

# UPGRADE OF THE 3 MeV LINAC FOR TESTING OF ACCELERATOR COMPONENTS AT J-PARC

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## Abstract

We have upgraded a 3 MeV linac at J-PARC. The ion source is same as the J-PARC linac's, and the old 30 mA RFQ is replaced by a spare 50 mA RFQ, therefore, the beam energy is 3 MeV and the nominal beam current is 50 mA. The main purpose of this system is to test the spare RFQ, but also used for testing of various components required in order to keep the stable operation of the J-PARC accelerator. The accelerator has been already commissioned, and measurement programs have 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 keep the stable operation, components such as scrapers of beam chopper at the medium energy transport (MEBT) should be constantly inspected. However, the actual J-PARC linac is a 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 [2]. This linac consists of a negative hydrogen ( $H^-$ ) ion source, a low energy beam transport (LEBT), a radio frequency quadrupole (RFQ) linac, and a diagnostics test bench. A four-vane-type RFQ, which was used for the J-PARC linac until the summer of 2014, was used for this 3 MeV linac: The design peak beam current of this RFQ is 30 mA (RFQ I [3]). In 2018, a new 50 mA RFQ [4], which is a spare of the J-PARC RFQ, replaced this

RFQ. By this upgrade, the 3 MeV linac becomes available for high-current operation. The duty factor of this linac is 0.3%, which corresponds to 0.5 kW. The accelerator itself has a capacity of at least 2 kW. However, the beam power is limited by radiation dose, because there are no radiation shields between the accessible area during the operation.

The accelerator has been commissioned and 50 mA beam is now available. Then, this linac will be used for inspection of scrapers, bunch-shape monitors, and others. We will be able to install new devices into the actual J-PARC linac after the full testing.

In this paper, details of the upgrade of this linac and the preliminary results of the first beam operation are described.

## EXPERIMENTAL APPARATUS

Figure 1 shows the schematic layout of the 3 MeV linac. This linac is a very compact system; all the components except for the cooling water supply are stuffed in one room with an area of  $40 \times 10 \text{ m}^2$ .

The same RF driven ion source for the J-PARC linac [5] 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 (SCT) located between the two solenoid magnets.

The RFQ was replaced from old RFQ I to a spare 50 mA RFQ. Figure 2 shows the decommissioning of RFQ I and the installation of the new RFQ. Table 1 lists the parameters of the new RFQ. The cavity of the new RFQ has monolithic structure. The cavity is longitudinally segmented to three modules, and the vane length is 3063 mm. Each module consists of four vanes and they are brazed together. The ma-

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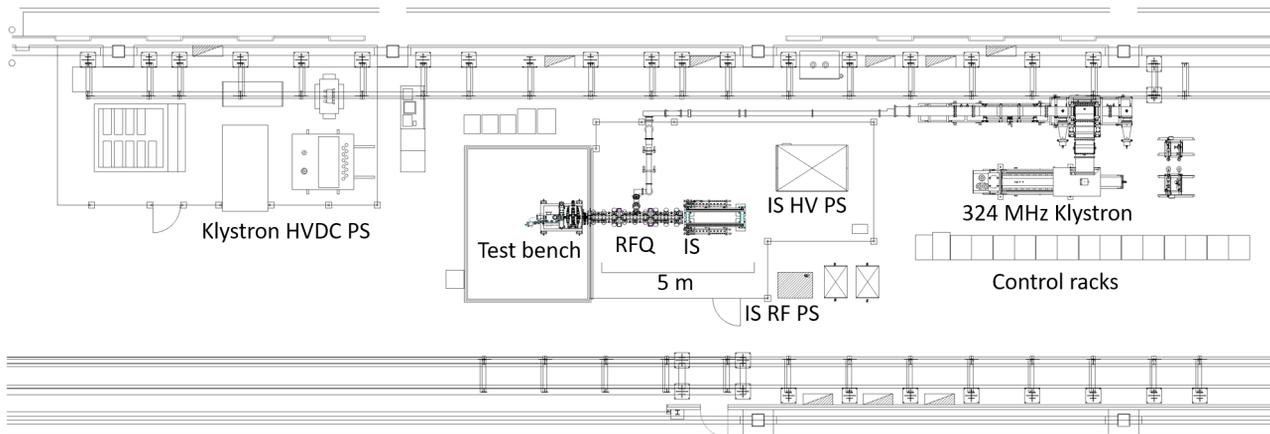


Figure 1: Schematic layout of the 3 MeV linac.



Figure 2: Decommissioning of RFQ I (upper) and installation of the new RFQ (lower).

terial of the cavity is pure oxygen free copper. The resonant frequency during the operation is tuned by adjusting the vane cooling water [6]. Two 1700 L/s (for N<sub>2</sub>) cryopumps, and two 400 L/s ion pumps are used for vacuum pumping. The pressure is measured with a Bayard-Alpert gauge attached to

Table 1: Parameters of the New RFQ

Beam species	H <sup>-</sup>
Resonant frequency	324 MHz
Injection energy	50 keV
Extraction energy	3 MeV
Design beam current	60 mA
Vane length	3063 mm
Average bore radius ( $r_0$ )	2.64 ~ 6.24 mm
$\rho_t/r_0$ ratio	0.75
Inter-vane voltage	61.3 ~ 143 kV
Maximum surface field	30.3 MV/m (1.70 Kilpatrick)
Nominal peak power	380 kW
Repetition rate	50 Hz
RF pulse length	600 $\mu$ s
RF duty factor	3%

the cavity. Typical pressures are  $6.0 \times 10^{-6}$  Pa with the beam off, and  $5.0 \times 10^{-5}$  Pa under the 50 mA beam operation. At the lower-right quadrant (view from the upstream), a loop-type RF coupler is inserted. The RF power is generated by a 324 MHz klystron (Toshiba E3740A).

The extracted beam from the RFQ is measured with the diagnostics test bench consists of three quadrupole magnets, a bending magnet, as shown in Figure 3. It has 0 deg and 23 deg beam lines, both have beam dumps. The default

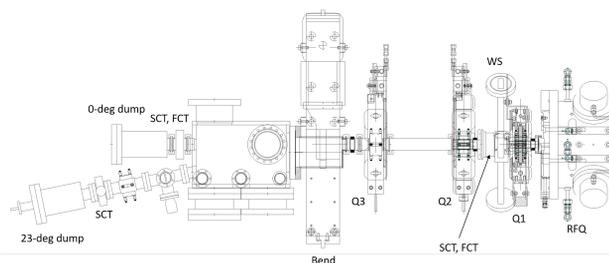


Figure 3: Schematic drawing of the test bench.

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beam diagnostics of this bench are three SCTs, two fast current transformers (FCT), a wire scanner monitor (WS), and various diagnostics can be added on demand. This test bench is contained in a laser hut to be capable of conducting laser experiments.

## COMMISSIONING

First of all, conditioning of the new RFQ was conducted in March 2019. Figure 4 shows the conditioning history.

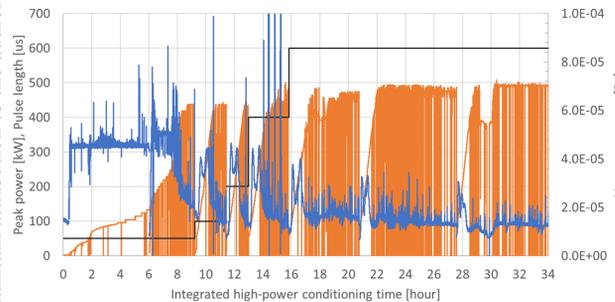


Figure 4: Conditioning history of the new RFQ. The orange line shows the stored peak power (absolute value is not calibrated), the black line represents the pulse width, and the blue line indicates the vacuum pressure.

The conditioning was started with a pulse width of 50  $\mu\text{s}$  and a repetition rate of 25 Hz. The input power was gradually increased by a script program via the EPICS channel access, keeping the vacuum pressure less than  $5 \times 10^{-5}$  Pa. After nine hours, the peak power reached to the nominal value, then the pulse width was extended; it reached to 600  $\mu\text{s}$  after 18 hours. The conditioning was continued with 10% larger inter-vane voltage than the nominal value.

After the conditioning, we started the beam operation. Figure 5 shows the typical beam pulse. In this case, the beam pulse is formed to be 50  $\mu\text{s}$  by modulating the input energy into the RFQ with approximately 10 kV. The peak currents inputted to and outputted from the RFQ were 59 mA and 55 mA, respectively. Figure 6 shows the measured and simulated transmission through the RFQ. The absolute transmission of 93% was measured using the SCTs at input and exit of the RFQ with the nominal inter-vane voltage. The transition behavior in the lower inter-vane voltage region was measured with the FCT just downstream the RFQ to distinguish the accelerated beam by extracting only the 324 MHz component from the beam signal [7]. The simulation is done using RFQGEN [8] with waterbag input distribution of  $0.2 \pi$  mm mrad rms transverse emittance. The measurement and simulation agreed each other very well.

## MEASUREMENT PROGRAM

Subsequently to the beam commissioning of the RFQ, the measurement of various components will be started. The scraper of the beam chopper at the MEBT will be tested. Double-slit type emittance monitors at the scraper chamber are used to decide the beam profile for this test. A bunch

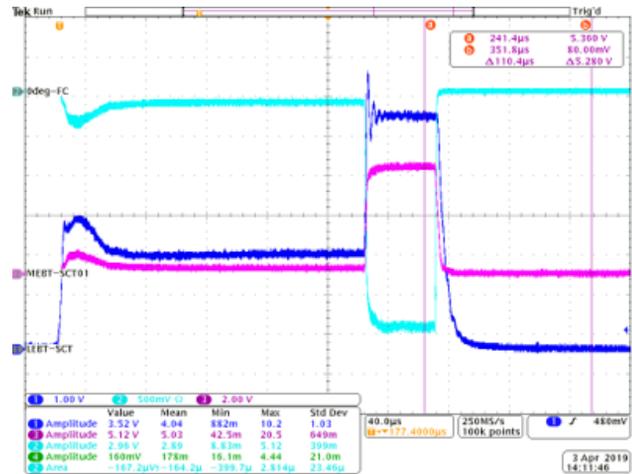


Figure 5: Typical beam pulse. Blue: RFQ input. Magenta: RFQ exit. Cyan: 0 deg beam dump.

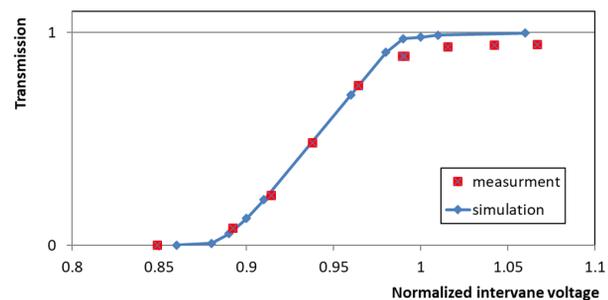


Figure 6: Measured and simulated transmission of the RFQ. The red squares and blue diamonds are measured and simulated transmission of the RFQ, respectively.

shape monitor for MEBT will be installed and tested. In the future, laser charge exchange experiments will be conducted.

## SUMMARY

A 3 MeV linac for the testing of various accelerator components has been upgraded to 50 mA peak current. The linac consists of an  $\text{H}^-$  ion source and an RFQ. After the RFQ, beam diagnostics for each experiment are configured. A spare RFQ of J-PARC linac is used, and conditioning has been conducted. First beam of this linac was extracted in March 2019, and subsequently, beam measurement of the RFQ was performed. Further experiments of such as bunch shape monitors, beam scrapers of the MEBT chopper, and so on will be conducted utilizing this compact test linac.

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