How J-PARC recovered from the big earthquake

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Outline

● About J-PARC
● The earthquake
● Damage on J-PARC
● Recovery plan
● Beam study results
● Summary
J-PARC (Japan Proton Accelerator Research Complex)

Joint Project between KEK and JAEA

Materials and Life Science Experimental Facility (MLF)

Hadron Beam Facility

Linac
181MeV(400MeV)

Nuclear Transmutation (Phase 2)

3-GeV Rapid Cycle Synchrotron (RCS)
(25 Hz, 270kW (1MW))

Neutrino to Kamiokande (T2K)

30(50)-GeV Main Synchrotron Ring (MR)
(200kW (0.75 MW))

Pacific Ocean
Main Synchrotron Ring (MR)
(30 (50) GeV, Period: 2.6~6.0sec, φ500m)

Linac (E:181MeV-> 400MeV (2013)
L:120m -> 250 m)

Rapid Cycle Synchrotron (RCS)
(3GeV, 25Hz, φ100m)

v-beam line (Super Conducting Mag.)
Goals at J-PARC

- Proton (p) 3 GeV, 30 GeV
- Neutron (n)
- Target Nucleus
- Pion (π)
- Muon (μ)
- Neutrino (ν)
- Kaon (K)
- Anti Proton (p̅)

Materials & Life Sciences at 3 GeV
Nuclear & Particle Physics at 30 GeV

- Design beam power: 1MW for MLF & 750kW for T2K
  (current beam power is 0.2 MW for both experiments)
Beam was provided to all users from April 2009. Users run of JFY2010 was stopped as scheduled at 7:00 on March 11, 2011. Just linac group continued the beam study in the daytime…..

Disaster we had in March 2011

1. The biggest earthquake (Mar., 11, 14:46)
2. Tsunami near J-PARC (Mar., 11, 16:52)
3. First hydrogen explosion of the nuclear power plant in Fukushima (Mar., 12, 15:36)
The Great East Japan Earthquake

March 11, 2011

1st 01:54
2nd 06:45
3rd 07:44
4th 14:46

78th 23:56

Seismic intensity map of the main shock on March 11, 2011, and epicenter distribution from March 11 to 18, 2011.

by National Research Institute for Earth Science and Disaster Prevention (NIED)
Tsunami simulation result near J-PARC

Tokai nuclear power plant
Tsunami max height : 5.4 m
Tsunami Protection : 6.1 m
(On Mar. 09 2011, 3.3m -> 6.1m)

J-PARC
Tsunami max height : 6.6 m
Tsunami Protection : 8 m
Air dose rate measured by an airplane (April 2011)
On March 17 the water level was only 1 cm, but it increased to 10 cm (100 tons) on March 24. The water was pumped out with a rented electric generator. PH=11 and tons of acid were necessary to neutralize water.
Linac measured position (Apr. 2011)

Red broken line: New beam line after the earth-quake
Rapid Cycle Synchrotron (RCS, 3GeV)

- No serious damages on the equipment/instruments in RCS tunnel.
- Position of all equipment/instruments were measured.
  The maximum displacement is 3.7mm vertically & 10mm horizontally.

Blue: Reference positions of the magnet
Red: Measured positions after the earthquake
(Please note the magnitude of displacement is amplified x2000.)
Main Synchrotron Ring (MR, 30GeV)

- There were no serious damages on all MR equipment/instruments, such as magnets. It, however, appeared they misaligned in both vertical and horizontal directions.

- Some magnets misaligned greatly are re-aligned with replacing a stage.

Orange: Reference positions of the magnet
Blue & Red: Measured positions after the earthquake (Please note the magnitude of displacement is amplified x2000)

Magnet displacement from the reference line
Green: vertical direction
Red: horizontal direction
Blue: beam direction
Demand from users (MLF, T2K) and the law fixed the MLF budget: Beam must be supplied to users during JFY2011 at least approximately two months.

Beam simulation to keep the beam loss as same as before:

Results:
*Linac must be re-aligned but V-shape is approved.
*RCS is usable without re-alignment if power ≤ 300kW
*MR must be re-aligned.

>> Minimum repair of the broken building has been done to resume the beam acceleration as soon as possible.
J-PARC Recovery Schedule (@2011.5.20)

2011

4 5 6 7 8 9 10 11 12 1 2 3

Infrastructure

Emergency Recovery → Full Recovery Work

Linac

Investigation → Recovery → Alignment

RCS

3GeV synchrotron

Investigation → Recovery → Cooling Water

MR

50GeV synchrotron

Investigation → Recovery → Test with electricity

MLF

Materials & Life Experimental Facility

Investigation → Shielding recovery → BL Components → New Hg Target → Extended Building

HD

Hadron Experimental Facility

Investigation → Recovery

NU

Neutrino Experimental Facility

Investigation → Recovery

Beam Test → Beam Commissioning → User Operation Start

MLF User Operation

NU or HD Operation

MLF User Program

HD Experiment

NU Experiment
History of beam delivery from RCS to MLF

In the last three days, 275 kW beam was delivered to MLF. Stable operation of 275 kW was successfully demonstrated.
History of beam delivery from MR to the T2K experiment

Operation for beam delivery to the T2K before summer 2012 was finished on June 9. T2K accumulated the beam of $\sim 3 \times 10^{20}$ POT.
Summary

- Although J-PARC had the big damage by the earthquake, it has been fixed in minimum to accelerate the beam.
- J-PARC resumed to accelerate beam from Dec., 2011.
- Experiments by user restarted in Jan., 2012.

- However a lot of troubles of the earthquake origin(?) still happen in the accelerators.
- Damage on the accelerator buildings of linac (wall, doors, cranes, floor) and MR (expansion joints, ground-water leakage) is not fixed yet.
Thank you very much!
Recovery Status of J-PARC from Damages by the 3.11 Earthquake

- Fortunately no victims at J-PARC, but severe damages on the facilities, such as piping systems, power devices, and instruments. We also had land subsidence at many places around buildings, water leaks, and misalignment of electromagnets and shielding blocks.

Damages and Recovery Status of Accelerator Facilities

- Leaking water depth in the LINAC tunnel reached to 10 cm.
- The approach to the LINAC entrance subsided more than 1 m. In contrast, the front road raised a few 10s cm.
- The road around the 3 GeV subsided more than 1 m at many places.
- The basis for transformers subsided ~1 m.
- Re-leveled the basis added concrete basis
Dose rate in KEK Tsukuba campus

NaI -survey meter

GM-survey meter
Linac major parameters

- Accelerated particles: $H^-$ (negative hydrogen)
- Energy: 181 MeV, The last two SDTLs are debunchers (400 MeV for ACS, 600 MeV for SCL)
- Peak current: 30 mA (50 mA for 1MW at 3GeV)
- Repetition: 25 Hz (additional 25 Hz for ADS application)
- Pulse width: 0.5 ms (Beam), 0.6 ms (RF)

Ion Source → RFQ → DTL → SDTL → ACS → SCC → ADS

50 keV 3 MeV 50.1 MeV 190.8 MeV 400 MeV 600 MeV
Drift Tubes in DTL

Observation of the shadow of the DT by an alignment telescope

Inside view of the DTL before installation
Alignment result of the linac

Bending angle at DTL end: 0.91-mrad horizontally, 0.28-mrad vertically.
In the SDTL & A0BT section, the displacement is 1.5-mm in maximum for horizontal direction.
Beam loss in RCS with the beam > 400 kW

Before the earthquake

- No large difference in beam loss

After the earthquake

- Significant difference in beam loss

Beam loss increased after the earthquake for 420 kW

- Particle loss before the earthquake: ~ 0.4%
- Particle loss after the earthquake: ~ 0.8%

In the summer of 2013, the entire adjustment of the RCS will be done
Problems after the beam resumption

Linac:
* HV terminals of Ion pump have the discharge problem.
* Almost temperature sensors were corroded.
* A HV rectifier in the oil tank for the Klystron was broken.
* Humidity in the tunnel is still high by the leakage of ground water.
* Cranes are still not usable.
* Floor is broken and tilted.

RCS:
MR:
* New leakage of the ground water found in the tunnel.
* Twisted expansion joints of the tunnel are not fixed.

Exp:
* Power supply of the magnetic horn for T2K was broken.
Neutrino Oscillation (T2K) Experiment

Super-Kamiokande

Atmospheric Neutrino
Accelerator Neutrino

Electronic Neutrinos

Mu Neutrinos

Mixing between the 1st and 3rd generation

Goal is to measure $\sin^2 \theta_{13}$ down to 0.01

Competition with Double Chooz, Daya Bay, FNAL, etc.
T2K electron neutrino candidates

11 candidate events are observed

$N_{\text{exp}} = 3.22 \pm 0.43$ for $\sin^2 2\theta_{13} = 0$

The probability (p-value) to observe 11 or more events with $\theta_{13} = 0$ is 0.08% (3.2$\sigma$)

Evidence of $\nu_e$ appearance

Vertex distribution

- Run 1+2 in FV
- Run 3 in FV
- non-FV