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OPERATION EXPERIENCES OF THE J-PARC LINAC

Kazuo Hasegawa*, for the J-PARC Linac group, J-PARC, JAEA/KEK, Tokai-mura, Japan

Abstract

The J-PARC linac has delivered beam to users since 2008. As of 2018, the linac provides a 40 mA beam at an energy of 400 MeV to the following Rapid Cycling Synchrotron. We have had many issues that impede high availability during the operation. One of them was troubles of high voltage power supply of klystrons. The other category is related to vacuum property in accelerating cavities. The cleaning of the inside surface of some acceleration cavities were performed after the big earthquake in 2011. The cooling water flow rate drop had been a long-time issue. We modified a cooling system to take better flow balances. As a result of these improvements, the availability is approximately 93% or more in these days. The operation experiences and availability improvement at 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 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 (FX) for the neutrino beam line (NU) for the Tokai-to-Kamioka (T2K) experiment, and a slow extraction (SX) 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-FX. To achieve the goal, the linac have had big upgrade work such as peak current and energy upgrade[2]. On the way of the beam operation, we have had many issues that impede high availability and also have taken countermeasures.

BEAM HISTORY

The history of the beam power from the RCS to the MLF is shown in Fig. 2. User operation was started in 2008. At that time, trip rate of the RFQ was high and operation days and power ramp-up were limited. The beam current was low at 5 mA, and the RCS beam power was 20 kW. This was mostly settled by the vacuum improvement work during the summer shutdown of 2009 [3]. The progress of beam power of the J-PARC linac by 2015 is described in Ref[4].

* hasegawa.kazuo@jaea.go.jp

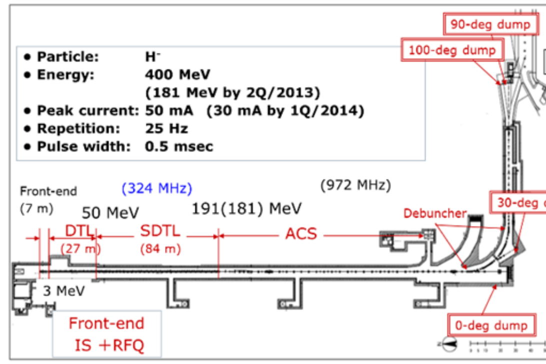

Figure 1: Configuration and main parameters of the J-PARC Linac

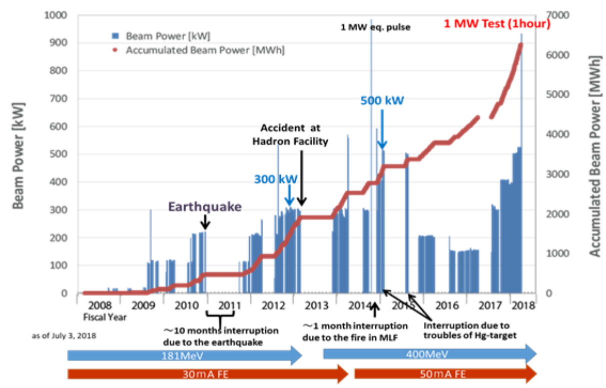

Figure 2: Beam power history for the MLF. (by courtesy of the MLF group, modified).

We had a crisis of the Great Earthquake in March 2011 and the J-PARC facilities were severely damaged. 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 and some of the SDTL cavities was serious. As conditioning and operation days continued for half a year, the number of trips decreased as vacuum conditions went better. As described later, the SDTL remained issues.

We have steadily increased a beam power after the energy upgrade (from 181 to 400 MeV) in 2013 and beam current upgrade (ion source and RFQ replacement, from 30 to 50 mA) in 2014. As a result of these upgrade, we demonstrated a 1-MW-equivalent single shot beam from the RCS successfully. For continuous operation, we need to mitigate beam losses and to consolidate some power supplies, but this was a great milestone to perform the potential of accelerators.

We have steadily increased the beam power up to 500 kW at the MLF. But we had two neutron production target failures in April and November 2015[6]. After that, we used a spare target and the power was limited to 200-150 kW. During the maintenance period of summer 2017, we exchanged for a target with a new design[7]. Then we have gradually increased the power from 300 kW, 400

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kW and 500 kW successfully, while checking target conditions.

OPERATION EXPERIENCE

The performance of accelerators is not only shown as a beam power but availability. Table 1 shows operation statistics in FY2017 (April 2017 to March 2018). Operation hours, which is defined by the shift-leader assigned time including RF conditioning, was 6,448 hours. The availability of 93% for MLF shows that the linac, the RCS and the MLF operated favorably.

Table 1: Availability for J-PARC facilities in Japanese Fiscal Year of 2017 (April 2017 – March 2018)

Facility	User time (hours)	Trouble, Acc. only (hours)	Trouble, Fac. only (hours)	Net time, (hours)	Availability, Total (%)
MLF	4,555	270 (5.9%)	35 (0.8%)	4,249	93.3
Neutrino (FX)	1,978	185 (9.4%)	35 (1.8%)	1,757	88.8
Hadron (SX)	1,601	506 (31.6%)	39 (2.4%)	1,055	65.9

Figure 3 shows downtime by major subsystems in FY2017. The "SlowExt" in the MR is due to nearly one month downtime by an electric static septum trouble. It was an exception in the year and the reason of the low availability of 66% for the MR-SX in Table 1. The linac (and the RCS also) is generally a key of the availability 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 degrade availability.

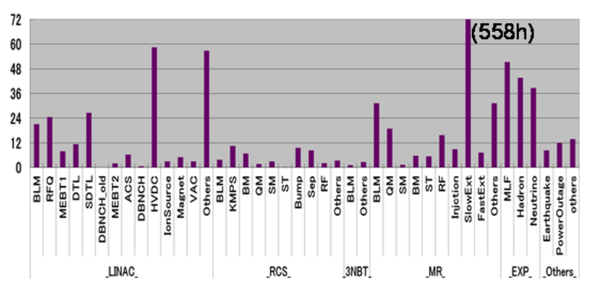

Figure 3: Downtime statistics in hours by components in FY 2017.

The categories "HVDC (high voltage power supply for klystrons", "Others", and "DTL and SDTL" are dominant causes in these years. These downtime variation from 2011 is shown in Fig. 4. We have had many countermeasures against troubles to improve availability.

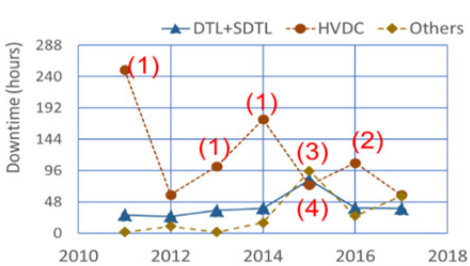

Figure 4: Downtime history for major causes.

Downtime in "HVPS"

Figure 5 shows a circuit diagram of the HVDC. The rectifier diodes at the 110 kV high voltage terminal were broken after the operation of 30,000 hours FY11, FY13 and FY14 as shown (1) in Fig.4. The reason was not clear at the beginning, but it was found out. Many steps of diodes are connected in series to rectify the high voltage. Capacitors are connected in parallel to the diode in order to reduce the influence of variations of the capacitance of the diode for the revers voltage. But due to the temperature difference in the insulation oil as well as aging effects, changing of the capacitance enhanced the voltage imbalance and the diodes were broken-down. As a measure, we have increased the series number of elements from 66 to 84 stages and better temperature characteristics capacitors. After that, we haven't had the same troubles, although not all the diode modules haven't replaced yet.

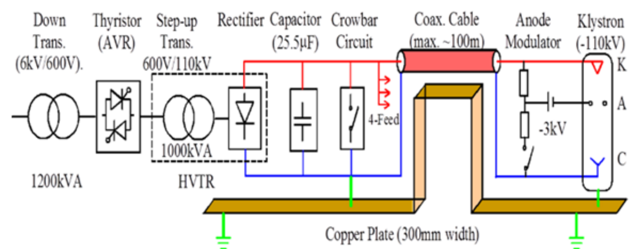

Figure 5: Circuit diagram of the HVDC.

We expected better downtime in 2015, but we faced another issues. Anode modulators, which consists of a bias power supply and a semiconductor switch as shown in Fig. 5, broken occasionally in FY16 as shown (2) in Fig. 4 and partly in FY15. The main reason is an aging of these parts. We replaced with new power supplies and switches, then the downtime reduces from 2017. But it was a mid-term measure and we should consider against root causes: cooling consolidation of the insulation oil and the circuits to take longer lifetime.

The "HVDC" is not limited to the power supply but covers high power RF components. Several defects comprised of a klystron failures and insulation breakdown of high voltage cables. We are using 20 324-MHz klystrons and most of the operation hour is roughly 50,000. When klystrons approach the end of life, number of discharges increases and availability goes down. We have 11 replaced klystrons as of summer 2018 and average operation time of these is 41,870 hours. It is important to take systematic procurement to keep operation availability.

Downtime in "Others"

The category of "Others" in 2015 as shown (3) in Fig. 4 is higher than usual. It consists of several utility related downtime. The cooling tower failure stopped for 19 hours, then we added a new cooling tower to be a redundant system. Cooling water valve failure stopped for 11 hours, Ventilation system was stopped for 32 hours due to grounding. We took leak current sensors but the grounding hasn't occurred again and the reason has not clear yet.

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Another cause in “Others” is related to network and control devices as a baseline of FY16 and FY17. Some of these components are 15 years old or more and it’s a timing to replace new ones. Some of the components’ faults are not easy to define the caused devices. It takes long time to identify and restart a beam.

Downtime by Cooling Water Flow Drop

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. As an issue at the linac in these years, some cooling water flow rates gradually decreased with the operation over several days to several weeks. When it drops below the preset flow rate, the beam stops to protect components. Then we have to enter the accelerator tunnel and re-adjust the flow rate. It stopped at least for several hours.

In the “DTL+SDTL” category in FY15 as shown (4) in Fig. 4, cooling water flow decrease stopped beam operation several times. We adjusted cooling water flow rates in the weekly scheduled maintenance day, but some of the flow rates dropped unexpectedly.

One of the reasons was that the flow of one cooling water pump was largely branched to the north (4,000L/min) and the south (1,200L/min), and the balance of the system was lost due to the many branches. In order to solve it, a pump for the south was added and separated from the north path[8]. Furthermore, in particular the flow balance in a narrow channel is more sensitive, the inner surfaces of the coil of the Q magnets were cleaned using compressed air and water to remove the accumulated sludge.

Figure 6 shows the flow rate before and after these measures for two months. The flow rate is stabilized after the measures.

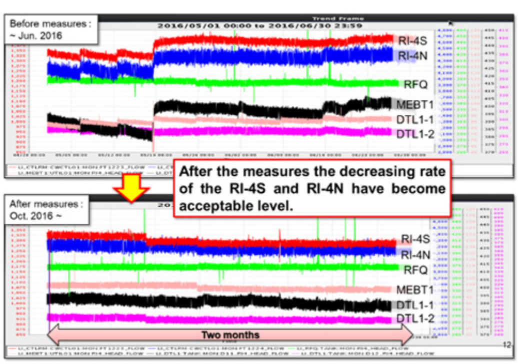

Figure 6: Cooling water flow rates for several cavity systems before (top) and after (bottom) the measure.

Multipacting at SDTL Cavities

Since the earthquake in 2011, several SDTL cavities became unstable (the reflection increased in the vicinity of the designed RF power), and since 2015 we have had an internal cleaning (wiping by acetone dipped cloth)[9]. As a result, good results have been obtained that the RF reflection decreases. Figure 7 shows the VSWR of the SDTL #5 cavities (it consists of two cavities of tank-A and B). The tank-B is stable by the cleaning in the previous year, but the tank-A has a high reflection area. As a result of cleaning, the unstable area disappeared. By that time, in order to avoid the unstable area, we had to operate at higher power level than the design value, but it is possible to operate with the design value. The discharge frequency of the cavities was also suppressed and stable operation can be performed.

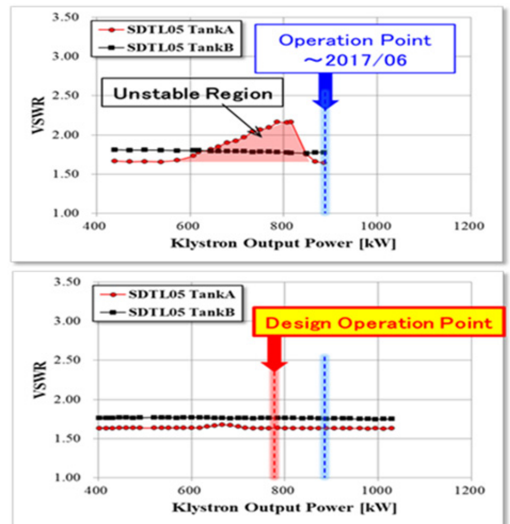

Figure 7: Voltage standing wave ratio for the SDTL#5 (Tank-A and B) cavities before (top) and after (bottom) the clean-up of the SDTL#05-tank-A cavity.

SUMMARY

The linac shows good performance to deliver beam to fulfil the J-PARC goal. We have had many hardware upgrades, modifications and beam commissioning to improve the performance. The linac and the RCS provide beams to the MLF and the MR. After the replacement with the new designed neutron production target at MLF, we increased a power step by step up to 500 kW for user operation. High power beam at 1 MW 1-hour was successfully demonstrated on July 3 before the summer shutdown 2018.

There are several sources of downtimes. Some of them come from aged components after 10 years of user operation. To obtain better availability in the limited resources, risk analysis like procedure and prioritization are to be processed.

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