RECENT STATUS OF J-PARC RAPID CYCLING SYNCHROTRON

K. Yamamoto†,
Accelerator Division, J-PARC Center, Japan Atomic Energy Agency (JAEA), Tokai-mura, Japan

Abstract

The 3 GeV rapid cycling synchrotron at the Japan Proton Accelerator Research Complex supplies beams with an power of more than 500 kW to the Material and Life Science Facility and the main ring synchrotron. In such a high-intensity hadron accelerator, losing less than 0.1% of the beam can cause several problems. Such lost protons can cause serious radioactivation and accelerator component malfunctions. Therefore, we have been continuing a beam study to achieve high-power operation. In addition, we have also improved and maintained the accelerator components, enabling a stable operation. Through these efforts, we established a 1-MW user operation in summer of 2020. This paper reports the status of the 3 GeV synchrotron over the last two years.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) was constructed to deliver very high-intensity proton beams for various physics programs. The 3 GeV rapid cycling synchrotron (RCS) was constructed to supply high-power proton beams to the main ring (MR) synchrotron and the Material and Life Science Experimental Facility (MLF) [1].

The most important problem in proton accelerators is radioactivation by beam losses. Therefore, we have continued the beam study and hardware improvements to reduce the beam losses. Currently, RCS delivers beams with an power of more than 500 kW for the neutron target. Simultaneously, RCS delivers the proton beam to the MR. Since the MR requires a beam with a smaller emittance than that for the MLF, we have continued to investigate the beam conditions that are suitable for both facilities. We continually conducted studies on the beam, improvement and development of the accelerator components, to significantly improve the capabilities and stability of the synchrotron.

IMPROVEMENT OF THE ACCELERATOR COMPONENTS IN RCS

Feedback System of Low-Level Radio Frequency (LLRF)

In RCS, the mitigation of the wake voltage in the accelerating cavity is essential for achieving a stable acceleration of the high-intensity beam. The radio frequency (RF) feedforward method had been employed in the original low-level RF (LLRF) control system [2]; however, its performance deteriorates at the beam power of 1 MW [3].

Therefore, a multiharmonic vector RF voltage control feedback implemented in the new LLRF control system was deployed in 2019 [4, 5]. The feedback system was tested using a 1-MW equivalent beam. The test result showed that the wake voltage due to the high beam cur-rent was well minimized by the new feedback system [6]. However, the beam loss in RCS was increased.

We investigated this occurrence with numerical simulations, which indicated that the wake voltage serves to increase the bunching factor. In the former feedforward system, the wake voltage could not be compensated completely. However, the remaining wake voltage shook the particle motion in the longitudinal phase space, resulting in flattening of the bunch. Therefore, the complete compensation of the wake voltage by the new feedback system caused a decrease in the bunching factor and increase in beam loss. To recover from this situation, the duration of the second harmonic RF voltage application was extended. Consequently, the beam loss was recovered to the same level as that of the feedforward system.

Radiation Shielding around Injection Chamber

As reported in previous proceedings [7], the major activated point is the injection foil chamber. The residual dose value on the surface of the injection foil chamber was about 10 mSv/h at 4 h after the halt of the beam supply, and the worker dose around the injection point was quite high compared to those at other regions. Therefore, we considered the measures of the radioactivation of the injection region to achieve an improved high-intensity operation. First, we considered changing the shape and location of the magnets near the injection point to install a permanent radiation shielding around the injection foil chamber [8]. However, Monte Carlo simulation results indicated that a permanent radiation shielding would not effectively reduce the activation because the radiation shielding itself is activated [9]. Therefore, we changed our policy to prepare a temporary shielding under the present configuration. Two 10-ton cranes were present in the accelerator tunnel, and we moved and installed the temporary shielding using those cranes. However, since the original base of the foil chamber could not withstand the weight of the temporary shielding, we needed to re-placed it with a new one. We designed a new base and temporary shielding that can be attached using a crane easily. The replacement work with the new base was carried out in the summer shutdown period of 2020. Since a large amount of radiation exposure was expected in this work, a detailed work plan was prepared. The work plan sheet included a work process, the working condition, job descriptions, positions, and dose rate. We evaluated the worker dose using these data and controlled the personnel doses so that it would not be concentrated on one person. Thanks to these preparations, the work was completed with the doses of all workers below the expected

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† kazami@post.j-parc.jp

value. Pictures of the injection point before and after the installation of the shielding are shown in Fig. 1.

Finally, we investigated the effect of this new temporary shielding. Figure 2 shows the measurement results of the dose rate near the foil chamber. The result indicated that the shielding worked well.

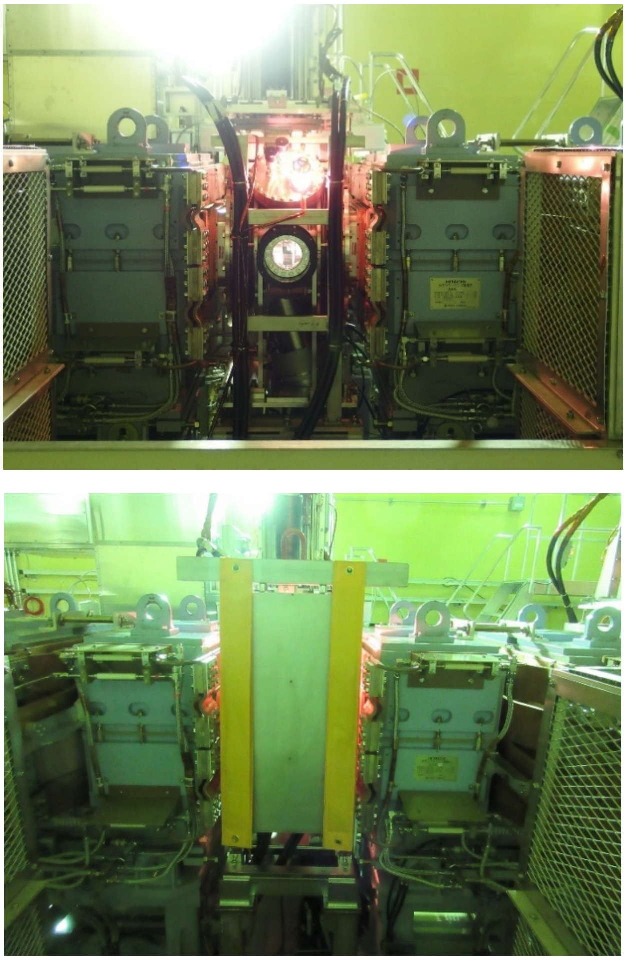

Figure 1: Injection point of RCS before (upper) and after (lower) the installation of temporary shielding.

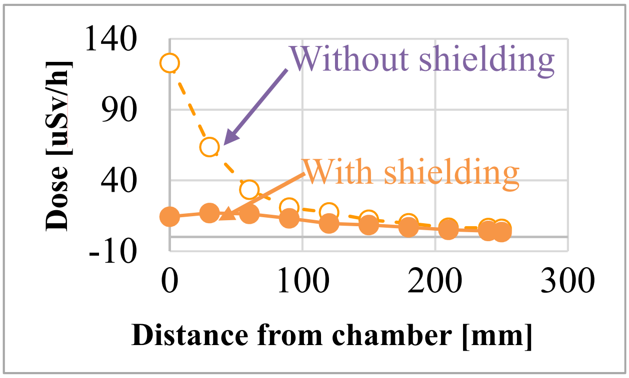

Figure 2: Dose value near the foil chamber.

OPERATIONAL STATUS

The operational status of the RCS was quite stable in JFY 2019. A beam with an power of more than 500 kW beam was delivered to the MLF. The operation time for the MLF over the year was approximately 2775 h, excluding the commissioning time, while the downtime was approximately 27 h. The availability for MLF was evaluated to be 99.0% based on these durations. For the neutrino and hadron users, the availabilities of RCS were almost the same as those in the MLF case, and the values were approximately 99%. In JFY 2020, the RCS continuously maintained its stability, and the beam power for the MLF was increased to 600 kW. However, the operation of all the J-PARC facilities was suspended because of the first wave of the COVID-19 pandemic in Japan. Other-wise, the RCS delivered a highly stable beam, and the availability was approximately 98.5%. Figure 3 shows the output power of the RCS in the last two years. In April 2021, the beam power for the MLF was increased to 700 kW.

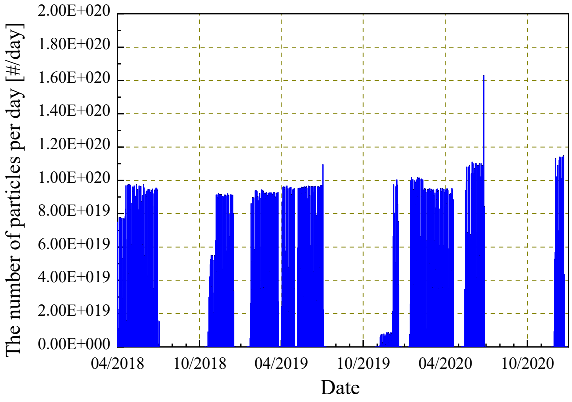

Figure 3: Change in RCS output power with time.

1-MW TRIAL

We demonstrated the 1-MW, 10 h continuous operation at the beginning of July 2019 and attempted a two-day user operation at the end of June 2020.

During the 1-MW continuous operation in 2019, no problem was encountered. Only three beam stops occurred because of the interlock of the linac RF trip, and we successfully recovered the operation in each case, immediately.

For the 1-MW operation in June 2020, two failures occurred in the capacitor and vacuum tube in the final stage amplifier of the RF cavity immediately after the 1-MW operation started. The recovery took approximately 12 h; thus, the 1-MW operation time was reduced to 36 h. We hypothesize that these failures were mainly caused by the aged deterioration, and the 1 MW beam power did not affect the deteriorations directly.

Contrarily, it was found that when the outside temperature increases, the supply temperature of the cooling water becomes uncontrollable and increases. This induces the temperature interlock of the vacuum tube in the RF final stage amplifier. We need to improve the RF and/or cooling water system to establish a stable 1-MW operation during summer.

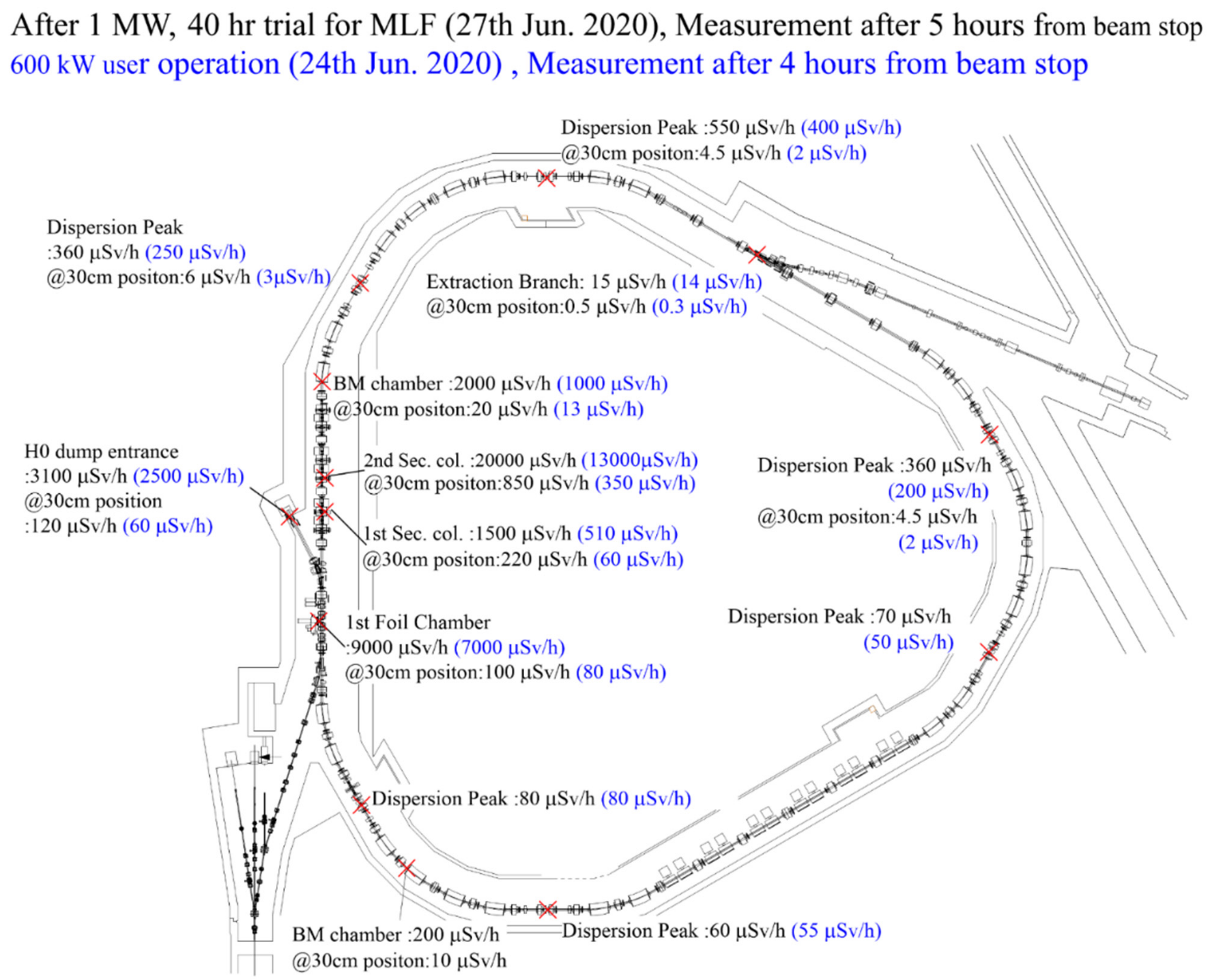

Figure 4: RCS residual dose distribution after 600-kW and 1-MW user operations.

After the 1-MW user operation in 2020, we measured the residual dose values around the accelerator components and found that were low enough to accept and same as the results of the previous year. Considering the beam loss, it is still possible to deliver the 1-MW beam for users. Figure 4 shows the residual dose values in the RCS after the 600 kW and 1 MW operations.

CONCLUSIONS

RCS has almost achieved a continuous, stable user operation. Presently, it delivers a 5.9e13 ppp (700 kW) beam to the MLF and 6.7e13 ppp (corresponding to a 515 kW beam of MR) beam to the MR. These values will be increased steadily with careful monitoring of the neutron target status and beam loss.

We attempted a 1-MW continuous operation in 2019 and 2020. The 1-MW continuous operation exhibited the problem of poor cooling water performance. To establish a stable 1-MW operation in all seasons, we shall consider improving the RF and cooling water systems.

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