ISBN: 978-3-95450-230-1 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2021-MOOB03

OVERVIEW OF RAON BEAM INSTRUMENTATION SYSTEM AND CONSTRUCTION STATUS OF THE LOW-ENERGY LINAC*

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Abstract

RAON is a heavy ion accelerator for researches using Rare Isotopes (RI) as a major research facility in Korea. RAON uses both In-flight Fragmentation and Isotope Separation On-Line methods to provide various RI beams. The ultimate goal of the driver Linac of RAON is to accelerate uranium and proton beams up to 200 MeV/u and 600 MeV, with a maximum beam currents of 8.3 pμA and 660 pμA, respectively. After 9 years of RAON construction, commissioning of the low-energy Linac front-end system that consists of 14.5 GHz ion source, low energy beam transport, a 500 keV/u radio frequency quadrupole, and medium energy beam transport has been carried out since late 2020. And beam injection to the low-energy superconducting Linac is planned to start in December 2021. Here, we introduce RAON beam instrumentation and diagnostics systems as well as the construction status of the low-energy Linac.

INTRODUCTION

RAON is a heavy ion accelerator facility to accelerate both stable and rare isotope (RI) beams up to the power of 400 kW with an energy higher than 200 MeV/u [1]. This facility is planned to have both Isotope Separation On-Line (ISOL) and In-Flight (IF) fragmentation method [2,3] to produce RI beams. Using both ISOL and IF method, this facility can provide the high intensity and quality RI beams to the experiment.

RAON accelerator is composed of an injector system and the superconducting linear accelerator. An injector system accelerates a heavy ion beam to 500 keV/u and creates the desired bunch structure for injection into the superconducting Linac. The injector system comprises two electron cyclotron resonance ion sources (ECR-IS), a low energy beam transport (LEBT), a radio frequency quadrupole (RFQ), and a medium energy beam transport (MEBT). The superconducting linear accelerator is divided into two sections, the low-energy superconducting Linac (SCL3) and the high-energy superconducting Linac (SCL2). Two superconducting Linac sections are connected by a Post-accelerator to Driver Linac (P2DT) which consists of a charge stripper and 180 degree bending system.

This article is to document the construction status of RAON. Beam instrumentation system and the early results of beam commissioning of the injector system will also be briefly discussed.

* Work supported by the IBS/RISP funded by the Ministry of Science and ICT and the National Research Foundation of the Republic of Korea under Contract 2013M7A1A1075764
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CONSTRUCTION STATUS OF RAON

Recently RAON construction project was evaluated thoroughly and it was decided that the whole construction project would be staged to two phases. The low-energy Linac section which consists of injector, SCL3 and low experimental system will be completed in the phase 1. ISOL system and high-energy experimental system are also constructed in the phase 1 as well. The high-energy superconducting Linac, SCL2 will be constructed in the 2nd phase launched in 2022.

The installation of injector system (14.5 GHz ECR-IS, LEBT, RFQ, and MEBT) was completed in October 2020, and immediately followed by the beam commissioning.

The superconducting cryomodule is being installed in the SCL3 tunnel since April 2020. As of August 2021, 22 QWR cryomodules, 13 HWR type-A (2 cavities) cryomodules, and 10 HWR type-B (4 cavities) cryomodules were installed in the SCL3 tunnel as shown in Fig. 1. The first beam injection to the SCL3 is planned to be in December 2021.

Figure 1: A photograph of SCL3 tunnel.

BEAM INSTRUMENTATION SYSTEM

For initial beam commissioning and component tuning, we will use $^{40}Ar^{9+}$ beam with ~30 eμA, 100 μsec pulse width, and a repetition rate of 1 Hz. Faraday Cup (FC), Wire Scanner (WS), Beam Viewer (BV), AC-Current Transformer (ACCT), and Beam Position Monitor (BPM) are properly used for beam tuning. During normal operation, on-line device such as BPM, ACCT, and Beam Loss Monitor (BLM) are used to monitor beam transport and acceleration function without destructing beam. The ACCT is to measure a beam current and transmission, and Differential Beam Current Measurement (DBCM) using ACCT networks is to primary detect beam loss in a certain section. Every BLM and the DBCM outputs will be linked to the RAON Fast Machine Protection System (MPS). Those on-

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line devices are designed to measure a beam current between typically 1 μA and 1 mA. We also install the 2D Emittance Meter (Allison Type); Strip-line Fast Faraday Cup (SFFC), and Beam Attenuator to measure beam emittance, bunch length, and reduce beam intensity, respectively.

The layout of RAON beam diagnostics is shown in Fig. 2. ISOL beam line is designed to transport the low energy and low intensity RI beam, therefore WS, FC, Plastic Detector (PD), Secondary Electron-BPM are main beam diagnostics devices. The diagnostics devices available in the injector are as follows: (i) 4 WSs, 3 FCs, 2 BVs, an ACCT in the LEBT. (ii) 4 WSs, 2 FCs, 6 BPMs, and 2 ACCTs in the MEBT (see Fig. 5). The WS consists of three 0.1 mm tungsten wires of horizontal, vertical, and 45 degree angled. The ACCT is the non-interceptive current transformer manufactured by the Bergoz Instrumentation [4]. Every warm section of the low-energy superconducting Linac, SCL3, a BPM and a BLM are installed. Also 4 WSs in 4 consecutive warm section (QWR 2~5, HWR-A 2~5, HWR-B 2~5) and 1 FC are installed to measure beam properties precisely. The high-energy superconducting linac, SCL2, has a similar configuration to SCL3.

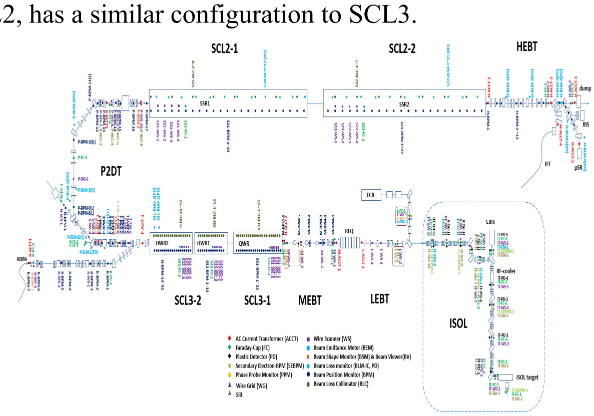

Figure 2: Layout of RAON beam diagnostics.

The BPM with 4 button-type electrodes is the non-interceptive position measurement device [5]. The BPM provides the beam phase as well as the beam position, and the beam induced phase information from two BPMs paired can be used to derive the absolute beam energy. A button (curved & square shape) BPM in SCL3, a large button (bent & square shape) BPM in P2DT, and a 150 mm long strip-line (curved & square shape) BPM in SCL2 are fabricated as shown in Fig. 3. All of SCL3 BPM were calibrated at wire test bench [6] and most of SCL3 BPM was installed in the tunnel.

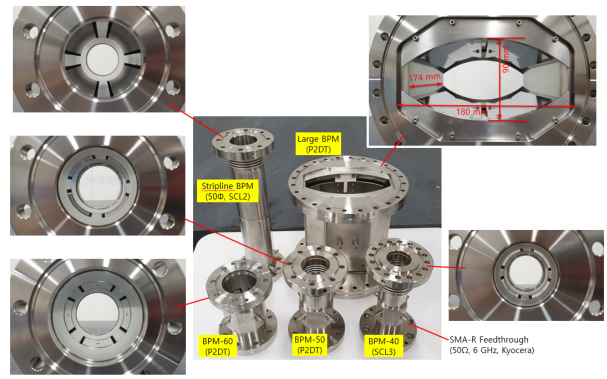

Figure 3: RAON Beam Position Monitor.

Both SCL3 and SCL2 adopt normal conducting quadrupole doublet focusing lattice in the warm section, where two quadrupole magnets are located between every cryomodules for beam focusing. The BPM in each warm section is mechanically aligned to the quadrupole magnet. Each beam diagnostics (or vacuum) chamber in the warm section has an inner diameter of 36 mm niobium ring, called as Beam Loss Collector (BLC) to directly collect any halo or strayed beam. The ring-type BLC in the warm section chamber is the main BLM in the SCL3 and combination of BLC, plastic detector, and proportional counter will be the BLM in P2DT, SCL2, and beam lines. However the DBCM with ACCT networks as described earlier will be utilized as the primary beam loss detection system.

Figure 4 shows the diagnostics DAQ system. BPM controller is designed and fabricated through domestic company [7]. The 8 channel pico-ammeter AMC board [8] in μTCA format is adopted to measure currents from WS, FC, and BLM (BLC). A standalone 1u chassis unit (upgrade of the previous cRIO system) is designed to measure ACCT outputs as well as DBCM processing which requires 100 MS/sec with 14 bit 4 ADC channels in the low-energy Linac. Those all three kinds of DAQ systems based on EPICS control support RAON global timing system, trigger, and interlock, etc.

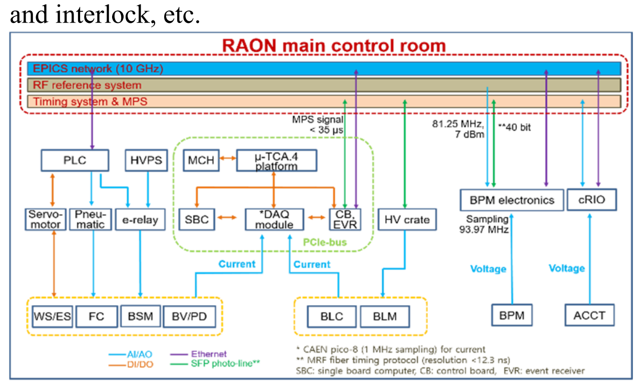

Figure 4: Diagnostics DAQ System.

INJECTOR BEAM COMMISSIONING

The 14.5 GHz ECR-IS is a compact permanent magnet ion source manufactured by the Pantechnik, France [9]. The 28 GHz superconducting ECR-IS is in the process of improving its performance. The LEBT is designed to transport and match ion beams extracted from the ECR-IS

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to the RFQ. Electrostatic quadrupoles were chosen rather than the magnetic quadrupoles for transport and focusing because these would be a more suitable for low velocities beams at LEBT. About 5 m long RFQ with 4-vane structure is designed to accelerate ion beams from 10 keV/u to 500 keV/u and it runs at 81.25 MHz of resonance frequency. The MEBT is to transport and to match ion beams accelerated from the RFQ to the low energy superconducting linac, SCL3. A total of eleven room temperature quadrupole magnets are chosen to transport and focus beams at MEBT. Four bunching cavities which run at 81.25 MHz of resonance frequency are also arranged to match the longitudinal beam size to the SCL3. Figure 5 shows the layout of the injector and diagnostics system.

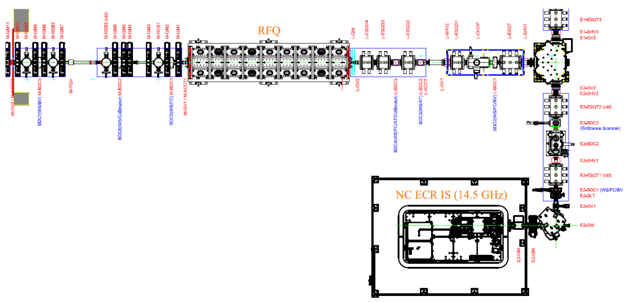

Figure 5: Instrumentation for Injector System.

The 14.5 GHz ECR-IS was commissioned with Argon and Oxygen, and proton beams and it could provide ion beams to the injector system from September 2020. The beam commissioning of the injector system has been started since October 2020. The $^{40}Ar^{9+}$ beam was successfully transmitted through LEBT, accelerated by RFQ, and transported to the end of MEBT. In the beam commissioning, a peak current of ~30 eμA continuous beam at LEBT was transported and an electrostatic chopper in the LEBT was used to generate a pulsed beam with a pulse length of 100 µsec and a repetition rate of 1 Hz. Figure 6 shows the BV image at LEBT and BPM signal at MEBT measured with 25 GHz sampling rate oscilloscope during beam commissioning in March, 2021.

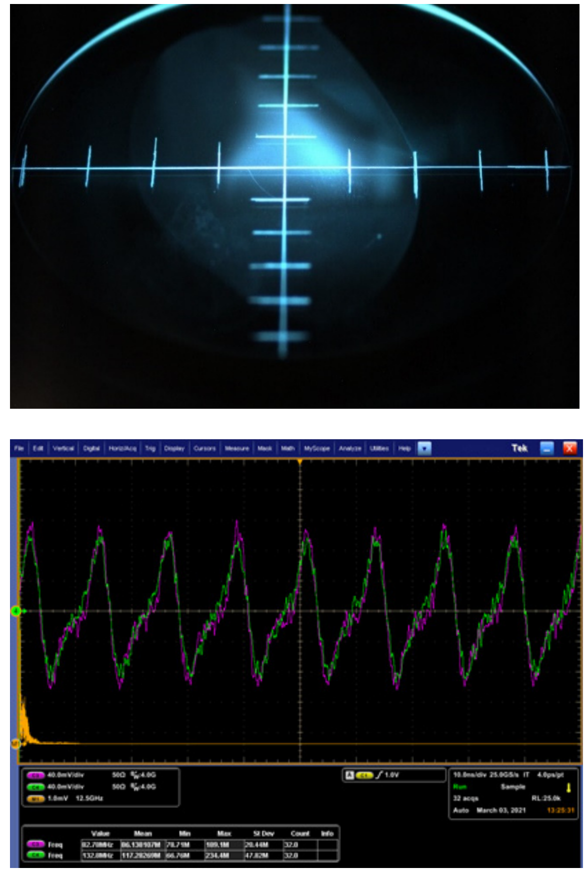

Figure 6: BV Image (Top) and BPM Signal (Bottom).

SUMMARY

Construction project of RAON is staged to two phases. The low-energy Linac, ISOL system, and high energy experimental system will be completed in the phase 1. Construction of the high-energy superconducting Linac, SCL2 is pushed to construct in the 2nd phase. The injector system for low-energy Linac is in the beam commissioning stage since October 2020. During beam commissioning, it was confirmed that each component and beam instrumentations of injector was functioning as designed and was working properly in an integrated fashion.

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