A 3 MeV LINAC FOR DEVELOPMENT OF ACCELERATOR COMPONENTS AT J-PARC

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Abstract

We have constructed a linac for development of various accelerator components at J-PARC. The ion source is same as the J-PARC linac's, and the RFQ is a used one in the J-PARC linac. The beam energy is 3 MeV and nominal beam current is 30 mA. The accelerator has been already commissioned, and the first development program, laser-charge-exchange experiment for the transmutation experimental facility, has been started. In this paper, present status of this 3-MeV linac is presented.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a multi-purpose facility for particle physics, nuclear physics, materials and life science, and study of transmutation. The J-PARC accelerator [1] consists of a 400-MeV linac, a 3-GeV rapid cycling synchrotron, and a 50-GeV main ring. The energy and peak beam current of the linac are 400 MeV and 50 mA, respectively. They were already achieved but to upgrade the J-PARC accelerator, components such as scrapers of beam chopper at the medium energy transport (MEBT) should be developed, and beam tests are necessary for these developments. However, the actual J-PARC linac is user operation machine, therefore, it is almost impossible to use it for the beam test of the components.

To this end, we constructed a 3-MeV linac on the first floor of the J-PARC linac building. This linac consists of a negative hydrogen (H^-) ion source, a low energy beam transport (LEBT), an radio frequency quadrupole (RFQ) linac, and a diagnostics bean line. A four-vane-type RFQ used for the J-PARC linac until the summer of 2014 (J-PARC RFQ I) is used for this 3-MeV linac: The design peak beam current of this RFQ is 30 mA, and replaced by a newly developed 50-mA RFQ. The duty factor of this linac is 0.6%, which corresponds to 0.5 kW. The accelerator itself has a capacity of at least 1 kW. However, the beam power is limited by radiation dose, because there are no radiation shields between the accessible area during the operation.

At first, we are planning to conduct experiments of the laser-charge-exchange development for the transmutation experimental facility. Then, this linac will be used for the development of scrapers, bunch-shape monitors, laser profile monitors, and others. We will be able to install new devices into the actual J-PARC linac after the full testing. Developments of ion sources can be carried out at this system, and also RFQs in the future.

In this paper, details of this linac and the preliminary result of the first application are described.

EXPERIMENTAL APPARATUS

Figure 1 shows a photograph of the 3-MeV linac.

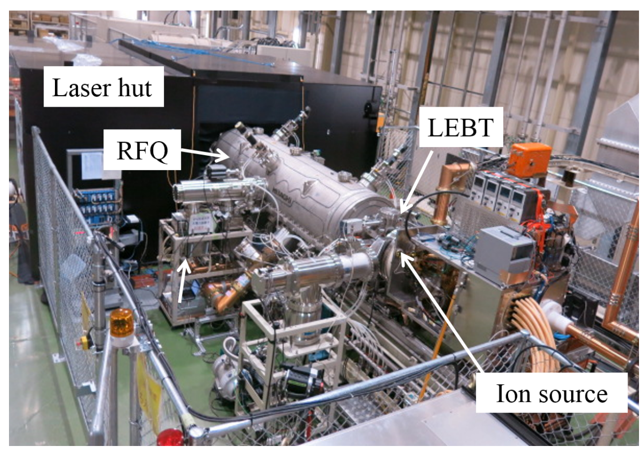

Figure 1: Photograph of the 3-MeV linac.

The same RF driven ion source for the J-PARC linac [2] is employed. The plasma is driven by a pulsed 2-MHz RF power, and a 30-MHz continuous wave RF is also used to ignite the plasma. A 60-kW solid-state amplifier system is used as the RF source. The extraction energy is 50 keV. The LEBT is equipped with two solenoid magnets, and the space charge neutralization effect is also used to focus the beam. The beam current injected to the RFQ is measured using a movable Faraday cup or a slow current transformer located between the two solenoid magnets.

Table 1 lists the parameters of the RFQ.

The cavity of J-PARC RFQ I is contained in a large vacuum vessel [3]. The cavity is not longitudinally segmented, and the vane length is 3115 mm. It consists of four vanes and they are bolted together. The material of the cavity is

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Table 1: Parameters of the RFQ

Beam species	H^-
Resonant frequency	324 MHz
Injection energy	50 keV
Extraction energy	3 MeV
Design beam current	30 mA
Vane length	3115 mm
Average bore radius (r_0)	3.7 mm
ρ_t/r_0 ratio	0.89 (ρ_t =3.29 mm)
Inter-vane voltage	82.9 kV
Maximum surface field	31.6 MV/m (1.77 Kilpatrick)
Nominal peak power	330 kW
Repetition rate	50 Hz
RF pulse length	600 µs
Duty	3%

0.2% silver doped oxygen free copper. This RFQ equips pi-mode stabilizing loops (PISLs) [4]. Owing to its increased high-field region and difficulty for fabrication, PISL is not suitable for high-duty RFQs basically. This is because we abandoned to use the PISL for our new RFQ [5]; however, finally we managed to operate RFQ I stably [6], thus the PISL itself is not a critical factor to prevent stable operation. Two 4000-L/s (for N_2) cryopumps, a 800-L/s, and a 400-L/s ion pumps are used for vacuum pumping. The pressure is measured with a Bayard-Alpert gauge attached to the ion pump manifold. Typical pressures were 8.0×10^{-6} Pa with the beam off, and 2.0×10^{-5} Pa under the 30-mA beam operation. In the lower-left quadrant, loop-type RF couplers are inserted. The RF power was generated by a 324-MHz klystron (Toshiba E3740A).

The extracted beam from the RFQ is used for various experiments. Currently, the setup for the laser-charge-exchange experiment is installed in the laser hut shown in Figure 1. The H^- beam is transmitted to the position of the laser exposure using three quadrupole magnets. Details of the setup will be described in the below section.

COMMISSIONING

RFQ I had been stably operated [6] until it was replaced by RFQ III in the summer of 2014. RFQ I is kept almost one year filled with a dry nitrogen gas, then installed into the first floor of the linac building. The conditioning was started from May 2016. However, the condition had returned to that of just after the vacuum improvement [7], as shown in Figure 2.

We guess that the contaminations once removed from the vane tips, but much contamination still remained inside the vacuum vessel and so on, then this is posited on the vane tip again during the two-years non-operation period. From the past experiences, it takes very long time to recover this situation, therefore, present conditioning time of 100 hours is not sufficient to achieve the stable operation with the nominal duty factor. Currently, is is operated with a pulse width of 100 µs and repetition rates up to 25 Hz.

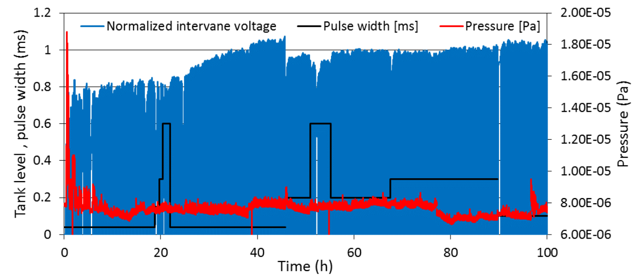

Figure 2: Conditioning history of the RFQ. The blue line shows the normalized intervane voltage, the black line represents the pulse width, and the red line indicates the vacuum pressure.

After the conditioning, we started the beam operation. The transmission up to 25 mA was investigated at the beginning of the operation of RFQ I [8]. Here, we checked the transmission beyond this current. Figure 3 shows the measured and simulated transmission.

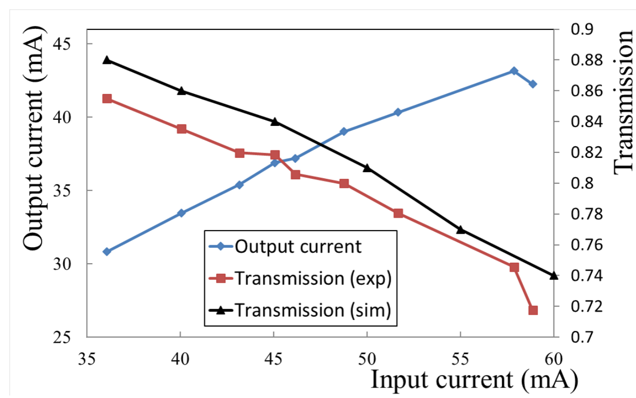

Figure 3: Measured and simulated transmission of the RFQ. The blue diamonds show the extracted current from the RFQ. The red squares and black triangles are measured and simulated transmission of the RFQ, respectively.

The simulation is done using PARMTEQM [9]. The output current saturates as the input current is increased more than 40 mA. Using this RFQ, it is better to limited the output current less than 40 mA.

EXAMPLE OF THE APPLICATIONS

After the commissioning, accelerator-components-development programs have been started. First program is a development of the laser-charge-exchange system for the experimental facility of transmutation [10]. Figure 4 shows the setup of this experiment.

The H^- beam is collided with the Nd:YAG laser light at the middle of a bending magnet. After the collision with the H- beam, the laser light is propagated to the termination point. The time structure of the laser light is measured with a biplanar phototube.

The H^- beam is bent by the bending magnet with a deflection angle of 23° and transported to the beam dump. The

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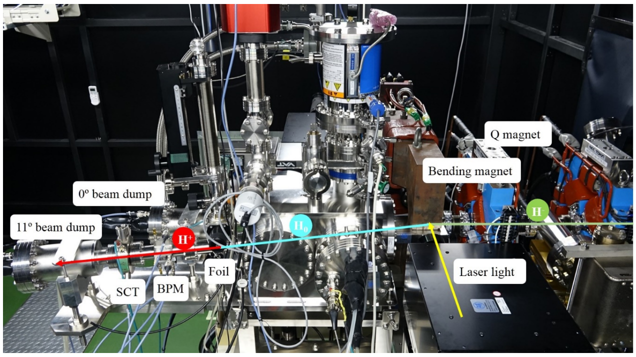

Figure 4: Setup of the laser-charge-exchange experiment.

Nd:YAG laser light exposed at the center of the bending magnet dissociate one electron from the H^-'s, then H^0 beam is transported to the 11° beamline and passes through the stripping foil. The H^0 beam is converted to the H^+ beam by passing the stripping foil. Figure 5 shows the waveform of the Nd:YAG laser light observed with the biplanar phototube and the H^+ observed with the SCT of the 11° beam line.

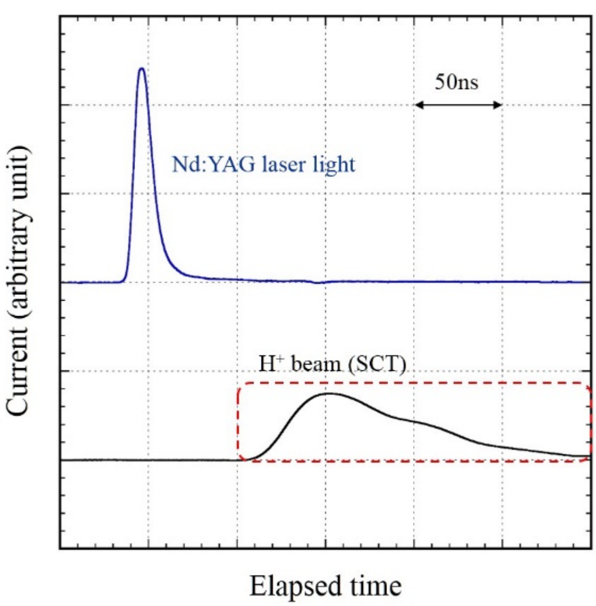

Figure 5: Waveform of the Nd:YAG laser pulse and the H^+ beam observed with the SCT of the 11° beam line.

The power of the H^+ beam was measured to be 0.026 W from the time integral of the current inside the dotted-red rectangle. The conversion efficiently of the laser-charge-exchange is enough for the transmutation experimental facility. Further experiments will be conducted after the summer shutdown.

SUMMARY

A 3-MeV linac for the development of various accelerator components has been constructed in J-PARC linac building. The linac consists of an H^- ion source and an RFQ. After the RFQ, beam diagnostics for each experiment is configured. A RFQ used in the J-PARC linac is reused, and reconditioning has been conducted. First beam of this linac was extracted in June 2016, and subsequently, a laser-charge-exchange experiment was performed. The signal of charge exchanged H^0 by laser light was successfully observed. Further experiments on the laser-charge-exchange and other developments such as beam scraper of the MEBT chopper will be conducted at this test linac.

ACKNOWLEDGMENTS

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