STATUS OF THE J-PARC 3 GEV RCS

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Abstract

The J-PARC rapid cycling synchrotron (RCS) was heavily affected by the last Great East Japan Earthquake. The damage to each device was investigated and an attempt was made to restore them, with successful beam commissioning of the the RCS beginning on 17th December 2011. On the 22nd, a 3 GeV beam was extracted to the MLF with beam currents that approached those obtained before the earthquake. Not only the recovery, but also an improvement of the RCS has been achieved, enabling high-power stable operation with low beam losses. Specifically, downstream beam losses due to the charge exchange foil were localized by installing a new collimator at injection area. As a result, the residual activation of this area was reduced by one order of magnitude and created the possibility of a higher beam power for the RCS. In a recent high-intensity trial of the RCS with a 420 kW equivalent intensity beam, significant progress toward design output beam power of 1 MW was demonstrated.

INTRODUCTION

The J-PARC accelerator complex consists of a liner accelerator (Linac), a 3 GeV rapid cycling synchrotron (RCS) and a main ring synchrotron (MR). A proton beam from the RCS is injected into the Materials and Life Science Experimental Facility (MLF) for neutron and muon experiments, and into the MR. The MR accelerates a beam up to 30 GeV. The beam is used for hadron and neutrino experiments.

The beam commissioning of the RCS began in October 2007, and the beam was delivered to the MLF and the MR for their beam commissioning in May 2008. Use of the MLF with a beam power of 20 kW, and a 25 Hz switching operation for the MLF and the MR began on December 23th 2008. The delivered beam power had increased to 220 kW for the MLF and an equivalent 300kW for the MR by March 11th 2011.

On the morning of March 11, beam use was halted as scheduled for a study of the beam at the Linac and radiation survey work in the RCS and the MR tunnels. While the beam was suspended to change the 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, J-PARC was not affected by the tsunami that occurred nearby, and no one was injured. A recovery schedule that planned for the initiation of beam tuning beginning in December was released in May 2011 with the user program restarted after 44 days by the end of March 2012[1]. Recovery efforts then began in earnest to meet this schedule. While not all of the repairs were completely finished, it was still possible to begin accelerator operation on schedule. Beam study using the RCS resumed on Dec.17th, and users received access on schedule beginning in January, 2012 with 120 kW beam power for MLF users and 300 kW equivalent beam power for the MR.

DAMAGE TO THE RCS

The RCS building is located approximately 400 m from the shore and on a hill approximately 15 m above sea level. The accelerator components are installed in the main tunnel in the second basement floor, and there is a sub-tunnel where the power supply cables and cooling water pipes are installed. There is an outdoor yard surrounding the building where many high-power devices are located, such as chilling refrigerators, cooling towers, capacitors, transformers, rectifiers, power distribution boards, and so on. Because the yard subsided by 30 cm to 1 m in many places, the high-voltage distribution boards were greatly inclined, and the transmission bus bars were damaged. Therefore, the power outage had to be maintained until repairs to the equipment were completed. The accelerator components in the yard also suffered serious damages. Many bases for the capacitors and transformers necessary for the resonant power supply and rectifiers for the RF cavities were inclined. In addition, hollow spaces existed at many points under the bases of these devices. The cable trays installed along the building and all four cooling towers for the water system were damaged. An investigation of the specific damage to the accelerator components was conducted in two steps during the power outage. First, a visual inspection of the components in the tunnel was carried out using a diesel generator to produce the necessary light. Then, with access to electricity from a single-power generation device that suffered little damage, a low power inspection of the vacuum pumping system, the diagnostics system, etc. was completed.

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

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During the restoration of the outdoor yard and the high-voltage electric boards, a complete power outage was necessary from the middle of June until the end of August, as shown in Fig. 1. Once the electric power was stated again in September, the restoration of the cooling water system was limited and a detailed check of the high-power components commenced. The biggest concern was the status of the ceramics chambers, because nearly half of the vacuum chamber in the RCS was made of alumina ceramics for the reduction of the eddy current effect [2]. Therefore, a vacuum test was conducted using six turbo molecular pumps. During the vacuum test, the vacuum pressured decreases to a level on the order of 10^{-4} to 10^{-5} Pa after 4h of pumping. Based on this result, it was determined that the chamber for the RCS did not have any major leaks, and that the ceramics chambers also did not suffer from any significant leaks. In addition, a low power check of the power supply and the monitors was also carried out. While some minor malfunctions were noted, there was no serious damage.

It was not also concluded that no serious damage occurred to the equipment/instrumentation in the RCS tunnel. The position and rotation errors for all the equipment/instrumentation based on magnets, including the rf cavity and the beam position monitors, were precisely measured using a laser tracker. The data are summarized in Table 1. The alignment errors indicate the difference from the reference position. Position errors for the horizontal and vertical planes cause closed orbit distortion, and thus reduce the physical aperture for the beam. To reduce this effect for the beam, it is necessary to correct the closed orbit distortion using steering magnets. The position errors for the longitudinal plane cause phase advance distortion and the rotation errors for the transverse plane and enhance the liner coupling resonance. Because it was found by simulation that the closed orbit distortion could be corrected with correction magnets, and the effects of the longitudinal misalignment and rotation error were small, it was decided that the realignment would be performed during the 2013 summer shutdown period [3].

Table 1: Position and rotation alignment errors measured using a laser tracker after the earthquake

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

BEAM OPERATION AND IMPROVEMENT WORK

The beam commissioning of the RCS resumed beginning on December 17th 2011. It was found that almost no beam losses existed from injection through to extraction in the case of the 300 kW equivalent beam extracted for the beam dump located in the beam transport line from the RCS to the neutron production target. Figure 2 shows the beam loss monitoring signal for the entire RCS before and after the earthquake in the case of the 300 kW equivalent beam extracted to that beam dump. There were six high-beam loss points in the RCS including one injection, three arc sections, one extraction, and one from the H^0 dump. Losses at the arc sections and extraction point are not real losses, but result because the sensitivity of these beam loss monitors is too high, and the residual activation is very small at these positions. A Loss at the H^0 dump point is caused by reflection from the H^0 dump. Significant numerous losses can exist in the injection area, because there are two types of beam collimators a ring collimator and a new collimator for localizing a scattered beam from a charge exchange foil [4]. The beam loss condition is the difference in the injection area before and after the earthquake, but the value was low, because the new collimator works well. In addition, the beam loss at the beam transport line from the RCS to the MR was nearly the same as it was before the earthquake in the case of the 300 kW equivalent beam. From these experimental data, which were consistent with beam simulation results, it was concluded that the realignment of the RCS components was not necessary in the case of 300 kW beam operation. Thus, the 300 kW beam was prepared for delivery to the MLF, and users resumed operations beginning in January 2012. Therefore, both the 120 kW beam power for the MLF and the 300 kW equivalent beam for the MR were back online on schedule. The beam power for the MFL was increased to 200 kW from middle of March and user operation has been performed with high stability.

While the repair work was being completed, the opportunity was taken to complete some upgrades to the system to realize a 400 MeV injection and a beam power of 1 MW [5]. Specifically, downstream beam losses due to the charge exchange foil were localized by installing a new collimator at injection area. A residual activation level of > 5 mSv/h was observed for this area in the case of 220 kW for the beam operating for 2 weeks. The residual activation was measured on the chamber surface 4 h after user operation was completed. This loss which is proportional to the number of foil hits, is one of the biggest issues that must be addressed if a higher beam power for the RCS is to be realized. Based on beam studies and simulations, it was concluded that large angle events with Coulomb scattering create a hot spot downstream of the foil. Therefore, the number of foil hits should be reduced by using a transverse painting injection and optimizing the foil size. These treatments for the beam loss have already been implemented, but it is impossible to reduce this loss to zero, because the loss lead to a high residual activation, a new collimator system was installed downstream of the foil to localize the uncontrolled beam losses. As a result, the residual activation of this area was reduced by one order of magnitude and created the possibility of a higher beam power for the RCS.

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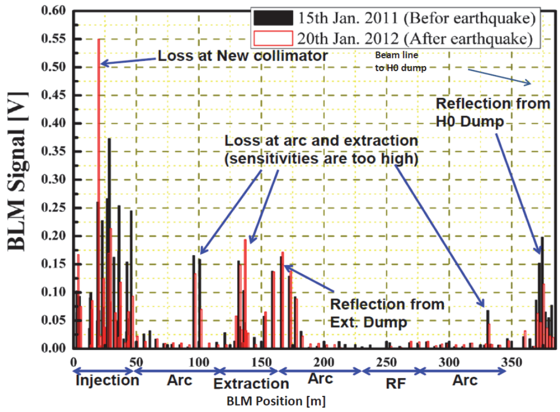

Figure 2: Beam loss monitor signal for the entire RCS before and after the earthquake in the case of the 300 kW equivalent beam extracted to the beam dump located at the beam transport line to the neutron production target. Black lines: before and red lines: after the earthquake.

Improvements have also been carried out for the 400MeV injection and beam loss reduction. To achieve a 400 MeV injection, a total of five power supplies, one for the injection bump magnet and four for the paint bump magnet, must to be improved. A new power supply for the paint bump magnet has been successfully installed and in-service for user operation [6]. The other four power supplies are under construction.

Figure 3 shows a signal of the wall current monitor in the case of the 420 kW equivalent beam extraction from the RCS to the beam dump located at the beam transport line to the neutron production target. No beam loss was observed from injection to extraction. In this high-intensity trial of the RCS with a 420 kW equivalent intensity beam, significant progress toward design output beam power of 1 MW was demonstrated, such as beam loss reduction using the painting injection technique, and beam loading compensation using a the multi-harmonic rf feed-forward method [7][8][9][10][11].

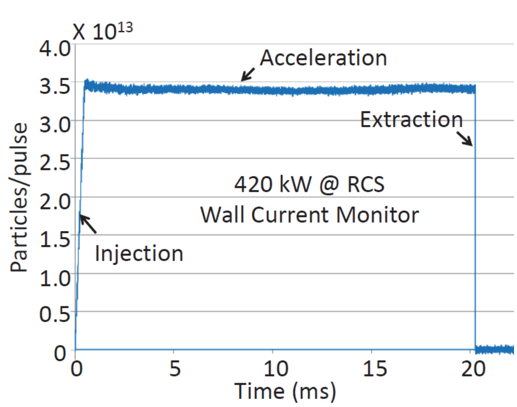

Figure 3: Signal of the wall current monitor in the case of the 420 kw equivalent beam extraction from the RCS to the beam dump located at the beam transport line to the neutron production target.

SUMMARY AND FUTURE PLANS

In the Great East Japan Earthquake, the RCS at J-PARC was seriously damaged. Restoration work proceeded smoothly; however, beam operation resumed on schedule beginning in January 2012 with a 120 kW beam power for the MLF and a 300 kW equivalent beam power for the MR. The next goal is to realize routine user operation with a 300 kW output beam power for the MLF and more than 300 kW equivalent output beam power for the MR. Because the new collimator installed in the injection area has worked well, the beam loss has been possible to reduce by one order of magnitude, and it has also been possible to deliver a > 300 kW beam to the MLF.

In addition, work to upgrade the beam energy from 181 MeV to 400 MeV has been performed, and installation work was planned to being in July 2012, but the schedule has been delayed for one year to allow for more user operation time in 2012. Therefore, the installation of an annular coupled structure (ACS) to achieve 400 MeV and a new RFQ and ion source to obtain a peak current of 50 mA is scheduled for the 2013 summer- autumn period. During this time, new injection bump power supplies for the 400 MeV injection and certain devices for beam loss reduction will be installed in the RCS. The realignment of the RCS components is also planned for the same period. The beam commissioning of the upgraded Linac will commence by the end of 2013.

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