STATUS AND PROGRESS OF THE J-PARC 3 GeV RCS

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Abstract

The J-PARC rapid cycling synchrotron (RCS) has been delivered more than 300kW beam to both the MLF and the MR with high reliability and small beam loss for user operation. To realize simultaneously two kinds of beam shape which are required from the MLF and the MR, two pulse dipole magnets for injection painting were installed in the beam transport line from the Linac to the RCS. It was successful to make two kinds of beam shape with injection painting bump magnets and these added pulse dipole magnets. This injection painting system is used for user operation and works well for reduction of beam losses. Not only user operation but also high power beam test was performed, and beam power of 524kW for 35 second was achieved with low beam loss in the RCS. Almost all beam loss was localized at the ring collimator and the loss rate was about 2% and this was acceptable because design value of the beam loss was 3%. This power corresponds to 1.6MW for 400MeV injection in terms of the Lasslett tune shift. In this high-intensity trial, significant progress toward design output beam power of 1 MW was demonstrated.

INTRODUCTION

The J-PARC 3-GeV rapid cycling synchrotron (RCS) is located in a 348 m long tunnel and will provide proton beam to a high power neutron spallation target as well as to the 50 GeV Main Ring (MR). The RCS beam commissioning in September, 2007 and we accelerated the 181 MeV beam injected from the linac to the designed beam energy of 3 GeV via the RCS, and extracted it to the beam transport to the muon and neutron production targets on October 31st, 2007 [1]. The 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 (Haron experiment and/or Neutrino experiment). The delivered beam power had increased to 220 kW for the MLF and an equivalent 300kW for the MR before the earthquake (March 11th, 2011). The RCS was also severely damaged by the earthquake on March 11th and beam was shut down [2]. The recover work proceeded and thanks to the great efforts of staff members and help of support, the accelerators restarted user operation from January 2012. Beam power smoothly recovered and high power beam could deliver to the MLF and to the MR with more than 300 kW in December 2012. In parallel we are challenging to realize higher beam power operations with better stability. This paper concentrates itself on the RCS status and progress for this one year, including the discussion on the issues of the high-power and stable operation.

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OPERATION FOR USER PROGRAM

User operation resumed from middle of January 2012 with 120 kW beam for the MLF and 300 kW equivalent beam for the MR, respectively after earthquake. The beam power gradually increased, and then beam power achieved 300 kW for the MLF user in 13th January 2013. There was no big trouble and an average availability was about 95 % for this one year. Activation of the RCS components was measured after 24 days user operation with beam power of 300 kW. The activation measured on surface of beam pipe and the point far from one foot after 4 hours from beam stop. There was almost no very high activation area because the highest value was about 1.2 mSv/h on surface of beam pipe close to the beam collimator. When we have to work close to this point, we should take care to reduce exposure and have already prepared for additional radiation shield for maintenance.

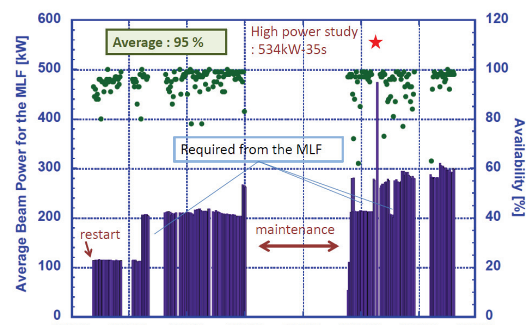

Figure 1: Restoration work at the RCS facility. Left: Repaved road. Right: Straightened capacitors and transformers on re-leveled bases.

PROGRESS

Mainly five progresses for stable and high intensity operation of the RCS during this one year. To reduce beam loss in the RCS and users treatment for leakage field and new painting scheme operation could be done. We have performed a high intensity beam trial of up to 540 kW and also have improved beam simulation code. Preparation for 400 MeV beam injection have continued and new power supplies for painting bump magnet have already been in-service for user operation. The detail of several progresses is described in this section.

1) Treatment for leakage field at the extraction area

One of beam loss source in the RCS is leakage magnetic field from the beam transport line (called the 3NBT line) at the extraction area. To reduce this leakage magnetic field, new vacuum chambers and bellows which were made by permeability alloy (called permalloy) were installed in the straight section of the extraction area. Since these chambers were installed close to steering magnets, the magnetic field strength of the steering magnet was decease in about 30 % caused by the permalloy bellows. However, it was no problem to do COD correction because the power supplies of the steering magnets had sufficient margin to do it. Table 1 shows the value of K0, skew-K0, K1 and skew-K1 estimated by the measurement value of the COD, optics and x-y coupling, respectively before and after installation of those permalloy chambers and bellows. The leakage magnetic field form the 3NBT line could be reduced more than 50 % for dipole, skew dipole and quadrupole components and more than 25 % for skew quadrupole component. These values are sufficient small for realizing much smaller beam loss in the case of 300 kW beam power user operation.

Table 1: Estimation of K0, skew K0, K1 and skew K value before/after installation permalloy chambers and bellows.

	before	after	Estimated by
K0 [mrad]	-1.14	-0.57	COD
Skew K0 [mrad]	-0.12	-0.0057	COD
K1 [m^{-1}]	0.0048	0.0019	Optics
Skew k1 [mrad]	-0.00112	-0.00085	x-y coupling

2) Difference beam shape for the MLF and the MR

There are two difference requirements for the beam of the RCS from the MLF and the MR, because the RCS is power source for the MLF and the injector for the MR. The MLF requires wide and uniform transverse beam distribution on the neutron production target to reduce damage of the target, on the other hand, the MR requires narrow one because the aperture of the beam transport line and the ring are limited. Since difference phase space painting at injection for each beam can meet the requirements, two pulse steering magnets were installed in the transport line form the linac to the RCS. In order to obtain relatively a smaller transverse emittance at extraction, those magnets were designed to perform a smaller injection painting for the MR beam as compared to the MLF one. These two magnets worked well and already in operation for switching to a painting are of 100 π mm mrad for the MR as compared to that of 150 π mm mrad for the MLF beam [3].

3) High intensity beam trial

We have performed a high intensity beam trial of up to 540 kW. Figure shows Signal of the beam current monitor (DCCT) and total beam loss rate in the case of the beam power form 105 kW equivalent to 539 kW equivalent. The beam power was controlled by the pulse length of the injection beam from the Linac. The pulse length was changed form 100 micro second to 500 micro-second. The beam was extracted from the RCS to the beam dump located at the beam transport line to the neutron production target.

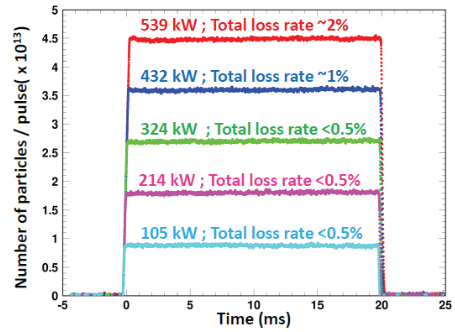

Figure 2: Signal of the beam current monitor (DCCT) and total beam loss rate in the case of the beam power form 105 kW equivalent to 539 kW equivalent. Horizontal is time and vertical is number of particles per pulse. The beam power was controlled by the pulse length of the injection beam from the Linac. The pulse length was changed form 100 micro-sec to 500 micro-sec.

Almost no beam loss was observed from injection to extraction in the case of less than 300 kW equivalent beam power, but obvious beam loss occurred more than 400 kW equivalent beam power [4].

Figure 3 shows beam loss monitor signal for the entire RCS in the case of 212 kW user operations and the case of the beam power form 105 kW equivalent to 539 kW equivalent in the high intensity beam test. Light Blue shows the beam loss distribution in the 105 kW-equiv. beam, Pink lone is in the 214 kW-equiv. beam, Green line is in the324 kW-equiv. beam, Blue line is in the 432 kW-equiv. beam, and Red line is in the 539 kW-equiv. beam in the upper graph. In the user operation the extracted beam from the RCS is transported to the neutron production target, and the beam is transported to the beam dump (called 3NBT dump) located at the beam transport line to the neutron production target in the case of beam test. Almost all beam loss was localized at the ring collimator and the loss rate was about 2% and this was acceptable because design value of the beam loss was 3%.

Beam loss source in the injection area is foil hitting of circulating beam in the ring because the beam loss increases linearly in beam power.

It was found that non-linear beam loss occurred in the collimation area. One of the causes of this beam loss is misalignment of the main component due to the earthquake damage because it was not found the beam loss in the case of 400 kW equivalent beam power before earthquake. Since the other cause of the loss is not cleared, we should continue to beam study and develop beam simulation code to realize the source of beam loss.

We estimated activation in the case of 540kW beam power user operation from data of 200kW operation and summarized in table 2. Activation is estimated 1.5mSv/h in the collimator and injection area, this is acceptable value to perform user operation. This 540 kW beam power corresponds to 1.6MW for 400MeV injection in terms of the Lasslett tune shift. In this high-intensity trial, significant progress toward design output beam power of 1 MW was demonstrated.

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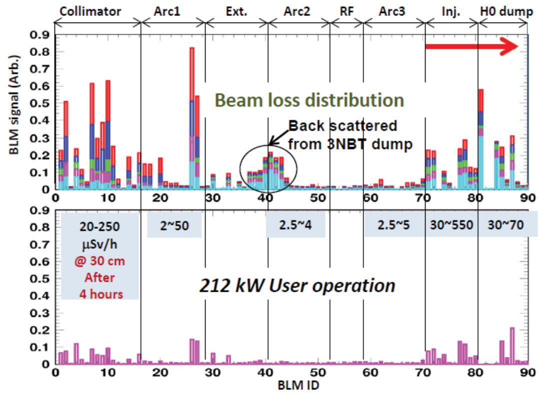

Figure 3: Beam loss monitor signal for the entire RCS in the case of 212 kW user operations and for the case of the beam power form 105 kW equivalent to 539 kW equivalent in the high intensity beam test. Light Blue shows the beam loss distribution in the 105 kW-equiv. beam, Pink is in the 214 kW-equiv. beam, Green is in the324 kW-equiv. beam, Blue is in the 432 kW-equiv. beam, and Red is in the 539 kW-equiv. beam in the upper graph. In the user operation beam is transported to the neutron production target, and the other the beam is transported to the beam dump (3NBT dump) located at the beam transport line to the neutron production target in the case of beam test.

Table 2: Measurement values of activation on the surface of beam pipe after 4 hours beam stop in the case of 212kW user operation for 3 weeks, and estimated activation in the case of 540kW operation.

Power [kW]	Activation [μSv/h]					
	Colli.	Arc1	Arc2	Arc3	Inj.	dump
212	<250	<50	<4	<5	<550	<70
	(measurement)					
540	<1500	<125	<10	<12.5	<1375	<175
	(estimation form 212kW operation)					

ISSUE

Big issue for the RCS is displacement of main magnets caused by last big earthquake because this makes beam loss more than 400 kW beam power. Since realignment of main magnet and other components is essential to realize higher beam power and stable operation, this work will be done in this maintenance period. At same time 400 MeV injection upgrade work should be done. Schedule and main work of maintenance and 400 MeV beam injection upgrade in the RCS in this maintenance period are shown in Fig. 4. User operation continues to end of July and only five months can be used for maintenance and upgrade work because beam study is planed from the first of January 2014.

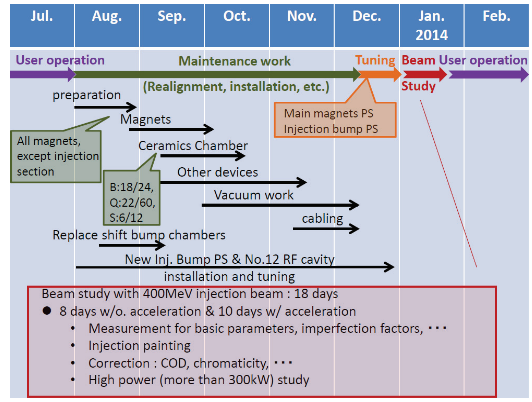

Figure 4: Schedule of maintenance and 400 MeV beam injection upgrade in the RCS in this maintenance period.

To minimize amount of realignment work, we decided that not all components moved to designed regular potions but also minimum components moved to the position which was secured design acceptance 486 π mm mrad. Positions of all ceramics chambers installed in main magnet were measured by laser tracker to measure displacement from the center of the magnet. These data were used for calculation of the beam acceptance, and we assigned components which should be realigned and decides moving range. Almost all components which are main magnets, rf cavity, and extraction magnets have to be moved in the range of 10 mm for horizontal, 3 mm for vertical and 9 mm for longitudinal, respectively. It is not necessary for he components installed in injection straight line to move because displacement of these components is less than +- 0.2 mm [5].

SUMMARY

The RCS is continuing stable user operation with beam power as demanded. At present, 300 kW to the MLF and 330 kW equivalent to the MR.

A beam, power of 540 kW has already been demonstrated with a beam loss of only 2 %. The RCS is ready to deliver 540 kW beam to the users. This beam power corresponds to 1.6MW for 400MeV injection in terms of the Lasslett tune shift. In this high-intensity trial, significant progress toward design output beam power of 1 MW was demonstrated.

There is too much work in the 2013 summer shutdown period. Entire adjustment of the RCS components has to be done and preparation for 400 MeV injection beam should also be finished in same time.

Beam study is planed from the first of January and user operation will be planed form end of January in 2014.

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