Contribution ID: 64

Current status of the cesiated RF-driven negative hydrogen ion source and its R&D activities for future facility projects at J-PARC

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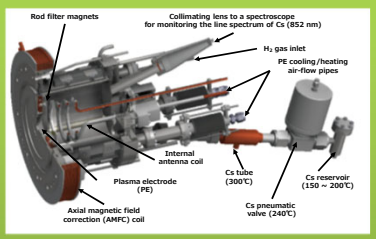
Abstract

It is important to note that more than a decade has elapsed since the radiofrequency (RF)-driven negative hydrogen (H^-) ion source initiated operation in the autumn of 2014 at J-PARC. Since the 2022/2023 campaign, H^- beams with a beam current of 60 mA have been generated by a single RF-driven H^- ion source during a campaign. The continuous operation time of the ion source reached 4,962 hours during the 2023/2024 campaign. In the 2024/2025 campaign, a single RF-driven H^- ion source functioned continuously for 4,289 hours to produce H^- beams with a beam current of 62.5 mA for the J-PARC users and 75 mA for the accelerator beam studies. The objective of these studies is to prepare for future delivery of a proton beam with a beam power of 1.5 MW to the Materials and Life Science Experimental Facility (MLF), which is currently operated at a maximum of 1 MW. Concurrently, we are engaged in R&D activities of the ion source for the future J-PARC projects.

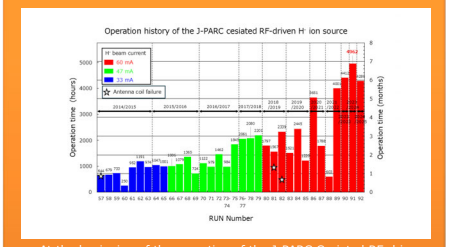
Activities of the J-PARC cesiated RF-driven H⁻ ion source from its inception to the present days

J-PARC high-intensity cesiated RF-driven H⁻ ion source



Typical specifications and parameters	
Discharge type	RF discharge by an internal antenna
Repetition rate	25 Hz
RF frequencies	30 MHz (cw, ~ 50 W for igniter) 2 MHz (0.8 ms pulsed, ~ 35 kW)
H_2 gas flow rate	21 sccm
Cs consumption	88 mg in 3651 hours (in 2021)
Beam energy	52.5 keV
Extracted H⁻ beam current	60 mA (for user operation) 72 mA (for accelerator beam study)

Operation history of the J-PARC cesiated RF-driven H⁻ ion source



At the beginning of the operation of the J-PARC Cesiated RF-driven H⁻ ion source, the continuous operation time was limited less than 2 months, and the ion source was replaced frequently during a campaign.

Because it was challenging to ascertain the operational longevity that the RF-driven ion source could deliver H⁻ beams without any significant issues necessitating the suspension of operations. During the several campaigns, the continuous operation time of the ion source has been extended year by year.

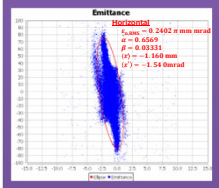
Eventually, in the 2022/2023 campaign a single cesiated RF-driven H⁻ ion source was functioned to deliver the H⁻ beam. Moreover, in the 2023/2024 campaign, the continuous operation time of the ion source was extended to 4,962 hours.

There were problems with the targets both at the Material and Life Experimental Facility and at the Neutrino Experimental Facility. This meant that the accelerator was stopped in May 2025. As a result, the ion source worked for 4,289 hours in the 2024/2025 campaign.

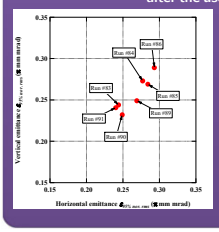
Beam emittance measurement after user operations

Emittances measured at the ion source test stand after the user operation (Run #91)

Operation conditions	
H2 gas flow rate	21 sccm
2 MHz RF amp. input power	27.1 kW
Axial magnetic field correction coil	0.0 V
Extraction voltage	10.0 kV
Acceleration voltage (DC) (pulse)	30.0 kV 12.5 kV
Applied current of solenoid magnet 1 2	500 A 650 A
Applied current of steering magnet 1 2	+5.0 A -3.0 A
Possible measured position	Entrance of RFQ



Recent results of the emittances measurement after the user operations



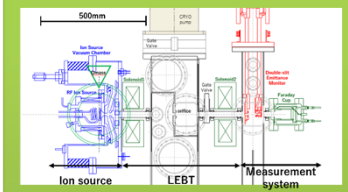
The emittances in the user operations seemed to be almost equal to the design values.

No significant difference was observed in the emittance measurements.

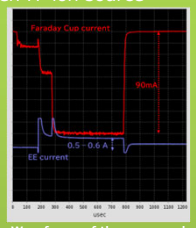
Those values were within the acceptable limits set out in the RFQ.

Activities for the future J-PARC upgrades

90-mA H⁻ beam extraction with the proper RFQ injection energy extracted from the J-PARC RF-driven H⁻ ion source



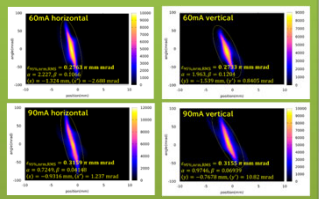
A schematic drawing of the J-PARC ion source test stand (IS-TS)



Waveforms of the measured H⁻ beam current at the Faraday cup in the LEBT and the EE current.

Comparison of operation parameters

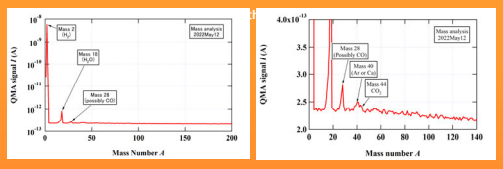
Operation parameters	Current J-PARC user operation	High intensity beam extraction test at IS-TS
RF input power	30 kW	36 kW
H_2 gas flow rate	21.0 sccm	19.5 sccm
Applied voltage between PE and EE	10.3 kV	10.6 kV
Applied voltage between EE and GE	42.2 kV	41.9 kV
Coil current of Solenoid 1	550 A	590 A
Coil current of Solenoid 2	680 A	710 A
Extracted H⁻ beam current	60-62.5 mA	90.0 mA



Measured phase-space distributions of the H⁻ beam at the position assumed at the RFQ entrance.

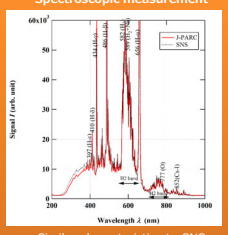
Achieved 90-mA H⁻ beam extraction with approximately 10% larger emittances than those in case of 60-mA operation.

Development of the J-PARC-made internal antenna coil



No remarkable impurities were emitted from the antenna.

Spectroscopic measurement



Similar characteristics to SNS (imported) antenna coils

Endurance experiment of J-PARC-made antenna

Test period	Input RF energy (kWh)	Converted J-PARC operation time (hours)
2023Mar10~Dec25	3515.6	5,859.3
2024Mar05~Apr21	3395.8	5,659.6
2024May15~Jul03	3344.2	5,573.6

The J-PARC-made antennas have a potential to endure the long-term operation more than 5,500 hours.

Beam extraction test of J-PARC-made antenna

A J-PARC-made antenna was utilized for 60-mA H⁻ beam extraction at the RFQ test stand, with a total of **approximately 5,200 hours of continuous operation thus far.**

Summary and prospects

The J-PARC cesiated RF-driven H⁻ ion source, initiated in the autumn of 2014, for the extraction of high-intensity H⁻ beams has been operational at the J-PARC accelerators and experimental facilities for a decade. The present extracted H⁻ beam current of 60 mA from the ion source is sufficient to meet the specified beam power requirements at the experimental facilities. At the present time, a single ion source is providing the H⁻ beam for a campaign that commenced in the autumn and is scheduled to conclude before the summer maintenance of the following year. Conversely, the onset of aging has been observed in specific components of the ion source.

In light of prospective enhancements to the J-PARC infrastructure, the maximum beam intensity of 90 mA with the beam energy of approximately 50 keV for the present Radio Frequency Quadrupole (RFQ) linac has been demonstrated by the J-PARC cesiated RF-driven H⁻ ion source. In order to facilitate the procurement of the RF internal antenna coils domestically, assessments of the J-PARC-made antenna have been conducted. In order to fulfil a requisite beam power of 1.5 MW for supply to the MLF with the 2nd target station, the validation of the continuous operation of the ion source with a beam current of 75 mA will be performed at the present J-PARC RFQ test stand, following the upgrade of the power supply for the extraction voltage.