	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
4.1	25/09/2019	Update cool down and warm up timing	RR
4	11/09/2019	Overall update planning	RR,HL,AM
3.1	21/08/2019	Update RF measurements items and order	HL,AM
		Add oparate of gate vale	
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	Work Time [days]	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	0.25	0.25			a	unloading					mobile crane, fork lift
						b	unpacking					
						c	ship previous CM to ESS					
2	Inspection	2	2		RF	a	external inspection	no visual damage				
	Warm measurements					b	cavity vacuum	< 10-5 mbar				
						c	RF check	cavity spectrum, external Q			VNA	
						d	cold tuner verification	piezo and stepper motor				
						e	multipin feedthrough				multimeter, test box	
3	Move CM next to bunker	0.25	0.25				move the cryomodule next to the bunker door					overhead crane
4	RF Doorknob	2	2		RF	a	install arc detectors					
						b	install doorknobs					
						c	connect waveguides					
						d	RF check					
5	Beam vacuum	0	0	0	VAC	a	install mobile clean room	wait over-night				
	for 1st CM only: 2 pumping stations					b	connect mobile pumping station				rest gas analyzer	
						c	pump vacuum	<10 -5 mbar (<10-3 mbar for leak detection)				
						d	leak detection	< 10-10 mbar l/s			helium leak detector	
						e	open valve to cavity vacuum					
6	Move into bunker	0.25	0.25	0.25			move the cryomodule into the bunker					overhead crane
7	Beam vacuum	1	0	0	VAC	a	install mobile clean room	wait over-night				
						b	connect mobile pumping station				rest gas analyzer	
						c	pump vacuum	<10 -5 mbar (<10-3 mbar for leak detection)				
						d	leak detection	< 10-10 mbar l/s			helium leak detector	
						e	open valve to cavity vacuum					
8	Insulation vacuum	1	0	0	VAC	a	connect lines and pumps					
						b	pump vacuum	< 10-5 mbar				
						c	leak detection	< 10-8 mbar l/s				
8	Cryogenic lines	2	2	2	CRYO	a	connect lines					
						b	purging					
						c	leak detection	< 10-8 mbar l/s		in parallel with step 5	helium leak detector	
9	RF lineas	1	0	0	RF		connect waveguides					
10	Instrumentation	1	0	0	CTRL	a	connect cables					
						b	instrumentation check				multimeter, test box	
						c	calibration ADCs etc				oscilloscope	
								done at 353MHz			VNA, power meter	
11	Interlocks	0.5	0	0	CTRL		test interlocks			in parallel with step 5		
12	RF Calibration	0.5	0	0	RF		calibration RF loop	done at 352.21MHz				
13	Close Bunker	1	0	0			close main bunker gate					
14	Warm conditioning coupler	6	6	6	RF	a	detune RF source frequency					
	24h/day operation					b	conditioning coupler	reach full power, pulse length				RF source
15	Cool down	2	2	2	CRYO	a	measure cavity frequency as function of temperature	continue during cool down			VNA	
						b	cool down of the thermal shield					
						c	close angle valve	around 200 K				
						d	cool down to 4 K	in parallel with (b)				Liquefier, LN2
						e	measure cavity frequency sensitivity as function of pressure	during cool down 4 to 2 K				
						f	cool down to 2 K					2K pumps
						g	cooling coupler					SHe pumps
13	Cold conditioning coupler	1	1	1			conditioning coupler	reach full power, pulse length				
14	RF Calibration	0.5	0.5	0.5	RF		CM cables re-calibration at cold	done at 352.21MHz				
15	Cavity cold tuning system	0.5	0.5	0.5	RF	a	test slow cavity tuners (stepper motor)					
						b	measure tuning range and sensitivity (stepper motor)					

Step	Process or Check Item	Work Time [days]	Overall Time [days]	In Bunker [days]	Team	Sub-step	Work Description	Acceptance Criteria	Check Sheet	Parts	Tools and Instruments	Utilities and Services
						c	test fast cavity tuners (piezo)					
16	Cavity accelerating mode	0.5	0.5	0.5	RF	a	fundamental mode (and HOM spectra)				VNA	
						b	Qpick-up					
						c	Qload (3dB bandwidth)					
17	Cold conditioning cavity (open loop)	2	2	2	RF	a	tune cavities on resonance	set a limit how much time to spend, then stop: max 1 day/cavity			RF source, LLRF	
	Multipacting					b	Onset and level of multipacting	in parallel				
	Field emission					c	Onset and level of field emission	in parallel				
18	Measurements (PID control)	1	1	1	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	Filling time	in parallel				
19	Long-term stability	0	0	0	RF		long term stability test with PID + piezo	4 hours at nominal operation with two cavities		in parallel with step 17		
	for prototype & 1st CM only											
20	Safety tests	0	0	0	RF		steppermotor disengagement mechanism	tbd				
	for prototype only											
21	Warm-up	5	5	5	CRYO	a	start warm-up of cryomodule					
						b	close beam vacuum valve	vacuum > 10-6 mbar				
22	Open bunker	0.5	0	0			open the main bunker gate					
23	Beam vacuum	0.5		0	VAC		disconnect pumping station					
24	Insulation vacuum	0.5		0	VAC	a	disconnect lines and pumps	in parallel with warm-up				
						b	break vacuum with GN2	T > 200 K ???				
25	RF lines	1	1	1	RF	a	disconnect RF waveguides					
						b	de-install doorknobs					
26	Cryogenic lines	0.5		0.5	CRYO		disconnect cryogenics lines					
27	Instrumentation	0		0			disconnect instrumentation					
28	Move out of bunker	0.25		0.25			Move cryomodule outside bunker					
29	RF Doorknob	1	1		RF	a	remove arc detectors					
						b	remove doorknobs					
30	Move CM to transport location	0.5	0.5				move the cryomodule next to the main entrance door					overhead crane
31	Inspection	1	1		RF	a	cavity vacuum	< 10-5 mbar				
						b	RF check	cavity spectrum, external Q				
						c	multipin feedthrough					
32	Prepare for transport	0.5	0.5				pack into crate for transport					
33	**Sub-total**	**37.5**	**29.25**	**22.5**								
34	Spare and wasted time	7.5	5.85	4.5			20% according DESY statistics					
35	**TOTAL**	**45**	**35.1**	**27**								

1 cryomodules (excl. wasted time)	37.5	29.3	22.5	days	
	7.5	5.9	4.5	work weeks	
	1.8	1.4	1.1	months	national holidays and vacation time not taken into account
1 cryomodule (incl. wasted time)	**45.0**	**35.1**	**27.0**	**days**	
	9.0	**7.0**	**5.4**	**work weeks**	
	2.1	**1.7**	**1.3**	**months**	**national holidays and vacation time not taken into account**
For 13 cryomodules	**585.0**	**456.3**	**351.0**	**days**	
	117.0	**91.3**	**70.2**	**work weeks**	
	27.9	**21.7**	**16.7**	**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 and decay time)	√	√
				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	√	