# STATUS REPORT ON SURVEY AND ALIGNMENT OF J-PARC AFTER THE EARTHQUAKE 

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## Abstract

The accelerator and experimental facilities located in the J-PARC were displaced by the large earthquake on March 11, 2011 in eastern Japan. At J-PARC a surveying network was prepared on the ground to cover the whole facility and GPS survey and leveling of the ground reference points were carried out in order to support recovery works. Also in the accelerator tunnel the device on the beam line was surveyed by using precise digital levels and laser trackers, and its alignment was carried out. J-PARC resumed its beam operation after the earthquake in December 2011. In this paper, we report the survey result in the accelerator tunnel after the earthquake and realignment of the J-PARC.

## INTRODUCTION

On March 11, 2011 the 9.0-magnitude Tohoku Region Pacific Coast Earthquake occurred. At K-Net Nakaminato [1] which is located about 10 km south of J-PARC facilities, the maximum acceleration of 546 gal in a horizontal direction and 412 gal in a vertical direction was recorded. According to Geospatial Information Authority of Japan, the coastal ground of Ibaraki Prefecture moved 1 m toward the ocean and subsided about 30 cm [2].


Figure 1: Bedrock contour around J-PARC facility.
Crustal shape around J-PARC facilities is complicated as shown in Figure 1 so uneven settlement was concerned from the beginning of construction. Main building differs in each facility and the main tunnel of the accelerator facility is held by driving piles into the basement layer (gravel mudstone layer). For each facility survey on the accelerator tunnel floor, reference points on the wall and
magnets are carried out every two years to observe changes across years. As a survey work immediately after the earthquake, GPS survey which can observe ground deformation around J-PARC without entering the building often was implemented in April and the precise levelling was carried out in July. Also leveling, traverse survey, laser tracker survey was implemented for each facility to understand the situation in the accelerator tunnel and realignment was carried out where it was necessary.

GPS SURVEY AFTER EARTHQUAKE


Figure 2: Observation network of GPS survey.

At J-PARC facility precise traverse survey and leveling are being implemented every two years. The last survey before the earthquake was in August 2010. After the earthquake GPS survey whose result can be quickly obtained was carried out at first in order to make use of it for recovery work of each facility [3]. Figure 2 shows an observation network of GPS survey. This observation network is the same as that of the precise traverse survey in 2010. Red line shows primary reference points and blue line shows the secondary reference points. Survey time is 4 hours and 2 hours respectively. However points set in the building using the secondary reference points were used for traverse survey using Leica TDA5005 and horizontal position was evaluated using the reference data obtained in the GPS survey.
Figure 3 shows displacement vector of reference points around Linac and RCS obtained in the GPS survey and changed between August 2010 and April 2011. Red displacement vector shows reference points above ground and on the roof of the building and blue displacement vector shows reference points in the tunnel. Survey accuracy of GPS is $\pm 5 \mathrm{~mm}$.
Reference points circled in red shows displacement of reference points set in Linac tunnel and on the $1^{\text {st }}$ floor of the building. As maximum displacement was 6.81 mm it was found out that the reference points did not move largely due to the earthquake.
Reference points circled in blue shows the reference points in RCS tunnel. As maximum displacement was 19.35 mm it was found out that the tunnel expanded in east-west direction.


Figure 3: Result of GPS survey around Linac and RCS.

Figure 4 shows displacement vector of reference points
around 3NBT and MLF. 3NBT is transport line of proton beam from RCS to MLF. MLF is an experiment facility of neutrons. Points circled in red show reference points set in 3NBT tunnel. Each point moved about 10 mm toward RSC side due to the earthquake and rotated clockwise. Points circled in blue are reference points set on the roof of MLF and show displacement between 22 mm and 33 mm . The building moved about 20 mm due to the earthquake and rotates counterclockwise.


Figure 4: Result of GPS survey around 3NBT and MLF.

Figure 5 shows displacement vector of reference points around Neutrino facility. Points circled in red are reference points of Neutrino beamline. Displacement of reference point was less than 10 mm . Vertical displacement was measured by another survey, which showed the displacement of less than a few mm . These results are acceptable value for the orbit correction.


Figure 5: Result of GPS survey around Neutrino facility.

Figure 6 shows displacement vector around MR and Hadron facility. Points circled in red are reference points set in MR tunnel and shows displacement from 11.61 mm to 5.41 mm . MR has 6 reference points. Among these, 2 points circled in a dashed line are the points that cannot be observed using through-holes. Displacement of these 2
points showed the maximum value. As direction of each displacement vector differed, it was figured out the tunnel largely deformed.


Figure 6: Result of GPS survey around MR and Hadron facility.

## STATUS OF ACCELERATOR FACILITY

## Linac

The cavities and magnets were measured by using a laser tracker. Horizontal and vertical displacements are shown in Figs. 7 and 8 respectively [4]. There is about 25 mm horizontal deformation at the straight section. The vertical displacement is consistent to the floor elevation. There are local settlements at the DTL/SDTL sections (more than 40 mm ) and at the end of the ACS section (about 20 mm ).
The blue line shows the result of the measurement after the re-alignment line of the straight section. It was necessary to move the DTL cavity by 20 mm or more to align the whole area of the straight section on the ideal straight line toward the dump. However, the range of the DTL movement is a few millimetres without re-wiring DTQs. Therefore aiming at an early restart of the beam operation, it was decided to steer the beam horizontally and vertically at the steering magnets located downstream of the DTL section. Longitudinally the accelerator tunnel of Linac extended about 9 mm at the upstream part of the SDTL section, and 1 mm at the downstream part of the ACS sections. This extension was absorbed smoothly by adjusting the magnets interval at the matching section between SDTL and ACS (about 15 m ).


Figure 7: Horizontal position of the Linac in the straight section.


Figure 8: Vertical position of the Linac in the straight section.

Figure 9 shows the relative position of the magnets after the first arc to the 90 degree dump. Displacements at the expansion joints are as follows:
$\bullet 0.8 \mathrm{~mm}$ in transverse, 1.1 mm in vertical, +1.0 mm in longitudinal, 0.3 mrad in bend at the exit of the first arc.

- 9 mm in transverse, 3 mm in vertical, +1.3 mm in longitudinal, -0.4 mrad in bend at the exit of the collimator section.
The beam transport section (from the first arc to the injection line to RCS) was adjusted to maintain the proper injection angle and position to RCS.


Figure 9: Relative position of the magnets after the first arc to the 90 degree dump.

## Rapid- Cycling Synchrotron (RCS)

At RCS survey of magnets using a laser tracker was implemented from May 2011 and precise leveling started in July 2011 [5]. The results are shown in Figure 10.


Figure 10: Misalignment of RCS magnets before/after the earthquake. Black dots are values taken before and red dots are values taken after the earthquake.

After that an orbit analysis using the measurement results was implemented. It was confirmed that even with the magnets placement after the earthquake, 300 kW beam operation same as before the earthquake was possible by COD correction. 3 GeV RCS restarted its beam operation in December 2011.


Figure 11: Displacements of magnets in horizontal direction which is standardized based on the injection straight.


Figure 12: Displacement of magnets in height direction which is standardized based on the height of magnets near collimators (QDL4 and QFL5)

The realignment of RCS magnets is planned from summer through fall in 2013. As for realignment, the most difficult part is adjustment of magnets (QDL4 and QFL5) near the injection collimator. Workability of this area is very low due to the shieldings installed to avoid high radiation dose this area caused by beam loss. Therefore for realignment it is planned for vertical direction to adjust QDL4 and QFL5 to the reference and
for horizontal direction to evaluate and adjust displacemenrt of each magnet so that misalignment of magnets at the injection straight section becomes as small as possible. The displacement of each magnet calculated from the result of the measurement in May 2011 is shown in figure 11 and 12. It was necessary to adjust the magnets about nearly 10 mm in horizontal direction. This displacement can be adjusted sufficiently within the range of the magnets movement.

## Main Ring (MR)

At MR survey of magnets using a laser tracker was implemented from May 2011. Figure 13 shows displacement in horizontal and longitudinal direction [6]. As a result of comparison with design values, the displacement range of horizontal direction was maximum 35 mm and longitudinal direction was maximum 13 mm .


Figure 13: Displacement of horizontal plane of MR magnet.


Figure 14: Displacement of vertical direction of MR magnet.

Leveling of the magnets was carried out in July 2011. Figure 14 shows displacement in height direction from July 2010. It is seen that the whole beam line showed settlement of about 2 mm . Around the injection straight line (INS-A) is the highest and the part from slow extraction beam line (INS-B) to QFX099 via Arc-B and the part from the end of Arc-B to the middle of first extraction beam line (INS-C) show large settlement. Compared this part to Figure 1, it is found out that change of height from QFX099 and QFN162 corresponds to the relief of basement layer. Settlement seen at QDN193 corresponds also to the lower part of basement layer located at the slightly upper part of the cross section of 3NBT line. Only the upper part of INS-B seems to be against settlement but this is considered because this part is supported by two buildings from both sides. As there was a large displacement throughout MR, alignment of the all magnets was implemented from August through November 2011. As for height of MR beamline it was decided not to change height of extraction sesptum magnets of First extraction and Slow extraction. Figure 15 shows the result of confirmation survey carried out after the alignment.


Figure 15: Survey result after alignment of MR.

For horizontal direction, displacement of about 8 mm occurred regardless of the alignment. When survey data is analyzed, usually through-hole data (6 points) measured by traverse survey is included. However this time through-hole data measured by GPS survey was used and among the 2 points could not be used due to the earthquake. Therefore it was considered that sufficient data accuracy could not be obtained. Effect of aftershock was also considered but the levelling data of the floor reference points implemented before/after the alignment (July and November 2011) showed displacement range of the tunnel of 0.7 mm so it was difficult to think of displacement of several mm in a horizontal direction.

Luckily the result of COD measurement without correction after restart of beam operation was better than that of before the earthquake so it was considered that the alignment status was good enough. The final conclusion of MR alignment will be made based on the result of the survey in summer 2012 carried out after through-holes are recovered.

## SUMMARY

As the main tunnel of the accelerator facility is held by driving piles into the basement layer (gravel mudstone layer), GPS survey found smaller displacement in a horizontal direction than that of reference points on the ground. However deformation in the tunnel and displacement between facilities were well identified. Displacement of the beam line was identified by the survey after earthquake. Displacement of RCS and MR in a vertical direction corresponded to the relief of basement layer. At Beam transport line displacement at expansion joints in a tunnel was large. Based on these results, alignment was carried out for all the facilities except for RCS and the beam operation restarted in December 2011.
Precise traverse survey of reference points on the ground is being implemented at this moment and more detailed data is expected to be obtained.

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