

## ESS SPOKE CAVITY CONDITIONING AT FREIA

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### Abstract

The first ESS double spoke cavity installed with RF power coupler was tested in the HNOSS cryostat at the FREIA Laboratory. Power coupler and cavity conditioning have been optimized in order to reach high efficiency and high availability by reducing the time and effort of the overall conditioning process. Meanwhile, an optimal procedure for ESS conditioning is studied. This paper presents the study result and experience of the RF conditioning procedure for the first ESS double spoke cavity.

### INTRODUCTION

The European Spallation Source (ESS) will adopt a total of 26 double-spoke cavities in the medium energy region [1]. The fundamental high power coupler (FPC) for ESS spoke cavity is designed and fabricated by IPNO. The testing of the double-spoke prototype cavity at high power has been conceded to Uppsala University, Sweden, where the Facility for Research Instrumentation and Accelerator development (FREIA) has been equipped with a superconducting cavity test facility [2].

The basic design parameters for the ESS spoke cavities and couplers are [3]:

Frequency: 325.21MHz

Pulse length at flat top: 2.86 ms

Repetition rate: 14Hz

Optimal Beta: 0.5

Loaded Q:  $2 \times 10^5$

Since the first quarter of 2017, the first ESS double spoke cavity equipped with FPC was tested in the HNOSS cryostat. A power conditioning stand and a RF test system is commissioned in this test. An optimal procedure for power coupler conditioning is thoroughly studied, with the purpose of addressing challenges at ESS with respect to high efficiency, high availability, as well as to reduce the time and effort of overall power coupler conditioning.

### ASSEMBLY IN THE CRYOSTAT

A double spoke cavity (Romea) has been fabricated and selected for the horizontal test. It completed its vertical test at IPNO with an excellent performance of maximum Eacc of 15 MV/m@  $Q_0 = 4 \times 10^9$  showing a successful cavity design and processing [4].

Equipped with the FPC and cold tuning system (CTS), this dressed cavity was shipped to FREIA and installed in HNOSS cryostat. The object of this test thus becomes the validation of the complete chain of high power RF amplifier, high power RF distribution, FPC, CTS, spoke cavity package and LLRF system.

The high power test stand at FREIA for ESS spoke cavities consists of a high power RF station running with TH595 tetrode tubes, an AFT circulator protection device, water cooling system, load, HNOSS horizontal cryostat system and LLRF based on either self-excited loop or signal generator. All these infrastructures provide a mechanical environment similar to its operation in the ESS linac. Note that the dressed cavity test has no cold magnetic shield and relies on the HNOSS magnetic shield which is located at room temperature in the vacuum vessel. Figure 1 shows the Romea cavity in HNOSS.

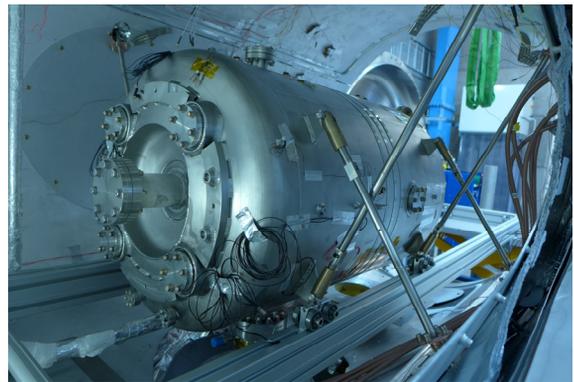


Figure 1: Romea cavity installed in the HNOSS

### CONDITIONING ALGORITHM

Prior to the high power test, the FPC went through RF power processing both at room temperature and 2K. In order to reach high efficiency and high availability by reducing the time and effort of the overall conditioning process, an automatic conditioning system, which consists of an acquisition system, a control system based on LabView software and feedback was developed at FREIA. The drive power level to the RF station can be controlled either manually or by this automatic conditioning system, while all essential safety interlocks are implemented in hardware.

In order to reduce damage from destructive factors, the cavity vacuum is chosen as a leading preventive indicator. The main idea of a RF-vacuum feedback system is to regulate RF power as a function of vacuum pressure around the coupler. In this way, vacuum limits avoid local overheating or electrical arcing within the vacuum side, which otherwise would damage the fragile ceramic window in the coupler. RF power conditioning at FREIA is done in standing wave regime at 14Hz repetition rate with different pulse lengths from 20 to 2860 micro seconds. During each phase of selected pulse length, the power is started from a low value and then ramped up step by step depending on various operating parameters. Finally, the maximum power of 120 kW is reached. Two software vacuum thresholds are adopted in this

conditioning procedure. As long as the coupler vacuum keeps below the first software threshold of  $5e-7$  mbar, RF power increases. Once above the first software threshold, the controller holds the RF output until the vacuum is recovered. Otherwise, RF power is decreased by 1dB if the vacuum gets worse, down to threshold  $1e-6$  mbar. Once the current phase reaches the targeted power, the system keeps the maximum forward power for a soaking time before the input signal is cut off. The next phase should not be executed until vacuum recovers below the first threshold. In parallel, an interlock system protects the RF components independently. Essential detective activities employed in the interlocks are arc, electronic events, temperature and vacuum.

The flow chart of FREIA conditioning is shown in Fig. 2.

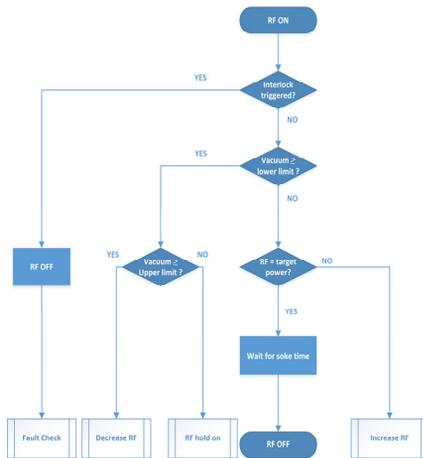


Figure 2: The flow chart of FREIA conditioning.

The FREIA automatic RF conditioning control program is based on LabView platform, as shown in Fig 3, with functions reading or publishing data from/into EPICS system. The whole program consists of several modules, to make debugging easier and future upgrading more flexible.

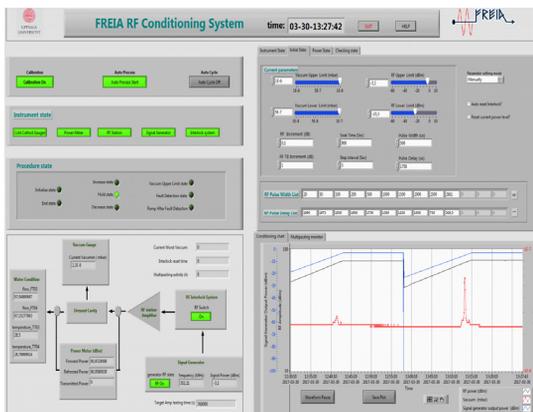


Figure 3: The FREIA automatic RF conditioning control program.

The main software control parameters are shown in Table 1.

Table 1: Main Parameters of Spoke Cavity Conditioning

Parameter	value
Loop control time (s)	1
Pulse repeat rate (Hz)	14
Vacuum upper limit (mbar)	$1e-6$
Vacuum lower limit (mbar)	$5e-7$
Initial pulse length ( $\mu$ s)	20
pulse length step	20 $\mu$ s, 50 $\mu$ s, 100 $\mu$ s, 200 $\mu$ s, 500 $\mu$ s, 1ms, 1.5 ms, 2 ms, 2.5ms, 2.86ms

The main devices for the RF conditioning process are:

- Signal Generator
- Power Meter
- Vacuum Gauge Controller (VGC)
- Cold Cathode Gauges (CCG)
- Arc Detector
- Electron Detector
- Fast RF Interlock Switch
- Vacuum Pumping Cart

### RF COUPLER PROCESSING

The warm and first cold RF processing was done using IPNO Orsay's system, followed by changing to the new FREIA conditioning system to verify its performance. All processes used a traditional signal generator driven loop. The warm RF processing procedure before cooldown took about 40 hours, lots of outgassing occurred through the forward power region of 50-80kW at short pulses. At the first phase, the coupler conditioning finished when 120 kW forward power was reached with 2.86 ms pulse duration. The FREIA conditioning system was then tested with ESS cavity package to verify the logic and related hardware. The overall FREIA system worked as expected: with little vacuum activity the forward power quickly ramped up to 120 kW with 2.86 ms. The well performance of FREIA's automatic conditioning system implies that it is ready for future conditioning missions.

### CAVITY CONDITIONING

The cavity package in HNOSS cooled down from room temperature to 4K within 25 minutes. From 4K to 2K it took an extra 20 minutes.

A major difference, compared to the FPC conditioning, is that the cavity RF conditioning is done by a self-excited loop (SEL). Since the tuner feedback controller is still under development, SEL naturally becomes a substitute for following the cavity resonant frequency without feedback. In order to produce pulses in the SEL, a RF switch controlled by a programmable trigger signal is introduced.

Cavity conditioning has been implemented above operational power level in two phases. The first phase introduces a frequency modulation (FM) around the resonant frequency at a very low power level, in order to sweep the field distribution forth and back along the

coupler walls in a controlled manner. FM modulation is completed by a digital phase shifter, based on NI FlexRIO FPGA and NI 5782R data acquisition modules. With this digital system, we can vary the loop delay with high-precision, where the loop delay is tightly related to loop frequency. Subsequent phase is also completed with the SEL but only ramp up the RF power with a fixed pulse length of 2.86 ms, which gives the higher efficiency of conditioning.

Figure 4 shows the major conditioning curves. Three major multipacting (MP) regions have been found during the cavity package conditioning. The first MP happened during the forward power from 22 to 30 kW, corresponding to a peak accelerating gradient from 4.5 to 4.8 MV/m. This MP was accompanied with worse coupler vacuum and higher electron current, which most likely happened at the area close to the interface between the cavity and coupler. The second MP barrier encountered was from 35 to 48kW with a peak gradient from 5.2 to 5.7 MV/m. While going through the third region from 67 to 76 kW, which was roughly from 7 to 7.5 MV/m, the performance of the cavity was stable. High X-ray activity was detected during the heavy MP, which caused an increment of the coupler temperature. Radiation was swapping between very high and low levels while helium gas spikes were found in the cryo-system. After about 30 hours of conditioning, the cavity package reached and was stably kept at 9MV/m peak accelerating gradient for more than 3 hours. The corresponding forward power was 110 kW.

During further measurements, all these three MP regions are repeatable but much easier to go through and less radiation is found.

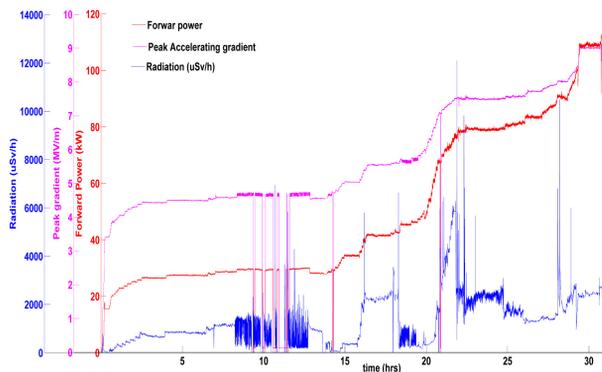


Figure 4: Cavity package conditioning history.

## CONCLUSION

The first ESS double spoke cavity installed with RF power coupler was tested in the HNOSS cryostat at the FREIA Laboratory. During both warm and cold RF conditioning, power levels above those required for nominal gradient have been demonstrated.

An automatic conditioning system, which consists of an acquisition system, control system based on LabView software and feedback was developed at FREIA. Optimal conditioning procedures both for coupler and cavity have

been demonstrated as an efficient method for controlling the remaining outgassing during conditioning.

## ACKNOWLEDGMENT

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## REFERENCES

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