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STATUS OF THE J-PARC 3 GeV RCS

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Abstract

Beam power of routine operation of the J-PARC rapid cycling synchrotron (RCS) increased gradually for the MLF user operation, beam power of 400 kW was achieved on 10th March, and 500 kW user operation has been stably performed from 14th April this year. Beam studies were also performed to demonstrate the capability of the RCS to operate at powers in excess of 1 MW. The study produced a beam intensity of 8.41×10^{13} protons during short time, an intensity equivalent to 1.01 MW operation on 10th January 2015.

INTRODUCTION

The J-PARC rapid cycling synchrotron (RCS) has been operated for the neutron and MLF users program from December 23rd, 2008. The RCS operations not only in support of the MLF but also were providing beam for the MR user program (Hadron experiment and/or Neutrino experiment). The RCS has been deliver stable beam of beam power of 300 kW to the MLS and the MR until December 2013 with the linac energy of 181 MeV [1]. To achieve the nominal performance of 1 MW at the RCS and 0.75 MW at the MR, the full energy (400 MeV) and higher peak beam current of the linac is necessary for the J-PARC facility. J-PARC has been done upgrade their linac from 181 MeV to 400 MeV with new ACS (annular coupled structure) linca, and user operation started from February 2014[2].

Beam injection energy of the RCS in J-PARC was increased from 181 MeV to 400 MeV, and user operation with beam energy of 300 kW for both the MLF and the MR was performed with high availability from February to Jun in 2014. Beam losses during beam injection period was decreased by reduction of space charge effect due to increase of beam injection energy. Since an ion source and an RFQ of the LINAC are replaced to realize 1 MW beam power at the RCS in summer maintenance period, injection beam peak current was increased from 30 mA to 50 mA. User operation was restarted from November with beam power of 300 kW. The beam power for user operation will be gradually increased after getting radiation safety permission from government. High intensity beam study was also performed and it was successfully to accelerate beam of 1MW equivalent with small beam losses. In this beam study it was cleared issues to realize 1MW routine operation in the RCS. Status of user operation and issues to realize high power routine operation in the RCS are presented in this paper.

ROUTINE OPERATION FOR USERS

The RCS could be delivered beam whose power was 300 kW to both the MLF and the MR for their user operation with an average availability of more than 95 % before the linac energy upgrade. Figure 1 shows output beam power and availability of the RCS from February 2014 to January 2015. Summer maintenance period is usually three months (from July to September), but it was four months last summer for replacement of front-end (ion source and RFQ) of LINAC. Beam studies were performed in spare moments from routine operation in the end of June, and end of December and middle of January which are sighed (1) and (2), respectively in Fig. 1. User operation resumed from 17th February 2014 with 110 kW beam only for the MLF after the linac beam energy upgrade (400MeV injection). The beam power gradually increased, and then beam power achieved 300 kW for the MLF users in 27th February 2014. Since the MR started user operation for neutrino experiment from middle of May, the RCS also started to deliver beam to both the MLF and the MR with beam power of 300 kW.

Beam power was limited 300 kW for the MLF due to government permission of radiation safety, but it was possible to be 1 MW beam routine operation at the RCS from December 2014 because we could get the permission from government. Beam power increased gradually for the MLF user operation, beam power of 400 kW was achieved on 10th March, and 500 kW user operation has been stably performed from 14th April this year. The beam power will be increased to 600 kW in the middle of May.

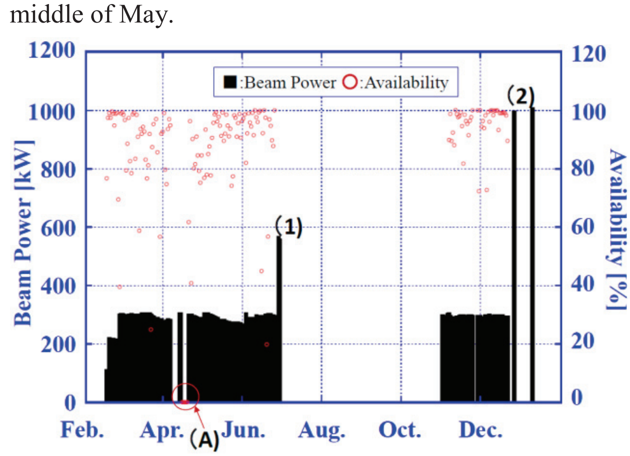

Figure 1: Output beam power and availability of the RCS from February 2014 to January 2015. Black line shows beam power and read circle shows availability. Beam studies were performed at the number (1) and (2) shown in this figure. Availability was zero at period of (A) shown in this figure due to failure of an oil cooling pump in the bending magnet choke transformer.

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The availability of the RCS was not so good before summer maintenance. Mainly two causes of machine troubles, one was failure of an oil cooling pump in the bending magnet choke transformer and down time was about 110 hours, the other was newly installed power supply for injection bump magnets. Total stop time was about 171 hours during one year, and almost 95% was occurred before summer maintenance. After restart of user operation from November, the RCS could be continue to be stable user operation.

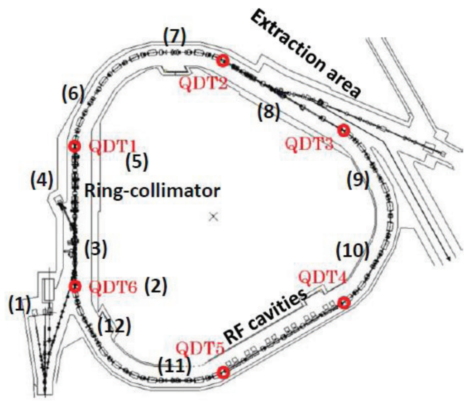

Figure 2: Residual does measurement points and new correction magnets installation points at RCS.

(1)100-degree dump, (2)injection branch, (3)1st charge exchange foil, (4)H^0 dump, (5)entrance of 1st arc at downstream of ring collimator, (6) Dispersion peak point, (7) Dispersion peak point, (8) Extraction septum magnet #3, (9) Dispersion peak point, (10) Dispersion peak point, (11) Dispersion peak point, (12) Dispersion peak point , and QDT1-6 : new correction magnets

The residual dose distributions of the RCS were measured several times during this one year. Residual does measurement points are shown in Fig. 2. These points shown in this figure were that the radiation level was more than 10 μSv/h. These values, typically measured on 1st July 2014 and 1st April 2015, were summarized in table 1. Three weeks user operation with beam power of 300 kW has been performed and high intensity beam study for two days was done on 1st July 2014, and the residual does was measured after four hours from beam stop. Two weeks user operation with beam power of 400 kW beam has been performed from 18th March to 1st April 2015, and the residual does was measured after four hours from beam stop. All values described in table 1 were residual does measured on contact each device. Residual does of beam dump (measurement point (1)) was very big in spite of temporary use. The reason why such a high activation was use of high residual material (thick nickel, thickness of 10mm) for vacuum window. This window was replaced with low activation material (thin titanium, thickness of 0.3mm). Residual does of the vacuum chamber of the 1st charge exchange foil (measurement point (3)) was huge due to neutrons which were produced by the interaction between foil and injection/circulation particles. Since this activation should limit beam power of the RCS, it is key issue to reduce the number of particles pass through the foil.

Table 1: Residual Does Measured on 1st July 2014 and 1st April 2015

Measurement point	Residual does on contact [μSv/h]	
	1st July 2014	1st April 2015
(1)	8000	Not measured
(2)	2200	6000
(3)	3300	15000
(4)	900	2100
(5)	170	1100
(6)	220	110
(7)	60	300
(8)	<10	40
(9)	<10	150
(10)	<10	80
(11)	<10	70
(12)	<10	110

MAINTENANCE AND IMPROVEMENTS

Several kinds of maintenance and improvements were performed during maintenance period [3]. The detail of typical progresses and exposure dose during maintenance period are described in this section.

1) Improvement of beam transport line

There was very big residual does near beam dump which was installed in beam transport line used for only the linac beam tuning now as described last section. Since this dump will be used not only for the linac beam tuning but also for shaping of injection beam from the linac to the RCS, we improved beam transport line near the beam dump as shown in Fig. 3. Thick vacuum window was replace with new vacuum window made by thin titanium covered with radiation shield. Rail was newly installed for moving and transporting this vacuum window for maintenance. Current transformer and wire scan monitor were installed to measure beam current and shape with high resolution.

2) Installation of correction quadrupole magnets

It is key issue to reduce the number of particles pass through the foil as described last section. The large transverse painting is one of candidate to realize it. It is difficult the reason why the beta function beating excites various random betatron resonances through a distortion of the lattice super periodicity, making the extra beam loss at present when performing large transverse painting[4]. To correct for the beta function beating

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caused by the edge focus of the injection bump magnets, newly six correction quadrupole magnets were installed in tunnel whose positions were shown in Fig. 3.

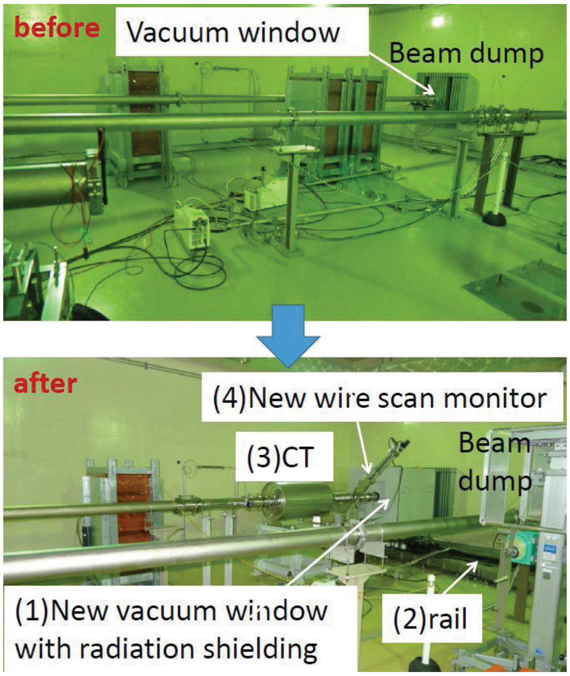

Figure 3: Pictures of beam transport line near beam dump (we call 100-deg beam dump, shown in Fig. 3(1)) before and after improvements in 2014 summer shut down.

3) Exposure dose during maintenance

Exposure does during summer maintenance in 2014 is summarized in table 2. It was 53 workers that the exposure dose of more than 0.01 mSv was detected. Corrective dose was 3.7 mSv, and averaged exposure dose was 0.07 mSv. Maximum exposure dose was 0.31 mSv due to vacuum leakage test in the injection area. It was found that our radiation protection and control for each worker worked well and the RCS tunnel was clean.

Table 2: Summary of Exposure Does During Summer Maintenance in 2014

Exposure does [mSv]	Number of workers
0.01-0.05	31
0.06-0.1	10
0.11-0.2	8
>0.21	4

HIGH POWER BEAM STUDY

Beam studies were also performed to demonstrate the capability of the RCS to operate at powers in excess of 1 MW [5]. The study produced a beam intensity of $8.41\text{x}10^{13}$ protons during short time, an intensity equivalent to 1.01 MW operation on 10th January 2015. Figure 4 shows circulating beam intensity over 20 ms from injection to extraction measured by current transformer. 1 MW operation requires modification of the RF anode power supplies this summer. The 1 MW operation has been enabled by the linac upgrade to 400 MeV and the front-end upgrade to 50 mA. Studies were performed to demonstrate the capability of the RCS to operate at powers in excess of 1 MW. The study results are very promising and suggest producing 1 MW is feasible, even without full amelioration of the RF issues.

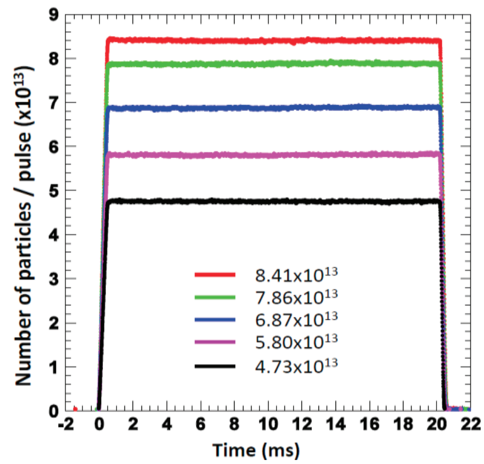

Figure 4: Circulating beam intensity over 20 ms from injection to extraction measured by current transformer (DCCT). Horizontal shows time and vertical is the number of particles per pulse measured by the DCCT.

SUMMARY

Beam power of routine operation of the RCS increased gradually for the MLF user operation, beam power of 500 kW user operation has been performed. The residual dose distributions of the RCS were measured several times after routine operation. Beam studies were also performed to demonstrate the capability of the RCS to operate at powers in excess of 1 MW.

As a result of measurement residual does after routine operation and high power beam studies, it was cleared that 1 MW stable routine operation required as follows,

(1) Modification of the RF anode power supplies to reduce longitudinal beam losses,

(2) Reduction of the number of particles pass through the 1st charge exchange foil to reduce residual does of the vacuum chamber of the foil.

We have to continue to solve those issues, and beam power will be increased gradually aim to the design power of 1 MW.

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