POST-EARTHQUAKE RECOVERY OF PF RING AND PF-AR

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Abstract

When an unprecedented scale of earthquake occurred in Japan on the afternoon of March 11, 2011, PF ring and PF-AR, two synchrotron light sources in KEK, also suffered various damages. It was fortunate that no magnets were turned over in the storage rings. At PF ring, half of the beam duct exposed to atmospheric air. At PF-AR, the wall cracked at the expansion joints of the ring tunnel, and groundwater gushed out from the cracks. At the middle of May, we managed to restart the beam injection, and the beam operation continued until the beginning of July. It was confirmed that full beam current could be stored and all beamlines could receive the synchrotron radiation. Some problems were found in the injection and in the vacuum system as an aftereffect of the earthquake in the beam operation. We continue maintenance and the magnet alignment in summer, and we will recover the regular user operation from October, 2011.

DAMAGES TO THE ACCELERATORS

Earthquake, 2011 Mar 11

On March 11, east Japan was struck by the 9.0-magnitude earthquake. Large tsunami of a scale once in 1000 years smashed many towns along Pacific coast of north-east Japan. The nuclear disaster of the Fukushima nuclear power plants was also caused by this tsunami.

The scale of the quake was so large that the hypocentral region was estimated to extend about 500 km in the north-south direction and 200 km in the east-west direction as shown in Fig. 1. KEK Tsukuba campus is located in south Ibaraki and about 350 km away from the epicenter. The seismic intensity was very strong, 6-lower on the Japanese scale. It was difficult to keep standing without holding onto the wall in our laboratory building. As Tsukuba is away from the shore, we did not have to worry about tsunami.

In north Ibaraki where J-PARC is located, a seismic intensity of 6-upper was recorded. J-PARC is along the shore, but tsunami did not reach the accelerator facility.

A blackout in the wide area occurred with the earthquake, and the power receiving equipment of Tsukuba campus was also broken down. The power receiving equipment was resumed in a few days, but serious electricity shortage continued in the whole east Japan because of the great disaster. It took about two weeks until the electric supply reopened to the accelerator facilities in Tsukuba campus.

8-GeV LINAC, a common injector for KEK B factory, PF ring and PF-AR, suffered most serious damage in Tsukuba campus. A triplet quadrupole magnet fell down to the floor and many magnet supports were moved or distorted. The beam duct was broken at several places and many RF acceleration tubes were exposed to atmospheric air. As KEKB factory stopped its operation for the major upgrade project since autumn 2010, only the downstream half of LINAC is operated to accelerate 2.5-GeV electron for PF ring and 3-GeV electron for PF-AR. They quickly recovered the downstream half of LINAC and the injection was enabledby the beginning of May.

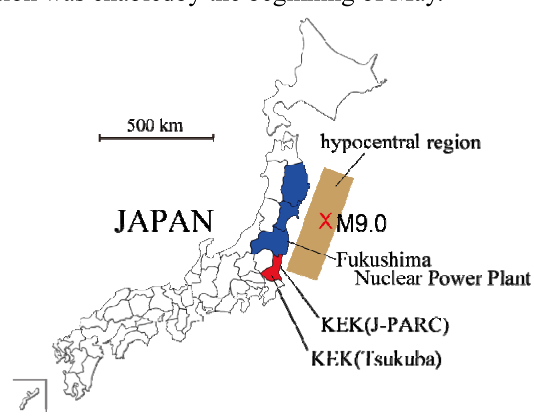

Figure 1: Epicenter and the hypocentral region of the Japan earthquake and the location of KEK.

PF Ring

At 2.5-GeV storage ring, PF ring, several components of the beam duct were damaged. It was fortunate that no magnet in the storage ring was damaged.

Many electronic racks and tool boxes which were not fixed fell downin the machine room as shown in Fig. 2. We realized that the anchor bolts are effective to prevent the fall of racks even at a largest earthquake. All the electronic racks that had no anchors were fixed at once.

A formed bellows in the ceramic duct of the wall current monitor was torn as shown in Fig. 3. The ceramic duct was installed next to the gate valve of the RF cavity section. In the RF section, the gate valves and sputter ion pumps were suspended using springs. Flexible support was likely to increase the rolling of these components. Then the formed bellows led to buckling and the supportrods of a welded bellows that tied the RF cavities were distorted. Rigid supports have been attached to all the components in the RF section after the earthquake.

At the 3.11 earthquake, the user operation had just been stopped on the morning of the same day, and all the gate valves in the storage ring and in the frontends had already been closed. During the blackout continuing for two weeks, the compressed air of the gate valve was completely lost and some gate valves could not keep the vacuum seal. As a result, almost half of the storage ring was exposed to air by the vacuum leak at one place.

Figure 2: Many electronic racks and tool boxes which were not fixed fell down.

By helium leak detection, a slow leak was found at the welding of the aluminium duct of the superconducting wiggler. The aluminium duct was tightly surrounded by lead blocks to protect machine components from the hard X-ray emitted from the wiggler. The rolling of the heavy lead blockswas likely to add an excessive stress to the aluminium duct. The leak of the welding was temporarily repaired using a liquid vacuum sealer.

In the beam operation from May to July, abnormal vacuum pressure rise occurred when the single-bunch high-current beam was stored. No leak was found by the helium leak detection. During a vacuum intervention, thermal damage was found at the elastomer O ring of an RF-shield gate valve. The movement of the RF shield mechanism became imperfect and the abnormal heating occurred in the gate valve. It was certainly an aftereffect of the earthquake.

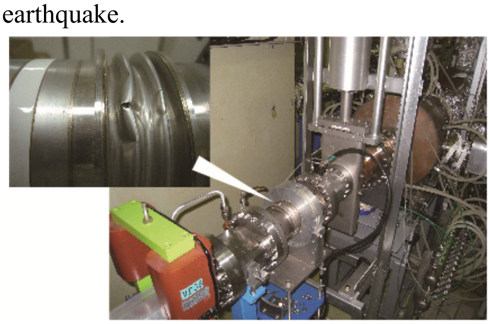

Figure 3: Formed bellows buckled and was torn.

The results of the magnet level survey after the earthquake are shown in Fig. 4. The magnet level surveyed twice in April and in July. For acomparison, the vertical displacement in a year from 2008 to 2009 is also drawn in the figure. Typically the vertical displacement of the magnets is less than 0.1 mm a year. In the survey in April, a depression of as large as 0.6 mm was observed in the right (east) half of the ring. It was recognized from the survey in July that magnet level moved 0.2 mm to 0.4 mm in three months. The large depression in the east half had a tendency to recover naturally. The alignment of ring magnets is being accomplished in August.

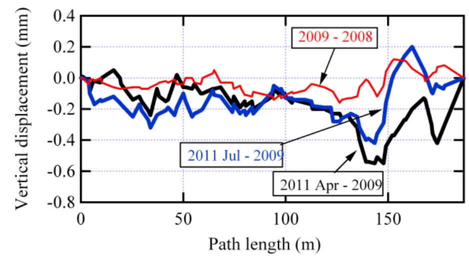

Figure 4: Vertical displacement of PF-ring magnet.

At first when we resumed the beam injection to PF ring, the injection beam loss was abnormally high without modification of the injection parameters and the injection orbit. In the beam transport line, misalignment of the order of 5 mm was found.One of two septum magnets had moved by 5 mm as the anchor bolt became loose. The alignment of the beam transport is also being accomplished in August.

PF-AR

PF-AR, a 6.5-GeV storage ring, is installed in the tunnel, 5 m below the ground. It was also fortunate that no magnets of the storage ring were damaged and the beam ducts kept the vacuum after the two-week blackout. No vacuum leaks were found in bellows, vacuum flanges and ceramic ducts just after the earthquake. But in the summer maintenance, a vacuum leak occurred at an all-metal gate valve. It is probable that the damage of gate valve is an aftereffect of the main earthquakes and many aftershocks occurred during this half year.

Many cracks were found on the wall at the expansion joints of the ring tunnel. At some of these cracks, inflow of groundwater increased temporarily. At the main earthquake on March 11, muddy water spouted out from a floor crack at the expansion joint. The mud splashed onto the top of several magnets and the beam duct near the expansion joint as shown in Fig. 5.

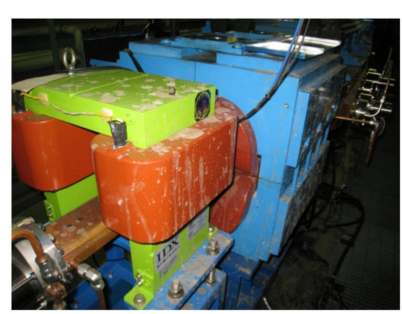

Figure 5: Muddy water spouted out from a crack on the floor of the PF-AR tunnel.

The increase of groundwater flow was observed commonly in the underground tunnels of 8-GeV LINAC and beam transport lines. Draining the water from the tunnel was one of serious problems after the earthquake. The quantity of groundwater flow gradually decreased to the normal level in a few months at PF-AR.

The results of the PF-AR magnet level survey after the earthquake are shown in Fig. 6. The vertical displacement in a year from 2008 to 2009 is also shown as a reference. The survey in April shows multi peaks of over 0.5 mm. The red straight lines indicate the location of the expansion joints of the tunnel. Most peaks appeared on the expansion joints. It is interesting that these peaks almost disappeared in the survey in July. Although the magnet alignment has not been accomplished yet, the magnet level near the expansion joints recovered naturally in four months after the earthquake.

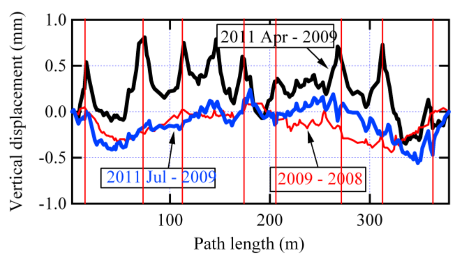

Figure 6: Vertical displacement of PF-AR magnet.

OPERATIONAL STATUS AND DEVELOPMENT

In Table 1 and Table 2, operational statistics and the mean time between failure (MTBF) of PF ring and PF-AR for recent four years are listed. As March 11 was the last day of the user operation in the FY2010, only the data before the earthquake are reflected in these statistics. The MTBF has been kept at high around 200 h in recent years at PF ring.

Table 1: MTBF of PF Ring

Fiscal year	2007	2008	2009	2010
Total operation time (h)	5104	5000	4976	5064
Scheduled user time (h)	4296	4032	4008	4080
No. of failures	23	18	24	18
Total down time (h)	91.1	23.8	42.7	29.2
MTBF (h)	186.8	224.0	167.0	226.7
Mean down time (h)	4.0	1.3	1.8	1.6

At PF ring, the top-up operation began in April 2009. A new injection method using a pulsed sextupole magnet (PSM) [1] has been developed and put into practical use from January 2011. The PSM is suitable for the top-up injection because the disturbance to the stored beam can be very small. A record of the beam current for a 6 day user operation is shown in Fig. 7. The stored current was stabilized within ±0.01% of 450 mA usually. When the top up injection was disturbed twice a day because of the injection to PF-AR, the beam current decreased by 2 to 10 mA depending on the disturbed period of time.

Table2: MTBF of PF-AR

Fiscal year	2007	2008	2009	2010
Total operation time (h)	4561	4969	5063	4608
Scheduled user time (h)	3624	4344	4392	4032
No. of failures	60	40	41	74
Total down time (h)	45.2	41.7	91.0	73.7
MTBF (h)	60.4	108.6	107.1	54.5
Mean down time (h)	0.8	1.0	2.2	1.0

A rapid-polarization-switching source is being developed at the PF-ring. It consists of two variably polarizing undulators and a fast local bump system using five identical bump kickers. In order to realize a specification of the switching frequency 10 Hz, the studies to control the local bump and to suppress the orbit leakage outside the local bump are in progress [2].

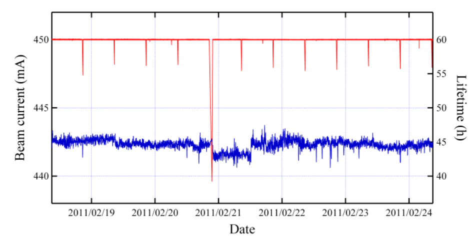

Figure 7: Top-up operation of PF ring.

The MTBF of PF-AR is rather shorter than that of PF ring. PF-AR needs a ramp up from 3 GeV to 6.5 GeV at every injection, and the top-up operation cannot be applied. One of the reasons that limit the MTBF is a sudden lifetime drop attributed to dust trapping.The dust trapping occurs about once a week during the user operation. In an experimental study to reproduce the dust trapping phenomena in PF-AR, trapped dust could be observed as a moving luminous body using a CCD camera [3]. We continue trying to settle the dust trapping phenomena.

SUMMARY

PF ring and PF-AR suffered various damages by the large earthquake on Mar 11. The trial beam operation was successfully accomplished from May to July. The maintenance and the magnet alignment are being continued in summer. We will recover the regular user operation from October, 2011.

REFERENCES

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