KEK 電子陽電子入射器の現状

PRESENT STATUS OF KEK ELECTRON/POSITRON INJECTOR LINAC

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Abstract

SuprKEKB project aims at a 40-fold increasement in luminosity over the previous KEKB project, in order to promote the understanding of flavour physics beyond the standard model of elementary particle physics. Hence, injector must have the ability to generate high charge electron and positron beam with low emittance and low energy spread, in order to realize extremely high luminosity. The first stage of SuperKEKB Phase III commissioning has been accomplished successfully in this July. During in the spring run, stable electron beam with comparable low emittance and low energy spread, which generated by RF gun, is injected into the high energy ring (HER) of SuperKEKB. More than 3 months continuous and stale electron injection is realized with low injection noise and low background. The positron beam is produced with updated positron source and damping ring. With the purpose of realizing stable injection, energy feedback system is also installed in the stage. Meanwhile, simultaneous top-up injections for 4 rings is realized firstly time on the basis of high-performance pulsed magnets. As result, integrated luminosity is improved largely. Unfortunately, a fire accident occurred in this April so it took three weeks to recover. The present status of SuperKEKB injector is introduced in this proceeding.

OPERATION AND PRESENT STATUS OF INJECTOR LINAC

In order to generate high quality electron and positron beam for SuperKEKB, as well as improve the injection efficiency and utilization for PF and PF-AR, improvements and updates have been done in injector linac. High charge electron beam with comparable low emittance is generated by RF gun, which is driven by more powerful and stable laser system. Long life time photocathode with higher quantum efficiency is adopted. Updated positron capture ensures the generation of high charge positron beam with qualified emittance and energy spread. With the assistance of damping ring, the positron beam is injected and stored in low energy ring (LER) successfully. For realizing four rings (HER/LER/PF/PF-AR) simultaneous injection, high performance pulse magnets are installed. Besides these, energy feedback and beam orbit feedback, as well as dispersion measurement and correction have been applied

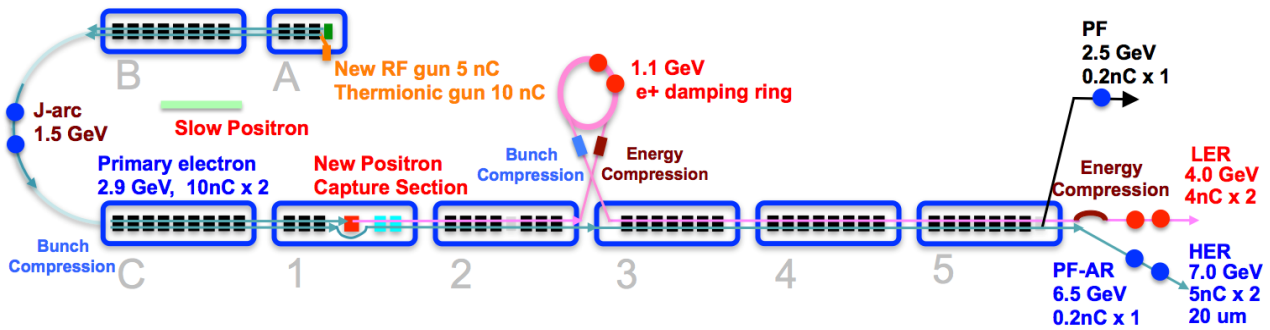

Figure1: Schematic layout of the SuperKEKB injector linac.

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during the operation of injector linac. With all the improvements, the new peak luminosity record, 122.9 × 10^{32} $cm^{-2}s^{-1}$, is achieved during the SuperKEKB 2019 spring run [1]. Meanwhile, full RF gun electron beam injection for HER is also realized for the first time. Most worth mentioning is the achievement of simultaneous top-up injections for 4 rings for the first time in history of injector linac.

The schematic layout of injector linac is shown in Fig. 1. Injector linac consists of 9 parts, they are A-Sector, B-Sector, J-ARC, C-Sector, 5 sectors from 1 to 5. Currently, 3 electron sources are installed at A1 injection point. One is thermionic gun, it generates electron beam for positron target, PF and PF-AR. The other two are RF gun, which are used to generate the electron beam with low emittance and low energy spread for SuperKEKB. Two bunch electron beam operation mode is available under 50 Hz repetition rate. The 10 nC electron beam generated by the thermionic gun is impinged into the target that is located in 1-Sector. The positron production target is made of tungsten because of its large cross section of the electron-positron pair creation and its high melting temperature. Generated positron is captured by a high efficiency flux concentrator and sent to the damping ring to reduce the emittance by radiation. There is a hole in the positron target for electron pass which are used for the injection of HER, PF and PF-AR. Depending on the pulse magnets in 5-Sector, the electron beams for different ring injection can be switched to different beam lines flexibly.

OPERATION STATISTICS (FY2018)

In FY2018, injector linac operated from April to July, after 3 months summer maintenance, the operation started again from October. In order to prepare for the 2019 spring run of SuperKEKB, the operation started up from January. Figure 2 and Fig. 3 show the operation time and machine failure. The operation time of FY2018 is 5284 hours, and the machine failure rate is about 2.71. Compare to the data of last year, the operation time increased while the machine failure is comparable low. It demonstrates that all the improvements are effective for the stable operation in phase III commissioning.

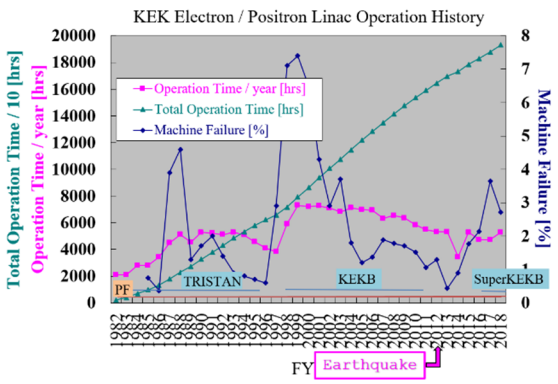

Figure 2: Operation time and machine failure.

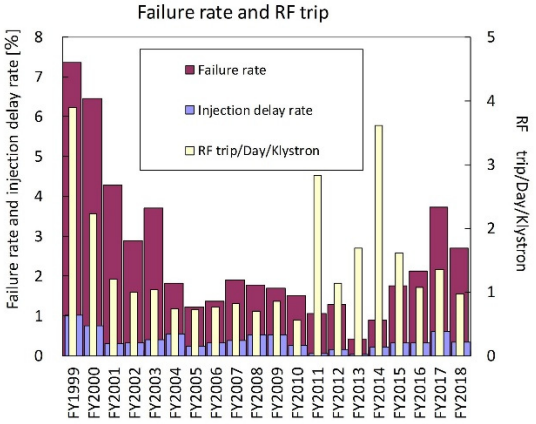

Figure 3: Failure and injection delay rate.

IMPROVEMENT AND UPDATE OF LINAC INJECTOR

During the 2018 summer and winter maintenance, several meaningful improvements and updates have been done at injector linac. By right of these improvements and the efforts of all the injector linac stuffs, some major achievements have been accomplished.

RF Gun and Drive Laser System

The layout of RF gun and thermionic gun is shown in Fig. 4. The thermionic gun is installed in the second floor for preserving the better emittance of electron beam generated by the RF gun. the primary RF gun with QTWSC configuration is installed in the beam line that is applied in 2018 all the year, a secondary RF gun is located in the 90-degree line.

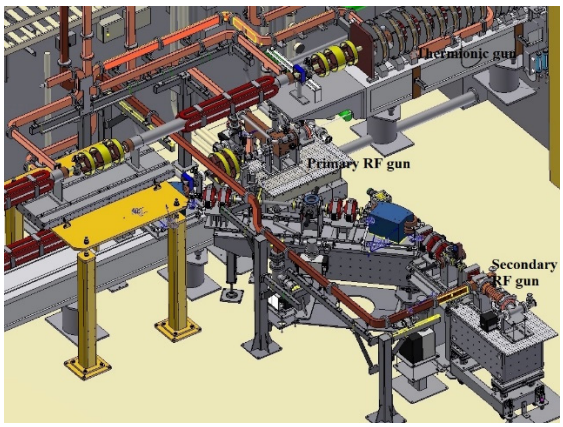

Figure 4: Layout of electron source section.

The RF gun drive laser system used in the 2019 spring run is almost the same as the one which was used in phase II operation [2]. In order to realize stable and continuous operation, the Yb/Nd hybrid laser system is updated in 2018 summer maintenance. Higher gain laser crystals are used to generate higher electron charge [3]. Temporary reshaping components are installed for low emittance.

Meanwhile, the application of more monitors in the laser system helps check the real-time laser status during operation. In addition, photocathode with higher quantum efficiency is adopted, which can be cleaned by electron beam heating. Currently, the highest charge of 5.3 nC is generated successfully. Stable and continuous 1.3 nC electron beam is achieved for 2019 spring run from the 1st day to the end without any problem occurred. Full RF gun operation for injection of HER is realized for the first time until now. In the following days, reshaping of laser pulse in temporal and spatial domain will be investigated for the generation of stable higher charge electron beam with lower emittance and lower energy spread [4].

Positron Source and Damping Ring

For the purpose of high luminosity for SuperKEKB, it is necessary to generate positron beam with high charge low emittance. At the same, in order to realize high injection efficiency with low injection noise, qualified emittance is crucial. High current positron generator and damping ring are used to generate the qualified positron beam for the LER of SuperKEKB. The positron generator is shown in Fig. 5.

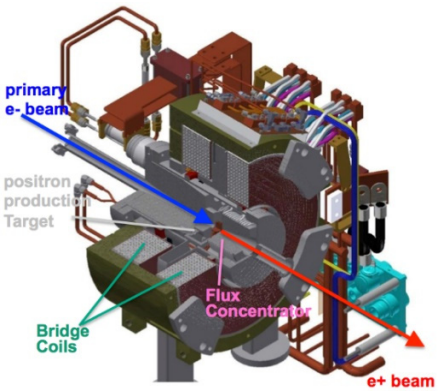

Figure 5: High current positron generator.

After the positron target, a flux concentrator (FC) which provides an external magnetic field is applied to increase the positron yield. A new FC was installed in January 2019 for the spring run of SuperKEKB. The new FC without work hardened is tested at 12 kA at test bench. During the first stage of phase III, for stable and continuous operation, 3.5 kA is applied and there is no damage occurred until now. Development has been being done for new FC to supress the discharge risk by use of copper alloy and Insertion of insulators in the slit. Update of positron source will be done in 2020 summer maintenance [5].

The damping ring is used to optimize the emittance of positron for better injection. Event-based control system for injection and extraction of positron beam, energy compress for injection, bunch compress for extraction work well. Meanwhile, the monitoring system for optimization of damping ring performance is stable, such as beam position monitors, synchrotron radiation monitor and wire scanners.

Pulse Magnets and Achievement of 4 Rings Simultaneous Top-up Injections

In order to realize 4 rings simultaneous top-up injection, the pulse magnets are applied at injector linac. In 2017, pulsed steering magnets and quadruple magnets had been installed from 3 to 5-Sector. In addition to this, a motor-controlled magnet support system is developed and installed, as shown in Fig. 6. Position of the support is monitored and feedbacked by six linear gauge with 10 μm precision. Alignment and beam tuning with this system are in progress [6].

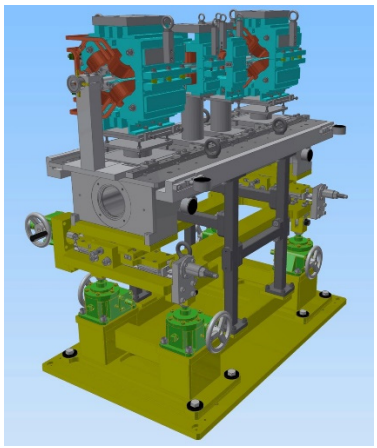

Figure 6: Motor-controlled magnet support system for 2 pulsed steering magnets and 2 pulsed quadruple magnets.

In 2018 summer and 2018 winter maintenance, pulsed magnets are installed in A, B and J-arc. Especially for the 24-degree merge line at A-Sector, pulsed bending magnets are used to do pulse to pulse switching for RF gun electron beam and thermionic gun electron beam [7]. This is the foundation to realize 4 rings top-up simultaneous injections. The pulsed magnets around merge point at 24-degree line at A-Sector as shown in Fig. 7.

Figure 7: Pulsed magnets at the merge point of A-Sector.

Depending on all of these contributions, 4 rings top-up simultaneous injections is achieved in 2019 spring run for the first time, as shown in Fig. 8. While compensating the beams with short life-time of SuperKEKB, the injections

for PF and PF-AR are operated simultaneously and independently. Thanks to this, the integrated luminosity of SuperKEKB is improved by 237% during the simultaneous injections [8]. The stored current situation in 4 rings during the top-up simultaneous injections is shown in Fig. 9.

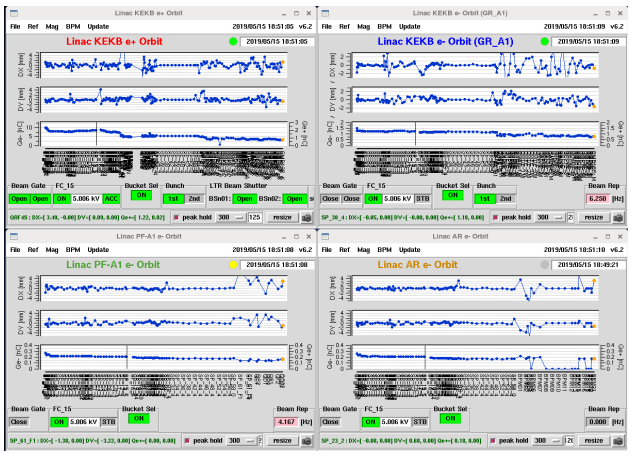

Figure 8: Injection orbits during 4 rings during the top-up simultaneous injections by RF gun electron beam and thermionic gun electron beams.

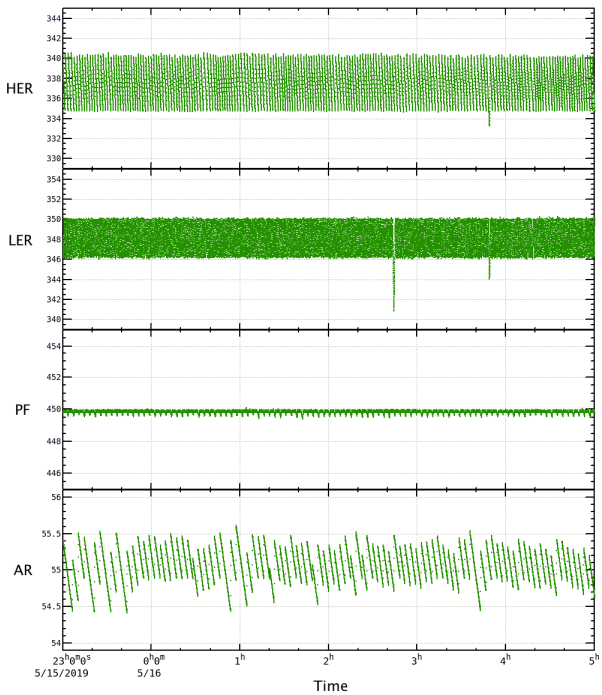

Figure 9: Stored currents in 4 rings during the top-up simultaneous injections.

Dispersion Correction and Orbit Feedback

With the purpose of realizing stable and effective electron beam and positron beam injections for HER and LER, some novel feedback and correction systems are applied in this spring run [9].

Because the beam position jitter has been found that is caused by the serious horizontal dispersion leakage from J-arc, the dispersion measurement and correction system is developed and applied. As shown in Fig. 10, before the correction, the dispersion is strong comparing with the design value. By tuning the strength of quadrupole magnets in J-arc, the residual dispersion is well corrected Meanwhile, a beam orbit feedback is also available. As shown in Fig. 11, a BPM at the end of linac shows the orbit. When the feedback is on for injector linac end, the orbit drift of the positron beam is corrected to be about 0.1 mm, while the previous orbit drift is about 1 mm. It is worth mentioning that the beam orbit feedback can be applied to any point at injector linac, and it will be deployed to J-arc sector upstream from next stage.

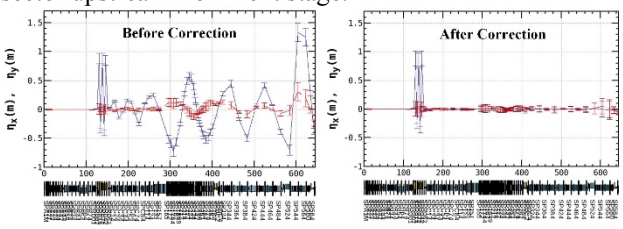

Figure 10: Dispersion measurement and correction.

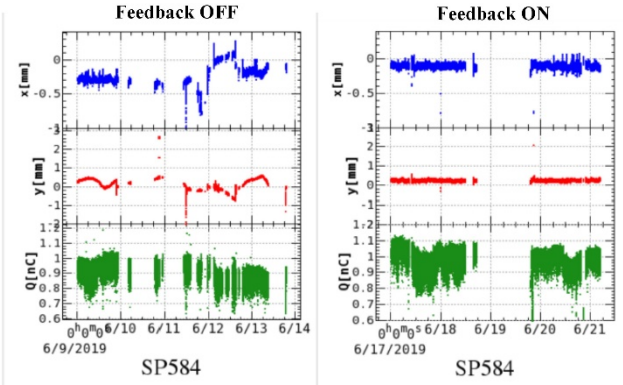

Figure 11: Beam orbit feedback at the end of linac for the positron beam.

Fire Accident and Recovery

Figure 12: Location of fire occurred (red rectangular shows the accelerating structure assembly room).

A fire accident occurred on 4th April 2019 in accelerating structure assembly room, as shown in Fig. 12. The most likely cause is puncture of plastic-case capacitors in modulator. There is no injury in this fire accident [8].

The injections for 4 rings had to be stopped until the recovery on 22nd April for 3 weeks. Although this is no direct damage to injector linac, carbon soot which are generated by the burnt everywhere could prevent high voltage operation of 60 high-power pulsed modulators, and high-precision operation of the injector facility. The partial clean-up is carried out for more than two weeks, the rest part will be done in the 2019 summer maintenance. After the clean-up, low-power and high-power test are performed successfully, and beam test also finished subsequently on 23rd April. Under the premise of ensuring that everything was ready, the injection for HER and LER started, and collision mode re-started on 26th. PF light source injection was started as originally scheduled on 7th May.

SUMMARY

Injector linac achieved the injection task successfully for the 2019 spring run of SuperKEKB and the operation for PF and PF-AR. Full time continuous and stable electron beam injection for HER is realized by laser and RF gun system. New FC is also working well without any problem occurred. Together with the damping ring, 1 nC positron beam is obtained at the end of linac. Application of pulsed magnets laid a solid foundation for the 4 rings simultaneous injection. With these efforts, 4 ring simultaneous top-up injections has been achieved successfully for the first time at KEK. Meanwhile, many flexible feedback systems are applied for achieving more stable and high-quality injections. Although a fire accident occurred in April, all the stuffs of injector linac worked together to overcome difficulties. The injector linac restarted to work after 3 weeks clean-up.

In order to generate high charge electron and positron beams with low emittance and low energy spread for the latter stages of SuperKEKB phase III commissioning, some improvements and updates have been being done from 2019. Temporal and spatial reshaping for the RF gun drive laser system will be done to get high quality electron beam. In addition, new laser system is under doing for more flexible adjustment. Novel copper alloy FC will be applied from 2020 to realize more stable and effective operation for the positron source. Furthermore, the feedback system will be deployed at J-arc section for low dispersion and stable beam orbit. All of them will greatly improve the performance of injector linac in the near future.

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