Completion of testing series double-spoke cavity cryomodules for ESS

UPPSALA UNIVERSITET

R. Santiago Kern, C. Svanberg, K. Fransson, K. Gajewski, L. Hermansson, H. Li, T. Lofnes, A. Miyazaki†, M. Olvegård, I. Profatilova, R. Ruber‡, M. Zhovner, Uppsala University, Uppsala, Sweden

R. Ruber, Thomas Jefferson National Accelerator Facility, Newport News, Virginia, United States

The FREIA Laboratory in Uppsala, Sweden, is a leading laboratory in accelerator R&D and currently responsible of testing the 13 double-spoke cryomodules (plus one spare) for the European Spallation Source (ESS) in Lund. These cryomodules have two double-spoke cavities each, are assembled at Laboratoire Irène Joliot-Curie (IJCLab), in Paris (France), and transported to FREIA for testing. In this regards FREIA counts with its own helium liquefaction plant and suitable radio-frequency power stations.

Challenges in Cryomodule Testing

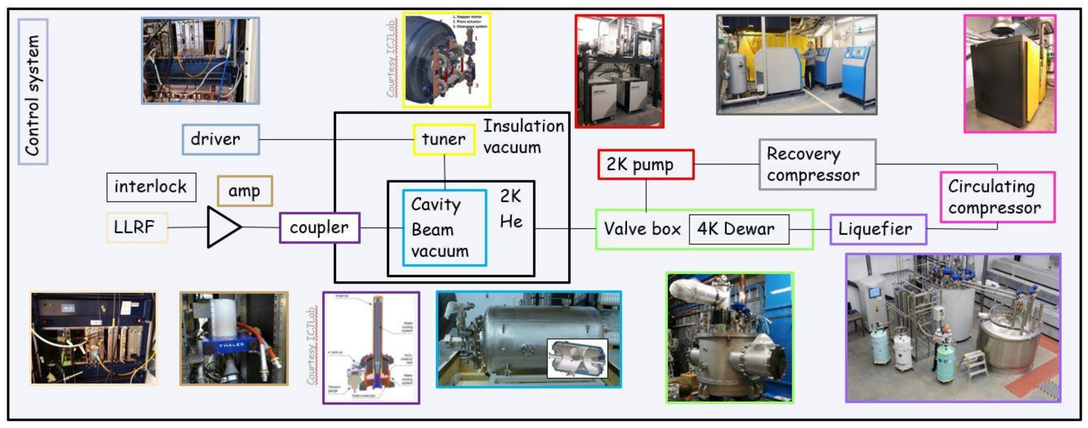

Figure 1. Infrastructure components for cryomodules testing in FREIA.

Table 1. An overview of the disqualified cryomodules and the reason for the disqualification.

CM #	Issue
CM02	Stepper motor lack of response
CM03	Stepper motor lack of response
CM04	Stepper motor lack of response Vacuum leak in FPC's double wall tube
CM09	Vacuum leak in FPC's double wall tube
CM10	Stepper motor lack of response

From the 13 cryomodules tested, 5 of them had to be sent to IJCLab for repairs, bringing the total number of tests done at FREIA up to 18. All these cryomodules were tested once again at FREIA after being repaired and all were accepted.

Standard Testing Schedule for Cryomodule

week	1st week																							
day	MON		TUE		WED		THU		FRI		SAT		SUN											
	m	a	m	a	m	a	m	a	m	a														
activity	departure from Orsay		transport						**reception**		reception test													

week	2st week																							
day	MON		TUE		WED		THU		FRI		SAT		SUN											
	m	a	m	a	m	a	m	a	m	a														
activity	doorknob mounting		installed in bunker		cryogenic connection		vacuum connection		RF calibration at warm		pumping													

week	3rd week																							
day	MON		TUE		WED		THU		FRI		SAT		SUN											
	m	a	m	a	m	a	m	a	m	a														
activity	coupler warm conditioning								LN shield cooling															

week	4th week																							
day	MON		TUE		WED		THU		FRI		SAT		SUN											
	m	a	m	a	m	a	m	a	m	a														
activity	cooling down to 4K		4 K filling	thermalization	2K pumping			multipacting conditioning		CTS test														
	f vs T measurement		coupler cold conditioning		f vs p		calibration at cold																	

week	5th week																							
day	MON		TUE		WED		THU		FRI		SAT		SUN											
	m	a	m	a	m	a	m	a	m	a														
activity	heat load measurement		start warming up		warming up				warming up completed															

week	6th week																							
day	MON		TUE		WED		THU		FRI		SAT		SUN											
	m	a	m	a	m	a	m	a	m	a														
activity	out from bunker		dismount doorknob, dry N2		out going test		departure		**arrival at ESS**															

Legend: Mechanical work | RF coupler conditioning | Cold test

Main part of the test takes **4 weeks.**

Warm RF coupler conditioning

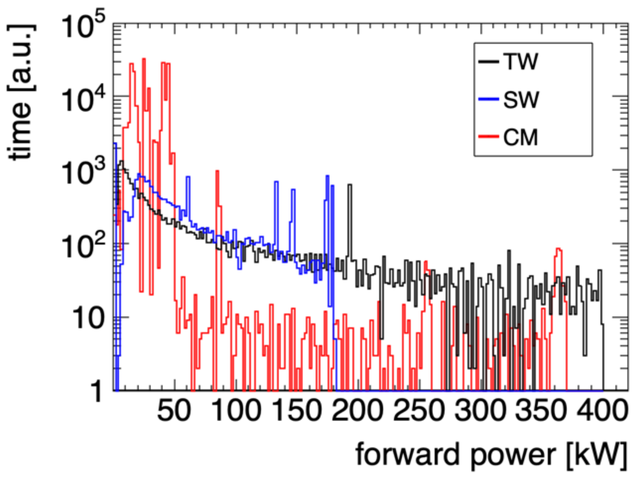

Figure 2: Comparison of the FPC conditioning. The fundamental power couplers, pre-conditioned at IJCLab in pairs via **travelling wave up to 400 kW** and **standing wave up to 170 kW**, are also conditioned at FREIA with **a standing wave up to 400 kW** at both room temperature and 2 K.

- Some couplers were repaired & recycled from disqualified cavity strings due to a vacuum leak.
- There is a big variation in conditioning time: from 10 h to 100 h, even under the same conditions.
- More active pumping during assembly might reduce the necessary conditioning time .
- RGA sometimes observed CH and oxygen have a negative correlation.

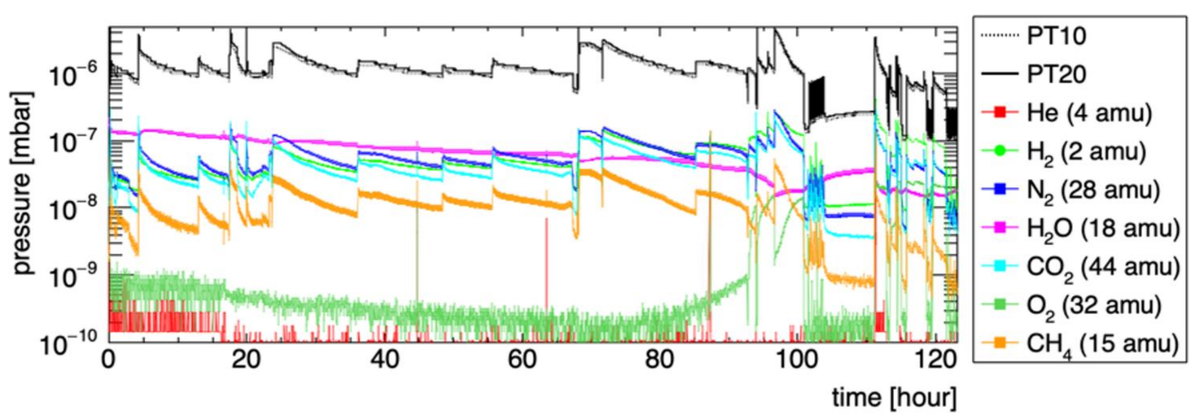

Figure 3. Data from RGA during warm RF coupler conditioning.

Cryomodules' Heat Loads and Q_0

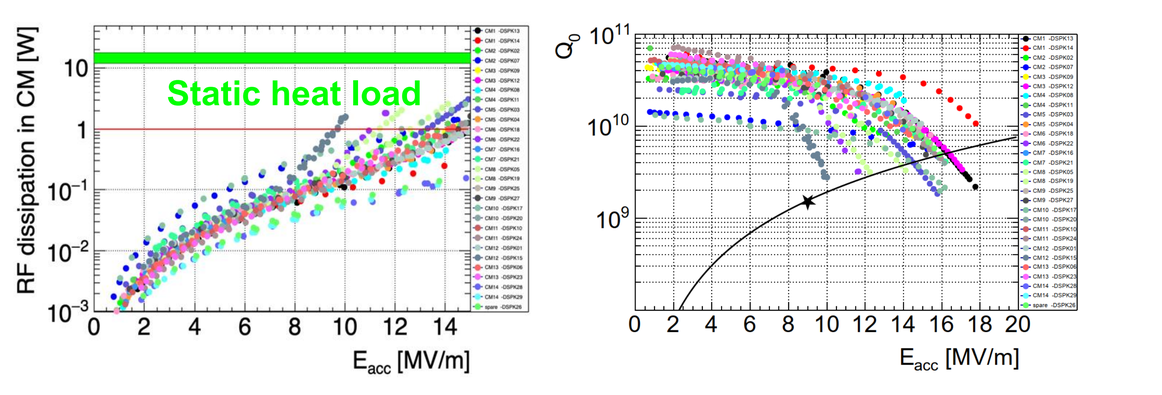

Figure 4: Power dissipated in the cryomodules at different accelerating gradients. An average of the static heat load and the measurement resolution are added for comparison purposes (left). Cavities' quality factor Q_0 values from the vertical tests at IJCLab (right)

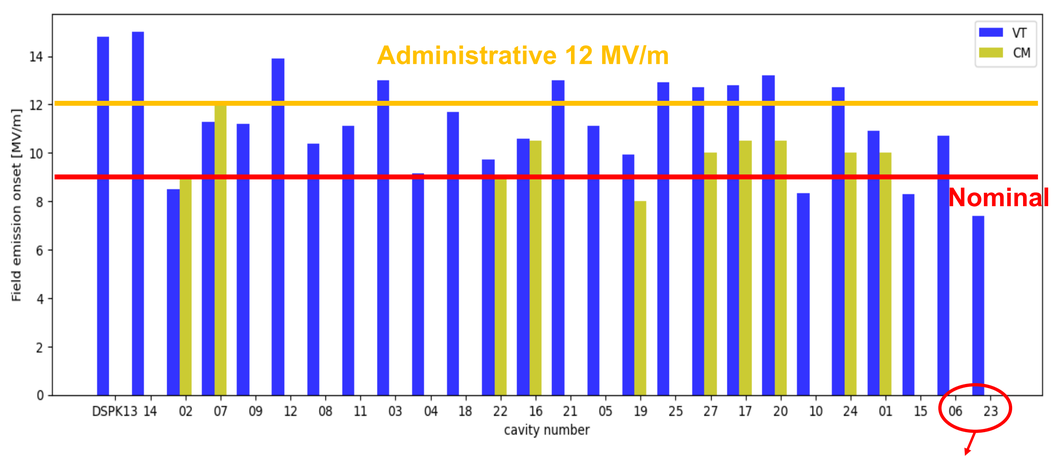

Figure 5: Field emission onset cavity (DSPK#) comparison between vertical VT (IJCLab) and cryomodule CM (FREIA) tests.

HPR after VT, not tested afterwards

Cold Tuning System

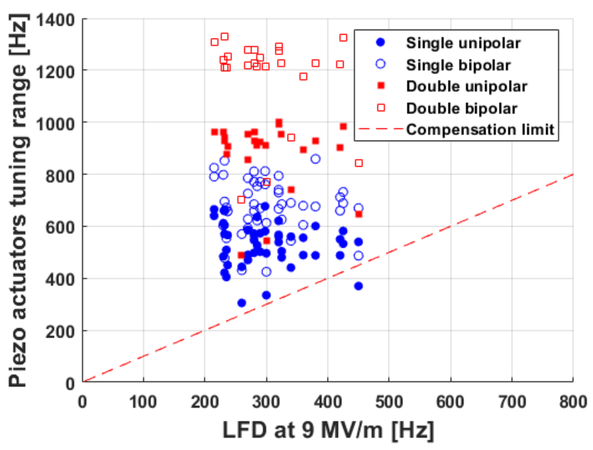

Figure 6: Measured tuning range of the piezo actuators in Hz with respect to hosting cavity's LFD at 9 MV/m.

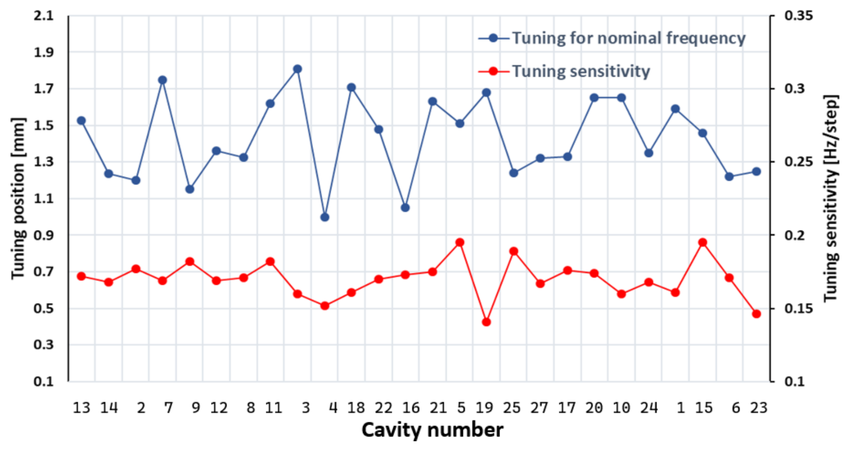

Figure 7: Motor tuning distance to nominal frequency and sensitivity.

Very important for future cryomodule developement to stress test one prototype and one series motor actuator

Lesson learned

From 2 ½ years of testing:

- Helium recovery capacity: increased mid testing (not a bottleneck)
- Heat load measurement: add new flowmeter with a lower range in parallel
- FPC cooling: add ScHe circuit
- RF stations
  - Failures with tetrodes, power supplies and amplifiers → problems with schedule
  - Careful optimization of operation parameters, risk analysis and availability of spare parts
- In day-to-day activities
  - Good planning and overview, and ⇨ **Necessary**
  - Good understanding of what processes or activities can be done or prepared in parallel

⇩

Essential

SRF2023, Paper: **THIAA03**, Rocio.santiago_kern@physics.uu.se Department of Physics and Astronomy, Uppsala University, Box 516, 751 20, Uppsala, Sweden

†Now at CNRS/IN2P3/IJCLab, Université Paris-Saclay, Orsay, France

‡Also at Thomas Jefferson National Accelerator Facility, Newport News, Virginia, United States