PROGRESS OF 7-GeV SuperKEKB INJECTOR LINAC UPGRADE AND COMMISSIONING

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Abstract

KEK injector linac is being upgraded for the SuperKEKB project, which aims at a 40-fold increase in luminosity over the previous project KEKB. SuperKEKB asymmetric electron and positron collider with its extremely high luminosity requires a high current, low emittance and low energy spread injection beam from the injector. Electron beams will be generated by a new type of RF gun, that will inject a much higher beam current to correspond to a large stored beam current and a short lifetime in the storage ring. The positron source is another major challenge that enhances the positron bunch intensity from 1 to 4 nC by increasing the positron capture efficiency, and the positron beam emittance is reduced by introducing a damping ring, followed by the bunch compressor and energy compressor. The recent status of the upgrade and beam commissioning is reported.

INTRODUCTION

The electron positron injector linac at KEK has delivered electrons and positrons for particle physics and photon science experiments since 1982. It has been rejuvenated since 2010 towards SuperKEKB collider, which aims at a 40-times higher luminosity over the previous KEKB project in order to increase our understanding of new physics beyond the standard model of elementary particle physics [1]. SuperKEKB asymmetric electron and positron collider with its extremely high luminosity requires injection beams with high current and low emittance in transverse and longitudinal directions [2].

Many hardware components will be installed this year in order to deliver beams to the electron and positron accelerator complex (Fig. 1).

ELECTRON BEAM DEVELOPMENT

The low emittance and high charge electron beam is generated with photo-cathode RF guns. High power laser was constructed with an Yb-doped fiber oscillator, several stages of fiber amplifiers and Nd:YAG thin-disk multi-pass amplifiers [3, 4]. An Ir_5Ce cathode shows stable quantum efficiency. And a quasi-travelling wave side-coupled cavity (QTWSC) accelerates electrons with high electric field to avoid space-charge effect. It has successfully injected the beam into the SuperKEKB high-energy ring (HER) at about 1 nC per bunch for 10 days during the Phase-I commissioning in 2016. The beam charge is gradually increased towards the 5-nC target in the Phase-III commissioning. The beam charge stability is also improved to be about 3% rms.

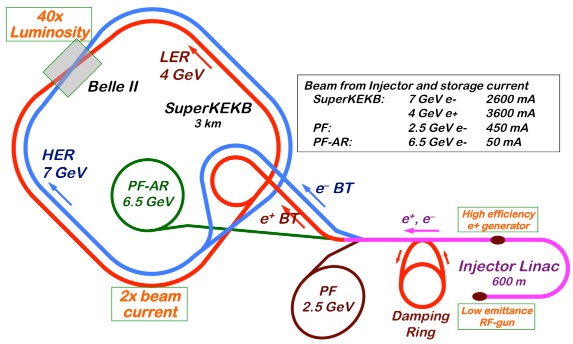

Figure 1: Layout of electron/positron accelerator complex.

In order to increase the availability, a new 90-degree RF-gun was constructed (Fig. 2). It is equipped with a newly designed cutdisk structure to have a larger aperture to accept a frontal laser injection, and Ir_2Ce cathode for higher conversion efficiency (Fig. 3).

As the beam quality management is so important that it is investigated with beam instrumentations for laser and

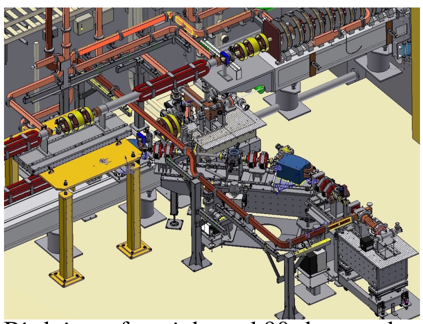

Figure 2: Birdview of straight and 90-degree photo-cathode RF-guns and a thermionic gun at the top.

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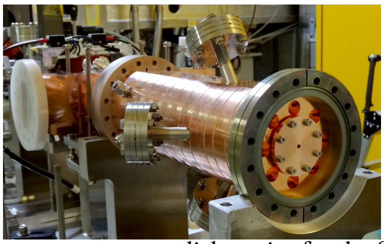

Figure 3: Large aperture cutdisk cavity for the 90-deg gun.

the beam at several places comparing with the simulation results [5, 6].

A thermionic gun is maintained for high-charge 10-nC primary electron beam in order to generate positron beam. The beam optics was analyzed and corrected at the 24-degree merger beamline. The bending magnets will be replaced with pulsed bending magnets to switch beams at 50 Hz as described later.

POSITRON BEAM DEVELOPMENT

The high-current positron beam is generated with a 14-mm thick tungsten target, a flux concentrator (FC), large-aperture S-band structures (LAS), series of solenoid magnets, and so on (Fig. 4, 5) [7]. The FC experienced a severe discharge in 2015 and the magnetic field was degraded. A new FC was fabricated with hardening process (Fig. 6), and long-term off-line processing was performed. A retraction mechanism for the FC assembly was designed and constructed to improve the availability.

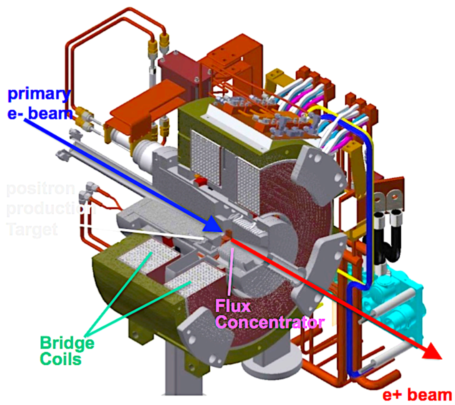

Figure 4: Flux concentrator assemply.

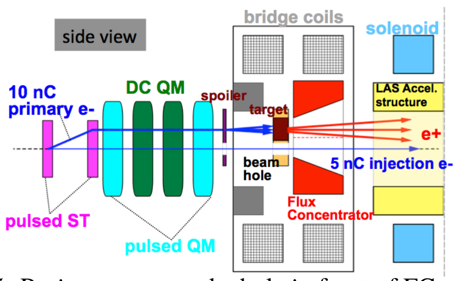

Figure 5: Positron target and a hole in front of FC and LAS.

A positron damping ring (PDR) is being constructed to damp the positron beam emittance. An energy compressor and a bunch compressor with S-band RF power modulators will be installed on the beam transfer lines before and after PDR in order to match the beam bunch between the linac and the ring. Beam instrumentation and beam bunch synchronization scheme are constructed carefully as well to optimize the overall beam delivery performance.

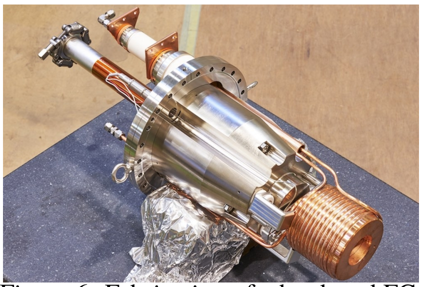

Figure 6: Fabrication of a hardened FC.

PULSED MAGNETS

In the previous KEKB project, injection beams were pulse-to-pulse modulated with moderate beam optics, and optics matchings were performed at corresponding beam transport lines [8]. However, for SuperKEKB injection the precise beam orbit and optics management is necessary within 0.1 mm in order to suppress the emittance blow-up [6].

Small form-factor (3U) power supplies were developed for quads with advanced design of specifications of 1 mH, 330 A, 340 V and 2-ms pulse width with recovery of energy from the magnetic coils up to 75%. The same pulsed power supplies are used to drive bending magnets to switch beams from a thermionic gun and RF guns. Power supplies for steering magnets were designed as well for 3mH and 10A. Girders were also designed in-house which is ready for 0.1-mm alignment in Phase-III commissioning (Fig. 7).

Those power supplies were designed with 0.5-ms flat top, and need pre-trigger before 3 ms before the beam. Such timing signals can be directly generated for SuperKEKB beams because linac and rings are tightly synchronized. It is, however, complicated to generate timing signals with a long

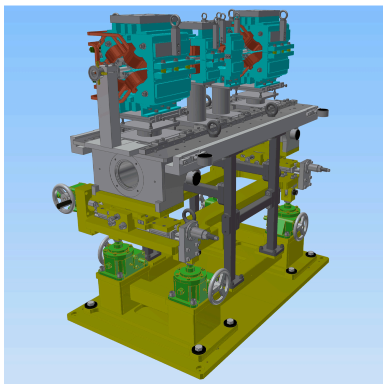

Figure 7: Girder design with precise alignment movers.

delay for light sources, because those rings are injected on accidental timing coincidence and those rings compensate the circumferences changing RF frequencies. The timing generation algorithm was developed to prepare pre-trigger and was confirmed.

Those pulsed magnets were examined at a test stand for a long term up to two months continuously in 50 Hz, and were confirmed to satisfy the specification of 0.1% (rms) stability (Fig. 8). They were also confirmed to operate at pulse to pulse with beams in 2016. Pulsed magnets of 30 quads, 2 bends and 36 steerings will be mass-produced and installed during 5-month shutdown in 2017.

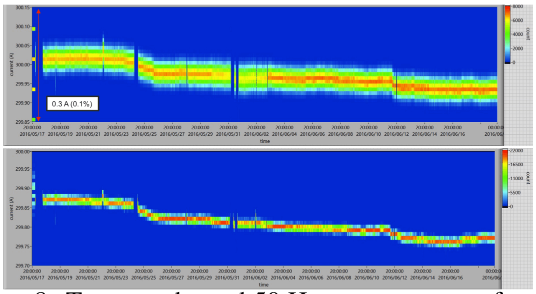

Figure 8: Two months and 50 Hz measurement of pulsed magnet stability.

SIMULTANEOUS INJECTION

Newly installed equipment and monitors are designed to operate at 50 Hz. They will be operated through event-based, global and synchronized controls in order to inject beams with different properties into four separate storage rings simultaneously [8, 9].

A single injector linac would behave as four virtual accelerators operating independently with hundreds of independent parameters modulated pulse by pulse at 50 Hz (Fig. 9). A new beam transport line for PF-AR direct injection helps this concept not to interfere between PF-AR and SuperKEKB HER, which shared the same beam transport line in the KEKB project [10].

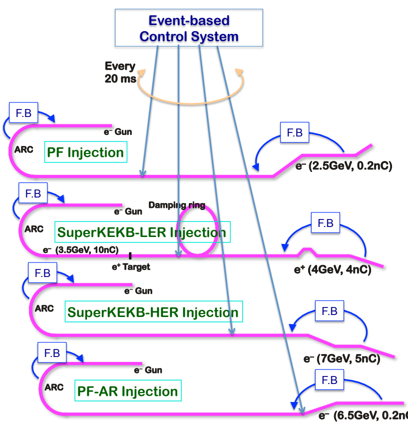

Figure 9: Single linac behaves as four virtual accelerators to inject their beams into four separate storage rings.

CONCLUSION

Overview of the schedule is depicted in Fig. 10. We have successfully performed light source injections even during constructions for SuperKEKB as well as the large earthquake recovery. We will soon initiate the Phase-II commissioning with much advanced fabrications, simulations and beam studies. Remaining equipment for SuperKEKB will be installed during 5-month long shutdown in 2017 just before the Phase-II commissioning. While we may still face certain challenges, they would be resolved with careful analysis.

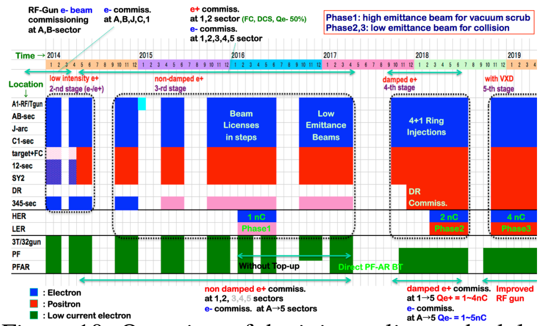

Figure 10: Overview of the injector linac schedule.

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