

# RECENT STATUS OF J-PARC RAPID CYCLING SYNCHROTRON

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## Abstract

The 3 GeV rapid cycling synchrotron (RCS) at the Japan Proton Accelerator Research Complex (J-PARC) provides more than 400 kW beams to the Material and Life Science Facility (MLF) and Main Ring (MR). In such a high-intensity hadron accelerator, even losing less than 0.1% of the beam can cause many problems. Such lost protons can cause serious radio-activation and accelerator component malfunctions. Therefore, we have conducted a beam study to achieve high-power operation. In addition, we have also maintained the accelerator components to enable stable operation. This paper reports the status of the J-PARC RCS over the last two years.

## INTRODUCTION

The 3 GeV rapid cycling synchrotron (RCS) at the Japan Proton Accelerator Research Complex (J-PARC) was constructed to supply 1 MW, high-power proton beams to the Main Ring (MR) synchrotron and Material and Life Science Experimental Facility (MLF) [1].

In proton accelerators, the most important issue is radio-activation caused by beam loss. High beam losses increase the failure rates of accelerator components and worker radiation doses during maintenance work. The output beam power then has to be limited to keep the exposure dose for the workers by the residual dose within acceptable tolerances. It is therefore important to reduce beam losses to achieve high-power (e.g., 1 MW) beam acceleration.

We have thus continued the beam study to reduce beam losses, and the RCS beam power for neutron targets has now reached 500 kW. On the other hand, the RCS simultaneously delivers the proton beam to the MR, and since this requires the beam with smaller emittance than the MLF, we have continued to investigate beam conditions that are suitable for both facilities. We have improved and developed the components needed to satisfy these requirements and have been able to establish both operation conditions.

## RCS COMPONENT IMPROVEMENTS

A wider beam profile is required to reduce the residual doses in the RCS and the peak charge density of injected beam for the neutron target. We achieved this by correcting the betatron oscillation resonance and extending the transverse injection painting region [2, 3]. On the contrary, the MR requires beam with smaller emittance to obtain smaller beam halo and thus mitigate beam losses.

Our study results indicated that the following two improvements were needed: introducing a bipolar sextupole excitation system and extending the duration of the power supply system for the correction quadrupole magnet.

The smaller emittance required by the MR enhanced beam instability. A better way to obtain smaller emittance without beam instability is to correct the chromaticity in the first phase of the acceleration cycle and to enhance it in the middle and final phases. This suppresses not only beam emittance growth during the injection period but also beam instability. In summer 2016, we improved old power supply system of the sextupole magnet, and tested its ability to achieve such chromaticity control. The results show that the new system can provide good instability suppression (see Fig. 1) [4].

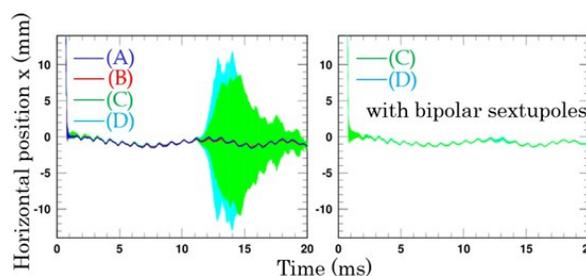


Figure 1: Horizontal beam position, measured over the entire 20 ms acceleration period [4].

After introducing the bipolar sextupole excitation system, we continued further beam study with an aim of achieving high-intensity, low-emittance beam with less beam halo in the MR. We found that the additional emittance growth occurred during the first 6 ms after injection, and that this loss could be reduced by manipulating the betatron tune. However, since we did not have any knob to switch the betatron tune between the MLF and MR operations, it was fixed to suit the MLF.

To optimize the beam operations for both the MR and MLF, we improved the correction quadrupole magnet system. This system was prepared to compensate for the edge focus of the injection bump magnets during injection and correct the beta modulation, enabling large transverse painting for the MLF.

We considered that this system could also be utilized to change the tune pulse-by-pulse, but the excitation duration of the original power supply system was not long enough. During the 2017 summer shutdown, we extended its duration from a few milliseconds to more than ten, enabling us to partially change the operation tunes. We were finally able to obtain emittances of about  $4.5\pi$  mm mrad in both the horizontal and vertical phase spaces.

## OPERATIONAL STATUS

During operation in 2015, cooling water leaks occurred twice in the neutron target at a beam power of 500 kW. After the second incident, the RCS output power to the MLF was limited to 200 kW to protect the target, due to the lack

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of a spare target. Since a new target was not available until summer 2017, the output power was also reduced to 150 kW after the summer 2016 shutdown period. After replacing the neutron target with a new one, the power of the beam to the MLF was gradually increased from 300 to 500 kW. Meanwhile, the MR output power was steadily increased as MR commissioning progressed. Figure 2 shows the change in RCS output power with respect to time.

During a short maintenance period in April 2016, one of the ring collimators broke down. A fault in the control system caused a vacuum leak in the fifth secondary collimator chamber. Since numerical simulation results indicated that the beam loss would still be acceptable without this collimator, we installed a spare straight duct instead of repairing the broken collimator.

This shortened the repair period by 8 days, but the accident meant that RCS availability was lower than that in the previous year. Over the course of the year, the total operating time of the MLF was approximately 3484 h, excluding commissioning and start-up time, with approximately 257 h of downtime, giving an availability of about 93%. The collimator failure was the most significant cause of this downtime. In summer 2016, the temporary duct was replaced by a new, fixed type collimator.

In contrast, RCS operation was quite stable in 2017. The total operating time of the MLF was 5348 h, with only 42 h of downtime due to RCS issues, giving an availability of more than 99%.

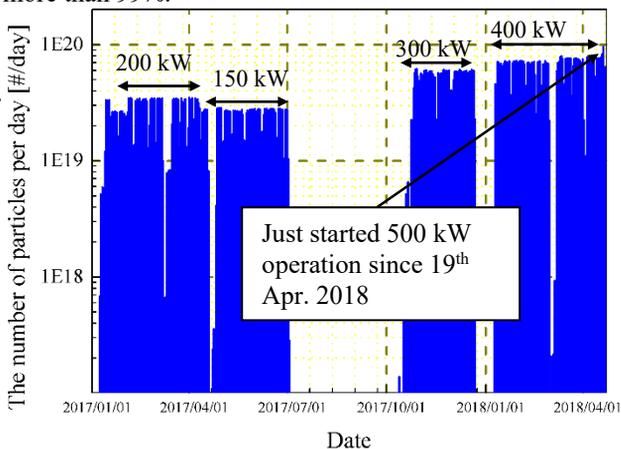


Figure 2: Changes in RCS output power over time.

## RESIDUAL DOSE DISTRIBUTION AND EXPOSURE DURING MAINTENANCE

Since the output power to the MLF was initially limited, the residual doses in the RCS were relatively small until summer 2017. A total of 41 workers were exposed to a dose of more than 0.01 mSv during the summer 2016 shutdown period, as shown in Table 1, and their collective dose was only 1.99 man-mSv. Only three workers were exposed to residual doses of more than 0.1 mSv, and the maximum dose received by any one worker was 0.19 mSv.

Although the number of workers who were exposed to a dose of more than 0.01 mSv increased in comparison with the previous fiscal year, the collective dose was significantly lower. This can be attributed to a foil maintenance

procedure being established, low output power to the MLF, and no serious work being conducted near the injection area. The maximum dose incurred while replacing the broken collimator with the temporary duct was 0.6 mSv, and that from replacing the duct with the new collimator was only 0.1 mSv. This was due to thorough preparation for the work, having sufficient cooling time, rotating the workers, and local shielding.

Table 2 summarizes the doses received by the workers during the summer 2017 shutdown period. A total of 41 workers were exposed to doses of more than 0.01 mSv, and their collective dose was 1.08 man-mSv. Only five workers were exposed to the residual doses of more than 0.1 mSv, and the maximum dose received by any one worker was 0.07 mSv. Both the collective and maximum doses were significantly reduced. This can be attributed to the foil maintenance procedure being established, low output power to the MLF, and no serious work being conducted near the injection area.

Table 1: Summary of Worker Radiation Doses During the Summer 2016 Shutdown Period

Residual dose [mSv]	Number of workers
0.01–0.05	28
0.06–0.1	10
0.11–0.2	3

Table 2: Summary of Worker Radiation Doses During the Summer 2017 Shutdown Period

Residual dose [mSv]	Number of workers
0.01–0.05	36
0.06–0.1	5

During the summer 2017 shutdown, the neutron target was replaced and the beam power to the MLF gradually increased from 300 to 500 kW. For beam powers of less than 500 kW, the RCS was operated in one-bunch mode. In this mode, only one of the two RF buckets was filled by the injection beam from the linac. Since RCS is designed to generate 1 MW beams in two-bunch mode, where 400 kW one-bunch beam corresponds to 800 kW two-bunch beams from a beam dynamics viewpoint. Doing this therefore enabled us to assess whether the RCS had the potential to operate at an output power of 800 kW.

The residual doses around the RCS increased in proportion to the output power until the end of 2017, when the 300 kW operation ended. However, when the output was increased to 400 kW in January 2018, we found higher beam losses than expected and the residual dose in the RCS tunnel was higher than ever before (see Fig. 3).

In particular, we found that highest dose was 8 mSv/h, just outside the injection branch where no significant doses had been observed before. After investigation, we found that the reference clock of the linac timing system had malfunctioned, making the energy of the injection beam unstable. Correcting this fault stabilized the beam and the resid-

ual dose fell by more than half. Even so, the losses still appeared to be higher in comparison with the preliminary

tests conducted in 2017. We will continue the beam study to identify the source of these increased losses.

## 400kW for MLF

Measurement: 7th Feb. after 4 hr cooling

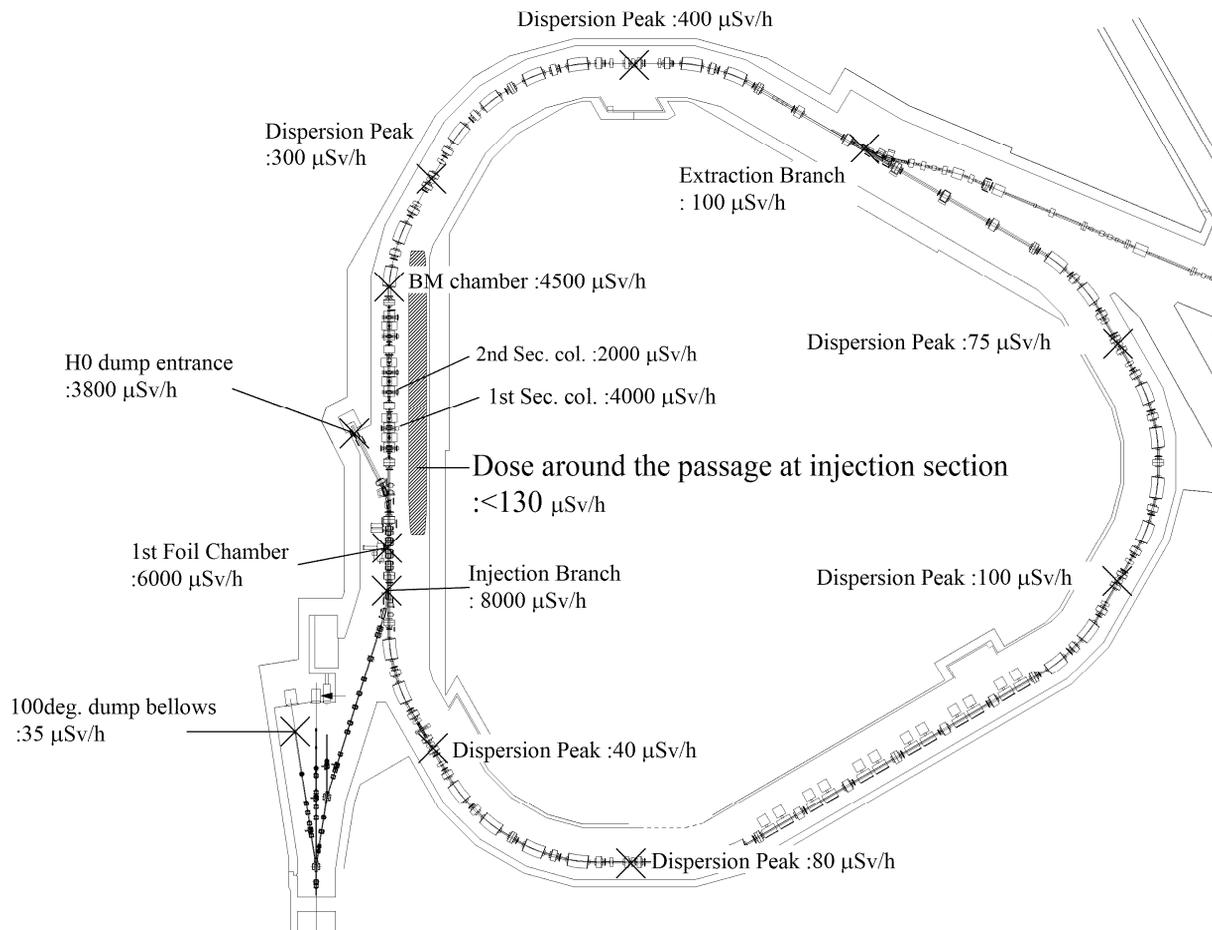


Figure 3: RCS residual dose distribution after operation at 400 kW.

## SUMMARY

RCS user operation continues to be almost stable. Currently,  $4.4 \times 10^{13}$  ppp beam, which are equivalent to 500 kW, are delivered to the MLF in two-bunch mode and  $6.2 \times 10^{13}$  ppp beam, which are equivalent to 750 kW at 25 Hz operation, are delivered to the MR. The output power will be further increased toward 1 MW step-by-step by carefully monitoring the status of the neutron target and beam loss.

We will continue the study, aiming not only to reduce losses further and generate smaller-emittance beam but also to increase output power further to 1.5 MW.

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