	FREIA Laboratory **Dept. of Physics and Astronomy** **Uppsala University**

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Engineering Specification

ESS Spoke Cryomodule

Acceptance Testing

Prepared by	*Checked by*	*Approved by*
FREIA team		

Distribution List

Revision	Date	History of Changes	Modifier
3	22/11/2017	Add separate list of test items for prototype and series	HL
2.6	21/11/2017	Add cool down of thermal shield	YS, RR
		Add optimization of LLRF during cold conditioning	
		Add use of rest gas analyzer on cavity vacuum	
2.5	20/11/2017	Combine all tests with cold tuning system in one step	HL, RR
		Remove LFD measurment step (was step 18)	
		Update cold measurement steps 14 through 19	
2.4	17/Nov/2017	Update required time for instrumentation, interlocks	RR
2.3	15/Nov/2017	Update cold measurements	HL
		Update the leak checking rate	
2.2	15/Nov/2017	Update cold measurements	RR
		Cavity spectra: include Qext measurement	
		Set LLRF feedback test time to "0" = not foreseen	
2.1	7/Nov/2017	Update all entries based on comments FREIA team	RR
2.0	2/Nov/2017	Add cavity vacuum check upon reception / inspection	RR
		Move insulation vacuum connection after cryogenic lines	
1.3	7/Dec/2016	Update summary for 1 and 13 cryomodules	RR, RSK
		Add cold tuner verification at step 1e (initial inspection)	HL
		Add RF calibration at step 9d (instrumentation check in bunker)	HL
		Modify step 17, no Qe measurement, no pick-up measurement	HL
		Modify step 17, add 3-dB measurement, temperature effect	VG
1.2	19/Oct/2016	Include the time for shipment	RR
1.1	19/Sep/2013	Include the time required for arrival and unloading	RR
1.0	17/Sep/2013	Overall update	RR
Draft	21/Jun/2013	Initial version	VG,RSK

ESS Spoke Cryomodule - Acceptance Testing at the FREIA Laboratory

Step	Process or Check Item	Overall Time [days]	In Bunker [days]	Team	Sub-step	Work Description	Acceptance Criteria	Check Sheet	Parts	Tools and Instruments	Utilities and Services
1	Arrival, unloading	0.5			a	unloading					mobile crane, fork lift
					b	unpacking					
					c	ship container back to sender					
2	Inspection	2			a	external inspection	no visual damage				
					b	mechanical parts					
					c	instrumentation connections	electrical			multimeter, test box	
					d	RF check	cavity spectrum, external Q			VNA	
					e	cold tuner verification	piezo and stepper motor				
					f	cavity vacuum	< 10-5 mbar				
3	Move into bunker	0.5	0.5			move the cryomodule into the bunker					overhead crane
4	Cavity vacuum	0	0	VAC	a	connect lines and pumps	if cavity vacuum > 10-5 mbar			rest gas analyzer	
					b	pump vacuum	<10 -5 mbar (<10-3 mbar for leak detection)				
					c	leak detection	< 10-10 mbar l/s			helium leak detector	
					d	open valve to cavity vacuum					
5	Cryogenic lines	2	2	CRYO	a	connect lines					
					b	purging					
					c	leak detection	< 10-8 mbar l/s		in parallel with step 5	helium leak detector	
6	Instrumentation	0	0	CTRL	a	connect cables					
					b	instrumentation check				multimeter, test box	
					c	calibration ADCs etc				oscilloscope	
					d	calibration RF loop				VNA	
7	Interlocks	0	0	CTRL		test interlocks			in parallel with step 5		
8	RF lines	2	2	RF	a	install doorknobs					
					b	connect waveguides					
9	Insulation vacuum	0.5	0.5	VAC	a	connect lines and pumps	in parallel with step 8				
					b	pump vacuum	< 10-5 mbar				
					c	leak detection	< 10-8 mbar l/s				
10	Bunker doors					close main bunker gate					
11	Warm conditioning coupler	2	2	RF	a	detune cavities					
					b	conditioning coupler	reach full power, pulse length				RF source
12	Cool down	2	2	CRYO	a	measure cavity frequency as function of temperature	continue during cool down			VNA	
					b	cool down of the thermal shield					
					c	cool down to 4 K	in parallel with (b)				Liquefier, LN2
					d	measure cavity frequency sensitivity as function of pressure	during cool down 4 to 2 K				
					e	cool down to 2 K					2K pumps
					f	cooling coupler					SHe pumps
13	RF Calibration	0.5	0.5	RF, CTRL		cables re-calibration					
14	Cavity cold tuning system	0.5	0.5	RF, CTRL	a	test slow cavity tuners (stepper motor)					
					b	measure tuning range and sensitivity (stepper motor)					
					c	test fast cavity tuners (piezo)					
					d	excitation of mechanical modes					
15	Cavity spectra	0.5	0.5	RF	a	fundamental and HOM spectra				VNA	
					b	Qpick-up					
					c	Qload (3dB bandwidth)					
16	Cold conditioning coupler + cavity	1	1	RF	a	tune cavities on resonance				RF source, LLRF	
					b	adjustment and optimization LLRF					
					c	conditioning coupler	reach full power, pulse length				
					d	test LLRF feed-forward for LDT compensation				LLRF with feed-forward	
17	Measurements	2	2	CRYO, RF	a	Q0 by dynamic heat load	average over both cavities			RF source, LLRF	
	Q0, Heat Load, Gradient				b	Eacc measurement (cross-check with Pt and Pf method)					
	Filling time				c	X-ray emission	in parallel				
	Multipacting				d	electron activity in coupler	in parallel				
	Field emission				e	Onset and level of multipacting	in parallel				
					f	Onset and level of field emission	in parallel				
18	Long-term stability	0.5	0.5	CRYO, RF		long term stability test	4 hours at nominal operation				
19	Warm-up	4	4	CRYO	a	warm-up of cryomodule					

Step	Process or Check Item	Overall Time [days]	In Bunker [days]	Team	Sub-step	Work Description	Acceptance Criteria	Check Sheet	Parts	Tools and Instruments	Utilities and Services
					b	open the main bunker gate					
20	Insulation vacuum	0	0	VAC	a	disconnect lines and pumps	in parallel with warm-up				
					b	break vacuum with GN2	T > 200 K ???				
21	RF lines	2	2	RF	a	disconnect RF waveguides					
					b	de-install doorknobs					
22	Cryogenic lines	0.5	0.5	CRYO		disconnect cryogenics lines					
23	Instrumentation	0	0			disconnect instrumentation					
24	Move out of bunker	0.5	0.5			Move cryomodule outside bunker					
25	Inspection	0.5									
26	Prepare for transport	1									
27	**Sub-total**	**25**	**21**								
28	Spare and wasted time	5	4.2			20% according DESY statistics					
29	**TOTAL**	**30**	**25.2**								

1 cryomodules (excl. wasted time)	25.0	21.0	days	
	5.0	4.2	work weeks	
	1.2	1.0	months	national holidays and vacation time not taken into account
1 cryomodule (incl. wasted time)	**30.0**	**25.2**	**days**	
	6.0	**5.0**	**work weeks**	
	1.4	**1.2**	**months**	**national holidays and vacation time not taken into account**
For 13 cryomodules	**390.0**	**327.6**	**days**	
	78.0	**65.5**	**work weeks**	
	18.6	**15.6**	**months**	**national holidays and vacation time not taken into account**

ESS Spoke Cryomodule - Testing Items at the FREIA Laboratory

Step	Process or Check Item	Condition	Team	Sub-step	Work Description	Prototype test item	Series test item
1	cavity spectrum and HOM	warm	RF		Get central cavity frequency and HOM spectrum	√	√
2	external Q	warm	RF		Simply estimate the coupling factor and Qe	√	√
3	coupler warm conditioning	warm	RF	a	reach full power, pulse length	√	√
				b	get an optimal procedure for RF conditioning	√	
4	frequency shift vs. T	cool down	RF		Frequency shift due to cool down	√	√
5	static heat loads at 4 K	cool down	CRYO	a	without level regulation	√	
			CRYO	b	with level regulation	√	
6	cavity level profile	cool down	CRYO		let the LHe evaporate to low levels (below 30%)	√	
7	frequency shift vs. Pressure	cool down	RF		Frequency shift due to pressure change from 4 to 2 K	√	√
8	static heat loads at 2 K	cold	CRYO	a	without level regulation	√	
				b	with level regulation	√	
				c	Effect of CV105 in heat load	√	
				d	Cavity's power limit: apply heat power until the level and/or the pressure in the cavity shows instabilities	√	
				e	Effect of different FPC cooling temperatures in heat load	√	
9	max. 2K pumps capacity at 2K	cold	CRYO			√	
10	coupler cold conditioning	cold	RF		reach full power, pulse length	√	
11	cavity package cold conditioning	cold	RF		reach nominal gradient ,full pulse length	√	√
12	central frequency and HOM	cold	RF			√	√
13	loaded Q and Qe	cold	RF	a	Get central cavity frequency and HOM spectrum at cold	√	√
				b	Loaded Q (-3dB bandwidth)	√	√
				c	Qe	√	
14	measurements	cold	RF	a	Q0 by dynamic heat load	√	√
	Q0, Heat Load, Nominal gradient			b	Eacc measurement (cross-check with Pt and Pf method)	√	√
	filling time			c	X-ray emission	√	√
	multipacting			d	electron activity in coupler	√	√
	field emission			e	Onset and level of multipacting	√	√
	max gradient			f	Onset and level of field emission	√	√
				g	Max gradient (Quench)	√	
15	dynamic Lorentz force detuning	cold	RF	a	Use oscilloscope (build in I/Q)to monitor the instantaneous frequency during pulse	√	
				b	Use FPGA to check the frequency shit during the pulse	√	√
16	cavity cold tuning system	cold	CRTL,RF	a	test slow cavity tuners (stepper motor)	√	√
				b	measure tuning range and sensitivity (stepper motor)	√	√
				c	test fast cavity tuners (piezo)	√	√
				d	excitation of mechanical modes	√	
17	stabilization of the cavity field with LLRF using only RF compensation	cold	CRTL,RF		stabilization of the cavity field only with LLRF power compensation	√	
18	long-term stability	cold	CRTL,RF		Stabilization of the cavity field with LLRF using both RF and piezo tuner compensation	√	√
19	frequency shift vs. Pressure	warm up	RF		Frequency shift from2 to 4 K	√	
20	frequency shift vs. T	warm up	RF		Frequency shift due to warm up	√	