QUICK RECOVERY OF THE KEK E-/E+ INJECTOR LINAC FROM THE GREAT EAST JAPAN EARTHQUAKE

Atsushi Enomoto, -KEK, Tsukuba, Japan

Abstract

The KEK 8-GeV e-/e+ injector linac is currently under operation for the 2.5-3 GeV KEK Photon Factory (PF) storage ring and 6-GeV Photon Factory - Advanced Ring (PF-AR). In addition the linac had just started the upgrade for the SuperKEKB project since the summer in 2010. On March 11, 2011, the linac suffered great damage from the Great East Japan Earthquake. Due to an extraordinary strong vibration, many bellows of vacuum pipes were violently torn and the entire linac vacuum was exposed to the atmosphere. Without electricity, highly humid air entered the inside of accelerator structures. Some people supposed the linac would not be recovered within a year. However, it resumed operation after only two months. We record the memorable disaster and the valuable experience how we recovered the linac so quickly.

INTRODUCTION

The KEK linac was initially constructed as a 2.5-GeV electron injector for PF (1978–1981), adding a positron source for TRISTAN (1982–1984), and further upgraded to provide 8 GeV electrons (e-) and 3.5 GeV positrons (e+) for KEKB (1994–1998). It has been operated for 5000-7000 hours annually since 1982. In FY2010 it again entered into a construction phase for SuperKEKB, while continuing the operation for PF and PF-AR. The PF and PF-AR injection is conducted by using the downstream part of the linac, which is isolated from the upstream by a thick radiation-shield concrete wall and can accelerate electrons up to ~3 GeV. In FY2011 the most severe and tough work was the recovery of the linac from the East-Japan earthquake happened on March 11, 2011. The PF and PF-AR injections were successfully resumed after two months by quickly repairing the downstream linac, though the upstream part is still under restoration because of severe damages along the entire length (~600 m) of the linacs.

QUAKE AND FIRST ACTION FOR RECOVERY

The peak earthquake strength was 6-lower in the Japanese scale which has been never experienced so far, and strong oscillation lasted nearly five minutes. The acceleration of the ground motion was recorded 0.3 – 0.4g in Tsukuba. Just after the quake went away a visual investigation was initiated in the darkness without electricity. And it was immediately turned out the linac was caused heavy damages: In the accelerator tunnel there were many vacuum bellows torn hardly, broken girders, a quadrupole magnet dropped down to the floor (Fig.1), inflow water coming from the tunnel joints and spilled over the floor, etc.

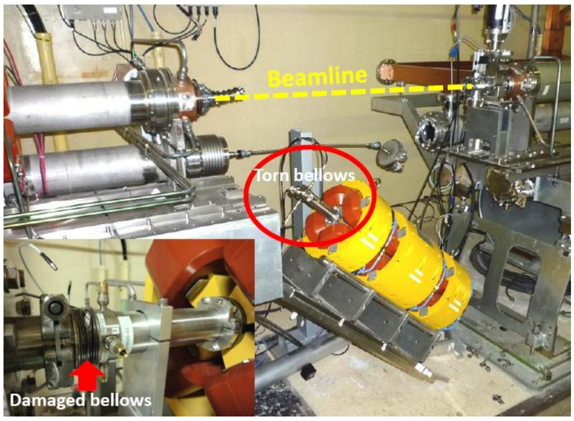

Figure 1: The linac damage in accelerator tunnel.

Figure 2: Inflow water into the tunnel.

Figure 3: The linac damage in klystron gallery.

The damages were found more as the investigation went on; and, the mostly feared thing was that ~240 pieces of accelerator sections in the tunnel were supposed to be damaged because they were purged to a very humid atmosphere under the non-ventilated condition with inflow water. The high-gradient performance of accelerator guides might be degraded if inner surface becomes eroded; in a worst-case situation, they might be unusable if metallic dusts flying from torn bellows enter inside. Therefore, it was an issue of vital importance that the atmosphere inside the accelerator guides was evacuated as soon as possible. Taking account of this concern, the following procedures were introduced:

(1) The first action was, for all of the accelerator guides, to make "nitrogen purge" (to purge wet atmosphere inside accelerator by dry nitrogen).

(2) Recovery of the downstream part was prioritized in order to quickly resume the PF and PF-AR injection.

(3) The remaining part of the linac (the upstream 5 sectors) is then recovered for the SuperKEKB injector by the end of FY 2014.

TOWARDS OPERATION

The next step is to resume the linac operation. The vacuum should be recovered to an operation level (< 10-4) and the entire beamline must be established. To repair beam position monitors (BPMs) was one of the critical works. The broken bellows were removed using a lathe and new ones were welded. To save time it was carried at KEK workshop. After a performance check the BPMs were incorporated into the beamline. Iterations of vacuum leak search and its repair were continued. Due to an extended damage of vacuum components, it took one month to fix the downstream 3 sectors. In addition to the vacuum recovery, the accelerator girders were reinforced. The standard accelerator girder mounts four 2-m accelerator sections with service equipment such as waveguides, a vacuum manifold, and a cooling-water header. The net load is ~2 tons. It adopted a quake-absorbing structure with damper. After the quake, it was found it has a resonance frequency at around 3.5 Hz in longitudinal direction. Since the resonance is supposed to enhance the damage the immediate improvement was required. The girder oscillation is restricted with a massive stopper at the mid-bottom instead of the damper. By the end of April infrastructure necessary for the linac operation was recovered. The inflow water was suppressed by grout injection into the tunnel joints. Then the linac was conditioned with high-power RF up to an operational strength. The PF and PF-AR injections were resumed on May 16 and July 1, respectively..

"Nitrogen replacement" takes the process as follows: After the broken components are replaced, the accelerator is roughly evacuated. When the vacuum pressure can reach ~1 Pa, then it is purged with dry nitrogen (~0.1 MPa = ~1 atom). Though the linac recovery was prioritized over the other facilities at KEK, it was initiated under the limited condition of infrastructures, such as electricity, compressed air, and cooling water. Nevertheless, it was done within two weeks, since this task was addressed by a support from outside of injector vacuum groups.

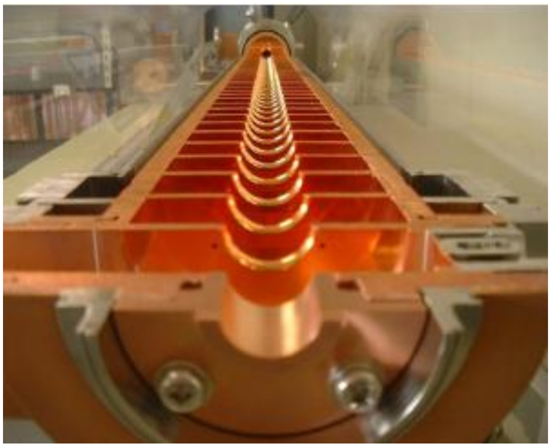

Figure 4: A cut-view of 2-m accelerator section.

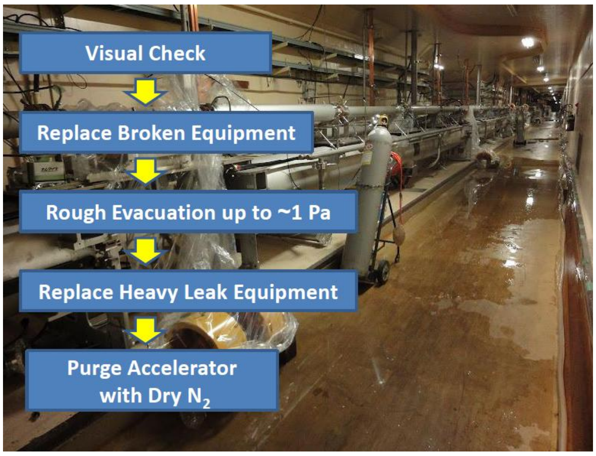

Figure 5: The linac vacuum purge with dry nitrogen.

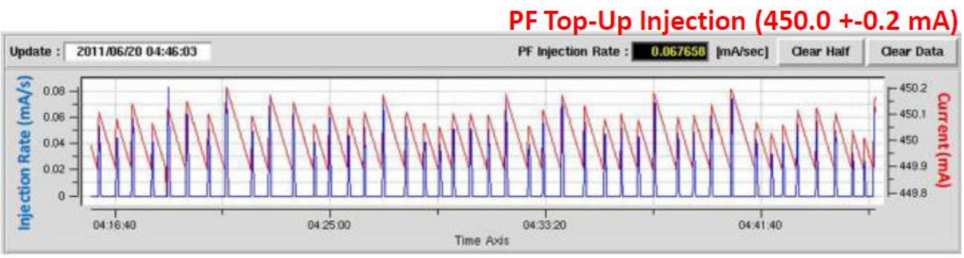

Figure 6: Accumulation current and rate of the PF storage ring.

THE ENTIRE LINAC RECOVERY

The upstream recovery necessary for the SuperKEKB upgrade was started on July 2011 and is still continuing while operating PF injections. For this purpose, it is really helpful that the upstream part had been separated by thick concrete wall in FY 2010. In the upstream part, many accelerator girders are put on square logs because their support legs are left broken. The beamline among them are not repaired. Thefore, the vacuum recovery of the upstream 40 accelerator units were made by isolating them from the beamline. Thus the accelerator vacuum was finally recovered by the end of November. A high-power test was finished by mid December and it turned out that the accelerator did not have a severe damage. It is planned the entire beamline will be restored before FY2014 when the linac commissioning for SuperKEKB start.

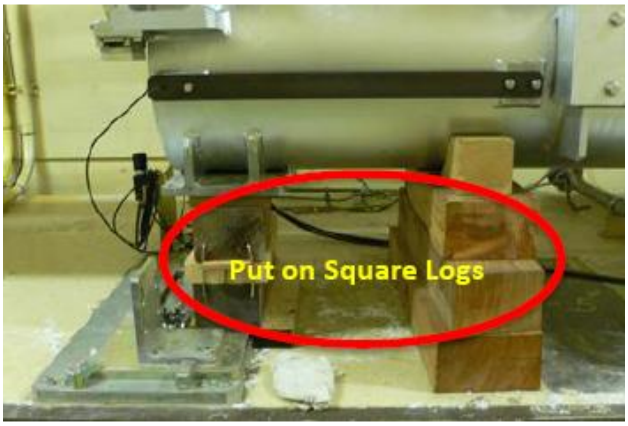

Figure 7: Broken girders are put on square logs.

Figure 8: Beamlines are not yet connected (upstream).

UPGRADING TO SUPERKEKB LINAC

TheThe R&D for upgrading the linac for the SuperKEKB was resumed in parallel. During the two-months summer shutdown in 2011, an RF gun system was installed just after the thermionic electron gun for the PF injections. It is a new type employing a disk-and-washer (DAW) structure for the accelerating cavity and LaB6 for the photo-cathode material. The beam-test is conducted using the linac machine-study time. The beam with an intensity of about 0.5 nC/bunch could be successfully accelerated to the end of the linac. Increasing and stabilizing the beam intensity is under investigation. For the positron source, a flux concentrator will be used because more intense magnetic field is necessary to increase positrons. For this purpose a conventional system which is already used in other laboratories will first be used and a new type to produce more intense field is under R&D. Together with strengthening the focusing field, the aperture of the positron capture sections will be expanded. An L-band accelerator section was fabricated and is presently ready for the high-power test in the following fiscal year

Figure 9: RF-gun studies underway downstream of linac.

ACKNOWLEDGMENT

The author thanks to the injector linac people who committed to the hard recovery work as well as the people who helped us, especially for the linac vacuum recovery and alignment.

REFERENCES

[1] T. Higo, “Linac upgrade in intensity and emittance for SuperKEKB”, IPAC2012 (this conference), TUPPR005.