PERFORMANCE AND STATUS OF THE J-PARC ACCELERATORS

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Abstract

The J-PARC is a high intensity proton accelerator facility. A 1 MW equivalent beam, which is a design value if we can operate at 25 Hz, has been demonstrated and user operation has been performed at 500 kW from the 3 GeV Rapid Cycling Synchrotron to the neutron and muon experiments. The beam powers for the neutrino experiment and hadron experiments from the 30 GeV Main Ring have been steadily increased by tuning and reducing beam losses. We have experienced many failures and troubles, however, to impede full potential and high availability. In this report, operational performance and status of the J-PARC accelerators 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]. 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 goals of the beam power are 1 MW and 0.75 MW at the MLF and MR-FX, respectively.

STATUS OF LINAC AND RCS

User operation at the MLF by using 3 GeV beam from the RCS started in December 2008. Figure 1 shows a history of the beam power. The beam power at the beginning was low at 5 kW, but has been steadily increased by beam tuning and hardware upgrade. Some examples are the linac energy upgrade from 181 MeV to 400 MeV in 2013 and linac front end replacement for higher peak current in 2014 [2].

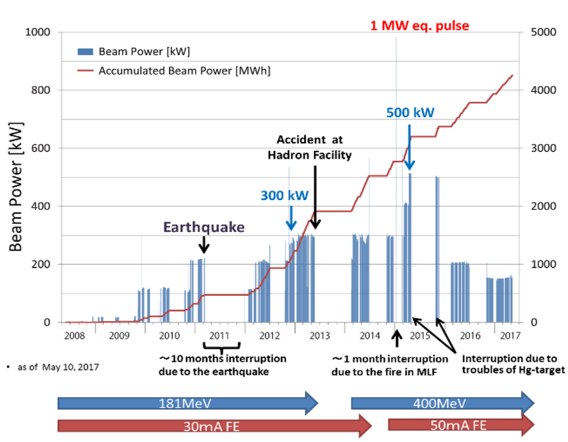

Figure 1: Beam power history for the MLF (by courtesy of the MLF group).

The RCS 1 MW one-shot demonstration was performed in January 2015 [3]. Then we increased beam power for the MLF user operation to 500 kW, but we had neutron production target failures twice. Since then for user operation, we have delivered beam at conservative beam power of 200 or 150 kW to protect the target. To improve the quality of the experiments even at the lower beam power, the linac and the RCS provide one bunch beam instead of two bunches, which makes shorter pulse and some MLF users (i.e. fast-TOF and muon) prefer.

Linac

A 50 mA H^- ion source is one of the essential components to meet our goal. A cesiated RF-driven ion source has been developed and the peak current of >60 mA has been achieved [4]. The operation history of the ion source since September 2015 is shown in Fig. 2. The ion source has successfully provided beams for accelerator study (higher beam current, at about 60 mA) and user operation (long time stable operation) without serious troubles. 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. The increase of the peak beam current helped the MR-FX beam power increase as well as results of the study at the RCS and the MR.

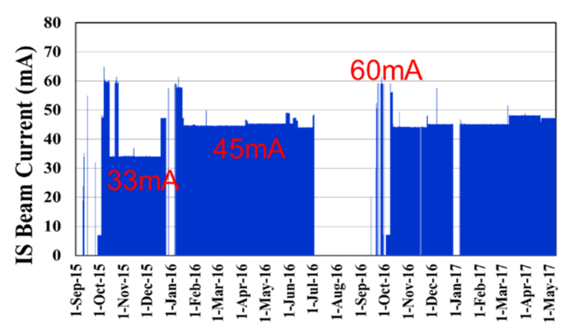

Figure 2: Beam current from the ion source.

Based on the linac study, the intra beam stripping has been identified as a dominant beam loss source after 190 MeV region (energy upgraded part). The beam loss reduction is a serious issue for increment of the peak beam current. We are looking for a new operation point with a relaxed transverse focusing to mitigate the beam loss.

RCS

The beam loss at the first trial of 1 MW was high for user operation level. It was interpreted as a longitudinal beam loss. Consolidation of the anode power supply for

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the RF system is underway to take enough compensation for the beam loading. The next issue for further beam loss reduction was to minimize the foil scattering at the injection. To reduce the number of foil hits and loss, we have studied and optimized foil sizes and painting parameters [5].

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. We have studied and taken optimized parameters for the painting for MLF and MR [6].

The extraction pulse kicker is the most dominant impedance source in the RCS. It causes a horizontal beam instability depending on operational parameters. We suppressed the emittance growth for the first 6 msec after the injection with DC sextupole correction, but the beam instability was enhanced after 10 msec as shown in the top of Fig. 3. A practical way to solve this instability is to dynamically manipulate chromaticity during acceleration. In order to realize this, we improved the sextupole magnet power supply to the bipolar type. The experiment confirmed that the beam instability is sufficiently damped as shown in the bottom of Fig. 3 [7].

The RCS beam commissioning is steadily progressing towards a routine operation at 1 MW for the MLF and 0.75 MW for the MR.

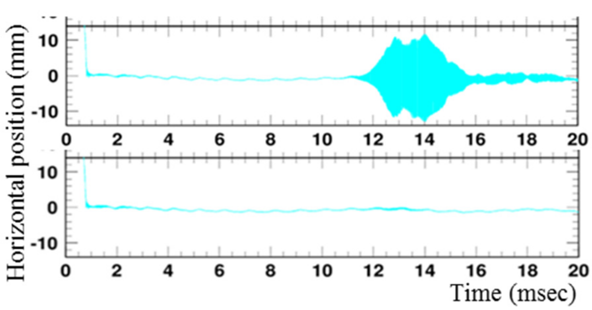

Figure 3: Horizontal beam positions with chromaticity correction with DC sextupole (top) and AC sextupole (bottom) conditions.

STATUS OF MR

A beam power history from the MR is shown in Fig. 4. There are two groups of beam power levels, FX and SX modes. Eight bunches of beams are injected to MR during the injection period of 0.13 second. The acceleration takes 1.4 seconds. The accelerated protons are extracted in one turn and the cycle time is 2.48 seconds for the FX mode.

At the SX in November 2015, we started taking a shorter acceleration of 1.4 seconds, which is the same as that in the FX mode, rather than previous 1.9 seconds. The SX cycle time was shortened from 6.0 to 5.52 seconds. This helped the beam power increase as well as the simplification of the SX beam tuning. As of April 2017, MR provides beam at 42 kW for months and at 44 kW in a week duration.

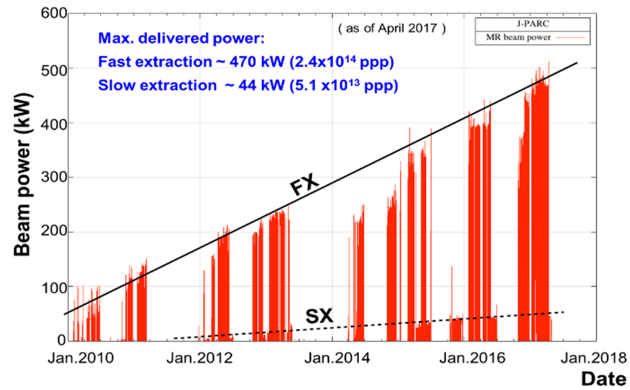

Figure 4: Beam power history for the MR.

We have explored the possibility of operation with the new betatron tunes [8]. The old operation tune was (22.40, 20.75), where we observed a serious linear coupling sum resonance of $\nu_x + \nu_y = 43$ within the space charge tune spread as shown in the left of Fig. 5. We have searched the area of 21.0 ~ 21.5 for both horizontal and vertical tunes, where there are no linear coupling sum resonances. Detail search was done and the tune setting of (21.35, 21.43) was the best for the beam survival as shown in the right of Fig. 5. 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. Finally, the beam loss was mitigated and the new tuning point was available for user operation. The operation tune has been changed from (22.40, 20.75) to (21.35, 21.45) and we successfully ramp up the power from 420 to 470 kW to the NU.

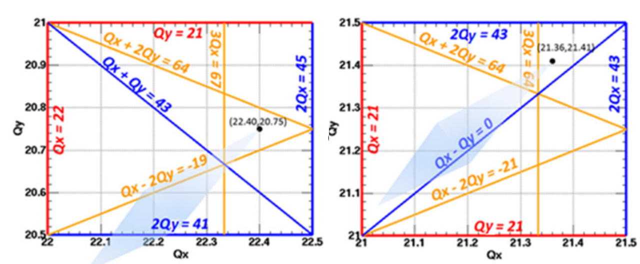

Figure 5: Space charge tune spread for the tunes of (22.40, 20.75) (left, beam power <420kW) and (21.35, 21.45) (right, beam power at 470kW).

Upgrade of MR

A scenario of the MR to achieve the design beam power of 0.75 MW for the FX, is higher repetition rate operation [9]. The cycle time will be shortened from the present 2.48 seconds to 1.3 seconds by replacing the main magnet power supplies, the RF cavities, etc. The first prototype power supply was installed and in operation. Based on the successful result of this, a higher scale power supply for the bending magnets is under construction. And also, construction of three new buildings to house new power supply system is underway.

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The RF cavities with high impedance cores, FT3L, have already replaced with the old ones and they have been used for routine operation. Nine sets of new cavities will generate higher RF voltage for faster cycle operation. Additional collimators are being considered to upgrade for the total power capability of 3.5 kW. The kicker magnets for injection and extraction are being improved and the septum magnets for injection [10] and extraction [11] are upgraded.

OPERATION STATISTICS

The performance of accelerators is not only shown as a beam power but reliability. 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 6,350 hours in FY2016 (April 2016 to March 2017). The net user operation hours and the beam availability rate of each experimental facility are as follows: 3,483 hours (93%) for MLF; 2,726 hours (77%) for NU; and 515 hours (84%) for HD. These statistics show that the linac, RCS and MLF operated favorably. Figure 6 shows downtime by major subsystems in FY2016.

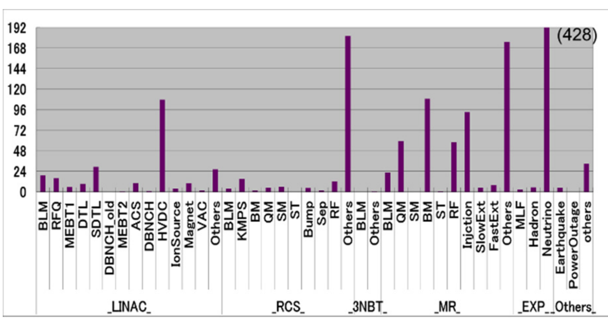

Figure 6: Downtime statistics in hours by components in FY 2016.

The linac was rather stable, and the highest cause was a group of HVDC (High Voltage DC power supply for klystrons). Several defects in this group comprised of a klystron failure, HV insulation breakdown, and switching devices and module failures. The linac uses twenty 324-MHz klystrons and twenty-five 972-MHz klystrons. The operation hours of 324 MHz klystrons is shown in Fig. 7, while 972 MHz klystrons have shorter operation hours after 400 MeV upgrade. Most of the operation hour is over 50,000 from the beginning of linac operation and some shorter times are replaced ones. We have seven failed klystrons and average lifetime is 38,600 hours (σ = 10,300). When klystrons approach the end of life, number of discharges increases and reliability goes down. We suppose if any klystron over 50,000 hours comes to the end of life. It is important to take strategic procurement of spares to keep operation reliability.

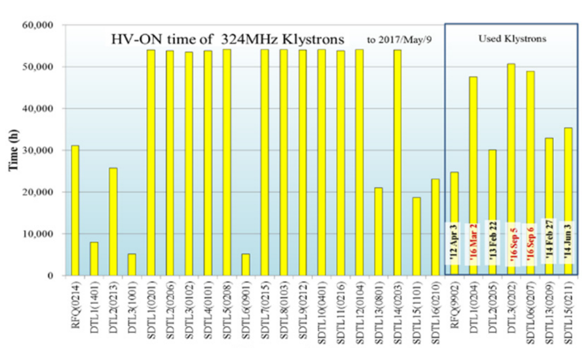

Figure 7: Operation hours of 324 MHz klystrons. Some of them (for DTL1, DTL3 and SDTL6) are rather new just after the replacement in spring or summer 2016.

The RCS was generally stable except for one event of vacuum leak at the collimator in April 2016. This is in the "RCS-Others" group in Fig. 6. The cause was a malfunction of control system and unexpected motions of some collimator blocks broke the vacuum. The leaked collimator unit was replaced with a temporary spare duct and resumed operation. It took about a week to recover. The temporary duct will be replaced with a proper (with shield) one in 2018.

There were several a-few-day-long trips at the MR. We had a water leakage from a coil at the bending magnet (group in "MR-BM"). And a small animal entered to an outdoor transformer in May and it stopped for 6 days (group in "MR-Others"). Some of the troubles came from new components for the performance upgrade (higher repetition rate power supplies). We took care of them, mostly grounding for noise suppression, and better reliability is expected in this year.

SUMMARY

We have had many hardware upgrades and beam commissioning to improve the performance as well as user operations. The linac and RCS provides beams to demonstrate a 1 MW equivalent beam. For user operation, however, we have experienced the MLF target troubles twice at 500 kW and we are taking conservative beam power of 150 - 200 kW for the time being. The high power beam commissioning is pending by the time of consolidation of targets. The MR has steadily increased the beam power at the FX and SX modes.

There are several sources of downtimes. We encountered several days beam stop troubles such as the vacuum leak at the RCS, the small animal entrance and the coil trouble at the MR. These affected the availability. Some of the causes came from aged components and some came from new components. We have treated the causes one by one like a debugging process and we expect better availability after that.

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

ACKNOWLEDGEMENT

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