Status and progress of J-PARC 3GeV RCS

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Abstract. J-PARC RCS was heavily affected by the last Great East Japan Earthquake. At the RCS, the circulating road went wavy and the yard area for electricity and cooling water devices was heavily distorted. The RCS have delivered beam progressively since 2008. The RCS ramped up the beam power, and delivered beam of 300kW equivalent and 220kW to MR and MLF, respectively, before the earthquake disaster. We have investigated damages of each device and also have tried to restore them, we could start beam commissioning of the Linac from 9th of December three days before the anticipated schedule. After the turn on at the Linac on the 9th, the beam was injected to the RCS on the 17th. On the 22nd, the 3 GeV beam could be extracted to Materials and Life experimental hall with beam currents that are approaching to those obtained before the earthquake. We have been performed not only recovery works but also improvement of the RCS for realizing high power stable operation with low beam losses.

Introduction

J-PARC accelerator complex consists of a linac, a 3 GeV synchrotron (Rapid Cycling Synchrotron, RCS) and a Main Ring synchrotron (MR). A proton beam from the RCS is injected to the Materials and Life Science Experimental Facility (MLF) for neutron and muon experiments, and is also injected the MR. The MR accelerates a beam up to 30 GeV. The beam is used for Hadron or Neutrino experiments.

Beam commissioning of the RCS was stared from October 2007, the beam was delivered for the MLF and the MR for their beam commissioning on May 2008. The user operation for the MLF with beam power of 20 kW was started and also on 25 Hz switching operation for the MLF and the MR from 23th December 2008. Beam power has been increasing 220kW beam for the MLF and 300kW equivalent beam for MR delivered, respectively on 11th March 2011.

On the morning of March 11, the beam for users was stopped as scheduled. The beam study at the linac, and radiation survey work at the RCS and the MR tunnels were carried out, respectively. When we suspended a beam to change a destination from the linac to the RCS, the earthquake occurred. The intensity was 6-minus at Tokai on the Japanese seismic scale of zero to seven. Fortunately, we had no effects of tsunami that happened nearby and no one was injured. We released a recovery schedule in May 2011, start beam tuning from December, restarted user program of 44 days by the end of March 2012[1]. In order to realize this schedule, recovery work has been carried out. Recovery work does not completely finished, but it could be prepared for starting accelerator operation on schedule. The RCS resumed beam study on Dec.17th, the user operation started from January on schedule with 120kW beam power for MLF users and with 300kW equivalent for the MR.

Damage or RCS from earthquake

The RCS building is located approximately 400 m from the shore and on the hill of 15 m above the sea level. The accelerator components are installed in the main tunnel in the basement second floor, and there is a sub tunnel where power supply cables and cooling water pipes are installed. There is an outdoor yard surrounding the building. We have many high power devices such as chilling refrigerators, cooling towers, capacitors, transformers, rectifiers, power distribution boards, etc. Since the yard subsided by 30 cm to 1 m at many places, high voltage distribution boards inclined greatly and the bus bars for transmission were damaged. A power outage has to be continued by the end of these repairs. The accelerator components in the yard suffered from serious damages. Many bases for capacitors and transformers for resonant power supplies and rectifiers for RF cavities inclined. There were many points where hollow spaces existed under the bases as shown in Fig. 1**.** Cable trays installed along the building and all 4 cooling towers for water system were damaged. We carried out an investigation into damage situation of accelerator components with following two steps under the power outage. At first, we made use of the light in the tunnel using a diesel generator and carried out a visual inspection of components. Then, we received electricity by a device which there was little of damages, and we made outlets usable and carried out low power inspection for vacuum pumping system, diagnostics, etc.

For the restoration of the outdoor yard and high voltage electric boards, we have had complete power outage from the middle of June to the end of August as shown in Fig. 2. After returning the electricity in September, we will start restoration of cooling water system and will perform the detailed check of the components with high power.

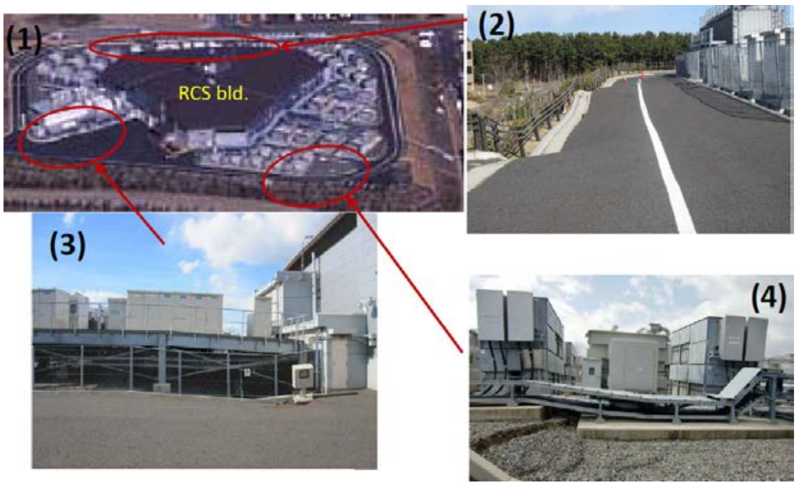

Figure 1. Pictures of RCS facility after earthquake. (1) Bird view of RCS building, outdoor yard, and the surrounding road. (2) Surrounding road of RCS. Wave road. Bump in the middle. Both sides of the bump were sinking. (3) Electric device for RCS facility. Stage for electric power devices leaned. (4) Capacitor bank and transformers. Capacitor bank and transformers were tilted. Cables were distorted with heavy weight on them.

Our biggest concern was the status of ceramics chambers, because almost half of vacuum chamber in RCS was made by alumina ceramics to reduce eddy current effect [2]. We conducted a vacuum test using 6 turbo molecular pumps. Figure 3 shows an arrangement drawing of pumps, gauges, and gate valves in the RCS. The RCS is isolated by 6 sections with gate valves. As a result, the vacuum pressured dropped to an order of 10^{-4}~10^{-5} Pa after 4hours pumping.

Figure 2. Restoration work of RCS facility. Left: The road was repaved. Right: Tilted capacitors and transformers were straightened after re-leveling the bases.

From this result, there was no large leak in the chamber of the RCS and it proved that there were not large leaks and the ceramics chambers were almost healthy. In addition, we carried out possible check of power supply and monitors by low power. There were some minor malfunctions but no serious damages.

No serious damage on equipment/instruments in RCS tunnel. Position and rotation error of all equipment/instruments which are magnets, rf cavity and beam position monitors were precisely measured by laser tracker. The data are summarized in table 1. The alignment errors mean the difference from reference position. Figure 4 shows a schematic view of actual positions and reference positions of magnets for horizontal plane. The magnitude of displacement is amplified 1000 times. Position errors for horizontal and vertical plane cause the closed orbit distortion therefore reduce the physical aperture for the beam. In order to reduce this effect for the beam, it is necessary to correct the closed orbit distortion by the steering magnets. The position errors for longitudinal plane cause the phase advance distortion and the rotation errors for transverse plane enhance the liner coupling resonance. Since it was found by simulation that closed orbit distortion could be correct with correction magnets, and the effects of longitudinal misalignment and rotation error were small, therefore we decided that we perform realignment not at this moment but in the 2013 summer shutdown period.

Table 1. Alignment errors of passion and rotation measured by laser tracker after earthquake.

Item	Alignment Error
Position (horizontal)	-4mm ~ +6mm
Position (vertical)	-3mm ~ +1mm
Position (longitudinal)	-3mm ~ +3mm
Rotation (transverse)	-0.4mrad ~ +0.2mrad

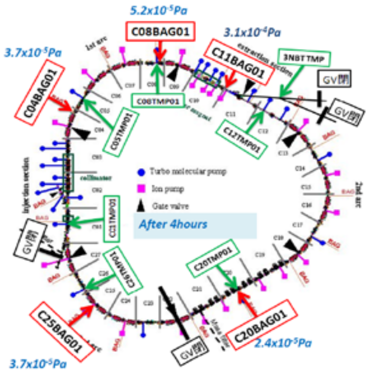

Figure 3. Arrangement drawing of vacuum components in the RCS. Blue circles show turbo molecular pump, red squares are ion pumps and black triangles are gate valves, respectively. To check the status of ceramic chambers, 6 turbo molecular pumps indicated by green arrows were used.

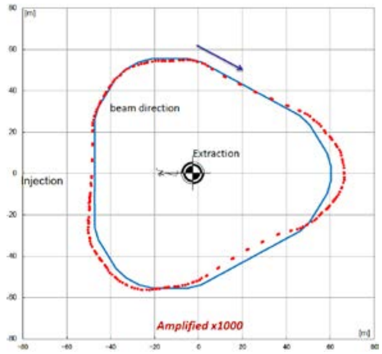

Figure 4. Schematic view of actual position of RCS components measured by laser tracker and reference positions. Red: Actual position, Blue: Reference position. Please note the magnitude of displacement is amplified x 1000.

Beam operation and improvement work

Beam commissioning of the RCS could be resumed from 17th December 2011. It was found almost no beam losses exist from injection to extraction in case of 300kW equivalent beam extracted to beam dump located in beam transport line from RCS to neutron production target shown in Fig. 5. Figure 6 shows beam loss monitor signal in the whole RCS before and after earthquake in case of 300kW equivalent beam extracted to that beam dump. There are 6 high beam loss points which are 1 injection, 3 arc sections, 1 extraction and 1 from H0 dump, in the RCS. Loss at arc sections and extraction is not real loss but the cause is that sensitivities of these beam loss monitors are too high, because residual activation is very small of these positions. Loss at H0 dump is caused by reflection from H0 dump. Many and big losses exist at injection area because there are two kinds of beam collimators which one is ring collimators and the other is new collimator for localizing scattered beam from charge exchange foil. Beam loss condition is difference between before and after earthquake at injection area but the value becomes low, because new collimator works well. Moreover beam loss at beam transport line from RCS to MR was also almost same as it before earthquake in case of 300kW equivalent beam. From these experimental data, realignment of RCS components is not necessary in case of 300kW beam operation and this is consistent with beam simulation results. We already prepared for delivering 300kW beam for MLF users. User operation has been resumed from January on schedule with 120kW beam power for MLF users and with 300kW equivalent for the MR. The RCS components work with high stability from resuming user operation, but accelerator stability is no so good, because beam trip number is about 50 times per day. Figure 7 shows the number and time of beam trips from January 7th to February 22th, 2012. The number and time of beam trips due to the RFQ discharge is dominant, and trip time. The situation was similar to the restoration of the RFQ discharge problem in 2009. Based on the experience, the condition will be getting better, but the trend should be carefully watched. Some improvement work and beam study was carried out as well as recovery work to realize 400MeV injection and beam power of 1MW. In order to localize beam losses downstream of charge exchange foil, new collimator was installed at injection area during this period as well recovery work from earthquake.

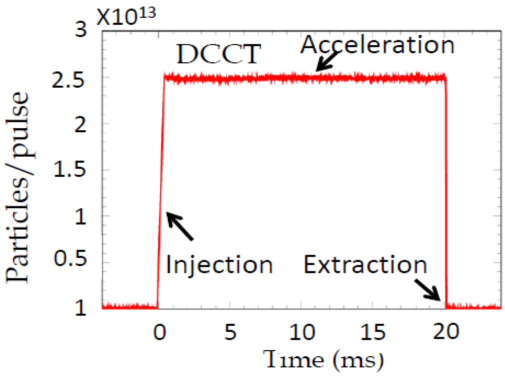

Figure 5. Signal of beam current monitor in case of 300kw equivalent beam extraction from the RCS to beam bump located at the beam transport line to the neutron production target. No beam observed loss from injection to extraction.

Residual activation level of more than 5 mSv/h was observed this area in case of 220kW for 2 weeks user operation. The residual activation was measured on the chamber surface after 4 hours of user operation finished. This loss is one of biggest issues for realizing higher beam power of the RCS. This loss is proportional to the number of the foil hits. We conclusion from beam studies and simulations, the large angle events with Coulomb scattering make a hot spot downstream of the foil. The number of foil hits should be reduced by transverse painting injection and by optimization of the foil size. These treatments for beam loss has been already done, but since it is impossible to reduce this loss to zero and this loss makes high residual activation, a new collimator system was installed downstream of the foil to localize uncontrolled beam losses. Residual activation of this area becomes less than one order small due to this collimator. This result opens the door to realize higher beam power of the RCS.

Improvement work not only for localization beam loss of foil scattered beam but also for 400MeV injection and beam loss reduction has been carried out. In total five power supplies, 1 for injection bump magnet and 4 for paint bump magnet, have to be improved for 400 MeV beam injection. New 1 power supply for paint bump magnet has been successfully operated, and this is in-service for user operation. The other 4 power supplies are under construction.

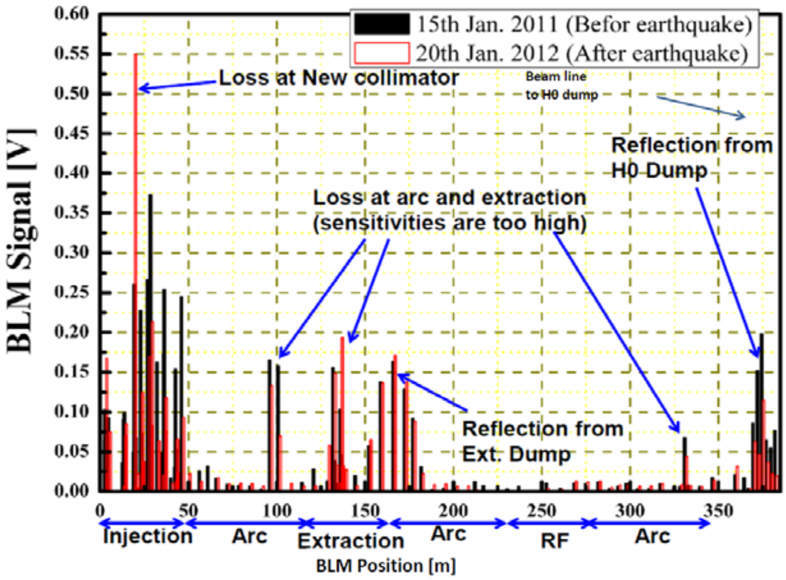

Figure 6. Beam loss monitor signal in the whole RCS before and after earthquake in case of 300kW equivalent beam extracted to the beam dump located in beam transport line to the nrutron production target. Black lines: before and Red lines :after earthquake.

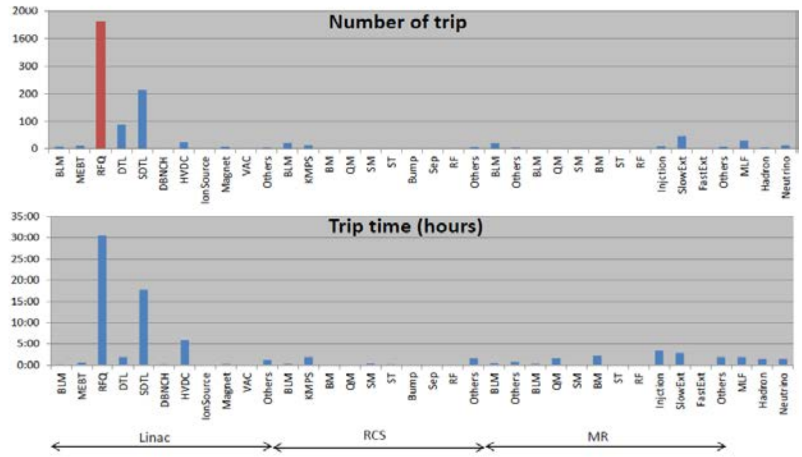

Figure 7. Number and time of beam trips in RUN#40 (Jan.7th-Feb.22th , 2012)

Some work for reduction of beam loss also has been performed. In order to reduce magnetic leakage field from beam transport line at extraction area, a vacuum chamber and a bellows with permeability alloy have been developed. With this chamber and bellows magnetic leakage field become less than one order small, and this is satisfied with requirement to reduce beam loss. The RCS has recently performed a high intensity trial with 420 kW equivalent intensity beam, in which we got several significant progresses leading to realizing the design output beam power of 1 MW, such as beam loss reduction by the painting injection technique, and beam loading compensation by the multi-harmonic rf feed-forward method[3][4][5][6].

Summery and Future plane

In the Great East Japan Earthquake the RCS was seriously damaged. The restoration work was smoothly performed and user beam operation could be resumed from January on schedule with 120kW beam power for MLF users and with 300kW equivalent for the MR. The next goal is to realize the routine user operation with 300 kW output beam power for the MLF users and more than 300 kW equivalent output beam power for the MR. Since new collimator which was installed at injection area worked well, so it was possible to reduce beam loss to less than one order, it was possible to deliver more than 300 kW beam to the MLF.

Beam energy upgrade which is current energy of 181MeV to 400 MeV work has been performed, and installation work was planned from July 2012, but the schedule was delayed for one year to keep much more user operation time in 2012. Therefore, the installations of the ACS for 400 MeV and the new RFQ and ion source to get a peak current of 50 mA are scheduled in 2013summer-autumn period. In this period new injection bump power supplies for 400Mev injection and some kinds of devices for beam loss reduction will be installed in the RCS. The realignment of the RCS components will be planned in same period. The beam commissioning of the upgraded linac will start by the end of 2013.

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