STATUS OF J-PARC ACCELERATORS

K. Hasegawa#, M. Kinsho, H. Oguri, J-PARC/JAEA, Tokai, Ibaraki, Japan
T. Koseki, J-PARC/KEK, Tokai, Ibaraki, Japan

Abstract

The Japan Proton Accelerator Research Complex (J-PARC) resumed beam operation in December 2011, after nine-months of beam shutdown by the Great Earthquake in March 2011. The operations were started at low duty for beam tuning, and in the beginning of January 2012, at the full repetition rate of 25 Hz at the linac and the 3 GeV Rapid Cycling Synchrotron (RCS). After the tuning, the beams were provided for the user programs at the Materials and Life Science Experiment Facility (MLF), the Neutrino Experimental Facility (NU) and the Hadron Experimental Facility (HD). Since then we have gradually increased beam power for these facilities, and also demonstrated new record power beyond 500kW from the RCS in 2012. Here, the updated status of the J-PARC accelerators is presented.

INTRODUCTION

J-PARC consists of the linac, the 3 GeV RCS, the 30 GeV Main Ring synchrotron (MR) and three experimental facilities [1]. A proton beam from RCS is injected to MLF for neutron and muon experiments. MR has two extraction systems: one is a fast extraction for the Tokai-to-Kamioka (T2K) experiment at NU; and the other is a slow extraction for experiments at HD.

Although J-PARC was extensively damaged by the earthquake on March 11, 2011 [2], the restoration work was accomplished and we started beam tuning in December 2011 and user programs in January 2012 [3,4].

OPERATION BEFORE SUMMER 2012

Low power tuning in December 2011

Thanks to the effort and support of staff members, the restoration work from the earthquake was accomplished on schedule. We started beam tuning at the linac on December 9 2011, which was 3 days ahead of the announced schedule. A beam test from the linac, RCS, MR and to MLF and NU was successfully completed by December 27 2011.

Though the operations were low duty such as single-shots or 1 to 2.5 Hz for beam tuning, we successfully accelerated the beam current to almost the same as before the earthquake: the peak current of 15 mA and the pulse length of 500 μs at the linac.

User programs resumption

At the beginning of January 2012, we started beam tuning at the full repetition rate of 25 Hz at the linac and RCS. During the tuning, we performed a 300 kW test from RCS and confirmed that we could increase the power when the neutron target became ready.

After the tuning, the user programs at MLF and NU started at 120kW and 60 to 87 kW, respectively. These powers were modest compared with 200 kW and 145 kW before the earthquake. The beam history of MLF (nearly equivalent to the RCS output) and MR are shown in Fig. 1 and 2, respectively. The detailed status and progress of RCS and MR are described in elsewhere ([5] and [6], respectively).

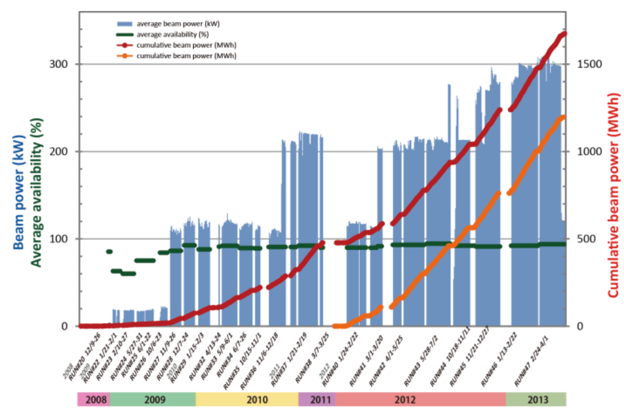

Figure 1: Beam history of MLF: beam power (kW), availability (%) and cumulative beam power (MWh).

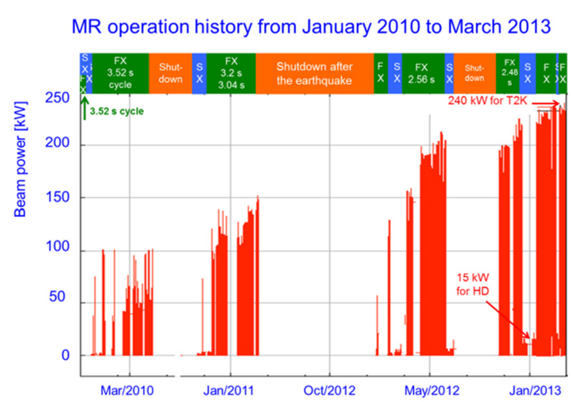

Figure 2: Beam history of MR.

In February, the beam from MR was tuned and delivered to HD. As a result of the tuning, beam power of 10 kW was attained in a test, and beam of 3.3 kW with a duty factor of 30% was delivered to the hadron experiments successfully.

A beam current from the linac was temporarily increased from 15 to 20 mA and a 420 kW tuning with RCS was carried out to examine the impact of misalignment of the RCS magnets due to the earthquake. It appeared that we could reduce beam loss in RCS and in the downstream beam transport line by adjusting the

#hasegawa.kazuo@jaea.go.jp

operating parameters of RCS. The amount of beam loss is at an acceptable level, but still higher than that before the earthquake. Therefore, we decided to perform realignment of the RCS magnets, which will take several months, in the summer of 2013 during the scheduled shutdown for the energy upgrade of the linac.

In March, beam injection to NU was started at 140 to 150 kW. Then by shortening the cycle time from 2.8 to 2.6 seconds, the beam power was increased to 170 to 180 kW, which is higher than that before the earthquake. At the same time, beam injection to MLF for user programs was started at 200 kW, which was the same power as before the earthquake.

The J-PARC accelerator facilities had been operating successfully until March 22 2012. However, the operation stopped due to the trouble in the linac klystron power supply caused by the diode breakdown in the high voltage transformation unit. It took more than two weeks to restart the user programs.

Stable Beam Operation to Users

After recovering from the klystron power supply failure, the beam powers increased to 210 kW and 170 to 180 kW for MLF and NU, respectively.

With increasing beam power, MR faced an issue of increased a beam loss from resistance degradation at the injection kickers. Therefore, the beam power was gradually reduced at the degradation to limit the beam loss and damaged resistors were replaced on scheduled maintenance days. As a result, the beam power was restored to 180 kW. Improvement of the resistors against the degradation is in progress [7].

An extraction current from the ion source of the linac was increased from 15 to 16 mA and the continuous operation at 190 kW to NU was carried out in May 2012. The beam power, however, was reduced to 160 kW shortly to limit the radioactive level in the exhaust gas at one of the MR machine buildings.

The beam of MR was switched from NU to HD in June 2012, and the user program for HD was started at 3.5 kW as in February. After beam tuning, beam at 6 kW with extraction efficiency of 99.5 % was successfully delivered to HD. Beam power for MLF was raised from 215 to 275 kW for 3 days at the end of the run in June, which was a prelude to the beam power increase demonstration.

MAINTENANCE AND UPGRADE WORK DURING 2012 SUMMER SHUTDOWN

Beam operation was suspended for summer maintenance from July to September 2012. In addition to routine maintenance work, installation and adjustment work of some components for performance upgrade, and preparation work for linac energy upgrade were carried out.

Linac

One of the acceleration cavities, SDTL5#B, did not work properly within the designed RF amplitude after the earthquake restoration. We made various efforts to recover its performance such as increasing vacuum speed, replacing oil rotary pumps with oil-free ones, and baking with warm water to enhance a degassing process.

Restoration work from the earthquake damage of the linac building had started from July 2012. Repair work of the cranes in the klystron gallery and in the accelerator tunnel was completed. In addition, walls and pillars also repaired, and grout was poured to hollow spaces under the floor before the resumption of beam operation in September 2012.

RCS

In RCS, realignment of the magnets was planned [8] during the linac energy upgrade in summer 2013. As preparing for that, a spatial relationship between the ceramic chambers and the electromagnets was measured by a laser tracker.

The pulsed steering magnet system was installed at the injection part of RCS. Although the same property beam had been injected to MLF and to MR, this system is to adjust painting to reduce beam loss for each beam destination [9].

The leakage magnetic field from the electromagnet in the extracted beam transport line was about 1 mT, causing a major beam loss at RCS. To reduce the magnetic field to an order of magnitude, the existing vacuum ducts and bellows were replaced with products made of a magnetic material (permalloy).

MR

The beam power of fast extraction for long-time operation was restricted to 160 kW due to a radioactive level of exhausted gases at the machine building. As a countermeasure, two air duct dampers were replaced with high airtight ones during the summer shutdown 2012.

Modification of the ring collimator was also carried out to increase the maximum acceptable beam loss power from 450 W to 2 kW.

Installation of three octupole electromagnets and the 9th unit of RF acceleration system and replacement of an end plate of the septum magnet made with titanium, etc. were done to improve performance.

OPERATION AFTER SUMMER SHUTDOWN IN 2012

After the beam tuning of the linac, RCS and MR, beam supply to MLF and NU started in the middle of October 2012. The beam power was 210 kW for MLF and 160 to 175 kW for NU. These power levels were almost the same as those before the summer shutdown.

We had an accelerator study time in November. To demonstrate a capability of higher beam power operation, an extraction beam current from the ion source was increased from 15 mA to 27 mA (at the linac exit). After the tuning of the linac and RCS, a 524 kW beam was injected to MLF for 35 seconds at a 25 Hz repetition condition. This is a record of the 3 GeV RCS output power.

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In the next operation run, beam power was increased to 200 kW for NU by taking a faster MR cycle time of 2.48 secconds. Beam power for the HD was increased to 11 kW by taking a cycle time of 6.0 sec compared to 6 kW in June 2012.

After the new-year's holidays, beam power to HD was increased to 15 kW, and then beam use of MR was switched to NU with 220 kW in mid-January 2013.

As an extraction current from the ion source has been slightly increased, beams with 300 kW and 230 kW have been constantly delivered to MLF and NU, respectively since March 2013. Although the beam destination was switched to HD for the user programs at 15 kW in the middle of March, the beam was stopped due to a trouble in one of the slow extraction septum magnets. The destination was switched back to NU, and the off-line repair work of the septum magnet was carried out. Beam tuning to HD restarted on April 27.

OPERATION STATISTICS

Though the J-PARC operation is almost continuous, the operation runs in the fiscal year (FY) 2012 ended on March 31 and the first (operation) run of a new fiscal year started from April 1. The total operation time is 6,328 hours and the user operation hours and the beam availability rate of each experimental facility in the FY2012 (from April until March) are as follows: 4,664 hours (93%) for MLF; 3,323 hours (89%) for NU; and 907 hours (89%) for HD. These statistics indicate that there were no big troubles in FY2012.

Figure 3 shows the statistics of total downtime in hours of each problem origin. At the beginning of the J-PARC operation in 2008, we had encountered a trouble in the RFQ, which caused the accelerator system down. Although this problem was resolved by improving vacuum during the 2009 summer shutdown, the RFQ became a dominant source of downtime (~50 trips/day) again at the beginning of beam resumption after the earthquake. This is because the vacuum pumps hadn't worked for several months and the vacuum condition went worse. However, in recent days, the number of trips caused by the RFQ reduced to several trips per day, and

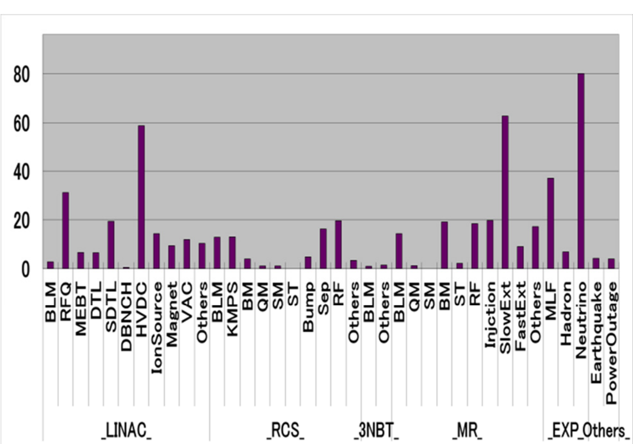

Figure 3: Downtime statistics in hours by components in FY2012 (April 2012 - March 2013).

the main reason of the downtime is the high voltage power supply system (HVDC) of the linac. There are many causes: discharge in anode modulators, discharge in some klystrons, malfunctions of the protection system by some noises, etc. We are studying steadily to improve the reliability.

FUTURE SCOPE

A full energy (400 MeV) and higher peak beam current linac is definitely required for J-PARC to reach the nominal performance of 1 MW at RCS and 0.75 MW at MR. For the beam energy upgrade, we plan to install a new accelerating structure ACS (Annular-ring Coupled Structure) and a 400 MeV RCS injection system. And we also need to increase a peak beam current from 30 mA to 50 mA by replacing the ion source and the RFQ. The details of the linac upgrade is described in elsewhere [10].

The MR fast extraction aims at the design power by shortening the repetition cycle from the present 2.48 to 1 second. To implement this, the development of a main electromagnet power supply with a high repetition rate and low ripple and an acceleration system with high gradient is the key. Currently the power supply is under development [11] and the mass-production test of high gradient magnetic alloy core is performed [12].

SUMMARY

J-PARC had severe damage by the earthquake, but the beam has been restored within 9 months. User programs were resumed in January 2012. The performance of the J-PARC accelerators has been progressing than before in terms of the beam power and the availability, though some components need more work for the reliability improvement. Users accumulate data and many fruitful results are published.

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