Fabrication and frequency tuning of QWRs for the SRILAC

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Collaborators

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Upgrade of the RIKEN Heavy Ion Linac

- A heavy ion linac, RILAC is consisted of normal conducting cavities.
- Beam intensity and energy will be upgraded by introducing superconducting linac (SRILAC) for the experiment of super heavy element synthesis and RI production.
- SRILAC has ten Quarter-Wave Resonators (QWRs) made of bulk niobium. VT for prototype and QWR-01 were performed (Sakamoto [TTC, Feb 2018], SRILAC Yamada [WG-1, Tuesday]).
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Design parameters of the cavity



Frequency tuning table (QWR prototype for SRILAC)

Fabrication, Polishing, Pumping, Cooling processes	Δf(kHz)	Frequency (kHz)
Cavity frequency cold in operation Eacc = 6.8 MV (Vgap = 1.2 MV)		73 023.507
Gap voltage 1.2 MV to 0 MV	0.041	73 023.548
Lower helium pressure from 0.13 to 0.1 MPa		
Warm cavity up to room temperature (4.2K to 293 K) {thermal. exp.}		
Add deformation by temperature variation (4.2 K to 293 K)	-124.147	72 899.401
Vent rf space from vacuum to 0.1 MPa		
Frequency shift due to dielectric constant of air (1 atm, humid. 40%)	-15.437	72 883.964
Add back BCP of cavity surface (BCP2: 20 um)	-7.166	72 876.798
Undo annealing (750°C、3 h) BC	P	72 873.491
Add back BCP of cavity surface (BCP1: 119 um)	-25.373	72 848.118
Add weld shrinkage for bottom dome (0.51 mm) Fabrica	ation	
Indium wire thickness clamping bottom dome (0.6625 mm)		
Add back cut of the straight section of bottom dome (3.4 mm)	22.217	72 870.335
Add weld shrinkage for center/outer conductors and top dome (0.7 mr	n)	
Indium wire thickness clamping center/outer cylinder and top dome (0,	.6 mm)	
Add back center/outer cylinder cuts(11.1 mm)	-669.242	72 201.093

Division of parts

- Partitioning was optimized by considering welding process.
- The formed parts are combined by EBW into 4 parts: top dome, stem, outer conductor, and bottom dome.
- Before welding the parts, RF measurements was required to adjust straight sections for frequency tuning.



RF measurement

- The first RF measurement was performed by clamping 4 parts.
- To improve RF contact and to obtain correct result,
 - cavity was set upside down (stem is pulled down)
 - Indium wires are clamped between the parts
- Gap length was adjusted by pressing beam port (elastic or plastic deformation, thermal expansion was taken into account.)
- After top parts were welded together, no indium wire was used in the second measurement due to nice RF contact.



2018/06/27 Bottom dome

Frequency tuning by cuts of straight sections

- Frequency sensitivity against the length of straight sections was calculated by CST MWS using sensitivity analysis.
- Cut lengths for one cavity (MRQ-01) are shown below.

Straight section	Sensitivity (kHz/mm)	Cut length (mm)	⊿f (kHz)	
Both stem and outer conductor	54.2	10.097	547.257	EBW1&
Stem (inner conductor) only	61.9	0.821	50.820	EBW2
Bottom dome	-6.73	6.034	-40.609	EBW3

 Sensitivity of "Stem cut only" was used to align beam ports and pipe. Alignment of them was checked before welding bottom dome (EBW3), by inserting a MC Nyron shaft into beam pipe.



Frequency tuning table (MRQ-01 for SRILAC)

Fabrication, Polishing, Pumping, Cooling processes	Δf (kHz)	Frequency(kHz)
1/2 of slow tuner frequency shift	7.000	73 000.000
Remove FPC	1.000	
Remove helium vessel	1.280	
Undo tuning by beam port		
Cavity frequency cold in operation Eacc = 6.8 MV (Vgap = 1.2 MV)		
Gap voltage 1.2 MV to 0 MV	0.041	
Lower helium pressure from 0.13 to 0.1 MPa		
Warm cavity up to room temperature (4.2K to 293 K){thermal. exp.}		
Add deformation by temperature variation (4.2 K to 293 K)	-124.147	
Vent rf space from vacuum to 0.1 MPa		
Frequency shift due to dielectric constant of air(1 atm, humid. 40%)	-15.437	
Add back BCP of cavity surface (BCP2: 20 um)	-7.166	
Undo annealing(750°C、3 h)	-3.307	
Add back BCP of cavity surface (BCP1: 130 um) [119 um for prototype]	-25.373	
Add weld shrinkage for bottom dome (0.51 mm)	on	
Indium wire thickness clamping bottom dome (0.01755 mm)		
Add back cut of the straight section of bottom dome (6.034 mm)	40.609	72 874793
Add weld shrinkage for center/outer conductors and top dome (0.7 mm)		
Indium wire thickness clamping center/outer cylinder and top dome (0.4 mm)		
Add back center/outer cylinder cuts(10.918 / 10.097 mm)	-598.077	72 213.256

Frequency tuning table (MRQ-01 for SRILAC)

Time sequence

Fabrication, Polishing, Pumping, Cooling processes	Δf (kHz)	Frequency (kHz)
1/2 of slow tuner frequency shift	7.000	73 000.000
Remove FPC	1.000	
Remove helium vessel	1.280	
Undo tuning by beam port		
Cavity frequency cold in operation Eacc = 6.8 MV (Vgap = 1.2 MV)		
Gap voltage 1.2 MV to 0 MV	0.041	
Lower helium pressure from 0.13 to 0.1 MPa		
Warm cavity up to room temperature (4.2K to 293 K){thermal. exp.}		
Add deformation by temperature variation (4.2 K to 293 K)	-124.147	
Vent rf space from vacuum to 0.1 MPa		
Frequency shift due to dielectric constant of air (1 atm, humid. 40%)	-15.437	
Add back BCP of cavity surface (BCP2: 20 um)	-7.166	
Undo annealing(750°C、3 h)	-3.307	
Add back BCP of cavity surface (BCP1: 130 um) [119 um for prototype]	-25.373	72839.859 (+7.97)
Add weld shrinkage for bottom dome (0.51 mm)	on	
Indium wire thickness clamping bottom dome (0.01755 mm)		
Add back cut of the straight section of bottom dome (6.034 mm)	40.609	72 874793
Add weld shrinkage for center/outer conductors and top dome (0.7 mm)		
Indium wire thickness clamping center/outer cylinder and top dome (0.4 mm)		
Add back center/outer cylinder cuts(10.918 / 10.097 mm)	-598.077	72 213.256

Frequency tuning table (MRQ-01 for SRILAC)

Time sequence

Fabrication, Polishing, Pumping, Cooling processes	Δf (kHz)	Frequency(kHz)
1/2 of slow tuner frequency shift	7.000	73 000.000
Remove FPC	1.000	
Remove helium vessel	1.280	
Undo tuning by beam port		
Cavity frequency cold in operation Eacc = 6.8 MV (Vgap = 1.2 MV)		
Gap voltage 1.2 MV to 0 MV	0.041	
Lower helium pressure from 0.13 to 0.1 MPa		
Warm cavity up to room temperature (4.2K to 293 K) {thermal. exp.}		
Add deformation by temperature variation (4.2 K to 293 K)	-124.147	
Vent rf space from vacuum to 0.1 MPa		
Frequency shift due to dielectric constant of air (1 atm, humid. 40%)	-15.437	
Add back BCP of cavity surface (BCP2: 20 um)	-7.166	
Undo annealing (750°C、3 h)	-3.307	
Add back BCP of cavity surface (BCP1: 119 \rightarrow 130 \rightarrow 110 um)	-25.373	72839.859 (+7.97)
Add weld shrinkage for bottom dome (0.51 mm)	on	
Indium wire thickness clamping bottom dome (0.01755 mm)		
Add back cut of the straight section of bottom dome (6.034 mm)	40.609	72 874793
Add weld shrinkage for center/outer conductors and top dome (0.7 mm)		
Indium wire thickness clamping center/outer cylinder and top dome (0.4 mm)		
Add back center/outer cylinder cuts (10.918 / 10.097 mm)	-598.077	72 213.256

Frequency sensitivity by cuts of straight sections

• Sensitivities for the cut of top and bottom dome were estimated by changing the length.



Frequency tuning table (QWR MRQ-01 for SRILAC)

Fabrication, Polishing, Pumping, Cooling processes	Δf (kHz)	Frequency (kHz)
1/2 of slow tuner frequency shift	7.000	73 010.928
Remove FPC	1.000	
Remove helium vessel	1.280	Beam port
Undo tuning by beam port	-4.067	Is needed.
Cavity frequency cold in operation Eacc = 6.8 MV (Vgap = 1.2 MV)		73 016141
Gap voltage 1.2 MV to 0 MV	0.038	73 016.180
Lower helium pressure from 0.13 to 0.1 MPa		
Warm cavity up to room temperature (4.2K to 293 K) {thermal. exp.}		
Add deformation by temperature variation (4.2 K to 293 K)	-124.147	
Vent rf space from vacuum to 0.1 MPa		
Frequency shift due to dielectric constant of air (1 atm, humid. 40%)	-15.437	72 876.377
Add back BCP of cavity surface (BCP2: 18.2 um)	-7.484	72 868.893
Undo annealing(750°C、3 h)	-3.307	72 866.547
Add back BCP of cavity surface (BCP1: 114.3 um)	-26.688	72 839.859
Add weld shrinkage for bottom dome (0.51 mm)	on	
Indium wire thickness clamping bottom dome (0.01755 mm)		
Add back cut of the straight section of bottom dome (6.034 mm)	40.609	72 874793
Add weld shrinkage for center/outer conductors and top dome (0.7 mm) $$		
Indium wire thickness clamping center/outer cylinder and top dome (0.4 mm)		
Add back center/outer cylinder cuts (10.918 / 10.097 mm)	-598.077	72 213.256

Progress of fabrication

All the cavities (up to 12) are in process. For eight cavities, frequency data were obtained. 73000 • MRQ-01 • MRQ-02 MRQ-03 72800 Frequency [kHz] • MRQ-04 MR0-05 MRQ-06 72600 ° MRQ-A ° MRQ-B -VT O MV - VT 8.8 MV/m 72400 Annealing ⁴ Parts -2 Parts -Welded gang. BCP1 72200 72000 3 2 5 6 7 8 9 10 0 of process #

Summary

- In fabrication process of RIKEN QWR, frequency tuning is performed by adjusting straight section at top and bottom of the cavity.
- Pretuning by the beam port tuner is scheduled for the first cavity for SRILAC after prototype (MRQ-01), by -11 kHz.

- Frequency sensitivity for beam port tuner was calculated by MWS.
- Δf/Δx=-37.9 kHz/mm (Δx is a displacement of a beam port flange)
- To tune by -14 kHz, required displacement is $\Delta x = 0.37$ mm.

Nb cavity with Ti vessel: Each beam port is pressed by 6,000 N.

