PROGRESS AND OPERATION EXPERIENCES OF THE J-PARC LINAC

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Abstract

The J-PARC linac started beam commissioning in 2006 and had delivered beam to users since 2008 at an energy of 181 MeV. The linac with an energy of 400 MeV and higher peak beam current of 50 mA was required to reach the goal of the J-PARC project. We installed a new accelerating structure, Annular-ring Coupled Structure (ACS) in 2013 for energy upgrade. The ion source and the Radio Frequency Quadrupole linac (RFQ) were replaced to increase the beam current in 2014. As a result of these, the linac provides beams to demonstrate a 1-MW-equivalent beam at the RCS and also beams for user programs at higher beam power. The progress and operation experiences of the J-PARC linac are presented.

INTRODUCTION

The J-PARC facility consists of a linac, a 3 GeV Rapid Cycling Synchrotron (RCS), a 30 GeV Main Ring synchrotron (MR) and three experimental facilities [1]. The linac started beam commissioning in 2006. The present linac consists of a negative hydrogen ion source, a 3 MeV RFQ, a 50 MeV DTL (Drift Tube Linac), a 191 MeV SDTL (Separated-type DTL) and a 400 MeV ACS (after the upgrade) as shown in Fig. 1. RF frequencies are 324 MHz and 972 MHz for the low energy section (RFQ, DTL and SDTL) and for the high energy section (ACS), respectively. A proton beam from the RCS is injected to the Materials and Life Science Experimental Facility (MLF) for neutron and muon experiments. The MR has two beam extraction modes; a fast extraction for the neutrino beam line (NU) for the Tokai-to-Kamioka (T2K) experiment, and a slow extraction for the Hadron Experimental Facility (HD).

The goal of the J-PARC project is to deliver a 1 MW beam from the RCS and a 0.75 MW beam from the MR. To achieve the goal, the linac peak current and energy should be 50 mA and 400 MeV, respectively, while initial configuration provided a 30 mA and 181 MeV beam. Therefore, we took the energy upgrade, and then, the peak current upgrade [2].

PROGRESS OF PERFORMANCE

Operation in the Early Days

Beam commissioning of the linac started in November 2006 and 181 MeV acceleration was achieved in January 2007. The progress at that time seemed to be smooth. But trip rates of the RFQ unexpectedly increased in autumn 2008 and the incident limited the operation days and power ramp-up. The beam current was limited to 5 mA, and the RCS beam power for the MLF users was 20 kW. The history of the beam power of the MLF is shown in Fig. 2. Note that the small bars in 2008 and 2009 are not

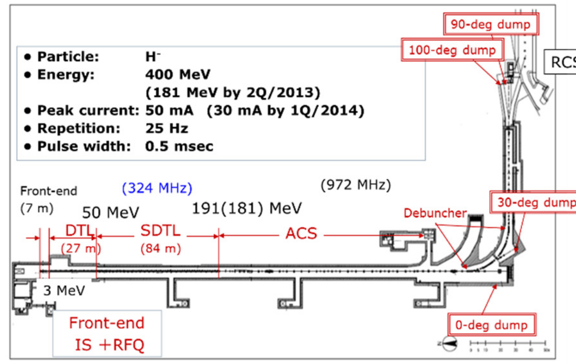

Figure 1: Configuration and main parameters of the J-PARC Linac.

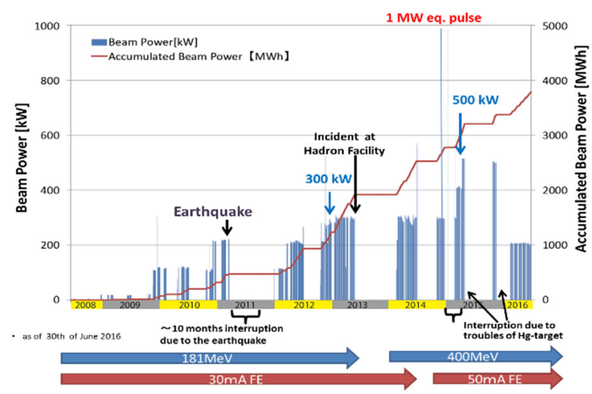

Figure 2: Beam power history for the MLF. (by courtesy of the MLF group).

noises but our suffering days. This was mostly settled by the vacuum improvement work during the summer shutdown of 2009 [3]. We increased the beam power in November 2009; beam pulse length from 0.1 to 0.2 msec, and peak beam current from 5 to 15 mA, thus giving a 6 fold increase from 20 to 120 kW. Since then, we had kept stable operation for users, concretely 90 to 95% availability.

Earthquake in 2011

Based on the stable operation, we planned to step up the beam power to the MLF. We increased the power from 120 to 200 kW in November 2010. The linac beam current and average power were 15 mA and 12 kW, respectively. We also performed 400 kW (equivalent current beam) acceleration in January 2011 for the next step up.

But we had a crisis after two months; the Great earthquake in March 2011. The J-PARC facilities were severely damaged [4]. Thanks to the significant effort of restoration, we resumed beam operation in December and user operation in January 2012 [5].

We started beam operation sooner, but several aftereffects were left. The number of trips in the RFQ was seri-

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ous. Some carbon related components, such as 28 (CO), 44 (CO_2), and 12 (C) went higher in the residual gas. The possible reason was that we had in poor vacuum condition due to a power outage at the earthquake. But as conditioning and operation days continued for half a year, the number of trips decreased as these carbon related components reduced [6].

The condition became better after the summer shutdown of 2012. We increased the beam power from 200 to 300 kW and stable operation was conducted by the incident of the HD in May 2013 [7].

Energy Upgrade

The energy upgrade project started in March 2009. We installed the ACS acceleration modules and some subsystems during the summer shutdown of 2013 as planned before the HD incident. The beam commissioning of the linac was started in the middle of December and the designed beam energy of 400 MeV was achieved in January 2014. After the commissioning of the linac, beam tuning of the RCS started for the upgraded injection energy. Then we performed a high intensity beam trial up to 550 kW. A beam loss at the injection clearly shows an advantage of the energy upgrade [8].

The user operation of the MLF was resumed in February 2014 with a beam intensity of 300 kW. The 400 MeV linac has been successfully commissioned as planned [9].

Beam Current Upgrade

The next step is an intensity upgrade in 2014 to perform 1 MW from the RCS. The peak beam current should be increased to 50 mA and the linac beam power is 133 kW. The upgrade involves the replacement of a front end, i.e. an ion source, an RFQ, and a chopper system between the RFQ and the DTL.

A 50 mA H^- ion source is one of the essential components. A cesiated RF-driven ion source has been developed and peak current of >60 mA was achieved [10]. An RFQ for 50 mA operation was constructed. A front-end test stand was built to perform a beam test of the ion source and the RFQ before installation to the linac tunnel [11]. A 24-hour continuous beam test was demonstrated for a month, in June 2014. The new front-end system was installed in the linac tunnel.

In order to chop the 50 mA beam for making the intermediate time structure of the linac beam pulse, an RF chopper cavity was also replaced with a newly fabricated one, which has a larger aperture and longer gap length between electrodes to decrease unexpected beam loss.

The beam study operation of the linac was started in September and achieved 50 mA in October. The RCS successfully demonstrated the beam acceleration and extraction with the intensity up to 773 kW-equivalent (6.44×10^{13} particles) in a single-shot operation mode. After the accelerator study, user operation was restarted for the NU and the MLF. The delivered beam powers were 220 – 260 kW and 300 kW for the NU and for the MLF users, respectively.

We tried high power beam acceleration in the RCS in December 2014 and January 2015. As a result, the RCS successfully accelerated and extracted a 1-MW-equivalent beam (8.32×10^{13}) in the single shot mode [12]. This achievement of 1-MW-equivalent beam acceleration was an important milestone for the J-PARC accelerator.

OPERATION EXPERIENCE

The operation history of the ion source after the beam current upgrade is shown in Fig. 3 [13]. The ion source has successfully provided beams for accelerator study (higher beam current) and user operation (stable operation) without serious troubles except for an antenna failure in October 2014. The RCS 1-MW one-shot demonstration was performed at 60 mA in January 2015 as mentioned. From January 2016, beam current from the ion source for user operation increased from 33 to 45 mA, where linac output current is roughly 30 to 40 mA, respectively.

By the increase of the peak beam current as well as results of the study at the RCS and the MR, the beam power to the neutrino facility was increased to 330 - 390 kW from February, while it was 300 - 330 kW at 30 mA by the end of 2015. The beam power at the MLF for user operation was increased from 300 to 400 and 500 kW as shown in Fig. 2.

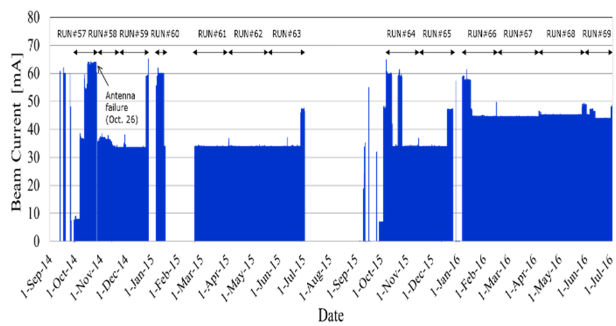

Figure 3: History of the beam current from the RF-driven ion source after the beam current upgrade.

The performance of accelerators is not only shown as a beam power but reliability. Figure 4 shows beam down time by major subsystems in FY2015 (April 2015 to March 2016). Operation hours, which is defined by the shift-leader assigned time including RF conditioning, was 6,350 hours.

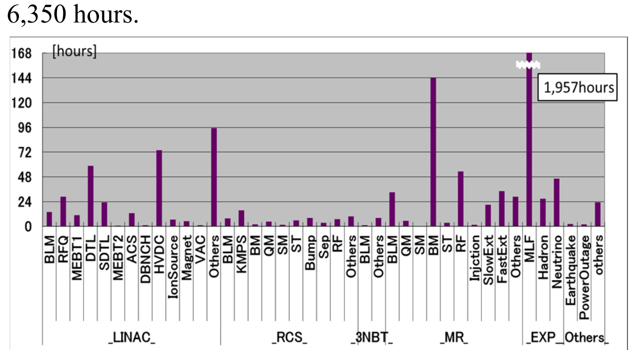

Figure 4: Downtime by components in JFY2015.

We had two target failures at the MLF and long downtime of 1,957 hours (over scaled) for the replacement. During the stop of the MLF, the accelerator delivered beam to the NU or HD users by way of the MR.

We had a trouble at a coil of the bending magnet at the MR. One event counted long downtime. In this case, we provided beam to the MLF.

The linac (and the RCS also) is a key of the reliability of the whole J-PARC facility because all the beams stop when these upstream facilities down. The RCS is rather stable, and the linac contributes most of the downtime, which makes beam stops and worsens reliability.

A characteristic one in this year was that there were a lot of troubles grouped in "Others", which may not occur so often. Most of the events were utility or building related and this made up a cooling tower failure (19 hours), a cooling water valve failure (11 hours), ventilation system stops (three times, 32 hours in total) and so on.

The next highest cause was an HVDC (High Voltage DC power supply) for klystrons. This is not limited to the power supply but covers high power RF components. Several defects in this group comprised of a klystron failure (22 hours for unscheduled replacement), insulation breakdown of an HV cable (12 hours), and several switching devices and module failures. The 324 MHz klystron operation hours is shown in Fig. 5. We are using 20 klystrons and most of the operation hour is roughly 50,000. When klystrons approach the end of life, number of discharges increases and reliability goes down. We have 7 failed klystrons so far and average operation time for 5 (excluding prototype) is 39,000 hours. It's not surprising if any klystron at around 50,000 hours comes to the end of life. It is important to take systematic procurement to keep operation reliability.

Some other linac downtimes were groups in "DTL" and "SDTL". The condition of the cavities is not poor except for some SDTL cavities with multipacting due to the aftereffects of the earthquake. Most of the downtimes were counted by cooling water flow decrease. Once the flow monitor fires, it takes at least 3 to 4 hours to enter the tunnel under our rule. It's time consuming even if it doesn't take long time for the flow adjustment work. We

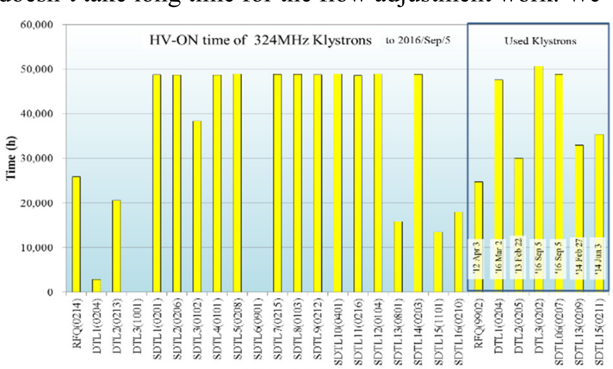

Figure 5: Operation hours of 324 MHz klystrons. Some of them (for DTL1, DTL3 and SDTL6) are rather new just after the replacement in spring or summer 2016.

adjust cooling water flow rates at the weekly scheduled maintenance, but some of the flow rate drops unexpectedly. To mitigate the state, we have introduced remote control valves, re-consideration of cooling water flow branches, clean-up of the cooling channel, and consolidation of cooling water system.

NEXT SCOPE

Since we have performed upgrade work towards the goal of the J-PARC, next upgrade scope is under discussion. Construction of Transmutation Experimental Facility (TEF) is proposing for the next J-PARC upgrade phase. The TEF requests 25 Hz beam at 400 MeV. To fulfill this operation, the linac will be upgraded from 25 Hz to 50 Hz operation. Some of the linac components are designed at 50 Hz operation from the beginning, but mainly, reinforcement of cooling capacity is needed.

Another reasonable candidate is about 50% beam power upgrade by increasing both the beam current by 20% and pulse length by 20% [14]. Consolidation of the ion source, the beam stopper for chopper is important and some R&D is needed. A voltage sag compensation in the klystron power supply may also be needed.

SUMMARY

The linac shows good performance to deliver beam to fulfill the J-PARC goal after the 400 MeV and 50 mA upgrades. The linac provides beams to demonstrate a 1-MW-equivalent beam at the RCS and also for routine operation for user programs. The beam commissioning results are shown in other paper [15]. We still need some study work for reduction of residual radioactivity before 50 mA user operation. We have experienced the MLF target troubles twice at 500 kW and we are taking conservative beam power of 200 kW for the time being. The high power beam commissioning is pending by consolidation of targets.

There are several sources of downtimes. Some of them come from aged components. To obtain better availability in the limited resources, risk analysis like procedure and prioritization are to be processed.

The next scope is discussing for the TEF delivery and beam power upgrade.

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