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Status of the RF-driven H^- ion source for J-PARC linac

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For the upgrade of the Japan Proton Accelerator Research Complex linac beam current, a cesiated RF-driven negative hydrogen ion source was installed during the 2014 summer shutdown period, with subsequent operations commencing on September 29, 2014. The ion source has been successfully operating with a beam current and duty factor of 33 mA and 1.25% (500 μs and 25 Hz), respectively. The result of recent beam operation has demonstrated that the ion source is capable of continuous operation for approximately 1100 h. The spark rate at the beam extractor was observed to be at a frequency of less than once a day, which is an acceptable level for user operation. Although an antenna failure occurred during operation on October 26, 2014, no subsequent serious issues have occurred since then. © *2015 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4935641]

I. INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton accelerator facility that aims to perform the cutting-edge research support of numerous scientific fields. The J-PARC accelerator comprises a linac, 3 GeV rapid cycling synchrotron (RCS), and main-ring (MR) synchrotron. To realize the nominal beam power performance of 1 MW at the RCS and 0.75 MW at the MR, an upgrade of the linac peak beam current (from 30 to 50 mA) was required. A cesium-free negative hydrogen ion source driven with a lanthanum hexaboride (LaB_6) filament[1] was used since linac operation began in 2006. Although it satisfied the J-PARC's initial stage requirements of 30 mA, it was proven that this current level did not increase by cesiation.[2] Thus, in order to satisfy linac upgrade requirements, a cesiated RF-driven negative hydrogen ion source has been developed. The new ion source was tested on an off-line test stand for about five years, and it was found to successfully produce a peak current of more than 60 mA within the acceptance of the following RFQ linac with the required beam duty factor of more than 1.25%.[3] The RF-driven ion source was installed in the summer of 2014 and ultimately commenced operation on September 29, 2014. In this paper, several functional parameters and beam stability characteristics of the RF-driven ion source are provided via long-term user operational findings.

II. ION SOURCE

A schematic of the cesiated RF-driven negative hydrogen ion source is shown in Fig. 1. The ion source mainly comprises a stainless-steel (SUS) plasma chamber, a beam extractor, and a large vacuum chamber with two turbo molecular pumps (TMPs) of 1500 L/s for differential pumping. In the plasma chamber, source plasma is produced by a RF discharge using an internal antenna that was developed at SNS[4] and confined by a multicusp magnetic field produced by permanent magnets surrounding the chamber wall. Two SUS pipes for installing rod-filter-magnets[5] are inserted into the chamber near a plasma electrode (PE). A cesium injector comprising a reservoir (Cs reservoir), remotely controlled valve (Cs valve), and tube (Cs tube) are installed on the end flange. The amount of cesium in the chamber is monitored by measuring the intensity of the 852 nm spectrum emitted from the CsI. The beam extractor comprises three electrodes such as the PE, an extraction electrode (EXE), and a grounded electrode (GE). The size of the PE beam aperture is 9 mm in diameter. The PE temperature is controlled by changing the temperature and the flow rate of the air flowing through a SUS pipe brazed on the PE temperature control plate. Two pairs of permanent magnets are mounted inside the EXE to produce a dipole magnetic field that deflects electrons extracted along with the H^- ion. The 50-keV H^- ion beam is extracted by applying approximately −10 kV to the extraction gap between the PE and EXE and approximately −40 kV to the acceleration gap between the EXE and GE.

III. ION SOURCE PERFORMANCE

A. Operation parameters

Typical operational parameters of the ion source are listed below in Table I. The ion source was operated in two separate modes: a low-current mode of 33 mA for user operation and a high-current mode of greater than 50 mA for the accelerator study. To maintain a stable ion source condition, the pulse length and repetition rate of the RF discharge are consistently maintained at 700 μs and 25 Hz, respectively, although the length and repetition rate of the H^- ion beam are arbitrarily varied depending on the study items. If the beam is not required, the discharge is delayed with respect to the time when the extraction voltage is turned off. The emittance

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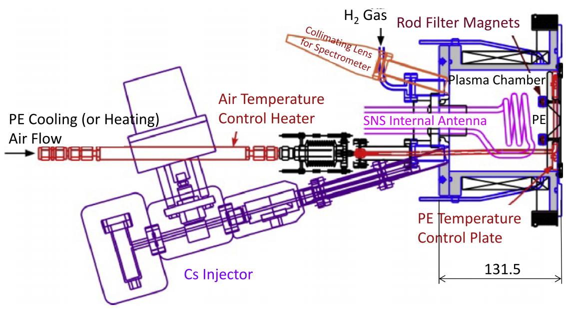

FIG. 1. Schematic of the J-PARC H$^-$ source.

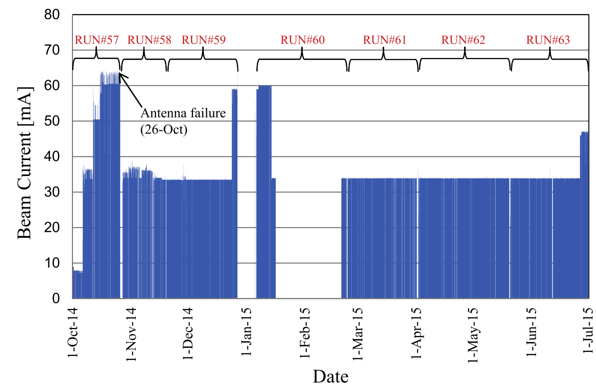

FIG. 2. Operational history of the ion source.

has been measured using two sets of movable slit and movable slit with Faraday-cup.[6] Because there is no space to install the emittance monitor at the beam line, the emittance is measured at the off-line test-stand before installing to the beam line.

B. Operation history

The operation history of the ion source from RUN#57 (October 2014) to RUN#63 (June 2015) is shown in Fig. 2. For RUN#57, the J-PARC accelerator entailed a one-month accelerator study. The linac had resumed beam operation on September 29 and ultimately achieved a 50 mA beam acceleration on October 15. On October 26, the RF antenna of the ion source was broken during a 63 mA test, with beam operations resultantly interrupted. By visual examination of the antenna surface, spotted damage on the antenna coating was observed. The failure was probably caused by Cs^+ ion bombardment due to the large amounts of cesium being injected during conditioning operations for increasing the beam current to 63 mA. Because antenna lifetime is one of the main restrictions for the ion source maintenance cycle, we continue to make efforts to extend its lifetime experimentally[7] and theoretically.[8] After the accelerator study, user operation was restarted on November 2 (RUN#58) with the ion source beam current set at 33 mA. On January 10 (RUN#60), the RCS successfully demonstrated beam acceleration and extraction with an intensity of 1 MW equivalent with a single-shot operation mode[9] with the ion source beam current of 60 mA. At RUN#62, the ion source successfully demonstrated 1100 h of continuous operation with a beam current and duty factor of 33 mA and 1.25%, respectively.

TABLE I. Typical operation parameters of the ion source.

	Users operation	Study operation (RUN#60)
H$^-$ ion beam current	33 mA	60 mA
Beam energy	50 keV	50 keV
RF power	32 kW	41 kW
Beam pulse length/rep.	500 μs/25 Hz (constant)	100–500 μs/1–25 Hz (variable)
RF pulse length/rep.	700 μs/25 Hz	700 μs/25 Hz
Plasma electrode temp.	57 °C	70 °C
Cs reservoir temp.	190 °C	160 °C
H_2 gas flow rate	24 SCCM	22 SCCM
RMS emittance (norm.)	0.22π mm mrad	0.32π mm mrad

Figure 3 shows the variation of the spark rate at the beam extractor with operation time. The spark rate is defined as the frequency of spark phenomena per day. The blue and red bars denote spark rate occurrence in the acceleration and extraction gaps, respectively. The spark rate was found to decrease with operation, and eventually reached less than one per day, which is an acceptable level for user operation. On November 17, the continuous spark in the extraction gap occurred intermittently (48 times in total), and then, the spark decreased without the implementation of any countermeasures. We consider the spark was induced by the cesium in the plasma chamber due to the relatively large amount of cesium that was injected on November 15.

C. Beam current feedback control

To stabilize the beam current, a feedback control system was used during the operation.[3] Typical trends of the beam current, RF power, Cs spectrum intensity, and Cs valve status are shown in Fig. 4. The decrease of the beam current is mainly compensated by increasing the RF power (“A” area in Fig. 4). When the RF power reaches the upper limit value (33 kW in this case), the RF power increase is suspended and the cesium is injected by opening the Cs valve for 5 s automatically (“B” point in Fig. 4). According to the feedback system, the beam current is kept constant within errors of ±0.1 mA. To prevent large amounts of cesium from injecting into the plasma chamber accidentally, the system always monitors the Cs spectrum

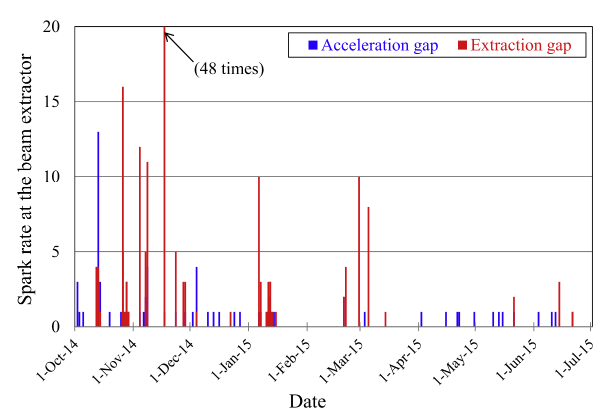

FIG. 3. Spark rate at the beam extractor of the source.

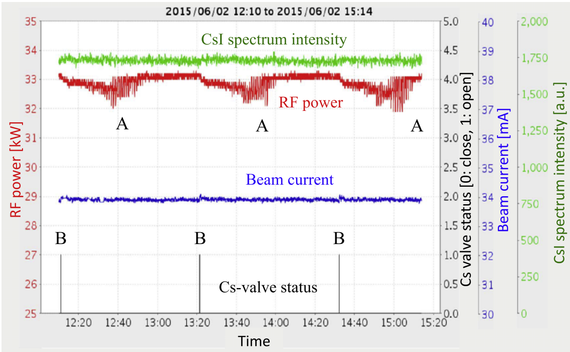

FIG. 4. Operational status using feedback system.

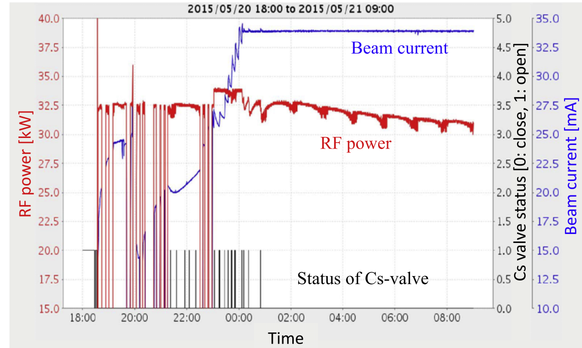

FIG. 5. Typical conditioning operation status.

intensity. The Cs reservoir heater cuts off automatically when the intensity exceeds the upper limit value set by the operator.

IV. ION SOURCE MAINTENANCE

Ion source maintenance work is regularly performed at J-PARC. At the maintenance, the RF antenna, plasma chamber, and plasma electrode are typically replaced. To perform such tasks efficiently, the replacement components are unitized and preconditioned using the ion-source test stand before installation to the beam line.[7] After the replacements are installed, vacuuming operations are commenced expeditiously. When vacuum pressure, which is measured at the beam transport between the ion source and the RFQ, reaches less than 2×10^{-5} Pa (it takes about 4 h for this level to normally be reached), baking of the PE, Cs valve, and Cs tube is started. When the vacuum pressure reaches less than 1×10^{-5} Pa under the baking process, the ion source conditioning operation is initiated. Figure 5 depicts typical conditioning operation status. The beam is then extracted for approximately 3 h without additional cesium injection. During the operation, the applying RF power and hydrogen gas is suspended for approximately 7 min in order to evacuate gaseous impurities from the chamber. When the beam current tended to saturate, the PE temperature is decreased from 300 °C to an operational level of approximately 60 °C by supplying cool air to the PE (at 20:00). When the beam current tended to saturate again, cesium injection was started by opening the Cs valve intermittently (at 21:15). When the beam current reached an operational level of approximately 33 mA, the feedback system was made active (at 00:10). A total time of approximately 6 h was necessary to accomplish the beam conditioning operation in its entirety.

V. CONCLUSION

A cesiated RF-driven negative hydrogen ion source was initiated on September 29, 2014 in response to the need for upgrading J-PARC's linac beam current. Thereafter, the subject ion source has been successfully providing the required beam current to the accelerator without any significant issues other than a single-incident antenna failure. Continuous operation for approximately 1100 h was achieved with a beam current and duty factor of 33 mA and 1.25%, respectively.

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