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PROGRESS AND STATUS OF THE J-PARC 3 GEV RCS

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Abstract

Big issue for the J-PARC rapid cycling synchrotron (RCS) was displacement of main magnets caused by last big earthquake because this made beam loss more than 400 kW beam power. Since realignment of main magnets and other components was essential to realize higher beam power and stable operation, this work has been done during maintenance period in 2013. To achieve the nominal performance 1MW beam power at the RCS and 0.75MW at the MR, beam energy of linac was increased from 181 MeV to 400 MeV with a new accelerating structure ACS (Annular-ring Coupled Structure) linac from this January. It was successful 400 MeV beam injection and 3 GeV beam extraction at the RCS, and user operation has been performed with beam power of 300 kW. An equivalent beam power of 550 kW with a beam loss of less than 0.5 % could be achieved during short time for high intensity beam study.

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 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. 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 [1]. 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 [2]. Main magnets and other components were displaced by the earthquake, but we didn't perform realignment of these components, because we put rapid restart of user operation before realignment of them. Since this displacement made beam loss in the beam power of more than 400 kW, realignment of those components was essential to realize higher beam power and stable operation. On the other hand, 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. These heavy two work which were realignment and 400 MeV beam injection upgrade in the RCS have be done at same time (from July to December in 2013). In parallel we were challenging to realize higher beam power operations with better stability. This paper concentrates itself on the RCS status and progress for this one year.

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OPERATION FOR USER PROGRAM

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. 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. The availability of the beam delivery after 400 MeV injection was not so high at first because several kinds of devices, for example newly installed power supply, oil cooling system for power supply, and so on, stopped for one day and more, but it has become better and has reached more than 90 % at present.

MAINTENANCE AND IMPROVEMENTS

Realignment and preparation for 400 MeV injection were main work in this maintenance period. The detail of these work and several progresses is described in this section.

1) Realignment of RCS

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. The amount of the realigned components, moving range and realigned ceramics vacuum chambers are summarized at table 1. Ceramics chambers have to be moved to the center of magnet. Almost all components which were main magnets, rf cavities, and extraction magnets had to be moved in the range of ~17 mm for horizontal, ~4 mm for vertical and ~10 mm for longitudinal, respectively. It was not necessary for the components installed in injection straight line to move because displacement of these components was less than +-0.2 mm. Position of the magnet, rf cavity and other components was measured by laser tracker and their positions were adjusted within +-0.2 mm compared with design value. This work was successfully completed on schedule by total manpower of 2200 person-day.

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Table 1: The amount of the realignment components, moving range and realignment ceramics vacuum chambers

Component	The number of realignment	Total number
BM	24	24
QM	53	60
SM	18	18
Ext. Septum	2	3
Ext. Kicker	2 vacuum chambers (8 kicker magnets installed in 2 vacuum chambers)	
RF Cavity	11 and new 1 cavity installed	12
monitors, vacuum pumps, etc.		
The number of connected flanges : 336		
Moving range		
Horizontal [mm]	-6.8 - +9.8	
vertical [mm]	-2.6 - +1.2	
longitudinal [mm]	-8.7 - +1.1	
Ceramics chambers		
for BM	18	24
for QM	23	60
for SM	10	18
Each chamber was aligned at the center of magnet.		

2) Replacement of ceramics chambers and capacitors

Since withstand voltage of capacitor which was 250 V was much less than induced voltage of the shift bump magnet, capacitors were broken due to the shift bump magnets operation. More than 90% capacitors cutoff in situ were to escape broken of the ceramics chamber due to discharge of the capacitors. Since this work made unbalance configuration of the rf-shield, this condition caused kick field to the beam due to dipole field induced in the rf-shield by eddy current of the bump field [3]. Symmetric configuration of the rf-shield was important to reduce beam loss, and the reason why was this work. Ceramics chamber was installed in each shift bump magnet, and totally there were four ceramics chambers in this area. Two ceramics chambers were replaced with new one and only capacitors were replaced with new high withstand voltage ones for another two ceramics chambers, because there were not enough spare ceramics chambers.

3) Improvement of charge exchanger #2 and #3

There were three charge exchangers in injection area for H^- beam injection from linac. Since the charge exchanger #1 was mainly used for charge exchange, the design of it was convenient to maintain, on the other hand, there were some issues for maintenance of the #2 and the #3 charge exchanger because the configuration of them was very simple. These charge exchanger were replaced with new one which has been solved those issues.

4) Vacuum condition improvement in the injection line

Inner periphery of the injection branch of the RCS had a high activation which was a few mSv/h on surface of the vacuum chamber measured on 4 hours after of beam stop for user operation. The user operation has been performed with beam power of 300 kW for 3 weeks. This high activation was due to H^0 beam, whose electron was stripped by the molecules in beam pipes during the beam transportation through the beam transport line from the linac to the RCS. They were not bended by the injection magnets and hit a wall of the vacuum chamber. To solve this issue, two vacuum pumps were additionally installed in this area. The effects of this work are described in detail on ref. [4].

5) Installation of new scrapers in the injection beam line

Small size injection beam by removing halo of the beam is essential to reduce beam loss at injection area, especially downstream of the charge exchange foil and the injection dump in the RCS. However, previous scraper for halo reduction which was installed in the beam transport line from the linac to the RCS was not useful, because the scraper made beam loss at downstream of it due to large angle scattering caused by too thick scraper head. To solve this issue, new scraper which was optimized scraper head for mitigation of the radiation around it. Structure and preliminary result for this work is described in detail on ref. [5].

6) Replacement of MA cores and new cavity installation

We have been replacing the old magnetic alloy (MA) cores with buckling-free type ones for 2 cavities during this maintenance period. Replacing MA core work have done totally 9 cavities. A new cavity was installed this year, then the number of cavities became 12 which was design number for the RCS. At present total 12 cavities works well.

7) Preparation for correction Q-magnets

To correct an unwanted edge focusing effect due to the injection bump magnet and a tune during the beam acceleration period of 20ms, correction quadrupole magnets (QDTs) have been developed. Total 6 QDTs and their beam pipe made by alumina ceramics were installed in the RCS. Cabling between their magnets and power supply was also finished. Power supplies are under construction at present and this correction system will be operated from this autumn.

SUMMARY OF MAINTENANCE

Corrective dose for each work operation is summarized in table2. Many people, max. ~100 persons per day, worked in the RCS tunnel for maintenance, however, corrective dose was not so high. It was found that our

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radiation protection and control for each worker worked well and the RCS tunnel was clean.

Table 2: Corrective dose for each work operation

work	Corrective dose [μSv]	Personal maximum exposure dose [μSv]
realignment	50	20
Replacement of ceramics chamber and capacitors	1467	300
Improvement of charge exchanger	234	60
Monitor maintenance in injection area	420	170

Corrective dose of any other work was less than 10 μSv.

400 MEV BEAM INJECTION AND ITS EFFECTS

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. At the RCS preparation for 400 MeV injection, beam commissioning and user operation have been carried out.

New power supply for injection shift bump magnet (SB) was operated to accept 400 MeV beam from the linac. Beam loss source of the RCS is excitation of coherent beam oscillation due to the SB induced dipole ripple. Figure 1 shows beam position moving due to the SB induced dipole ripple both previous and new power supply. In previous power supply and original rf-shield with the lack of capacitors, beam position moved more than +- 2mm, on the other hand, new power supply and modified rf-shield without the lack of capacitors, in the flat top beam position was stable and only in starting ramping down of the field beam moved +- 1.5 mm for horizontal. From this result new power supply works very well, however, stable operation has not realized yet.

Beam commissioning with injection energy of 400 MeV was started from 30th January for no acceleration mode to tune and adjust injection parameters at first. Adjustment, tuning and measurements for injection, acceleration and extraction have been performed during beam commissioning operation for two weeks, and high intensity beam trial was also carried out. An equivalent beam power of 550 kW with a beam loss of less than 0.5 % could be achieved during short time for this high intensity beam study. The results of beam commissioning and high intensity beam study are described in detail on ref. [6].

By the commissioning after the shutdown, 300 kW operation condition was established. In this condition, the doses of most areas were kept at the same level as 181 injection energy operation or decreased except to the injection foil chamber, 100 degrees and H0 dumps. First result of user operation with new injection energy indicated that the residual dose on the vacuum chamber of the charge exchange foil became higher, the residual doses near the injection H^0 dump were increased by the halo of injection beam, and the dose at the injection septum magnet was reduced due to improvement of vacuum pressure in beam transport line from the linac to the RCS and higher injection energy. The results of measurement of the residual dose are described in detail on ref. [7].

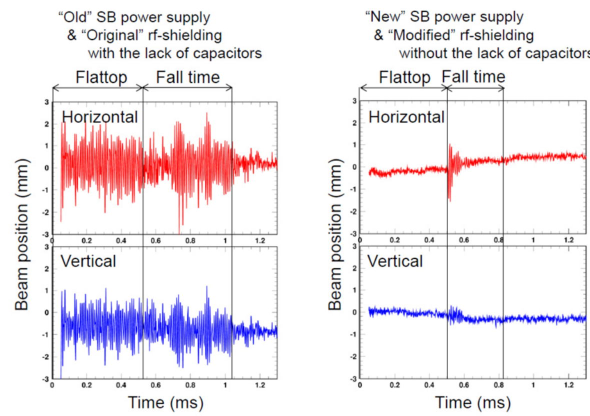

Figure 1: Beam position moving due to SB induced dipole ripple both previous and new power supply.

SUMMARY

Realignment work and injection energy upgrade were successfully finished on schedule. The RCS is continuing stable user operation with beam power of 300 kW to both the MLF and the MR as demanded at present. An equivalent beam power of 550 kW with a beam loss of less than 0.5 % could be achieved during short time for high intensity beam study.

As a result of the linac upgrade, realignment, and developments, the RCS could be achieved high intensity with very small loss. However, there are some issues as follows,

(1) Increase of residual dose around injection point after injection beam energy upgrade
(2) Unstable operation of newly installed power supply of the shift bump magnet

We have to continue to solve those issues, and are planning high intensity trial aim to 1MW equivalent beam in this autumn.

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