STATUS OF J-PARC MAIN RING AFTER RECOVERY FROM THE GREAT EAST JAPAN EARTHQUAKE DAMAGE

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Abstract

The J-PARC facility was seriously damaged due to the Great East Japan Earthquake on March 11th, 2011. For the Main Ring synchrotron (MR), a few tens of cracks were found in the tunnel and many of them leaked groundwater. Displacements of magnet positions after the earthquake were larger than ±15 mm in horizontal and ±5 mm in vertical. After 9-month recovery work from the earthquake damage, operation of the accelerators was re-established in late December of 2011. On the other hand, we also made various improvement work to increase the MR beam power during the long shutdown period. In this paper, the recovery work, the improvements and operation status after resuming the user run are presented.

INTRODUCTION

The J-PARC facility consists of an H- linac, a rapid-cycling synchrotron (RCS), a slow-cycling main ring synchrotron (MR) and three experimental facilities. The RCS provides a 3.0-GeV proton beam to the Materials and Life Science Experimental Facility (MLF) and also to the MR. The MR accelerates the beam up to 30 GeV and provides the beam to the hadron experimental hall using a slow extraction (SX) system or to the neutrino beamline using a fast extraction (FX) system for the T2K experiment.

The J-PARC facility was damaged heavily by the Great East Japan Earthquake on March 11th, 2011[1]. In the recovery plan made in May 2011, we aimed at the restoring the beam at J-PARC by the end of December 2011. By the effort of the whole J-PARC members, the first beam after the earthquake was accelerated on December 9th, 2011 in the Linac. The beam was injected to the RCS on December 17th and beam from the RCS was delivered to the MLF and the MR on December 22nd. Beam accelerated by the MR was extracted to a neutrino target on December 24th.

The beam delivery for the MLF users started on January 24th with a beam power of 100 kW. In March 2012, the delivered beam power of 200 kW, the power before the earthquake, was recovered. For the MR, we made re-commissioning of slow-extraction (SX) mode and delivered the beam to the hadron hall users from Jan. 28th to Feb. 21st, 2012. The delivered beam power for user operation was 5 kW in the maximum. Since March 5th, high power beam operation for the T2K experiments were restarted. The delivered beam power was gradually increased and reached 190 kW in April 2012, while the maximum power before the earthquake was 145 kW [2].

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RECOVERY FROM THE EARTHQUAKE

In the tunnel of the MR, a few tens of cracks were found and many of them leaked groundwater just after the earthquake. The groundwater poured on the magnets and vacuum ducts of the MR. Urethan and high-molecular compound were filled in the cracks to stop the water leaks.

Figure 1 shows measured displacements of the magnets after the earthquake. The displacements were larger than ±15 mm in maximum in the horizontal and 10 mm peak-to-peak in the vertical [3]. We have performed re-alignment of all magnets and monitors in the ring in the autumn 2011.

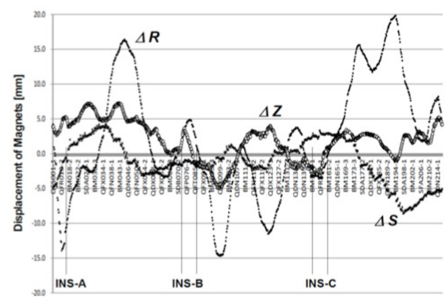

Figure 1: Measured displacements of the magnets after the earthquake. Horizontal (R), Vertical (Z) and longitudinal (S).

IMPROVEMENTS

We made work not only for the recovery from the earthquake damage but also for improvements to increase beam power in the 9-month long shutdown period after the earthquake. The main subjects of the improvements are as follows;

Installation of additional shields in MR collimator section: Loss power capacity of the MR collimator section will be increased from 0.45 kW to 2 kW by installing additional shields and absorbers in the 2011 shutdown, and an additional set of collimators in the 2012 shutdown [4]. Figure 2 shows iron shield walls installed on both sides of the MR collimator in the autumn of 2011. They are mounted on a linear motion guide rail for easy maintenance.

Replacement of the injection kicker system: The traveling-wave type injection kickers used until March 2011 had problems of discharge in a vacuum chamber and a high beam coupling impedance. Figure 3 shows the newly installed kicker magnets [5]. The new kicker has a simple structure of lumped-constant type. It has well shaping pulse form and lower beam coupling impedance.

Installation of the 7th and 8th rf systems: Two rf systems are added to obtain a higher accelerating voltages

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than 200 kV for higher beam intensity operation. They can be operated also as a second harmonic system by changing resonance frequency for manipulation of longitudinal bunch form to reduce the effect of space charge force [6].

Installation of new collimator system in the slow extraction straight section: The new collimator system are installed to reduce residual radioactivity on a quadrupole magnet, which is located downstream of electrostatic septum (ESS). Figure 4 shows the SX collimator installed in the SX straight section. The SX collimator has movable jaws to cut beam halo in horizontal and vertical directions. Each jaw is made of tungsten alloy.

Installation of skew quadrupoles and octupoles: Four skew quadrupoles for correction of the linear coupling resonance and three octupoles to suppress the instability [7] are installed.

Figure 2; Iron shield walls installed in the MR collimator section.

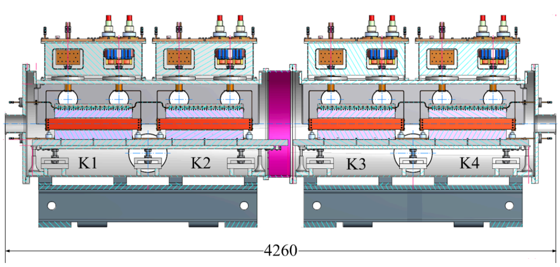

Figure 3: Newly developed lumped inductance type injection kickers.

Figure 4: New collimator system installed in the SX straight section.

BEAM OPERATION

J-PARC facility resumed beam operation in December 2011. Transportation of low intensity beam of 4×10^{11} ppb (protons per bunch) from the linac to the targets in MLF and neutrino beam line with the nominal beam energies was successfully demonstrated in December 2011. In January 2012, the user operation has been restarted. Figure 5 shows beam power of the MR after the restart of the user operation.

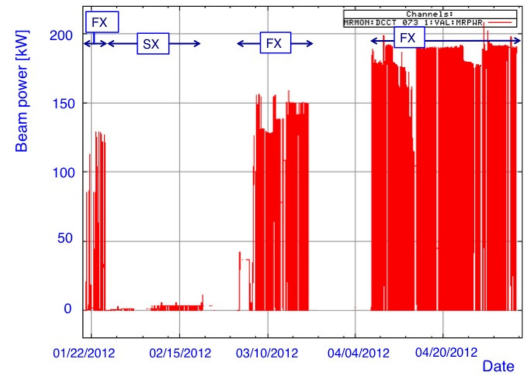

Figure 5: Beam power history since January 22nd, 2012, after restart of the user operation.

Slow Extraction

The MR was operated in the SX mode and delivered the beam to the hadron experimental hall from January 28th to February 21st. The delivered beam power was 3.3 kW for routine operation and 5.3 kW for 2 hours for a government inspection of newly installed radiation shields in a target area of the hadron experimental hall. The extraction efficiency of the SX is 99.6 % during the 3.3 kW beam operation. The beam power and extraction efficiency were restored the performance in the autumn of 2010, before the earthquake.

As reported in the previous papers [8,9], the most serious issue to be solved in the SX operation is a spike-like time structure of the extracted beam. The structure is caused by fluctuation of the betatron tune, which is due to current ripples of $\Delta I/I \sim 10^{-4}$ for the main magnet power supplies. The duty factor, an index to evaluate the quality of time structure of the extracted beam, is ~17 % in the run of 2010 autumn [2]. In the operation after the recovery from the earthquake, we switched on a transverse rf system, which fed an rf field with a narrow band around the frequency of the betatron oscillation to a strip line kicker. It increases the amplitude of the oscillation and pushes the beam to the third-order resonance for the extraction. In order to suppress vacuum pressure rise due to the multipactoring effect in the strip line kicker, 12 sets of solenoid coils were installed on the beam duct of the strip line kicker in the shutdown period. The duty factor in the user operation of February 2012 was improved from 17 % to 30 % using the transverse rf system [10].

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High Power Operation for the T2K Experiment

The beam delivery to the T2K experiment restarted on March 5th, 2012. Before the earthquake, the accelerating time from 3 GeV to 30 GeV was ~1.9 s and total cycle time was 3.04 s in the shortest. The two rf systems, which additionally installed in the 2011 shutdown period, make possible to achieve faster accelerating time of 1.4 s in the shortest. The cycle times of the operation was set to 2.92 s in March 2012 and set to 2.56 s since April 8th, 2012.

As shown in Fig. 5, the delivered beam power was gradually increased and reached 190 kW in the maximum with 2.56 s cycle. The extracted number of protons exceeded 100 T ppp (protons per pulse). The beam loss in the 190 kW operation is localized in the collimator section and 400 - 450 W, the same level as the present collimator limit of 450 W.

In the high power operation, coherent oscillations of betatron sidebands are observed during the beam injection and acceleration in the MR. The instability is excited by transverse resistive-wall impedance of the stainless-steel vacuum chambers and impedance of the injection and FX kicker magnets [11]. To suppress the beam loss due to the instability, a bunch-by-bunch feedback system is switched on in the user operation. In addition, chromaticity is set to be ~ -1 ~ - 5 during the injection and beginning of the acceleration.

Figure 6 shows a history of integrated number of protons on the target in the neutrino beam line. Before the earthquake, the total delivered number of proton was 1.4×10^{20}. After the earthquake, the total number increased 1.9 times in the operation for 1.5 months.

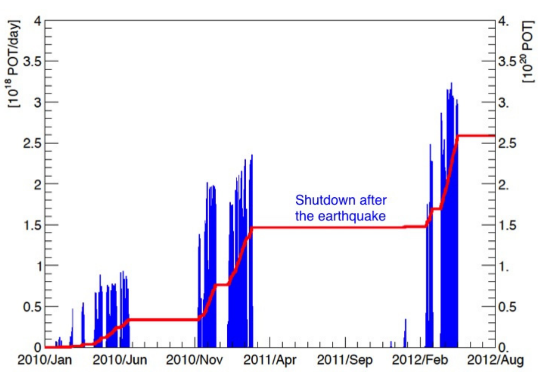

Figure 6: A history of delivered proton number to the neutrino target (by courtesy of the T2K experiment).

SUMMARY AND NEAR FUTURE PLAN

After the recovery from the earthquake, J-PARC facility has restarted the user operation since January 2012. The maximum delivered beam power of SX and FX modes in 2012 are 5 kW and 190 kW, respectively. These beam powers exceeded the pre-earthquake powers, 3.6 kW for the SX and 145 kW for the FX modes.

Power upgrade plan of the MR in near future is shown in Table 1. In the 2012 summer shutdown, we are planning to install the additional rf cavity. The 9th rf system is necessary for routine operation with second harmonic cavity in the 2.56 s cycle operation. As mentioned already, upgrade of the MR collimator system is planned in the 2012 summer. The most upstream collimator unit (1st collimator, which is called scatterer) will be replaced with newly designed one and additional one unit will be installed in the space between the existing 2nd (catcher2) and 3rd (catcher3) collimator units [4]. The loss capacity of the MR collimator section will be increased from 450 W to 2 kW after the upgrade. In 2013 shutdown periods, three collimator units will be additionally installed. The detailed design of the new collimator configuration for the 2013 shutdown period is now under discussion. For the SX, a part of the stainless-steel vacuum chambers of the ESS and magnetic septa will be replaced with newly fabricated ones, which made of titanium in the 2012 and 2013 shutdown periods.

Table 1: Near Future Plan of MR Power Upgrade

	Fast Extraction	Slow Extraction	
	Improvement/ Expected beam power	Improvement/ Expected beam power	
Dec/2011 – June/2012	190 kW Users operation	3-6 kW Users operation	10 kW Study
July/2012 - Sep/2012 (shutdown)	- Upgrade of ring collimator section - Installation of one rf system	Installation of Titanium chambers in magnetic septum section	
Oct/2012 – June/2013	200 - 300 kW Users operation	10 kW Users operation	50 kW Study
July/2013 –Jan./2014 (shutdown)	- Upgrade of ring collimator section	Installation of Titanium chambers in ESS section	
Feb./2014 –June/2014	300 - 400 kW Users operation	~ 50 kW Users operation	100 kW Study

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