REINSTALLATION OF HEAVY CRYOMODULE FOR SCL3 BEAMLINE MAINTENANCE

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Abstract

This paper presents a case study on the reinstallation of heavy weight cryomodule (HWR-B #11, HWR-A #9 & #13) for the SCL3 beamline maintenance. Our RAON accelerator, HWR-B combines a cryomodule with a warm section assembled with a quadrupole magnet and a vacuum chamber, with a total weight exceeding 12.5 tons (HWR-A is approximately 7.0 tons). After each annual beam commissioning, some low-efficiency modules were identified to require inspection and repair during maintenance for the following year's beam operation. In particular, the processes of disassembling a large HWR-B or HWR-A cryomodule from the beamline and moving it out of the underground accelerator tunnel needs very strict safety requirements and detailed planning and coordination among related systems and teams. During the first stage of the maintenance procedure, the HWR-B #11, HWR-A #9 & #13 cryomodules was safely removed from the SCL3 beamline using a specially designed moving wheel and then delivered to the contractor for overhaul. After maintenance and testing were completed, the HWR-B #11 cryomodule was reinstalled at its original position on the SCL3 beamline. (However, as HWR-A #9 and #13 required long-term repairs, only the warm sections were reinstalled.) At this time, These tasks required significant effort to prevent steel frame overlap, quadrupole magnet balancing, pipe collisions, and cable breakage in the very narrow space between the HWR cryogenic modules on the beamline. This first in-house beamline maintenance experience provided valuable insight and expertise for the ongoing operation of an accelerator beamline.

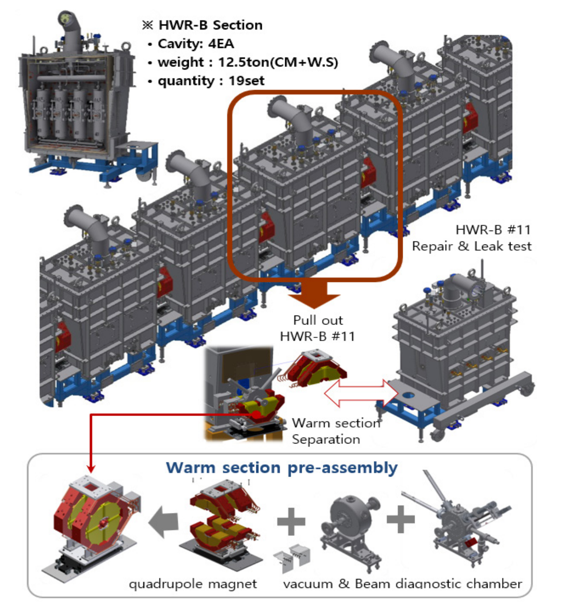
SCL3 MAINTENANCE PLAN

During the 1st cool-down and beam commissioning of the SCL3, a low-energy accelerator section, several device repairs and system improvements were required, so beamline maintenance was carried out to improve the cold leak of the several superconducting cavities & modules, stabilize the RF system, add a beam diagnostic device, repair the vacuum TMP, and repair the electromagnet power supply. Through this improvement work, we aimed to contribute to continuously providing stable beams to accelerator experiment users from 2024 to the present [1].

In the case of the HWR-B #11 Crymodule(CM), rather than a simple on-site repair to improve the cold-leak, a precise Overhaul through the manufacturer was decided. Accordingly, beamline disassembly (relevant module), repair and performance inspection & test, and reinstallation were required. In the case of HWR-A #09, #13 CM requiring long-term overhaul and inspection, only the warm section was separated and reinstalled on the beamline for improved beam operation.

HWR-B #11 Maintenance Scope

The main tasks of SCL3 beamline maintenance involve cutting the helium supply pipes of the cryogenic valve boxes connected to each cryomodule, dismantling the work platform, disconnecting the RF rigid coaxial pipes and DC bias, dismantling the module beamlines, disconnecting Warm section, moving to the SRF facility, performing cryomodule repairs and performance tests, and finally completing on-site reinstallation and beamline connection. Figure 1 shows the configuration of the HWR-B cryomodule of the SCL3 beamline, and shows the HWR-#11 configuration and maintenance schedule of the SCL3 beamline [2].

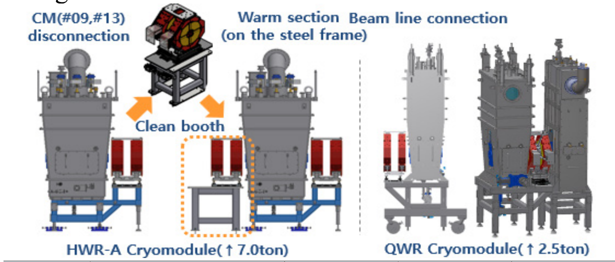


Task	date	Assignment	Remark
• Module Beamline Gate Valve closing	6.5	M.S Kim, Y.J Choi	B#10(R), B#11(F,R), B#12(F)
• SCL3 Warm up	6.12~6.30	T.K Ki 外 Cryogenic team	
• RF Rigid Coaxial Line & DC bias disassembly	6.21~6.23	O.R Choi, J.W Choi	#10, #11, #12 remove(6.22, 7.14)
• Signal & Control & Power cable line separation(String vacuum)	6.26~6.30	M.S Kim, J.W Choi, Y.J Choi, J.S Kang	CM, W.S(6.27), String Vacuum(7.18)
• Cryogenic pipe cutting & Pneumatic line separation	7.3~7.6	J.H Shin(I.M Park), Outsourcing1	7.6(inner pipe separation) 7.13~7.18
• Taking to pieces of cat-walk(only HWR-B#11 area)	~7.6	J.H Shin(I.M Park), Outsourcing1	Front & back CM of HWR-B #11(2set): 7.18
• Quadrupole magnet top-side opening(4set, warm section)	~6.30	J.S Kang, J.W Kwon	Front & back CM of HWR-B #11(2set): 6.28
• Preparation of moving clean booth to HWR #11 area	7.7~7.19	J.W Kwon, E.H Lim, H.J Shon	Front & back CM of HWR-B #11
• Separating Beamline & HWR #11 W.S(Clean booth)	7.7~7.19	J.W Kwon, E.H Lim, H.J Shon	Front & back CM of HWR-B #11
• Separating HWR-B#11 CM & move to ISOL	7.20 & 21	J.W Choi, Y.H Lee(外 7persons)	Preparing to load on a vibration-free truck
• area & leave to SRF building	7.20 & 21	J.W Choi, Y.H Lee(外 7persons)	7.21, 15:00P.M (SRF building)
• Repair and maintenance(Cryogenic inspection)	7.24~11.06	Y.W Jo, J.W Choi, M.K Lee	HWR-B@SRF test facility : 7.24~11.10
- Decomposition & Assembly / 4.5 K cool down test(1st)	~10.13	Y.W Jo, Outsourcing1	
- 4.5K / 2K cool down test(2nd)	10.26~10.31	Y.W Jo, M.S Kim, Outsourcing1	LN2 pre-cooling
- Warm up(HT bunker)	11.01~11.09	Y.W Jo, M.S Kim, Outsourcing1	11.2~11.03 HT finish & delivery preparation
- Delivery to ISOL building & Bring in the basement	~11.10	Y.W Jo, M.S Kim, Outsourcing1	ICABU(11.8~10)
• Putting a warm section on HWR-B#11(alignment)	11.13~14	J.S Kang, J.W Kwon, C.S Seo	SRF → ISOL building, CM+WS Assembly
- Lift & Move HWR-B#11 to SCL3 tunnel	11.13	J.W Choi, Y.H Lee(外 7persons)	Foot Base, spacing between the beam pipes
- Alignment	11.13	C.S Seo, J.H Jo, Outsourcing1(SAE)	(x, y, z) < +- 1 mm, ICABU 2023
- Place HWR-B#11 on the foot-base & bolting	11.14	J.W Choi, Y.H Lee	Caution with VBx pip connections
- Final alignment	11.14	C.S Seo, J.H Jo, Outsourcing1(SAE)	Final beamline alignment
• Clean assembly & Vacuum slow pumping(HWR-B#10-11)	11.15~11.17	J.W Kwon, E.H Lim, H.J Shon	11.16(Assembly), 11.17(Leak test/move)
• Clean assembly & Vacuum slow pumping(HWR-B#11-12)	11.20~11.24	J.W Kwon, E.H Lim, H.J Shon	11.22(Assembly), 11.23(Leak test)
• Assembly cat-walk (B-#11 area)	11.27~	J.H Shin(I.M Park), Outsourcing1	11.24
• Pipe Connection between VBx and HWR-B#11CM	11.27~12.01	J.H Shin(I.M Park), Outsourcing1	welding(11.27), MLI, duct, vacuum, check
• Cryogenic pipe & Pneumatic pipe connection	11.27~12.01	J.H Shin(I.M Park), Outsourcing1	Due date: 7.14~12.11
• Signal & Control & Power cable line connection	12.04~12.08	M.S Kim, Y.J Choi, J.S Kang, J.W Kwon	
• Module & Cavity Vacuum, CM-VBx pre-commissioning	12.04~12.15	J.W Choi, M.K Lee, J.H Shin, M.S Kim	Before cool-down, Vacuum/venting(~12.15)
• RF Rigid Coaxial Line & DC bias assembly	12.11~12.15	O.R Choi	HWR-B-#10, #11, #12
• SCL3 beamline Cool down	'24.1.2~	T.K Ki 外 Cryogenic team	Central control system & vacuum check

Figure 1: HWR-B CM configuration & Schedule.

HWR-A #09, #13 Maintenance Scope

The HWR-A CM #09, #13 was removed for long-term repair and performance testing due to reduced efficiency, and only Warm section part(Q.M+ vacuum chamber + transmission pipe + steel frame) was reinstalled on the beamline. Figure 2 shows the HWR-A cryogenic module configuration and maintenance schedule.



No.	Task	Assignment	Planned			Actual		
			duration	Start	Finish	duration	Start	Finish
● **HWR-A #09, #13 Cryomodule Tunnel separation**		**Y.S Jung, Y.H LEE**						
1.Outsourcing contract	• Design and delivery of beam pipes for CM replacement (2EA)	J.H Jo, H.J Son			2025-03-07			2025-02-28
	• Design and delivery of Warm Section Steel support(2EA)	J.S Kang			2025-03-07			2025-02-28
	• Preparation of cryogenic work	I.M Park, M.K Lee		2025-01-09	2025-03-31		2025-01-20	2025-03-21
2. Preparation work	• Cryomodule Gate Valve Close	M.S Kim, Y.J Choi, J.W Choi	1d	2025-01-17	2025-01-17	1d	2025-01-17	2025-01-13
	• RF Rigid Coaxial Line & DC bias disassembly	O.R Choi, K.T Son / J.W Choi, M.S Kim	1d	2025-01-17	2025-01-17	1d	2025-01-17	2025-01-16
3. Beamline clean separation	• Signal & Control & Power cable line separation(String vacuum)	M.S Kim, Y.J Choi, J.W Choi, H.J Son	1d	2025-01-17	2025-01-17	1d	2025-01-17	2025-01-15
	• Cryogenic pipe cutting, Pneumatic line & Cat-walk separation	I.M Park, J.H Shin, sub-contractor A	10d	2025-01-20	2025-01-31	5d	2025-02-03	2025-02-07
	• Separation of the upper part of the QM(#8-#9, #12-#13)	J.S Kang, Y.H Lee		2025-02-03			2025-01-22	2025-01-23
	• Lunar New Year holiday						2025-01-25	2025-02-02
	• Beamline separation work (compact clean booth)	J.W kwon, H.J Son, sub-contractor B	5d	2025-02-10	2025-02-14	3d	2025-02-10	2025-02-12
	• HA#09, HA#13 CM delivery to ISOL area / SRF building	J.W Choi, Y.H Lee etc.(7pesons)	3d	2025-02-17	2025-02-19	2d	2025-02-17	2025-02-18
4. Valve box work	• By-pass box installation(HA#09, HA#13)	I.M Park, J.H Shin, sub-contractor A			2025-02-28	5d	2025-02-24	2025-02-28
	• KGS Inspection (Pressure Test, NDT, Leakage Test)	I.M Park, J.H Shin, sub-contractor A			2025-03-07	4d	2025-03-04	2025-03-07
● **HWR-A #09, #13 Quadruple Magnet & Beam Pipe Clean Assembly**		**Y.S Jung, Y.H LEE**						
5. Beamline Clean Assembly	• Installation & alignment of HA#9, HA#13 W.S+steel support	J.S Kang, Y.H Lee, J.H Jo	4d	2025-03-10	2025-03-13	3d	2025-03-11	2025-03-13
	• Beam pipe assembly, vacuuming, and venting(HA#13, HA#12)	J.W kwon, H.J Son, sub-contractor B	6d	2025-03-17	2025-03-24	6d	2025-03-17	2025-03-24
	• Beam pipe assembly, vacuuming, and venting(HA#09, HA#08)	J.W kwon, H.J Son, sub-contractor B	6d	2025-03-24	2025-03-31	6d	2025-03-24	2025-03-29
6. Other work	• Assembly cat-walk	I.M Park, J.H Shin, sub-contractor A	1d	2025-04-01	2025-04-01	1d	2025-03-30	2025-03-30
	• QM upper part assembly and BPM cable connection	J.S Kang, Y.H Lee					2025-04-01	2025-04-03
	• Signal & Control & Power cable line connection	J.W kwon, H.J Son, Y.J Choi, M.S Kim	2d	2025-04-02	2025-04-03	2d	2025-04-02	2025-04-03
	• String vacuum line connection and inspection	J.W Choi, M.S Kim	4d	2025-04-03	2025-04-08	4d	2025-04-03	2025-04-08
	• RF Rigid Coaxial Line & DC bias assembly	O.R Choi, K.T Son / J.W Choi, M.S Kim			2025-04-10			2025-04-10
7. Cooling preparation	• SCL3 beamline Cool down	Cryogenic team			2025-04-14			2025-04-14

Figure 2: HWR-A CM configuration & Schedule.

CM Separation Work Details

Figure 3 below, In order to separate the CM connected to the beamline and helium valve box, preliminary work such as cutting the cryogenic pipe, separating the cat-walk, RF rigid coaxial pipe, DC bias and quadrupole magnet cooling water pipe, various signal/control/power cables disassembly, separating the pneumatic pip and several vacuum devices was required. In addition, to separate the beam line, vacuum work and beam pipe separation work must be done under the same conditions as the clean assembly environment after closing the gate valve.

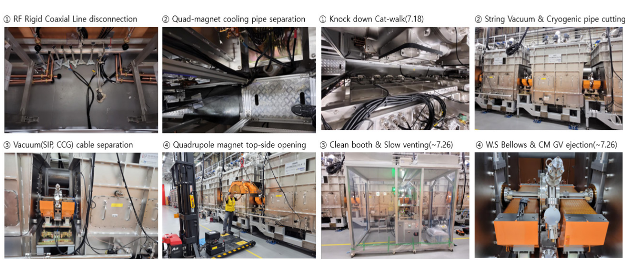


Figure 3: Several Separation work for HWR-B.

Method for Moving Heavy Cryomodule

The carrying method of the heavy cryomodule separated from the beam line was in the reverse order of the method used for CM installation, using several transport equipment (custom-made wheels & brackets, hydraulic jack), and a foot-base was prepared to temporarily storage of the HWR-B #11 at the ISOL. Figure 4 below shows the transport method of the large cryomodule in sequence.

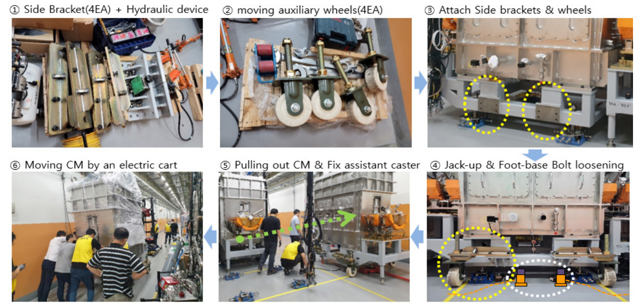
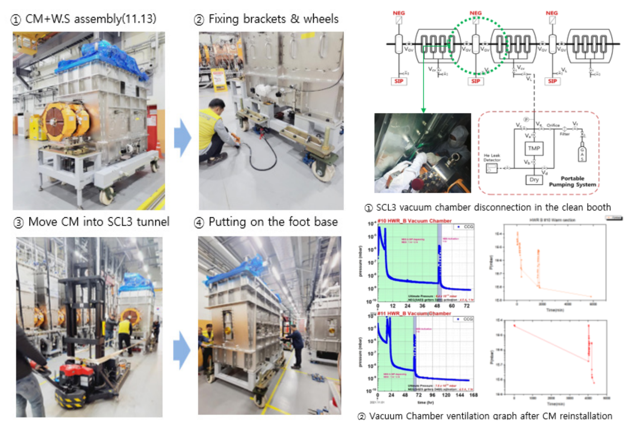


Figure 4: Moving Sequence for Heavy Cryomodule.

In particular, a safe and detailed heavy-duty handling plan was established for the dismantling, removal, and re-installation of the massive HWR-B #11 CM, and moving devices (side brackets, auxiliary wheels, and electric carts) and tools (hydraulic jack-up devices) were prepared.

Reinstallation Work Details

During the initial installation, the modules were installed sequentially, but upon reinstallation, the modules had to be placed back in their original positions on the beamline. Therefore, significant concentration and precise handling were required to avoid interference and collisions between rear modules. The most difficult part was installing the modules on the foot base after rotating them 90° horizontally within a narrow gap of about 2cm on each side to align them parallel. Figure 5-(a) below shows the reinstallation process for HWR-B#11, HWR-A #09 & #13.



(a) (b)

Figure 5: HWR-#11 reinstallation(a), Vacuum work(b).

Vacuum work was performed in a clean assembly environment using slow pumping and venting. After reassembling the low-temperature module, the NEG installed in the vacuum chamber of the warm section was activated to reach a vacuum pressure value that satisfies the required vacuum level (Fig. 5-(b), Fig. 6 compares photos taken before and after the installation was completed following the completion of the maintenance work [3].

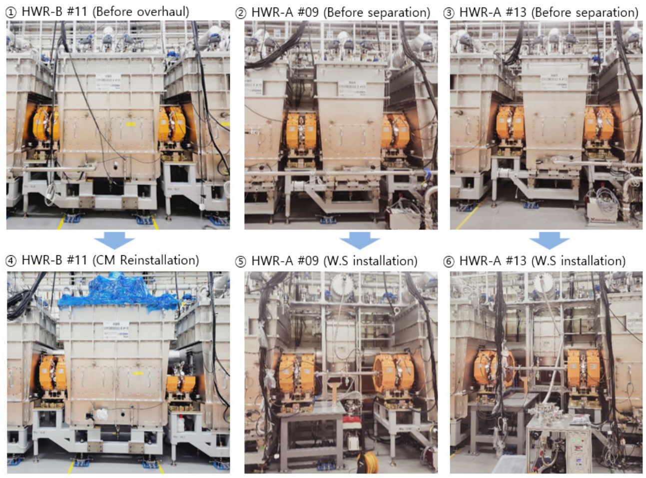


Figure 6: Comparison before and after CM reinstallation.

Scheduling(revision) & Progress Management

We established an overall maintenance schedule plan, shared it for collaboration among relevant teams, and continuously managed it to prevent work delays and change orders. Although it was delayed by 1.3 months compared to the initial plan, we were able to shorten the schedule by carrying out concurrent tasks (catwalk, VBx-CM pipe welding, and cabling) in parallel.

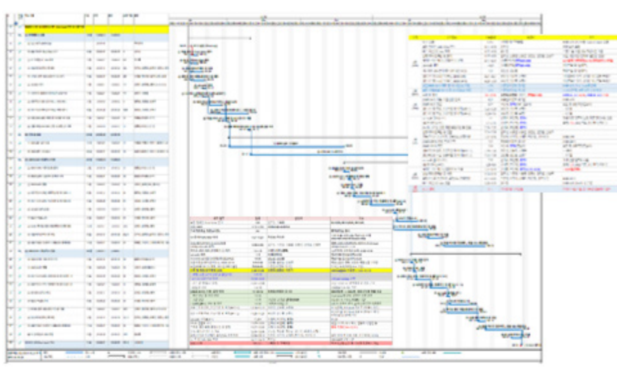


Figure 7: HWR-#11 maintenance plan & actual schedule.

Finally, Fig. 7 above shows the summarized schedule and the actual schedule achieved for HWR-#11 Crymodule maintenance.

Table 1: Cost Saving (estimated) & Schedule Change

No.	HWR-B #11	HWR-A #09 #13
Cost saving	*KW* 150M	*KW* 80M
Duration	6.8month(+1.3)	2.9month(-0.1)

In addition, as can be seen in the last Table 1, by performing module disassembly and transfer in-house during the maintenance period, we were able to complete the work without delay to the scheduled beam operation schedule and achieve expected cost savings.

CONCLUSION

This study describes the process of reinstalling the heavyweight cryogenic modules HWR-B and HWR-A for the maintenance of the SCL3 beamline. Initial beam commissioning revealed defects, such as cold air leakage and low efficiency, in some modules (particularly HWR-B #11), indicating that repairs and performance testing were required for next year's beam experiments. Specifically, the large cryogenic modules HWR-B #11, HWR-A #09, and #13 were safely detached using custom-made auxiliary wheels and handed over to the manufacturer. After completing precision inspections and vertical testing, the HWR-B #11 cryogenic module was safely reinstalled in its original beamline position, while HWR-A #09 and #13, requiring long-term repairs, were reinstalled by separating their warm sections for subsequent beam operations. This in-house beamline maintenance experience provided RAON with valuable insights, expertise, and confidence for the continuous operation of the accelerator beamline in the future. In addition, we are doing our best to improve the performance of RAON through maintenance know-how and to properly install HWR-A #09 and #13, which will be repaired and brought in by the end of 2026, so that we can transmit beams to low-energy experimental facilities (ISOL/KoBRA/NDPS).

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