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DESIGN OF CRYOMOUDLE FOR RAON *

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Abstract

The accelerator will be built in Korea called RAON has four kinds of superconducting cavities such as QWR, HWR1, SSR1 and SSR2, and those cavities are operating in 2.1 K expect for the QWR cavity that operating in 4.2 K. Current status of cryomodules design is reported in this paper. The issues included in the paper are thermal and structural analysis results for the components such as thermal shield, support post, two phase pipe, and so on.

INTRODUCTION

The layout of the RISP accelerator is shown in Fig. 1 [1]. The complex consists of a heavy ion linear accelerator as the driver, called as Driver Linac, for the IF(In-flight Fragmentation) system, a proton cyclotron as the driver for the ISOL(Isotope Separation On-Line) system and a post-accelerator for the ISOL system. The Uranium ions produced in an electron cyclotron resonance ion source are pre-accelerated to an energy of 300 keV/u by a radio frequency quadrupole and transported to the superconducting cavities by a medium energy beam transport. The driver linac is divided into three different sections: low energy superconducting linac (SCL1), charge stripper section and high energy superconducting linac (SCL2). The SCL (superconducting linac) utilizes four types of superconducting cavities made of Niobium such as QWR (Quarter Wave Resonator, β=0.047), HWR(Half Wave Resonsator, β=0.21), SSR1(Single Spoke Resonator1, β=0.3), and SSR2(β=0.51) in order to accelerate the ion beams. The SCL3 has same configuration with SCL1. The summary of the cavities and cryomodules is shown in the Table 1. The operating temperature of QWR is 4.2 K but that of other cavities are 2.1 K. Also, there are some changes in the specification of the cryomodule compared to the previous report [2]. The most updated current status of the cyromodule design is reported in this paper.

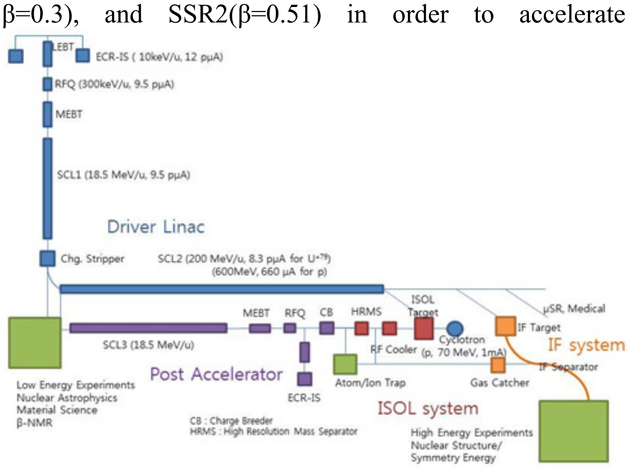

Figure 1: Schematic layout of RAON.

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Table 1: Summary of Cavity and Cryomodule

	SCL1 / SCL3			SCL2	
Cavity	QWR	HWR		SSR1	SSR2
Frequency (MHz)	81.25	162.5		325	325
Q_0 (10^9)	1.83	4.05		9.2	10.5
Ep (MV/m)	35	35		35	35
Operating T (K)	4.2	2.1		2.1	2.1
No. of cav. in CM	1	2	4	3	6
No of CMs	22	13	18	23	23
Beam output (MeV/u)	2.7	6.0	18.5	56.5	200

CRYOMODULE DESIGN

Generals of Cryomodule

The functional requirement of the cryomodules to achieve the proper performance of the accelerator is listed in Table . The requirements for the support system are the maximum allowable acceleration during the transportation and assembly procedure [3].

Table 2: Functional requirement of Cryomodule

Conditions		Requirement
Vacuum in cryomodule		~10^{-5} torr
Cavity alignment	X, Y	±0.25 mm
	Z	± 0.5 mm
	Tilt	± 0.1 °
System pressure rating	2 K pipe and reservoirs	4 bar
	4.5 K pipe	20 bar
	40 K pipe	20 bar
Support system	Vertical down and longitudinal dir.	4 g
	Transverse dir.	2 g

Another important functional requirement of the cryomodule is thermal insulation. The temperature of the thermal shield is changed form 70 K to 40 K. Also, the

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thermal intercepts are cooled to 40 K and 4.5 K. The operating temperature change of the QWR cavity mentioned previously changes the thermal load of the SCL. The most recent thermal load of each segment in the SCL is listed in Table . The thermal load valve of the table is the 4.2 K equivalent one that the thermal load of each temperature level is converted with the equation (1).

$$q_{4.2K\,eq} = 3q_{2.1K} + q_{4.2K} + 0.1q_{40K} \qquad (1)$$

The thermal load in Table does not include the thermal load of the transfer line, distribution box, valve boxes, superconducting magnets in IF (inflight fragmentation) system and the margin due to the imperfection of the thermal load estimation. The total thermal load of the whole accelerator would be 13 kW without margin, and it would be 20 kW with 50 % margin.

Table 3: Thermal Load Estimation of SCL

Segment	CM	Thermal load (W)		
		Static	Dynamic	Total
SCL1 /SCL3	QWR	114	266	380
	HWR1	174	250	424
	HWR2	341	730	1071
SCL2	SSR1	475	1014	1489
	SSR2	790	5009	5800
CS	HWR1	27	38	65
P2DT	HWR1	13	19	33
Total (W)		2563	8572	11135

The P&ID of the QWR and SSR1 cryomodule is shown in Fig. 2. The cryomodules holding cavities operating in 2.1 K are similar configuration of SSR1 shown in Fig. 2. 40 K gaseous helium is supplied from the HRS (helium refrigeration system) and it cools the thermal shield ans thermal intercept. The 4.5 K supercritical helium (SHe) also comes from the HRS and produces 4.2 K liquid helium during passing through the first JT valve in the cryomodule. The QWR has only one JT valve to produce 4.2 K liquid helium but others has one more JT valve to produce 2.1 K superfluid helium. The 4.5 K thermal intercept is cooled by loop thermosiphon connected with 4.5 K liquid reservoir. During the cool-down process, cold helium gas can flow to the bottom of the cavity helium jacket with the appropriate flow resistance in the two phase pipe. Thus, a cool-down valve can be eliminated in the cryomodule. The relief valves are installed at every reservoir and 40 K pipe line. The relief system consists of solenoid valve, re-seat relief valve and rupture disk. The vacuum vessel also has relief system. The solenoid valve at the 2 K reservoir relief system can be used for the cool-down process. The warm return gas flow after cooling the cold mass can return the warm gas return line, it is not shown in the Fig. 2, through the solenoid valve. The warm gas does not warm-up the inlet cold gas in the heat exchanger. The bayonet connection is employed for the individual maintenance of the cryomodule except for the QWR cryomodule using flange with helicoflex seal and VCR fitting connection.

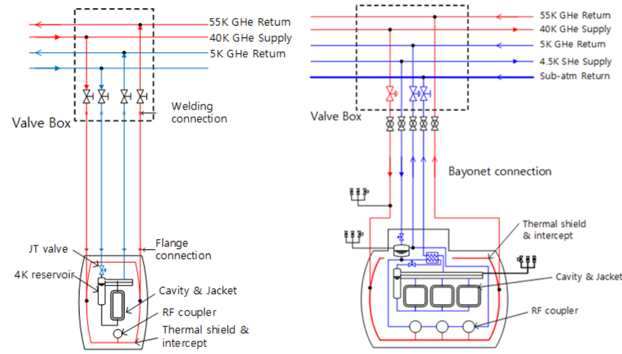

Figure 2: P&ID of QWR (left) and SSR1(right) cryomodule.

Layout of Cryomodule

Currently, the prototyping of the cryomodules are on-going with domestic vendors. The engineering design for the QWR, HWR1 and HWR2 cyromodules are already done but the conceptual design of SSR1 and SSR2 cyromodule is on-going. The 3D layouts of the cyomodules are shown in Fig. 3 and Fig. 4.

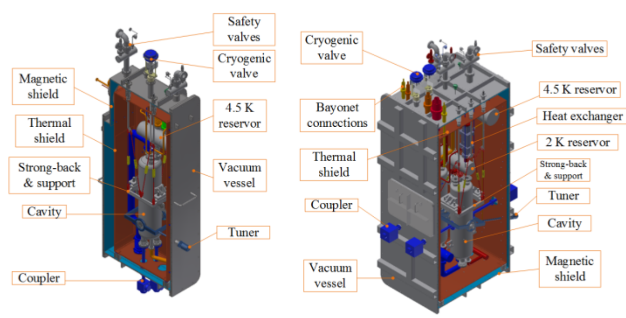

Figure 3: 3D layout of the QWR(left) and HWR1(right) cyromodule.

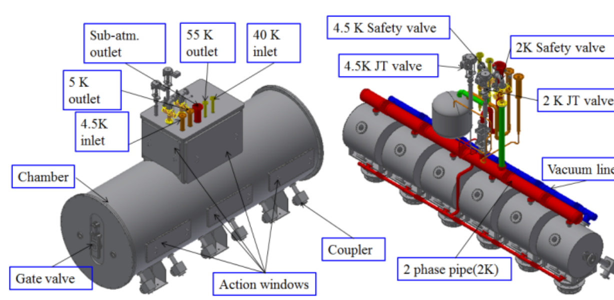

Figure 4: 3D layout of SSR2 cryomodule.

The QWR and HWR cavities are vertically installed on the strong-back and supported by the invar rods to minimized displacement after cool-down due to the thermal contraction while SSR cavities are horizontally installed and supported from the bottom the cryomodule. The two phase pipe whose diameter is approximately 150 mm is located above the cavity string. The thermal shield made of copper whose thickness is 3 mm is installed. The magnetic shield made of Mu metal is installed inner

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surface of the vacuum vessel to shield the earth's magnetic field less than 15 mG.

Component Design

The main components in the cryomodule are cryogenic pipe lines including two phase pipe, support post, strong-back, vacuum vessel and so on. The thermal and structural design of components is on-going. The structural simulation results of the vacuum vessel when the inside of the vessel is evacuated for the QWR and HWR2 cryomodule is shown in Fig. 5. The stiffeners are installed to reduce the deformation of the beam port is approximately 1 mm.

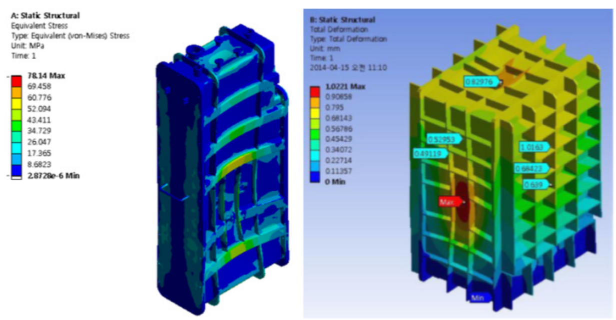

Figure 5: Deformation of QWR (left) and HWR2 (right) vacuum vessel .

The size of the two phase pipe is determined considering steady-state operation and accidental operation. For the steady-state, the minimum size of two phase pipe is determined to maintain the internal flow scheme as stratified two phase flow when the relative speed of the gas phase is less than 4 m/s. When the vacuum break-down occurs, huge amount of heat is transferred from the ambient with the gas inflow [4].

Then, vigorous evaporation occurs and the evaporated gas should be vented through the two phase pipe and the vent pipe. The situation in the SSR2 cryomodule is simplified as shown in Fig. 6. The pressure drop including minor losses [5] can be estimated when the inner diameter of the two phase is 150 mm and that of vent pipe is 85 mm. The estimation result is listed in the Table . When the set pressure of the rupture disk is less than 3.5 bar, internal pressure in the helium jacket can be less than 4 bar.

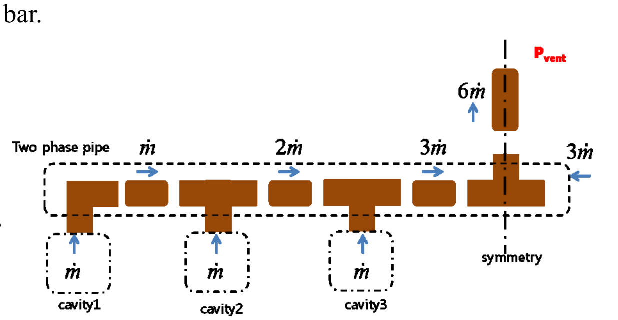

Figure 6: Schematic diagram of the vent flow in SSR2 cryomodule.

Table 4: Pressure Drop at Each Cavity

Set pressure	Δ P1 (bar)	Δ P2 (bar)	Δ P3 (bar)
2.50	0.31	0.27	0.26
3.00	0.29	0.26	0.24
3.50	0.27	0.24	0.23
3.75	0.27	0.24	0.22

The cavity string of the QWR and HWR is hung on the top of the vacuum vessel and that of the SSR is put on the strong-back. The deformation of the support post and strong back is simulated as shown in Fig. 7. The maximum deformation of the strong-back for the HWR2 and SSR2 are less than 0.1 mm and it is sufficient for the alignment requirement.

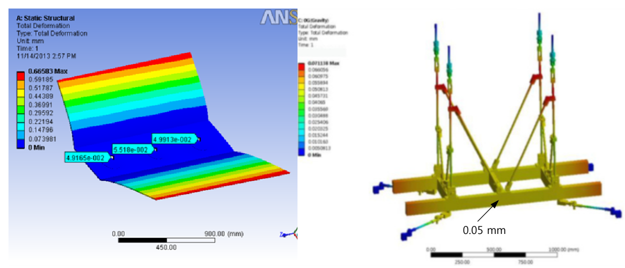

Figure 7: Deformation of the strong-back of SSR2 (left) and HWR2(right) cryomodule.

CONCLUSION

The prototyping of the cryomodules for the heavy ion accelerator are on-going. The most updated design status and the some examples of component design results are shown. The fabrication of the cryomodules for QWR and HWR cavities is already started and the engineering design of the SSR cryomodules will be started soon.

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