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Performance and Operational Experience of SCRFQ in KAHIF

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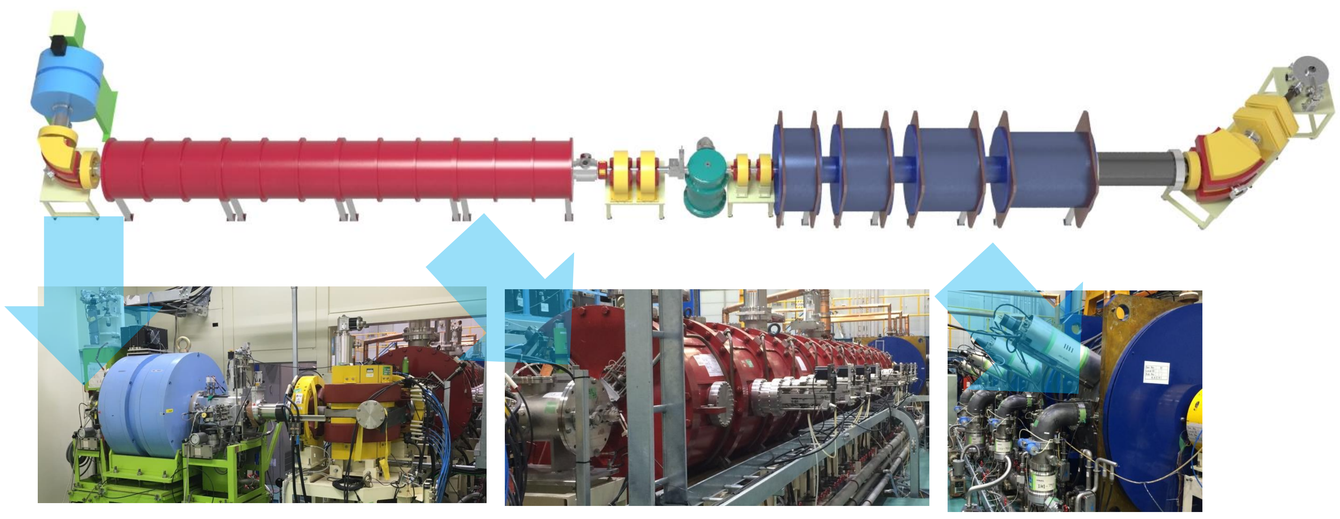
Abstract: KAERI Heavy ion Irradiation Facility (KAHIF), an RF-based linear accelerator at the Korea Atomic Energy Research Institute in Daejeon, is utilizing for nuclear fusion and materials science research. Nuclear fusion energy, recognized as a key sustainable energy solution, necessitates high-performance materials for reactor environments. Components like the first wall endure extreme plasma heat and intense neutron and ion irradiation, demanding exceptional material stability. Heavy ion beam irradiation facilities, such as KAHIF, are essential tools for evaluating material performance under fusion-relevant conditions and investigating radiation damage mechanisms. KAHIF is dedicated to nuclear fusion materials research, and it is projected to significantly advance fusion energy technologies.

The facility is primarily utilized for nuclear fusion structural material investigations, including neutron irradiation damage assessment. Commercial fusion reactor realization requires extensive material research and databases, for which ion beam irradiation offers an efficient and economical approach. Furthermore, KAHIF supports broader nuclear materials research, enhancing radiation, temperature, and corrosion resistance through controlled ion beam studies.

The facility comprises a linear accelerator capable of accelerating ions up to approximately 1.0 MeV/u. Ions from an 18 GHz Electron Cyclotron Resonance (ECR) source are isotopically separated by dipole magnets. A 25.96 MHz Radio Frequency Quadrupole (RFQ) then accelerates these ions to approximately 178 keV/u. While capable of further acceleration to 1.0 MeV/u via a re-buncher and Interdigital H-type Drift Tube Linac (IH-DTL), current operation emphasizes stable, high-flux beam delivery post-RFQ. Consequently, subsequent acceleration stages are presently off-line. Although the design and fabrication of key accelerator components, including the SCRFQ, were primarily led by KEK, the originating institution, performance validation and operational expertise have been acquired at KAHIF through extensive long-term operation following its relocation to Korea. Notably, KAHIF stands out as the sole Korean institution employing SCRFQ as a primary accelerator device, distinguishing it within the accelerator-based facilities. This paper details the performance and operational experience of the 25.96 MHz RFQ at KAHIF.

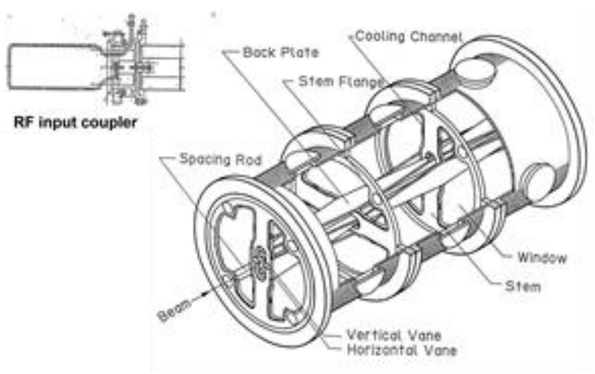
KAERI Heavy ion Irradiation Facility



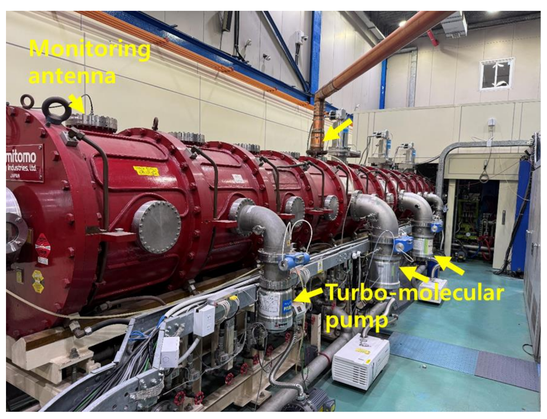
☐ KAHIF layout and components of KAHIF (left: 18 GHz ECR-IS, center: 25.96 MHz RFQ, right: 51.91 MHz IH-DTL)

Specification of SCRFQ	
Resonance frequency	25.96 MHz
Charge-to-mass (q/a)	>1/28
Input energy	2.0 keV/u
Output energy	178 keV/u
Normalized emittance	0.6 πmm·mrad
Cavity length	8.6 m
Cavity inner diameter	0.9 m
Number of unit tank	4
Number of module-cavity (per unit tank)	3
Mean aperture radius	0.9846 cm
Minimum aperture radius	0.5388 cm
Final synchronous phase	-30°

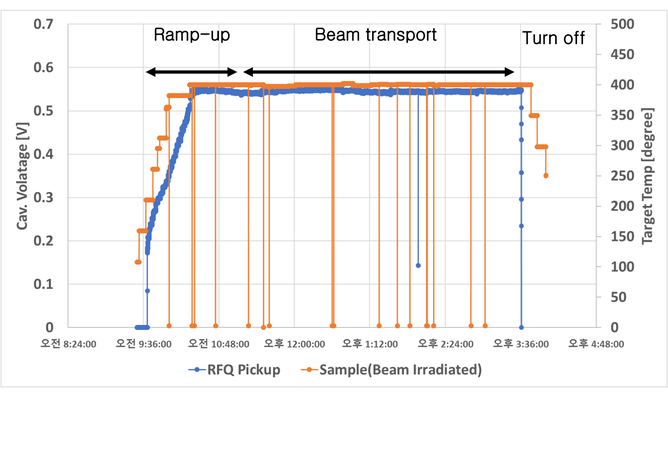
Performance of the Split-Coaxial Radio Frequency Quadrupole



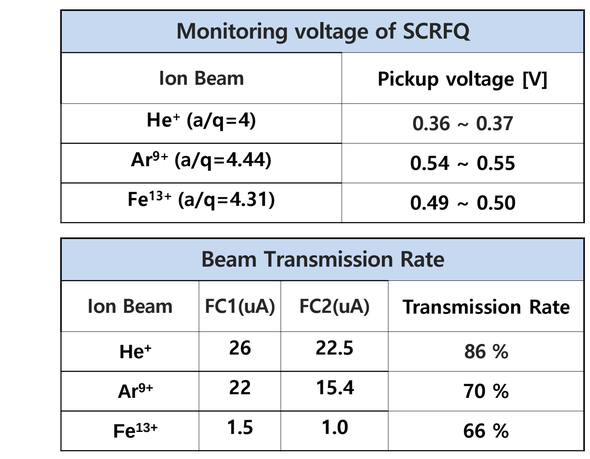
☐ Cross section view of SCRFQ and the RF input coupler (loop type antenna is adapted).



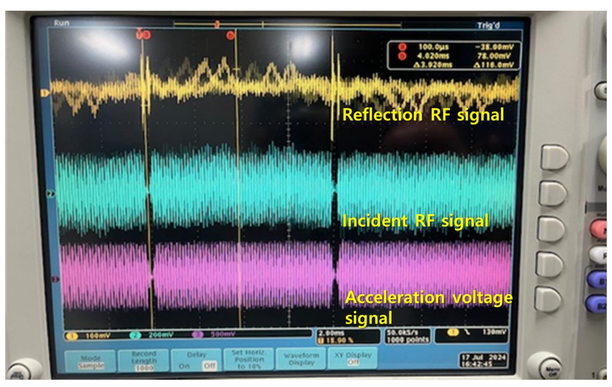
☐ The picture of the SCRFQ. The pumping system and RF transmission line are shown. The cryo-pumps are installed for the emergency case.



☐ High power RF ramp up section should be essential. The start frequency of the signal generator is 25.948 MHz, and the frequency, 25.968 MHz is the steady state with the applied RF power.



☐ When the RF power is applied to the RFQ, the vacuum level is affected by the RF events such as the multipacting of RFQ or input coupler. This is always measured when the RF is turn on and off.



☐ Monitoring signals by the oscilloscope (Pulse mode with the 98 % duty).

☐ The frequency tuning system of the SCRFQ. The plug type tuners with the step moters are assembled.

☐ When the sample reaches to the required temperature(which is 400 degree in the graph), the beam is irradiated. During the beam irradiation, the cavity voltage is monitored.

Monitoring voltage of SCRFQ	
Ion Beam	Pickup voltage [V]
He^{+} (a/q=4)	0.36 ~ 0.37
Ar^{9+} (a/q=4.44)	0.54 ~ 0.55
Fe^{13+} (a/q=4.31)	0.49 ~ 0.50

Beam Transmission Rate			
Ion Beam	FC1(uA)	FC2(uA)	Transmission Rate
He^{+}	26	22.5	86 %
Ar^{9+}	22	15.4	70 %
Fe^{13+}	1.5	1.0	66 %

☐ Operation parameters of SCRFQ for various ion beam transport are summarized in tables. The voltage of RFQ depends on the charg-to-mass of the ion beam. FC1 is the Faradaycup at the upstream of RFQ, and FC2 is one located at the downstream of RFQ.

Summary

- ☐ KAHIF is utilizing the SCRFQ as the main accelerator to deliver the various ion beams (He, Ar, Fe) in pulse mode (98% duty).
- ☐ The voltage, vacuum level, and frequency shift of RFQ is monitored during the beam transportation.
- ☐ The abrupt change of the vacuum level when the RF power is turn on/off is usually monitored during the RFQ operation. The multipacting event of RFQ or RF unput coupler is the one of the possibility to affect the vacuum level of RFQ.
- ☐ In order to deliver the ion beams stably, the schematics of the machine protection system based on the current monitoring system will be progress.

Reference

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