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COMMISSIONING STATUS OF THE RAON SUPERCONDUCTING ACCELERATOR

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Abstract

The Rare isotope Accelerator Complex for ON-line experiments (RAON) has been proposed as a multi-purpose accelerator facility for providing beams of exotic rare isotopes of various energies. It can deliver ions from hydrogen (proton) to uranium. Protons and uranium ions are accelerated up to 600 MeV and 200 MeV/u respectively. It can provide various rare isotope beams which are produced by isotope separator on-line system. The RAON injector was successfully commissioned in 2021 to study the initial beam parameters from the main technical systems, such as the ECR ion source and RFQ, and to find the optimized LEBT and MEBT RF set-point and matching conditions. In this paper, we present the current commissioning status of the RAON injector in preparation for the upcoming SCL3 beam commissioning.

INTRODUCTION

The RAON accelerator has been planned to study a wide range of cutting edge science programs in atomic physics, material science, bio and medical science, nuclear astrophysics, nuclear science, and interdisciplinary science programs at the Institute for Basic Science (IBS). In order to meet the diverse demands, it can deliver various high intensity stable ions from protons to uranium atoms with a final beam energy, for example, 200 MeV/u for uranium and 600 MeV for protons, and with a beam current range from 8.3 pμA (uranium) to 660 pμA (protons) [1–3]. It can provide various rare isotope beams which are produced by isotope separator on-line (ISOL) system. The facility consists of three superconducting linacs of which superconducting cavities are independently phased and operating at three different frequencies, namely, 81.25, 162.5 and 325 MHz.

The accelerator facility is shown in Fig. 1. 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 an electron cyclotron resonance ion source, a low-energy beam transport, a radio-frequency quadrupole, and a medium-energy beam transport. The superconducting driver linac accelerates the beam to 200 MeV/u. The driver linac is divided into three different sections, as shown in Fig. 2: a low-energy superconducting linac (SCL3), a post-accelerator to driver linac (P2DT) and a high-energy superconducting linac (SCL2). The SCL3 accelerates the beam to 18.5 MeV/u. The SCL3 uses two different families of superconducting resonators, i.e., a quarter wave resonator (QWR) and a half wave resonator (HWR). It consists of a total of 22 QWR operating at 81.25 MHz of resonance frequency and 102 HWR operating at 162.5 MHz of resonance frequency. The SCL2 uses two different types of single spoke resonators (SSR1 and SSR2) and both types will operate at 325 MHz of resonance frequency. Both SCL3 and SCL2 adopts normal conducting quadrupole doublet focusing lattice in the warm section, where two quadrupole magnets are located between every cryomodules for beam focusing. The warm section also comprises a beam position monitor (BPM), a vacuum system, a beam loss monitor, and a dipole steering magnet integrated at the quadrupole magnet.

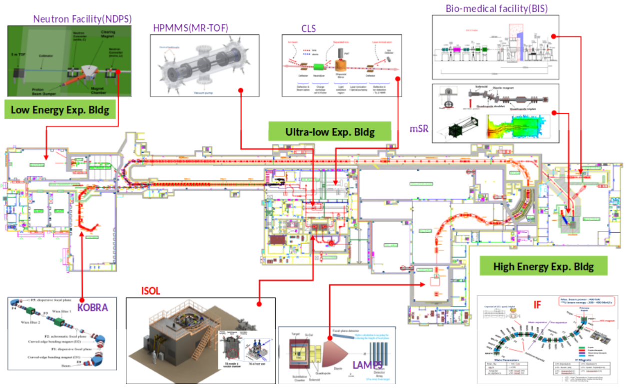

Figure 1: Layout of the RISP accelerator complex.

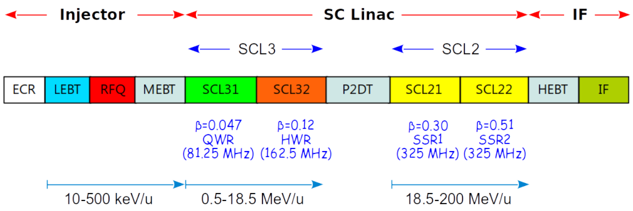

Figure 2: The RAON linear accelerator.

RAON INSTALLATION

As of November 2021, injector systems, 22 QWR cryomodules, 13 HWR type-A (2 cavities) cryomodules, and 19 HWR type-B (4 cavities) cryomodules were installed in the SCL3 tunnel, as shown in Fig. 3. The installation procedures are defined and well demonstrated, which take into account of a maintenance work including cryomodule disassembly from the beam line. The installation steps are as follows: (i) a warm section that consists of two quadrupole magnets, a beam position monitor, and a vacuum system is

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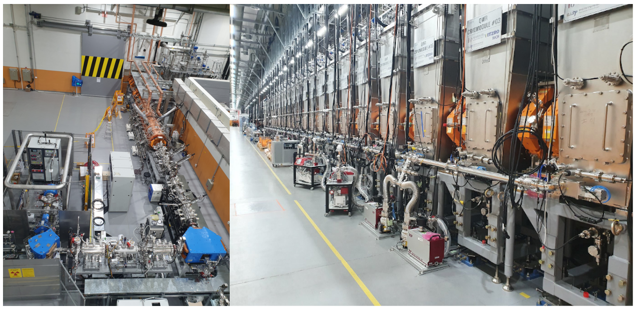

Figure 3: Injector(left) and SCL3(right) installed in the accelerator tunnel.

assembled and mechanically aligned as a single component; (ii) the warm section is placed on the cryomodule supporting girder, then is optically aligned to the cryomodule within 100 µm; (iii) the cryomodule is transported and installed at the tunnel; (iv) and the cryomodule is optically aligned within 100 µm to the first SCL2 cryomodule as the RAON alignment reference position (0,1500,0). Once the cryomodule is installed at the tunnel, a beam line flange in the warm section is assembled to the cryomodule gate valve. This assembly is strictly followed by the particle-free environment, which requires less than 100 counts/10 minutes for 0.5 µm and a bigger size of particles. All of SCL3 beam lines have been assembled in a movable clean booth, which provides a good clean environment having less than 30 counts/10 minutes. Each cryomodule is also connected to the cryogenic distribution system, which will provide cryogenic temperature to operate the accelerating cavity in the superconducting state.

INJECTOR BEAM COMMISSIONING

The 14.5 GHz ECR-IS is a compact permanent magnet ion source manufactured by the Pantechnik, France [4] and it started to extract beams from October 2020. 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 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 4 shows the layout of the injector system.

The 14.5 GHz ECR-IS was commissioned with Argon and Oxygen, and proton beams and provided ion beams to the injector system from September 2020. The beam commissioning of the injector system has been started since October 2020, and continued to this day after a six-month suspension.

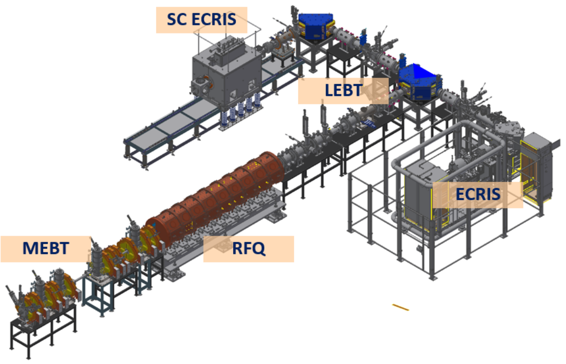

Figure 4: A layout of injector system.

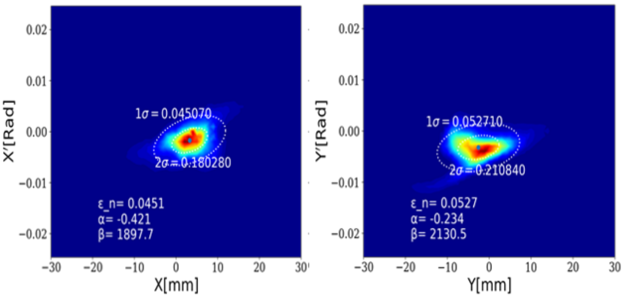

Figure 5: Transverse beam emittance obtained by Allison scanner.

The 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 used. An electrostatic chopper in the LEBT was used to produce a pulsed beam with a pulse length of 100 µsec and a repetition rate of 1 Hz. The beam diagnostics devices available in the injector commissioning are as follows: (i) 4 wire scanners (WS), 3 Faraday cups (FC), 2 beam viewers (BV), an AC current transformer (ACCT), and Allison scanner in the LEBT; (ii) 4 WSs, 2 FCs, 6 beam position monitor (BPM), 2 ACCTs, and beam shape monitor(BSM) in the MEBT. The Allison scanner was widely used for beam characterization and tuning. Figure 5 shows a phase portrait in position-angle phase space obtained by Allison emittance scanner. The emittance was measured with the quadrupole scan scheme as well. For example, horizontal rms emittances measured by Allison and quadrupole scan are 0.045 and 0.041mm-mrad, respectively. The WS consists of 3 0.1 mm tungsten wires of horizontal, vertical, and 45 degree angled, and provides data for beam profiles. The FC allows for precise measurement of the beam current by directly catching ion beams in the beam line. The BV consists of a fluorescent screen and a digital camera, and provides the direct beam images by intercepting ion beams in the beam line. The ACCT is the non-interceptive current transformer manufactured by the Bergoz Instrumentation [5], and provides the beam current without intercepting beams. The beam transmission rate of RFQ was monitored using ACCTs installed before and after RFQ. The dependence of an accelerated beam current on the RFQ voltage amplitude

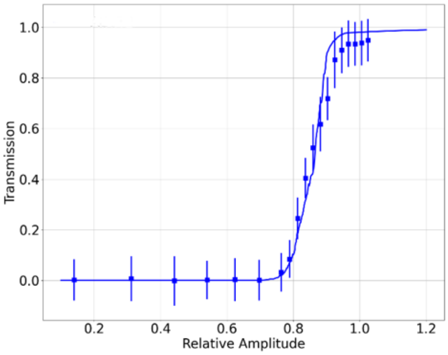

Figure 6: RF set-point determination of RFQ by measuring beam transmission rate.

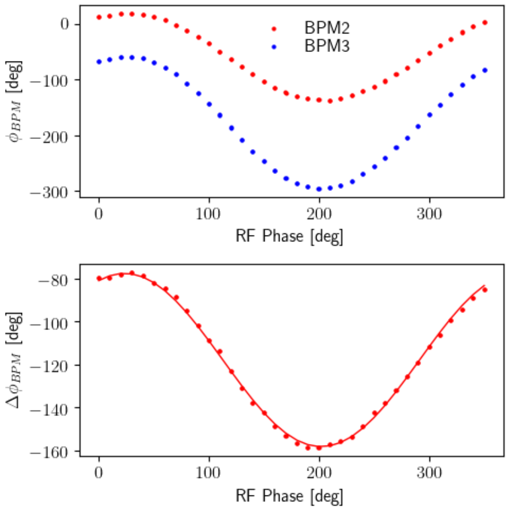

Figure 7: Measured phase scan curve for buncher #1.

by using the TRACK code [6] was calculated and compared with the measured data, as shown in Fig. 6. The BPM with 4 button-type electrodes is the non-interceptive position measurement device [7]. The BPM provides the beam phase as well as the beam position. The beam induced phase information from two BPMs paired can be used to derive the absolute beam energy. The RF set-point of bunchers in MEBT was set based on a phase scan signature matching [8]. The bunchers were tuned by scanning the RF phase and amplitude, and comparing measured beam phases of BPMs at downstream locations. For example, Figure 7 shows the beam phases measured by BPMs located at downstream of buncher #1, and the measured phase difference and model fitting. In order to measure the bunch length of ion beams, a stripline fast Farady cup(FFC) was designed and installed in the end of MEBT. The FFC measured a beam temporal structure as shown in Fig. 8. The measurements were obtained with 507 MeV/u Ar^{9+} beam. It shows that the beam bunch shape changed while changing the RF phase of the buncher.

SUMMARY

Construction of the low energy part of RAON heavy ion accelerator facility is now in final phase and the first beam injection to the SCL3 is planned to be in October 2022. The injector system for low energy superconducting linac was fully installed. The beam commissioning of the injector system has been started in October 2020. During beam commissioning, it was confirmed that each component of injector was functioning as designed, and injector system was working properly in an integrated fashion to provide beams to SCL3.

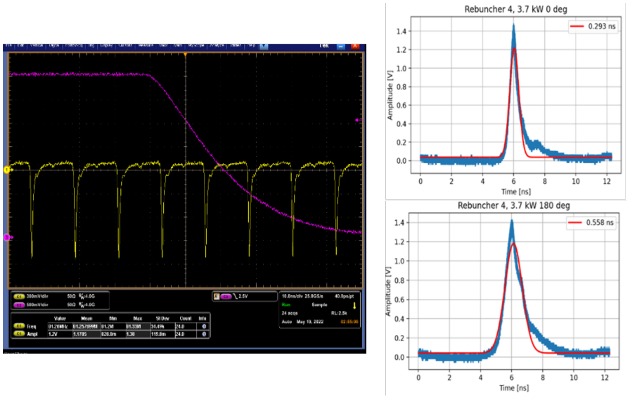

Figure 8: Oscilloscope signal of beam shape monitor(left) and difference of longitudinal beam shape for different buncher RF phase.

ACKNOWLEDGMENTS

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