OPERATION STATUS AND FUTURE PLAN OF J-PARC MAIN RING

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Abstract

The J-PARC main ring synchrotron (MR) has started users operation since 2009. The MR has two beam extraction systems. One is a fast extraction (FX) system for beam delivery to the neutrino beam line of the Tokai-to-Kamioka (T2K) experiment, and the other is a slow extraction (SX) system to the hadron experimental hall. For the T2K experiment, the maximum beam power of 145 kW was delivered continuously. For users of the hadron experimental hall, the beam power of 3 kW was delivered with extraction efficiency of 99.5 %. In this paper, status of the high power beam operation of the MR before the Great East Japan Earthquake on March 11, 2011 is presented. Recovery schedule after the earthquake and near future plan are also discussed.

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 [1]. The MR accelerates the beam up to 30 GeV and provides the beam to the hadron experimental hall using a SX system or to the neutrino beamline using a FX system for the T2K experiment.

OPERATION AND IMPROVEMENTS IN JFY2010

Figure 1 shows the delivered beam power of the MR during the Japanese fiscal year 2010. Before the summer shutdown period, the MR was operated in the fast extraction mode with a cycle time of 3.52 s and six bunches. The delivered beam power was limited around 50 kW because of a problem with the kick angle drift of the extraction kickers. The drift came from heating of the ferrite cores with the beam-induced wake field [2].

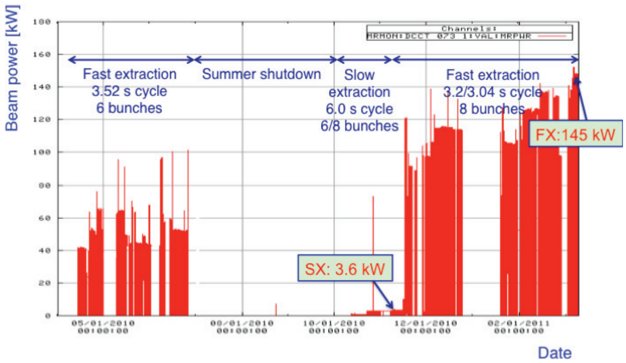

Figure 1: Beam power history of the MR in the Japanese fiscal year 2010.

Improvements in the 2010 summer shutdown periods

During the summer shutdown periods, we replaced the extraction kicker system with the newly developed one, which has a low beam coupling impedance to suppress the kick angle drift and has a faster rise time to make possible the operation with eight bunches instead of six bunches [2].

We also improved the power supplies of the bending magnets to decrease the cycle time. Energy recovery condensers of rectification circuits were adjusted to shorten the deceleration time of the magnet current from 30 GeV to 3 GeV excitations. As a result, the MR cycle time could be reduced from 3.52 s to 3.2 s or less for the fast extraction operation.

The other improvement was an upgrade of the beam collimators, which are located in the 3-50 BT (beam transport line between the RCS and the MR). Additional iron shields were installed in the 3-50BT collimators for operation with the future MW-class beam. The loss capacity of the 3-50 BT collimators is increased from 0.45 kW to 2 kW by the additional shields [3].

Slow extraction

The SX system has four bump magnets, two electrostatic septa (ESS1&2), ten magnetic septa (SMS1_1~SMS3_4) in the straight section, which is connected to the beam transfer line between the MR and the hadron experimental facility. Eight sextupoles to excite third integer resonance, $3\nu x=67$, are located in the arc sections. After the beam acceleration, the horizontal tune is gradually ramped up to the resonance line by changing one of the quadrupole families named QFN, which has 48 magnets and located in the arc sections.

The MR restarted the operation in the slow extraction mode in the autumn of 2010. The cycle time of the slow extraction is 6.0 s, which includes a long flattop period of 2.93 s for the extraction. In order to improve the extraction efficiency, a dynamic bump system has been adopted in the operation since October 2010 [4].

The dynamic bump system controls the strength of the four bump magnets to decrease a hitting rate of the beam on the ESS1 during the ramping of the QFN. As a result, the beam losses downstream of the ESS1 are reduced in the extraction. Figures 2 and 3 show beam loss distribution in the SX straight section and time dependence of the beam loss for fixed bump operation and dynamic bump operation, respectively. The beam loss is drastically improved for the dynamic bump operation. The extraction efficiency for the fixed bump operation is 98.3 %, and for the dynamic bump operation is 99.5 %, the world highest extraction efficiency for the slow extraction.

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The most serious problem to be solved in the SX operation is a spike-like time structure of the extracted beam [2, 4]. The structure arises from fluctuations of the betatron tune due to current ripples of the main magnet power supplies ($\Delta I/I \sim 10^{-4}$). To improve the time structure, we adopted a spill feedback system, which consists of two types of fast quadrupoles and a Digital Signal Processor (DSP) system, and a "trim coil short" method [5]. For the users operation in the autumn of 2010, the duty factor, an index to evaluate the quality of time structure of the extracted beam spill [4], of the delivered beam was calculated to be ~17 %.

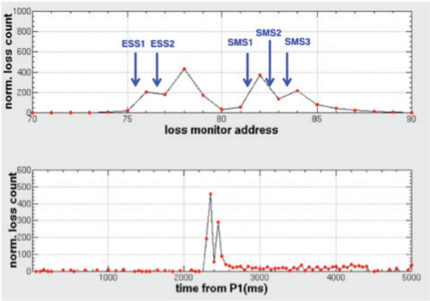

Figure 2: Beam loss distribution in the SX straight section (upper) and time dependence of the beam loss (lower) for the fixed bump operation.

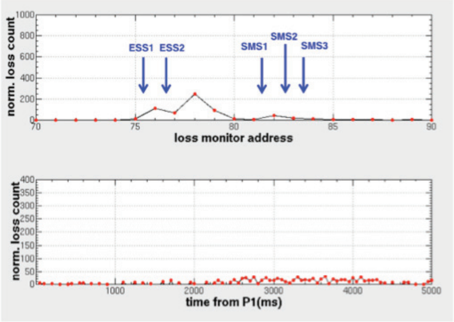

Figure 3: Beam loss distribution in the SX straight section (upper) and time dependence of the beam loss (lower) for the dynamic bump operation.

For further improvement of the duty factor, a method of ripple reduction by adopting transverse rf [6] was studied. A transverse rf field with a narrow band around the frequency of the betatron oscillation was fed to a strip line kicker and applied to the circulating beam during the extraction. This increased the amplitude of the betatron oscillation and pushed the beam to the third-order resonance. It was successfully demonstrated that the duty factor was increased ~30 % by applying a 20-MHz transverse rf. However, there was a pressure rise caused by the rf power in the strip line kicker section. The pressure rise came from discharges due to the multipactoring effect in the strip lines. Because of the pressure rise, transverse rf was switched off in the users operation in the autumn of 2010.

In the summer of 2011, we installed 12 sets of solenoid coils in the strip line kicker chamber. It was confirmed that more than 20 Gauss solenoid field completely supresses the pressure rise. The transverse-20 MHz rf are now ready for adopting in the user operation.

The residual activation in the SX section measured on 4 hours after 9 days of operation with a beam power 3~3.6 kW was 0.9 mSv/h on contact measurement and 0.1 mSv/h at a one foot distance measurement in maximum. Our guideline is that the residual-activation maximum for the SX section should be less than ~1 mSv/h at a one foot distance. We will increase the beam intensity while monitoring the residual activation levels carefully.

Fast extraction and high power operation

On November 16, we switched the operation mode from the SX to the FX. We delivered the beam to the T2K experiment with a cycle time of 3.2 s and eight bunches. The delivered beam power was gradually increased as shown in Fig. 1.

In the MR, coherent oscillation of betatron sidebands is observed above the intensity of 4×10^{11} ppb (particles per bunch) with a small bunching factor beam from the RCS (without rf second harmonics). In the routine operations, the chromaticity of the MR was set to be -5 ~ -7 to suppress the instability at the injection energy. Additionally, we adopted the bunch-by-bunch feedback system to suppress the instability in the autumn/winter run.

On March 7, the cycle time was shortened from 3.2 s to 3.04 s. Since then, the 145-kW beam power was delivered to the T2K experiment until the morning of March 11, the day of the Great East Japan earthquake. Beam loss in the 145-kW operation is around 200 W with bunch-by-bunch feedback system. The beam losses are almost localized in the ring collimator section during beam injection and on timing just beginning of acceleration.

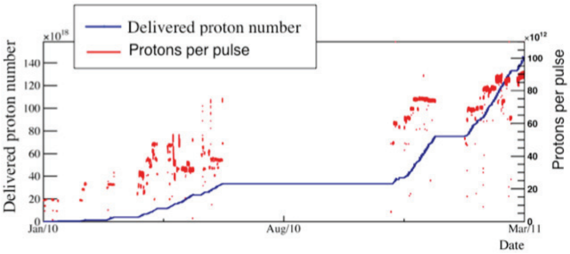

Figure 4: A history of integrated delivered proton number and number of particles per pulse to the T2K experiment.

Figure 4 shows a history of delivered proton number and number of particle per pulse to the T2K experiment since the start of physics data taking in January 2010. The total delivered number of protons on a graphite target is 1.43×10^{20}, 1.4 times larger than a total delivered number of the K2K (KEK to Kamioka) experiment by the KEK-PS for four years. On June 15, the T2K group announced that the T2K experiment had detected 6 electron neutrino candidate events based on the data collected before March 11, 2011 [7]. For the first time, it was possible to observe an indication that muon neutrinos are able to transform into electron neutrinos over distance of 295 km through the quantum mechanical phenomena of neutrino flavour oscillation.

Figure 5 shows distribution of the residual activation in the whole of the ring after the 145 kW operation. Red and blue symbols show the results measured on 26 days and 165 days after the beam stop on March 11, respectively. Since there were occasional strong aftershocks just after the earthquake, it was not easy to enter the MR tunnel and measure the activation. Therefore we don't have data just after the beam stop of the 145-kW operation.

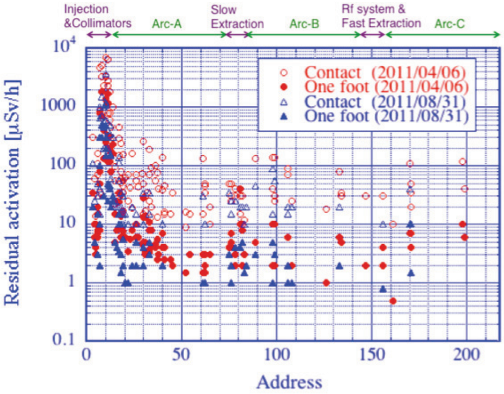

Figure 5: Residual activation after the 145-kW beam delivery to the T2K experiment.

AFTER THE EARTHQUAKE

The J-PARC facility was damaged heavily by the Great East Japan Earthquake [8]. For the MR tunnel, a few tens of cracks were found and many of them leaked groundwater in the tunnel. In contrast, no serious damages have been found so far in the accelerator components of the MR. A precise measurement of target positions of the all magnets shows displacements after the earthquake are larger than ±15 mm in maximum in the horizontal and 10 mm peak-to-peak in the vertical [9]. We have started re-alignment of all magnets and monitors in the ring in this August.

On a J-PARC recovery schedule, official comments of J-PARC center are as follows; (1) we will confirm the facility recovery by a beam injection, and (2) user program will be restarted with beam time of about 50 days until the end of March 2012. Note that the schedule is assumed to be valid when the budget requested is delivered on time, and the schedule is strongly influenced by the progress of infrastructural recovery of the linac and the RCS.

NEAR FUTURE PLAN

After the earthquake, near future plan of the J-PARC intensity upgrade has been reconsidered. In the original plan, energy upgrade of the linac from 181 MeV to 400 MeV by installing a new accelerating structure, ACS (Annular Coupled Structure linac), is scheduled in the 2012 summer/autumn maintenance period with 9-month shutdown. Additionally intensity upgrade from 30 mA to 50 mA by replacing the front-end part (ion source and RFQ) with the newly designed ones is scheduled in 2013 summer maintenance period with 3-month shutdown. In the new plan, however, both ACS and the front end are scheduled to install in the 2013 summer maintenance period with 7-month shutdown. The 2012 summer maintenance will be usual 3-month shutdown.

Table 1 shows power upgrade plan of the MR for the next three years. Some improvements of hardware are necessary to increase beam power. The loss power capacity of the ring collimator section will be increased by installation of additional shields and new collimator units [10]. Three rf systems will be added to increase accelerating voltage. Total number of the rf systems will be nine. Some of them are operated in second harmonic frequency for manipulation of longitudinal bunch form to mitigate the effect of space charge force. For the SX, installation of new collimator in the SX section is now being prepared. To reduce the residual activation on the extraction devices, some vacuum ducts made of stainless steel will be replaced with newly fabricated ones made of titanium.

Table 1: Power upgrade plan of MR for the next three years

	Fast Extraction	Slow Extraction	
	Improvement/ users operation	Improvement/ users operation/accelerator study	
Apr./2011 - Nov./2011 (shutdown)	- Upgrade of ring collimator section - Installation of two rf systems	Installation of SX collimator	
Dec/2011 – June/2012	> 100 kW user operation	3-5 kW users operation	5-10 kW study
July/2012 - Sep/2012 (shutdown)	- Upgrade of ring collimator section - Installation of one rf system	Installation of Titanium chambers in SMS section	
Oct/2012 – June/2013	200 - 300 kW users operation	10 kW users operation	50 kW study
July/2013 –Jan./2014 (shutdown)		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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