J-PARC RECOVERY STATUS

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Abstract

The beam commissioning of the Japan Proton Accelerator Research Complex (J-PARC) facilities started in November 2006. After that a provided beam power was increased by the beam commissioning. Just before the Great East Japan Earthquake in March 2011, the Rapid-Cycling Synchrotron (RCS) of the J-PARC provided 200kW proton beam to neutron users, and Main Ring (MR) provided 145kW proton beam to Neutrino target. However, the facilities of J-PARC were seriously damaged by the Earthquake. We completed not only the recovery work in only nine months, but also improved some devices. A beam operation after recovery work shows that those improvements enabled further high power operation. In the Linac and RCS, output power was not only reproduced but also increased to 275kW. In MR, extraction beam power in both modes (Slow extraction for Hadron experimental hall and Fast extraction for Neutrino target) were increased as well.

INTRODUCTION

The Japan Proton Accelerator Research Complex (JPARC) is a multipurpose facility for the physical experiments. The J-PARC facilities were constructed in the Tokai site of the Japan Atomic Energy Agency (JAEA). The accelerator complex consists of a linac (acceleration energy is 181 MeV so far and it will upgrade to 400 MeV by installing annular-ring coupled structure cavity (ACS) in 2013), a 3 GeV Rapid-Cycling Synchrotron (RCS), and a 50 GeV Main Ring synchrotron (MR) [1]. At the beginning, the beam commissioning of the linac started in November 2006 [2,3,4]. Construction of another accelerators and experimental facilities were continued afterwards, the RCS started to deliver proton beam to the MLF and MR in May 2008 [5]. The user operation for MLF started in December 2008 [6]. Concerning the MR, it has two extraction lines. One is the slow extraction line which deliver a proton beam to the hadron experimental hall, and the other is the fast extraction line which deliver the beam to the neutrino target for the T2K (Tokai-to-Kamioka) experiment. In January 2009, we achieved slow extraction for hadron beam line [7]. And neutrino beam line commissioning started in April 2009. The regular T2K experiment started in January 2010 to take the physics data [8]. After that, the beam power for users was increased and user operation was continued just before the Great East Japan earthquake in March 2011 [9,10]. However, the catastrophic earthquake caused many serious damages to all J-PARC facilities.

INFLUENCE OF THE EARTHQUAKE

LINAC

The linac is composed of an utility building of about 330 m length, a building of the Linac-3GeV RCS Beam Transport Line(L3BT) and the accelerator tunnel in the underground. The earthquake broke the ground around the linac and the water supply/drain pipes. Figure 1 shows the entrance to the linac building. At the inside of the building, some cranes were damaged. An air conditioning system and some water pipes were also broken, but the klystrons were able to work. There were ground water leakage in the tunnel and the floor is covered with water. The maximum depth of water reached 10cm. We immediately pumped up it by temporary power generators. It was found that there was no contamination by the radioactive nuclides in the water, but pH of water was 11. Therefore we neutralized it by a sulphuric acid before drain. After draining the water, we investigated the tunnel wall and floor. Then we found many cracks to be on the floor near the cavities of the separated drift tube linac(S-DTL). Due to the flood, a number of dry scroll pumps and pre-amplifiers that were directly put on the floor were damaged. Furthermore, some beam position monitors and Current transformers are broken and vacuum leakage occurred from those chambers. We checked the resonant frequency of the acceleration cavities such as RFQ (radio frequency quadrupoles), DTLs and S-DTLs, and there were no serious problems.

Figure 1: The entrance to the linac building, where a footpath subsided.

Measurement result of all magnet positions indicated that the maximum displacement of linac magnets is 25mm in horizontal plane and 40mm in vertical plane. The maximum displacement point is near the cracks on the floor. The margin of the adjuster of the base is not

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enough to fix 40mm displacement. To aim at an early restart of the beam operation, we decided to steer the beam at the steering magnets downstream of the DTL section horizontally and vertically. Thus, the magnets were realigned from the point of maximum displacement along a deflected line (See Fig. 2) [11,12].

RCS

The RCS utility building was constructed in the center of the RCS accelerator tunnel. The RCS tunnel and the utility building have many deep piles under those floors and they were able to endure a strong vibration. Therefore, the damage of the tunnel structure was only small amount of water leakage from the boundary of the building and tunnel. However, the ground around the RCS building subsided because it was newly developed and loose. The transformers and capacitors for the resonant circuit system of RCS bending and quadrupole magnets, an equipment of the water cooling system and an electric power receiving system in high voltage substation were put on the subsided ground. Thus those received serious damages [13]. Due to the breakdown of the electric power receiving system, we were not able to confirm power supply system of all magnets and RF system until it was fixed on Sep. 2011. Fortunately there was no damage in those power supply systems.

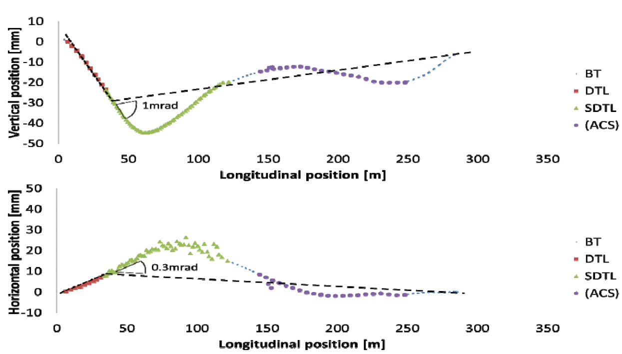

Figure 2: Displacement of the linac magnet and realignment plan. Vertical axis is the displacement of magnet, Horizontal axis is the longitudinal position of the magnet.

Regarding the accelerator components in the tunnel, there was no damage except the snapping of few cables. RCS vacuum chambers including the ceramic ducts were also no damage. When pumping started, the pressure fell to almost same as before the earthquake. Almost all the magnet positions were moved. At most, the magnet horizontally moved to 10mm and longitudinally moved by 5mm [14]. Figure 3 shows the loss estimation at 300kW operations before and after the earthquake. The simulation result indicated that an increment of the loss was enough small to accept [15]. For that reason, we decided to give user operation the highest priority, and the re-alignment will be done after the summer of 2013.

MR

MR has the accelerator tunnel of 1.6km, 3 buildings for power supply, 2 utility buildings, 2 preparation rooms with an crane and 3 emergency exit. The leakage of ground water also occurred, but there was no flood in the MR area because of a large volume of drain ditches in the tunnel.

The damage of the utilities in the MR area is smaller than the other accelerators, thus all air conditioning systems, cooling water systems and electric power receiving systems were worked again in May 2011. We carried out a test of the vacuum leak of all vacuum chambers, and found that the vacuum chamber in the fast extraction septum had large leakage. Therefore we fixed it as fast as possible [10].

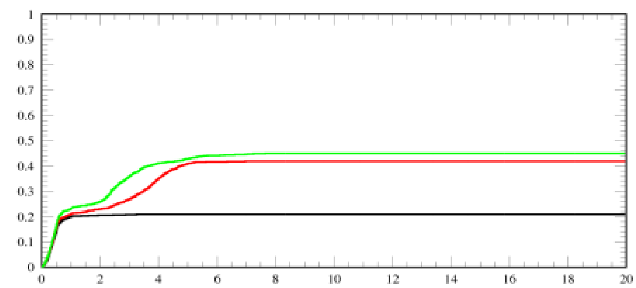

Figure 3: Loss rate estimation in the RCS. Vertical axis is the loss rate(%). Horizontal axis is the time progress from injection (msec).
Black line: Before the earthquake.
Red line: After the earthquake.
Green line: After the earthquake with tune manipulation to achieve low loss in the MR.

Figure 4 shows the measurement results of displacement of the MR magnets. The maximum displacement is 20 mm (in horizontal plane) and 10 mm (in vertical plane).

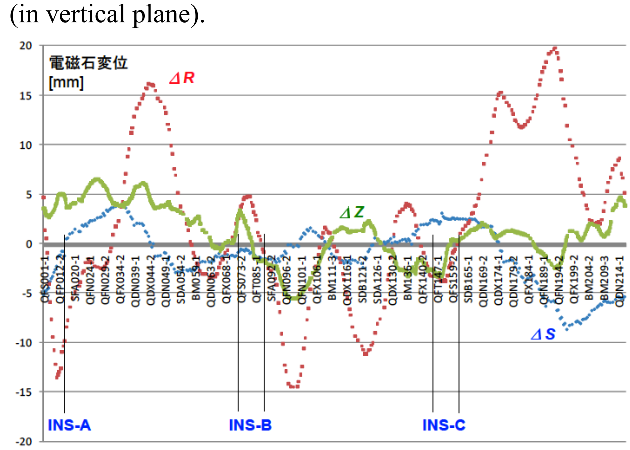

Figure 4: Displacement of the MR magnet. Vertical axis is the displacement of the magnet, Horizontal axis is the longitudinal position of the magnet.

In the MR, The influence of the alignment error on a beam is different from the RCS case. The calculation results indicated that it would bring large loss. Therefore

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we executed a re-alignment before restarting the beam operation [16].

ACCELERATOR OPERATIONS AFTER THE EARTHQUAKE

Restart of the Accelerator Commissioning

After the earthquake on 11 March, we immediately investigated all facilities and found above influences. From these results, we decided that we would restart the accelerator operations within the year. Recovery work was well done, and the accelerator commissioning was restarted in December according to the schedule [17].

Linac

Before the earthquake, the beam losses had been mainly caused by H^0 component generated in residual gas stripping of H^- ions, and hence they were insensitive to beam steering. However, we experienced significant beam losses which were sensitive to beam steering after earthquake. The beam commissioning results indicated that misalignment of some of the beam ducts made narrower aperture points and beam hit these ducts. Fine tuning and urgent realignment of some of the beam ducts reduced these losses, and the residual dose level became almost same as that of before earthquake. Thus, the linac was able to accelerate 200kW beam continuously. This is same power of before the earthquake [18,19].

The ion source is being operated for approximately 1,000 hours continuously with a beam current of 17 mA without any serious troubles [20]. On the other hand, the trip rate of some cavities is higher than the rate before the earthquake. In particular, condition of SDTL5B cavity is not so good. So we continued investigation of the SDTL5B cavity [21,22]. Two months after the restart of the user operation, the high voltage power supply (HV-PS) for the klystron of the front-end system broke down. This was due to the destruction of a diode in the HV-PS, but it is uncertain whether this trouble was an influence of the earthquake. Anyway, user operation was stopped two weeks [23,24].

In order to achieve a demonstration of the high power operation, we tried higher peak current of 25 mA operation. The study result showed that 25 mA peak operation caused higher discharge rate of RFQ. Though the earth quake broke the vacuum pumps, we did not have enough time to condition the RFQ. Therefore we used 20 mA peak beam for user operation. A bunch shape monitor is installing in this summer shutdown. This monitor enables us to observe the longitudinal motion in the linac, and this monitor is important to achieve longitudinal matching at the frequency jump we will introduce in 400MeV upgrade [25].

RCS

At the beginning of RCS re-commissioning, we set all parameters to the values that were used before the earthquake, and checked the distribution of the beam loss around the RCS. Figure 5 shows the integration of the beam loss monitor (BLM) signals at 300 kW output power operations before and after the earthquake.

The horizontal axis is the BLM position of the longitudinal direction. The origin of this axis means the first quadrupole magnet in the injection straight section. The circumference of RCS orbit is 348.3m, and the signals more than 350m position represented the BLM signals at the branch lines such as the H^0 dump line and the beam transport line from the 3GeV RCS to the neutron target (3NBT).

The loss can be seen to concentrate on 20-50m of the graph. These areas are devoted to the collimator. The peak of the vicinity of the dispersion maximum points (100, 330m) and the extraction septum (130-150m) are slightly large. These BLMs are more sensitive for a detailed observation. Thus, residual doses of only several μSv/hr are observed in these areas. The broad peak of about 170m position is due to the reflection of the secondary particles from the dump of the 3NBT line. The dump of 3NBT line is used for only beam commissioning, and this peak disappears when the beam direction is changed from the dump to the neutron target. The signals after 350m are also due to the reflection from the H^0 dump. Comparing between the BLM signals before and after the earthquake, the loss monitor signal at 20m became 2 times larger. This was owing to the loss at new collimator that installed in parallel with recovery work, and the loss by the foil scattering can be decreased less than 20% by this new collimator [26,27]. The loss of other area was almost same as before the earthquake. Thus, it seemed that there was no loss increment in the RCS [28].

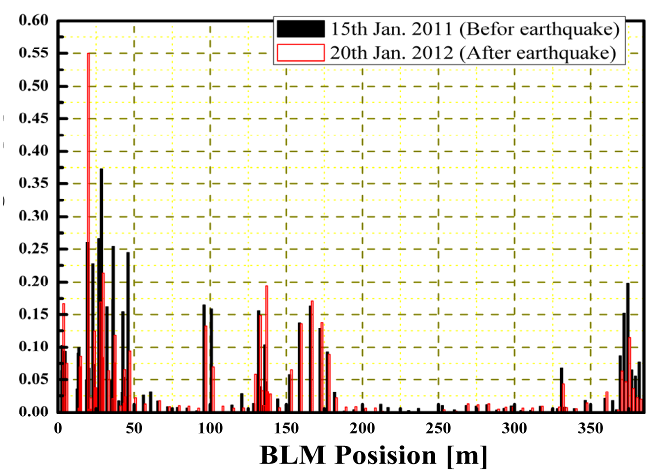

Figure 5: BLM signals at 300 kW output power operations before and after the earthquake.

Black lines show the BLM signals before the earthquake. Red lines show the BLM signals after the earthquake.

The user operation was restarted in January 2012 by 120kW output, and it was increased to 200kW afterwards. In spite of the same output power, the doses of the H^0 branch part was rather decreased less than 20%. This was due to the new collimator. Moreover, we successfully

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demonstrated 280kW output operation on three days just before the summer shut down of 2012. In this operation, the amount of the beam loss was proportional to the output power and it was enough low to accept [29].

MR

In the MR, not only the restoration from the earthquake but a lot of improvements had been performed.

First improvement is installation of additional shields and absorbers of ring collimators. Loss power capacity was increased from 0.45 to 2 kW by installing additional shields and an absorber. We plan to install further additional set of collimators in the 2012 and 2013 shutdown periods [30]. Installation of new collimator in the slow extraction straight section was also carried out. This collimator reduced the residual activation of the quadrupole magnet which is located downstream of Electric Static Septum magnet, and enabled higher power operation for slow extraction mode [31].

Second, we replaced the injection kicker system. The old kickers had many problems; Discharge in the vacuum chamber, beam loss due to extra kicks on circulating beam and high beam coupling impedance. Therefor we replaced kicker system with new one. The new kicker system uses Lumped constant type [32]. This is simple structure and low beam coupling impedance [33]. It has also smooth current waveform, and enables to reduce the extra kicks on circulating beams.

Third improvement point is the RF system. We installed additional 7th and 8th RF system. These new cavities make higher accelerating voltages and enable to manipulate the longitudinal bunch form to reduce the effect of space charge force [34].

Fourth we installed skew quadrupoles and octupoles. Four skew quadrupoles are used to reduce the linear coupling resonance and three octupoles are used to suppress the instability [35].

The last improvement is installation of solenoid coils on the rf exciter and new RQ (Ripple Quadrupole) power supply for spill feedback system. The solenoid coils suppress multipacting in the transverse RF exciter [36], and RQ system makes spill feedback in the high frequency regions (more than a few hundred Hz) [37]. These improvements make the duty factor of slow extraction better.

From these improvements, the maximum delivered beam power was increased to 200 kW by fast extraction mode [38]. Figure 6 shows the history of the output power of MR fast extraction. There were two problems between April and June, thus the output power was limited.

The first problem is deterioration of matching resistors in the injection kicker magnet. Worse quality of matching resistors brought about discharge and breakdown of itself. It deteriorated the kicker fields and beam loss exceeded a permissible level. The broken resisters were fixed on the scheduled maintenance period.

The second problem is a leakage of activation gas from air conditioning system. We found that the averaged radioactive level in the exhaust gas was higher than 0.5mBq/cc for over 180 kW operation at the machine building No.3 of the MR. If we continued over 180 kW operation, then the averaged radioactive level would become higher than the permitted value by law. Therefore the beam power was limited to less than 160 kW to suppress the radioactive level of the exhaust gas. We fixed it in the summer shut down of 2012.

We continued the operation of fast extraction for neutrino users until 9 June, and next we supplied the Hadron experimental facility with the beam by slow extraction. The beam power for hadron users was improved from 3.5kW to 6kW, and the duty factor was improved to 30% as well. The extraction efficiency at 6kW operation was about 99.5% [37]. Moreover, we demonstrated 14kW operation and confirmed that there was not hard problem. We will extract more than 10kW beam for hadron users nest operation.

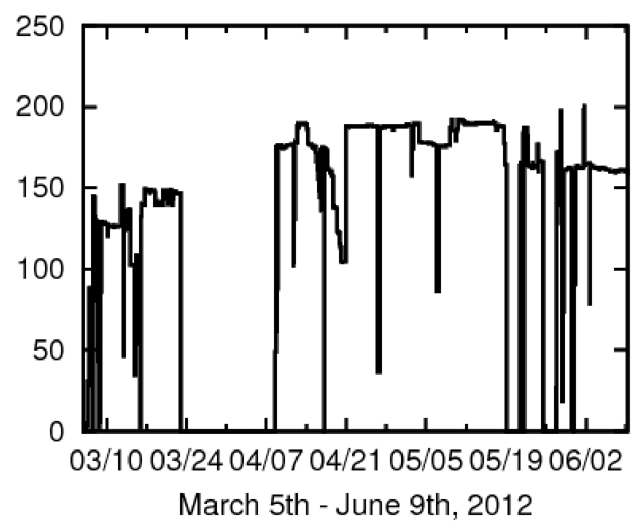

Figure 6: The history of the output power of MR fast extraction.

CONCLUSION

The Great East Japan earthquake broke not only the J-PARC accelerator facilities but also our living environments.

In spite of such difficult situation, we completed the recovery work in only nine months with sustained efforts of all J-PARC members. We also improved some devices, and those improvements enabled further high power and stable operation.

However, some problems occurred after restart of user operation. We have had to stop the user operation or to suppress the power by such incidents. We cannot judge whether the problems occurred due to the earthquake, thus we should carefully observe the accelerator status in future. We will also accomplish further upgrade of accelerators.

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