 MHz and with a beta of 0.86 (see Fig. 1). The desired operating gradient in the ESS linac is 19.9 MV/m with an unloaded Q of 5×10^9. For qualification testing purposes the target gradient is 22.9 MV/m.

Figure 1: High beta 704.42 MHz undressed cavity.

The technical requirements for the high beta cavity are displayed in Table 1. As part of the programme STFC will undertake the procurement of fine-grain niobium material and the fabrication of SRF dressed cavities through recognised specialist manufacturers, to ensure that timescales can be met, and the quality is maintained. The qualification testing of the cavities is to be performed at Daresbury laboratory.

Table 1: Requirements on High-beta Cavities

Requirement	High-beta
Frequency (MHz)	704.42
Beta	0.86
E_{acc} (MV/m)	19.9
E_{pk} (MV/m)	45
B_{pk}/E_{acc} (mT MV/m)	4.3
E_{pk}/E_{acc}	2.2
Iris diameter (mm)	120
RF peak power (kW)	1100
G/Omega	241
Maximum R/Q (Ohms)	477
Q_{ext}	7.6×10^5
Minimum Q_u	5×10^9

To meet the demands for the qualification of the cavities, the RF and cryogenic facilities at Daresbury STFC are being upgraded to facilitate the measurement of the ESS high-beta cavities. This includes: new helium liquefaction and recovery systems; new digital Low Level RF (LLRF) systems, new RF racking and instrumentation; shielding, clean room, and High Pressure Rinse (HPR) facility. Further information about the cryogenic and liquefaction facilities can be found in [2], in these proceedings. Therefore this work will concentrate on the RF systems such as the RF measurement system, the LLRF and also several coaxial resonators used to test and validate the systems. The test system has been designed so that three cavities can be tested separately during a single cooldown. Later it will be seen that this has implications for the test system as a high power switching network is required to switch power between cavities.

Low Level RF (LLRF)

An FPGA system has been developed in-house; based on a Self-Excited Loop (SEL) algorithm, see Fig. 2. This is essential, since with a Q of approximately 5×10^9, the standard 3dB bandwidth in transmission is on the order of 0.1 Hz. In order to test and verify the digital LLRF, at room temperature, a simple compact resonator was required to provide reliable validation. The ESS cavities are ellipsoidal with an outer diameter of approximately 400mm. Even a single cell cavity of this type would be expensive to manufacture, as well as quite bulky, so instead, compact coaxial resonators were designed, that operated around 704 MHz. These had an outer diameter of approximately 50mm and an ID of 14mm. They were supported in the middle by a disc of PTFE, where the electric field is a minimum.

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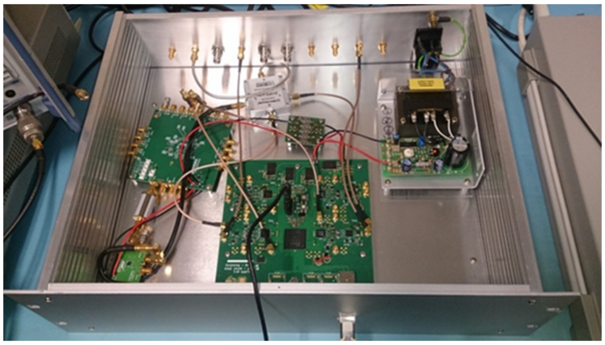

Figure 2: Digital LLRF system.

Figure 3: Copper coaxial resonators for validation.

Three such resonators are presented in Fig 3. A coaxial resonator is also much more suitable for integration into a cryocooler.

Using a copper coaxial resonator it has been possible to check the frequency tracking of the digital LLRF system. The tracking was verified using either a commercial can of evaporative coolant, and a heat gun. The frequency shifts in opposite directions for cooling and heating of the coaxial inner.

Main RF Measurement System

The main RF measurement system and Labview control system is taken from the design of T.Powers from JLAB [3]. Modifications have been made, to achieve greater safety in operation, as well as to meet the requirements for the testing of the ESS cavities. Most of the equipment is contained within a single rack housing which includes a 500W amplifier as well as power meters, signal generators, and a 500W load, which enables the system to be tested at full power, while the output is dissipated in the load. The 500W amplifier, with the load above it, is displayed in Fig.4.

Figure 4: The 500W amplifier and load.

The fact that 3 cavities are being tested during a single cooldown means that a high power switching network is required to distribute power to each cavity in turn. Figure 5 shows part of the switching network being constructed, along with a 2kW combiner (top left).

Figure 5: High power switching network in construction.

Niobium Coaxial Cavity for Validation

In order to validate the operation of the RF measurement system a Niobium (Nb) coaxial resonator has been designed that will fit inside a cryocooler. An aluminium version has also been designed, to aid training of staff in assembly. The dummy aluminium cavity can be seen in Fig 6. This resonator is considerably smaller than its copper counterpart, but this is necessary for integration in the cryocooler.

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Figure 6: Dummy aluminium coaxial cavity.

The design of the niobium coaxial resonator is different from that of the copper ones as it must be mounted vertically. This means the supports for the niobium inner must be at the ends, not in the middle. Due to the fact, that for a half wavelength coaxial resonator the electric field is a maximum at the ends, it means the dielectric supports at the ends must have extremely low dielectric loss, otherwise the overall Q of the resonator will be dominated by dielectric losses. The high electric field at the ends of the resonator is shown in Fig. 7. The only material with a sufficiently low loss tangent is single crystal sapphire.

Previous work has demonstrated sapphire whispering gallery resonators with overall Q's over 10^9 at approximately 10 GHz. Although a range of values are found from different suppliers [4]. This suggests that a range of loss tangent values are possible from different manufacturers. The supports have been designed as hollow tubes, to try and reduce the fraction of the electric field energy that is inside the sapphire and thereby reduce the dielectric losses further. Careful design of the supports has resulted in an electric filling factor of only 10%. Table 2 shows the possible overall Q values that could be achieved with different values of dielectric loss tangent. The overall conductor Q is assumed constant at approximately $1.4\text{x}10^8$.

Table 2 suggests that the overall unloaded Q of the niobium resonator could be in the region of 60 to 120 million, depending upon the loss tangent of the sapphire. Even if the Q were only 60 million, that would provide a reasonable Q to verify the operation of the LLRF, as well as a high enough Q to measure the decay time of the cavity.

Table 2: Overall Unloaded Q for Different Tand Values

Tand	**Dielectric Q Qd**	**Conductor Q Qc**	**Unloaded Q Qu**
10^{-6}	10^7	$140\text{x}10^6$	$9.3\text{x}10^6$
10^{-7}	10^8	$140\text{x}10^6$	$58.3\text{x}10^6$
10^{-8}	10^9	$140\text{x}10^6$	$123\text{x}10^6$

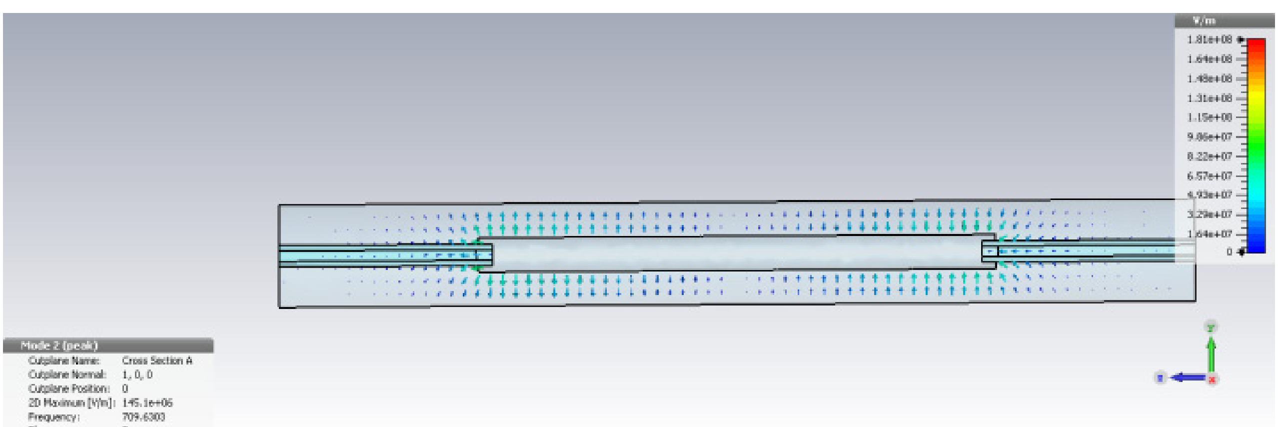

Figure 7: Cross section through the niobium coaxial resonator showing the Electric field pattern.

CONCLUSION

Overall, preparations are well underway for the upgrade of RF facilities at STFC Daresbury, to allow the characterisation of the ESS high-beta cavities. More compact coaxial cavities will provide an excellent starting point for the verification of these RF facilities.

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