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PERFORMANCE AND STATUS OF THE J-PARC ACCELERATORS

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Abstract

The J-PARC is a high intensity proton accelerator facility. We deliver 3 GeV beams for neutron and muon experiments. We had two neutron production target failures in 2015 and beam power was down to secure the target. After the replacement with a modified target in summer 2017, we have stepped up a power gradually. The beam powers for the neutrino and hadron experiments at 30 GeV were steadily increased. The operational performance and status of the J-PARC accelerators are reported.

INTRODUCTION

The J-PARC facility consists of a 400 MeV linac, a 3 GeV Rapid Cycling Synchrotron (RCS), a 30 GeV Main Ring synchrotron (MR) and three experimental facilities [1]. 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 experiment (NU, also called Tokai-to-Kamioka (T2K) experiment), and a slow extraction (SX) for the Hadron Experimental Facility (HD). The goals of the beam power are 1 MW and 0.75 MW at the MLF and MR-FX, respectively.

STATUS OF LINAC AND RCS

Figure 1 shows a history of the beam power from the RCS to the MLF. We steadily increased a user operation power up to 400 kW and we successfully demonstrated at 1 MW equivalent one-shot beam in January 2015 [2]. Then we increased beam power to 500 kW, but we had neutron production target failures twice in April and November 2015 due to water leakage. After the second replacement with a spare target, we delivered beam at conservative beam power of 200 or 150 kW to protect the target in 2016 and early 2017. Even in this low power condition, the linac and the RCS provided one bunch beam instead of regular two bunches in the RCS, which made shorter

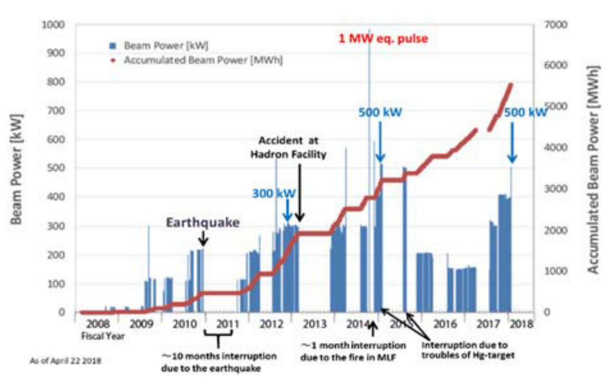

Figure 1: Beam power history for the MLF (by courtesy of the MLF group).

pulse and some fast-TOF and muon users preferred. We developed and constructed a modified target against troubles and replaced in summer 2017 [3]. After that, we have increased a power step by step, and delivered beam at 500 kW as of April 2018. We plan to have a beam study at higher beam power to confirm the new designed target performance before the summer shut-down of 2018. We expect further increase from the autumn operation based on the results.

Linac

We used a cesium-free LaB6 filament type ion source, but a cesiated RF-driven ion source has been used since September 2014 to increase a beam current [4]. The operation history of the ion source is shown in Fig. 2. The ion source has successfully provided beams for accelerator

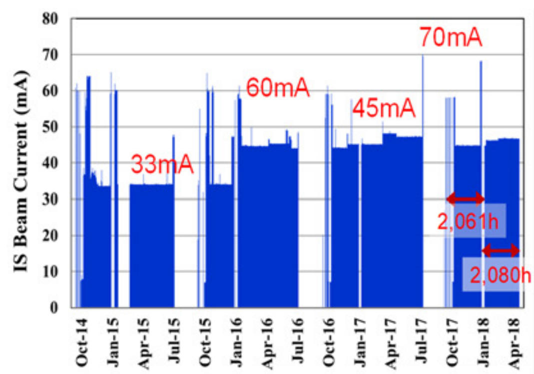

Figure 2: Beam current from the ion source.

study (higher beam current, at about 60 and 70 mA) and user operation (long time stable operation) without serious troubles. From January 2016, beam current from the linac for user operation increased from 30 to 40 mA, hence that of the ion source from 33 to 45 mA. The increase of the peak beam current helped the beam power increase as well as results of bam loss reduction study of the linac, the RCS and the MR. We gradually increase continuous operation days and about three months stable operations (2,061 hours and 2,080 hours, shown in Fig. 2) are successfully demonstrated. Based on these experiences, we changed the operation scheduling from 1.5 months to 3months in a single RUN cycle. That will serve more beam time to users since we can save an ion source replacement and start-up time.

We have two chopper cavities after the RFQ to make intermediate pulse structure. We encountered a ringing effect to make partially chopped beam, because one amplifier fed the two cavities in series. To solve this issue, in summer of 2016, separated amplifiers were prepared for the two chopper cavities. The RF pulses in the two cavities before and after the modification are shown in Fig. 3 [5]. The ringing

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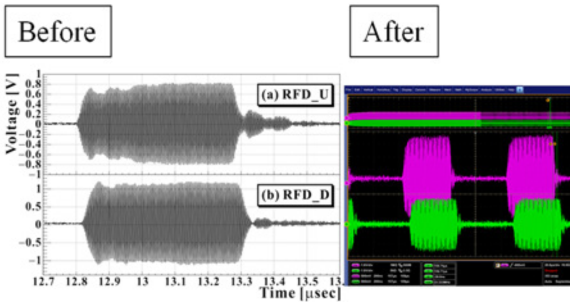

Figure 3: The RF pulses in the deflecting chopper cavities before and after the amplifier parallelization.

effects due to the series connection were cured.

A peak beam current of 50 mA is necessary to achieve the goal of 1MW at MLF. We have already operated at this condition in a few days duration and up to 2.5 Hz repetition. Further beam loss is studied to reduce residual radioactivity for long time user operation.

RCS

The repetition of the RCS is 25 Hz and most of the beams are provided to the MLF, while four pulses in the MR cycle time (2.48 seconds for FX, 5.02 seconds for SX at present) are provided to the MR by switching the beam destination. The beam parameter requirements from the MLF and the MR are different. The MLF requires a wide-emittance beam with low charge density to mitigate a shockwave in the neutron production target. The MR, on the other hand, requires a low emittance with less beam halo to mitigate beam loss in the MR. To optimize the beam operations for both the MLF and the MLF, we took several hardware improvements: bipolar sextupole excitation system and power supply for the correction quadrupole magnets [6]. Figure 4 shows a wide-emittance beam to the MLF and a narrow-emittance beam to the MR as requested by introducing the pulse-by-pulse switching of painting emittance, chromaticity and betatron tune, etc [7].

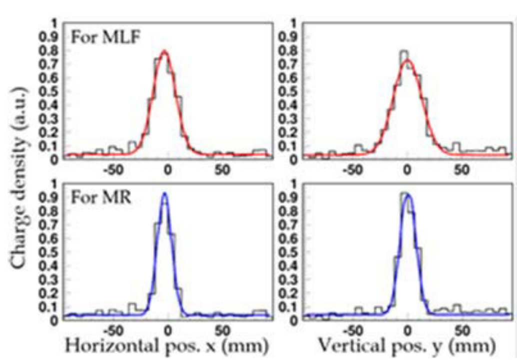

Figure 4: Beam profiles at extraction for the MLF and the MR destinations.

STATUS OF MR

A beam power history from the MR is shown in Fig. 5. We had used an operation tune (22.40, 20.75) since user operation started. However, we encountered the effect of the strong half resonance $\nu_y = 20.50$ over 400 kW level. We searched new operation point through beam dynamics simulations. In spring of 2016, we changed the tune to (21.35, 21.43), which had a wider area against resonances. We have had many corrections and optimization tunings; third order resonance corrections, linear coupling resonances, parameters of the bunch by bunch feedback, intra-bunch feedback, RF systems, chromaticity, and so on. As a result of these, we have successfully ramped up the power to 420 kW and 490 kW at present [8].

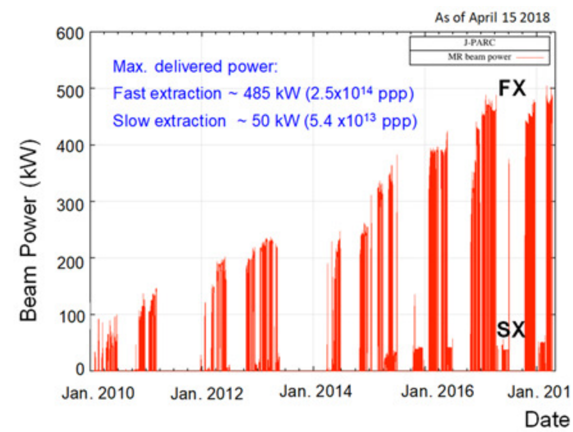

Figure 5: Beam power history from the MR.

At the SX in November 2015, we started taking a shorter acceleration of 1.4 seconds, which was the same as that in the FX mode, rather than previous 1.9 seconds. Therefore, the SX cycle time was shortened from 6.0 to 5.52 seconds. This helped the beam power increase from 42 to 44 kW as well as the beam tuning parameters optimization. In January 2018, the beam power was further increased to 51 kW, since we had shorter cycle time to 5.20 seconds with keeping a spill length of 2 seconds [8].

A scenario of the MR to achieve the design beam power of 0.75 MW for the FX, is higher repetition rate operation. The cycle time will be shortened from the present 2.48 seconds to 1.3 seconds by replacing the main magnet power supply system. The hardware upgrades are under construction. The further upgrade plan towards 1.3 MW is under discussion [9].

OPERATION STATISTICS

The performance of accelerators is not only a beam power but also shown as availability. Operation hours, which is defined by the shift-leader assigned time including RF conditioning at the linac, start up and beam study of the accelerators, was 6,448 hours in FY2017 (April 2017 to March 2018). The net user time and availabilities for each experimental facility are summarized in Table 1. The availability of 93% for MLF shows that the linac, the RCS

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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

and the MLF operated favorably.

Figure 6 shows downtime by major subsystems in FY2017. We have had many countermeasures against troubles at the linac in these years: stabilization of cooling water flow, inside cleaning of some SDTL cavities, replacement of old bias power supplies for HVDC. As a result of these, the availability has been improved than that in 2016. But the category of "HVDC", which is not limited with the Power Supply break down, is still concern. We had a 15 hours beam stop due to an insulation break of a high voltage cable to a klystron. Some circuits break in "Others" such as a reference signal generator, timing modules, network modules contributed the downtime. Some of them are deterioration over time.

We had a long downtime at the RCS in April 2016 due to a vacuum leak at one of the ring collimators. We had countermeasures for this trouble [6]. The RCS was rather stable in 2017.

The MR had several troubles in 2016, but thanks to many efforts, the reliability improved. One exception was an ESS trouble in "SlowExt" category. At the beam tuning on April 26, 2017, some ribbons in the ESS were cut and made a short circuit between the electrodes. We guess that the beam core becomes larger by a transverse instability and hit the ribbons. We have considered several countermeasures to avoid the instability and also hardware improvement against a short circuit. Beam tuning and Hadron user operation resumed about one month after the incident, on May 24 and June 1, respectively.

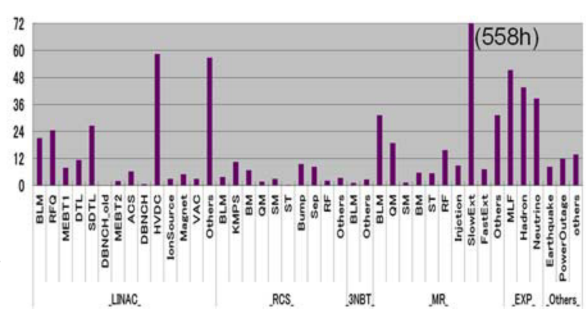

Figure 6: Downtime statistics in hours by components in FY 2017.

SUMMARY

We have had many hardware upgrades/modifications and beam commissioning to improve the performance. The linac and the RCS provide beams to the MLF. After the troubles of the neutron production targets at 500 kW, we reduced a beam power to 150 - 200 kW. But after the replacement with the new designed target, we increased a power step by step up to 500 kW. High power beam commissioning is anticipated towards the goal of 1 MW before the summer shutdown. The beam powers from the MR has steadily increased. We changed the operation tune for the FX mode and the power of 490 kW has been steadily delivered. The power of 51 kW has been achieved at the SX mode by reducing the cycle time.

In FY 2017, the availability is about 90% or more except for the ESS trouble. The J-PARC started user operation in 2008. Some of the trips have come from aged components.

We still need further study work and hardware treatment for reduction of beam loss and residual radioactivity before the routine operation towards the power goal.

ACKNOWLEDGEMENT

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