# STATUS OF THE J-PARC NEGATIVE HYDROGEN ION SOURCE

H. Oguri#, Y. Namekawa, K. Ohkoshi, A. Ueno, JAEA/J-PARC, Tokai, Ibaraki, Japan
K. Ikegami, KEK/J-PARC, Tokai, Ibaraki, Japan

*Abstract*

A cesium-free negative hydrogen ion source driven with a $LaB_6$ filament is being operated for J-PARC. The beam commissioning of J-PARC accelerators started in November 2006. As of June 2010, there have been 34 beam commissioning or supply runs. In these runs, the ion source has been successfully operated in two different modes such as low current mode of 5 mA and high current mode of 30 mA. According to the task of the run, one of the two modes was selected. However, the $H^-$ ion current has been restricted to less than 16 mA for the stable operation of the RFQ linac which has serious discharge problem from September 2008. The beam run is performed 1 month cycles, which consisted of a 4-5 weeks beam run and 4 days down-period interval. At the recent beam run, approximately 600 hours continuous operation was achieved, which is satisfied with the requirement of the ion source lifetime for the J-PARC first stage. At every runs, the beam interruption time due to the ion source failure is approximately one hour, which correspond to the ion source availability of 99 %.

## INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a multipurpose facility with a 1 MW class proton beam power. It is jointly operated by the Japan Atomic Energy Agency (JAEA) and the High Energy Accelerator Research Organization (KEK). In the first stage of the J-PARC, a $H^-$ ion beam with a peak current of 30 mA and a pulse width of 500 μs is accelerated up to 181 MeV by the linac and then injected into the RCS at a repetition rate of 25 Hz. It is necessary to increase the current from 30 mA to 50 mA at the exit of the linac to achieve the beam power of the J-PARC final stage (1MW). The present J-PARC ion source has been succeeded in producing the $H^-$ ion current of 36 mA with a duty factor of 1.5 % (pulse length and repetition rate are 600 μs and 25 Hz, respectively), which satisfies the requirement of the J-PARC first stage [1]. The ion source is being operated as the J-PARC beam injector without any serious trouble for four years. Experiment is being performed with an ion source test bench in order to produce the $H^-$ ion current of more than 60 mA, which is the requirement of the J-PARC final stage.

## ION SOURCE AND LEBT

A cross-sectional view of the present J-PARC ion source is shown in Figure 1. The ion source consists of a $LaB_6$ filament having a cylindrical double-spiral structure (DENKA [2]), a plasma chamber (100 mm in inner diameter and 133 mm in length), a -50 kV isolation ceramics insulator (500 mm in outer diameter and 100 mm in length) and a large vacuum chamber with two turbo molecular pumps (TMPs) of 1500 L/s for differential pumping. Cesium, which have an effect on increasing the $H^-$ ion production efficiency, is not used.

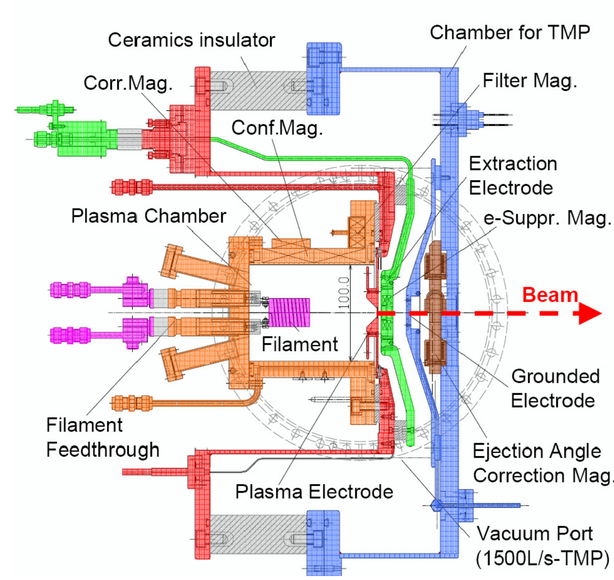


Figure 1: Cross-sectional view of the present J-PARC ion source.

The plasma chamber is made of oxygen-free copper (OFC). The source plasma is confined in the chamber by the multicusp magnetic field. Filter magnets, which produce a magnetic filter field, are attached to 2 of the confinement magnets attached to the side wall near the downstream end. Correction magnets, which produce a field-free region around the filament without changing the magnetic filter field in the extraction region, are attached to 4 of the confinement magnets attached to the side wall near the upstream end. The $H^-$ ion current enhanced approximately 10 % by using the magnets [1].

The beam extractor consists of 3 electrodes: a plasma electrode (PE), an extraction electrode (EXE), and a grounded electrode (GE). The 50 keV beam required for the RFQ is produced by applying approximately 10 kV to the extraction gap between the PE and the EXE and approximately 40 kV to the acceleration gap between the EXE and the GE, typically. The extraction and acceleration gap length are 3.0 mm and 12.0 mm, respectively. The acceleration gap length was optimized to obtain maximum beam transmission rate through the RFQ [1]. The PE is fabricated by boring a 45 degree tapered hole with a diameter of 9 mm on a molybdenum plate with a thickness of 16 mm. The taper angle is optimized in order to produce the highest $H^-$ ion current [3]. The EXE is an OFC plate with a thickness of 12.4

#oguri.hidetomo@jaea.go.jp

mm. Two pairs of Nd-Fe-B permanent magnets (electron suppression magnets) are mounted inside the EXE in order to produce a dipole magnetic field which deflects the electrons extracted along with the $H^-$ ion. The GE is a molybdenum plate with a thickness of 4 mm. The ejection angle error mainly produced by the electron suppression magnets is corrected by an electromagnet (ejection angle correction magnet), which is located just behind the GE. This electromagnet has four poles to deflect the beam both horizontally and vertically.

A J-PARC LEBT consists of 2 solenoid magnets (SM1 and SM2), a gate valve, and a diagnostic vacuum chamber in which a movable Faraday cup, an emittance monitor, a beam current transformer, a beam stopper, a vacuum gauge and vacuum pump are set up [3]. The length of the LEBT is approximately 650 mm. The solenoid magnets can produce a magnetic flux of 1.1 T. In September 2009, we replaced the vacuum chamber by a new one having many vacuum ports in order to improve the vacuum pressure in the RFQ during the operation. The length of the LEBT was not changed. Figure 2 shows a schematic drawing of the new configuration of the LEBT together with the ion source and RFQ. To reduce the amount of hydrogen gas flowing into the RFQ from the ion source, the LEBT vacuum pumping speed was increased from 1,000 to 5,600 L/s by installing a 500 L/s-TMP, a 1500 L/s-TMP and a 3600L/s-cryopump at the chamber, and a divider plate with an orifice having 15 mm in diameter was installed inside of the chamber for differential vacuum pumping. Moreover, the size of a beam aperture was reduced from 9 to 8 mm in diameter on the PE. As the result of the measures, the vacuum pressure at the LEBT was improved from $8.9 \times 10^{-4}$ Pa to $7.8 \times 10^{-6}$ Pa at the operation of 6 mA. The SM1 and SM2 current were changed from 511 A and 591 A at 30 mA to 620 A and 640 A at 16 mA, typically. The increase of the solenoid current in spite of the $H^-$ ion current decrease was probably caused by decreasing a space charge

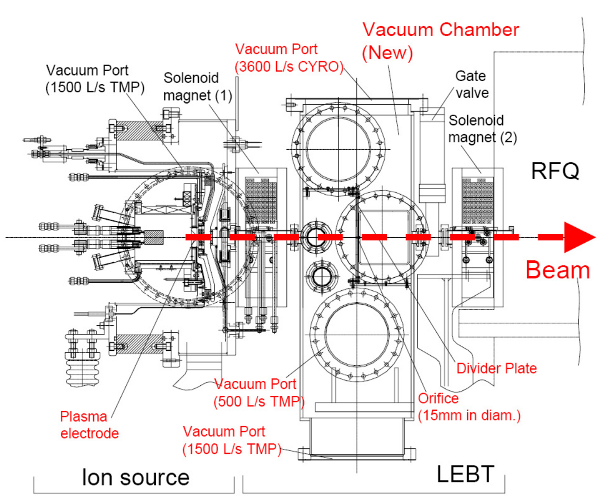


Figure 2: A schematic drawing of the new configuration of the LEBT.

neutralization effect with respect to the $H^-$ ion beam at the LEBT. The Q-mass analyzer measurement showed that mass species of 28, 44, 12, and so on, which are related to hydro-carbons, enter the RFQ when the gate valve at the LEBT opened. Because we suspect that RFQ discharges are related to this pollution, we replaced oil rotary pumps by oil-free scroll ones.

## PERFORMANCE DURING OPERATION

Operation status of the ion source in the last one year is summarized in Table 1. Notation of R#, T, I, A and t in the table 1 denote the beam run number, ion source operation time, typical $H^-$ ion current from the ion source, ion source availability and beam stop time due to the ion source failure, respectively. Typical ion source operation time is approximately 600 hours for each beam run. Although the ion source can produce the $H^-$ ion current of 36 mA, the maximum current is restricted to 16 mA for the stable operation of the RFQ. To keep the condition of the ion source constant, the repetition rate of the arc discharge is kept constant at 25 Hz, although the $H^-$ ion beam repetition rate was changed. If the beam is not required, the arc discharge is delayed with respect to the time when the extraction voltage is turned off. Typical beam stop time due to the ion source failure was approximately one hour for each run. The availability of the ion source is calculated to be more than 99 %. The ion source failure was mainly caused by ion source peripheral equipments such as the vacuum pump, the guage and so on. No failure occurred at the ion source itself.

Table 1: Operation Status of the Present Ion Source in the Last One Year

| R#* | Date | T** | I*** | A**** | Failure [t*****] |
|---|---|---|---|---|---|
| 25 | Jun-09 | 482 | 6 | ~100 | (non) |
| 26 | Oct-09 | 526 | 6 | 98.87 | Vacuum pump [6] |
| 27 | Nov-09 | 642 | 16 | 99.23 | Vacuum guage [2]<br>Vacuum pump [3] |
| 28 | Dec-09 | 568 | 16 | 99.65 | Vacuum guage [1]<br>Power supply [1] |
| 29 | Jan-10 | 605 | 16 | 99.75 | $V_{arc}$ O.V. [1]<br>Power supply [0.5] |
| 30 | Feb-10 | 492 | 16 | 99.69 | Vacuum pump [1.5] |
| 31 | Mar-10 | 323 | 16 | 99.94 | Interlock error [0.2] |
| 32 | Apr-10 | 704 | 16 | ~100 | (non) |
| 33 | May-10 | 609 | 16 | 99.93 | Power supply [0.4] |
| 34 | Jun-10 | 613 | 16 | 99.89 | $I_{arc}$ O.C. [0.7] |

* Beam run number
** Ion source operation time [h]
*** Typical beam current from the ion source [mA]
**** Ion source availability [%]
***** Beam stop time due to ion source failure [h]

After each beam run, the ion source is overhauled, cleaned and inspected for any damage to its internal elements. The filament, the plasma chamber and the PE are exchanged every maintenance. The plasma chamber and the PE are reused by polishing their surface with alumina powder. The filament, on the other hand, is replaced by a brand-new one every maintenance. Figure 3 shows a photograph of the filament after approximately 600 hours operation. Most area of the filament surface became darkly-discolored. The original color of the $LaB_6$ is violet, which is shown inside the yellow circle in Figure 3. The result of the surface elemental analysis by using the EDS (Energy-Dispersive x-ray Spectroscopy) method show that the discolored area is covered with boron [4]. Because the low temperature area around the connections with electric current terminals became also dark, it is recognized the discolored area is electron unemission area. We will try to use new type of the filament to increase the temperature uniformly during the operation.

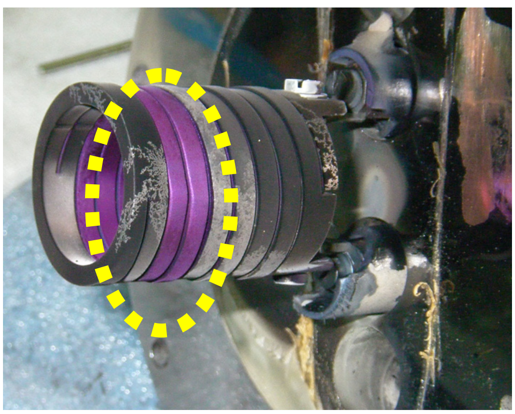

Figure 3: Photograph of the $LaB_6$ filament after approximately 600 hours operation.

## EXPERIMENT OF $H^-$ CURRENT ENHANCEMENT

We started to develop a Cs-seeded ion source by adding a Cs seeding system to a J-PARC test ion source which has the almost same structure with the present J-PARC source [5]. Figure 4 shows the measured dependence of the $H^-$ ion current on the arc discharge power driven with a $LaB_6$ or a tungsten (W) filament for Cs-seeded and Cs-free conditions. In the Cs-free condition, the maximum $H^-$ ion currents were around 18 mA for the cases with the $LaB_6$ and the W filament. In the Cs-seeded condition, on the other hand, the $H^-$ ion current increased by less than 45 % for the case with the $LaB_6$ filament and by approximately 4 times for the case with the W one. The surface elemental analysis suggested that the surface of the PE made of molybdenum, which was used for 24 hours ion source operation with a $LaB_6$ filament and without Cs seeding, was covered with boron [4]. Although we have not carried out the analysis of the PE used for ion source operation with the W filament, it should be completely covered with W because the evaporation rate of W filament is much higher than that of $LaB_6$ one. The large $H^-$ ion current difference is probably caused by the difference between the $H^-$ ion production efficiency. The adhered boron on the PE seems to prevent the cesium effect of decreasing the work function of the PE surface.

We consider the cesium is indispensable for 1MW source. We decided that Cs-seeded source driven with RF is the first candidate for 1MW source because the RF source is superior to filament one for reduction of the amount of cesium.

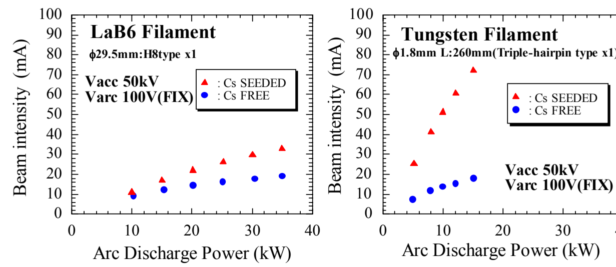


Figure 4: Dependence of $H^-$ ion current on arc discharge power driven with $LaB_6$ or W filament for Cs-seeded and Cs-free condition.

## SUMMARY

The present J-PARC ion source is being operated for approximately four years without any serious trouble. At the recent beam run, approximately 600 hours continuous operation with the $H^-$ ion current of 16 mA was achieved. In order to enhance the current required for the final stage of the J-PARC in the near future, we started to develop a Cs-seeded ion source. As a result, an $H^-$ ion current of more than 70 mA was obtained from the ion source using a tungsten-filament, which is satisfied with the requirement. Further development is in progress.

## REFERENCES


[1] H. Oguri, et al., "Status of Japan Proton Accelerator Research Complex H- ion source", PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 12, 010401 (2009).

[2] Denka Corporation, Chuo-ku, Tokyo, JAPAN, www.denka.co.jp.

[3] A. Ueno, et al., "Unique Features of the J-PARC Linac and Its Performance- Lessons Learnt", LINAC08, Victoria, September 2008, TU101, p. 343 (2008); http://www.JACoW.org.

[4] H. Oguri, et al., "Recent operation status of J-PARC $H^-$ ion source", Rev. Sci. Instrum. 81 02A715 (2010)

[5] K. Ohkoshi, et al., "Development of an $H^-$ ion source for Japan Proton Accelerator Research Complex upgrade", Rev. Sci. Instrum. 81 02A716 (2010).