COMMISSIONING STATUS OF SuperKEKB INJECTOR LINAC

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Abstract

The Phase I beam commissioning of SuperKEKB started in this February. The injector linac has successfully delivered the electron and positron beams to the SuperKEKB main ring. The linac beam studies and subsystem developments are also intensively going on together with the daily normal beam injection to both ring s of the SuperKEKB and two light sources. The main new significant subsystems are a positron damping ring, a positron capture system, a pulsed magnet, and a low emittance photo-cathode rf electron source. In this paper, we report the present status of Phase I beam commissioning. In addition, the commissioning plans of Phase II and Phase III are also described.

INTRODUCTION

The KEKB project has successfully completed in the June of 2010 after more than decade long operation. During the KEKB operation, the injector linac provided the different flavors of electron and positron beams to four independent storage rings; KEKB e-, e+, PF, and PF-AR rings. The target ring for the beam injection can be switched in every time interval of 20 ms since the linac parameters of timing and low level rf phase can be arbitrary controlled up to 50 Hz for the simultaneous top-up injection of three rings excluding PF-AR. The achievement of simultaneous top-up injection made a strong impact on the great success of KEKB project. It improves the KEKB and PF stored current stabilities up to 0.05% and 0.01%, respectively [1].

For the SuperKEKB project, the injector linac upgrade has been progressed since the final stage of KEKB project [2]. Figure 1 shows the layout of SuperKEKB injector linac with the total length of 600 m. Here, the beam energy at the J-ARC section is decreased from 1.7 GeV to 1.5 GeV since the main ring energy of electron is changed from 8 GeV to 7 GeV as shown in Table 1. It is effective for grabbing a standby klystron in Sector A and B. For the SuperKEKB injector operation, the most challenging issue is the high bunch charge transportation of low emittance beam required to the nano-beam scheme operation of main ring. For the high intensity positron generation, the flux concentrator and 10 large aperture S-band accelerating structures have been manufactured and installed into the beam line [3, 4]. As a low emittance and high intensity electron gun, we have designed and installed a photo-cathode rf gun cavity based on a noble new scheme in the summer of 2013 [5]. In addition, a new laser system has been also developed [6, 7].

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INJECTOR LINAC UPGRADE ISSUES

Outline

Towards SuperKEKB injection, the first beam commissioning started in the October of 2013. At the beginning phase of beam commissioning, we mainly devoted the tuning of rf gun laser system for aiming at the high intensity bunch charge generation. We have already obtained the maximum bunch charge of 5 nC which is the require-

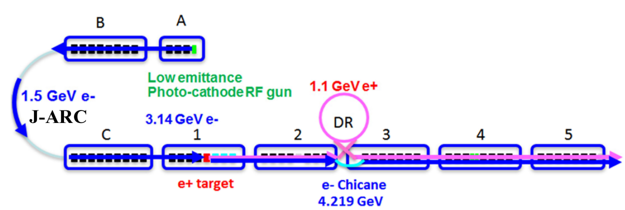

Figure 1: Schematic drawing of the SuperKEKB injector linac.

Table 1: Main Parameters of SuperKEKB Injector Linac

	KEKB		SuperKEKB (Phase III)	
	e-	e+	e-	e+
Beam energy (GeV)	8	3.5	7	4
Bunch charge (nC)	1	1 (10*)	5	4 (10*)
Normalized vertical emittance (mm·mrad)	100	2100	20	20
Normalized horizontal emittance (mm·mrad)	100	2100	50	100
Energy spread (%)	0.05	0.125	0.08	0.07
Bunch length (mm)	1.3	2.6	1.3	0.7
# of bunch	2			
Maximum beam repetition (Hz)	50			

*: Primary electron beam for positron production.

ment for the SuperKEKB Phase III operation. Although the both of electron and positron injection are generated by the photocathode rf gun in the original plan, it is not straightforward to generate the electron beam with the charge of 10 nC for positron production by the rf gun.

In order to pass the radiation control license examination and generate the positron production primary electron of 10 nC, the removed thermionic electron gun, a pre-buncher, a buncher, and two sub-harmonic bunchers have been reinstalled into the injector beam line in the May of 2015. The new beam line level of the thermionic electron gun has been changed from the original level of 1200 mm to the new one of 1950 mm as shown in Fig. 2 since the existing beam line is kept for a low emittance generation of the rf gun. At the downstream of second accelerating structure, the thermionic electron gun beam line is merged to the rf gun beam line by using two vertical bends with the bending angle of 24 degrees. Between two bends, a quadrupole triplet is situated for closing the vertical dispersion. The spare magnets were used for the beam line. The beam commissioning of this new thermionic electron gun beam line has successfully completed in the May of 2015. The second bend for merger line will be replaced by the pulsed bend for the future fast beam switching operation.

Low Emittance Preservation

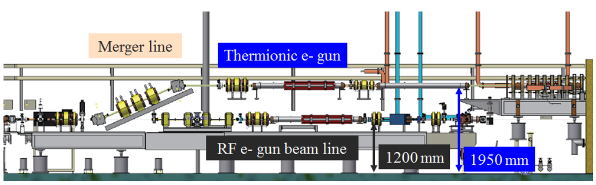

Figure 2: Current configuration of the injector beam line. The injector part was reconfigured for the reinstallation of thermionic electron gun in the May of 2015. The thermionic electron gun level is changed from 1200 mm to 1950 mm. Two bends with the bending angle of 24 degrees are used for merging with the rf gun beam line. The quadrupole triplet is used for closing the vertical dispersion.

The Phase I commissioning started in this February. In this stage, the both of required injection beam charge and emittance are same ones for the previous KEKB project as show Table 1 since the main issue during Phase I is mainly a vacuum scrubbing operation. After Phase II, the low emittance beam generation is inevitably required for the nano-beam scheme operation of SuperKEKB main ring. Although, for the Phase II electron beam commissioning, the required normalized vertical emittance is less than 20 mm·mrad with the bunch charge of 2 nC, the same value of emittance with the charge of 5 nC should be delivered to the main ring for the Phase III commissioning. The required parameters for the positron beam is almost same values of electron in each commissioning stage.

The low emittance preservation of electron beam is one of crucial issues because the high intensity electron beam should be transported to the main ring without a damping ring. For this purpose, we need a photocathode rf gun as a low emittance electron source, a fine component alignment, and the low emittance preservation operation by the fine beam orbit manipulation. The simulation works have been carried out for achieving the required emittance values as listed in Table 1 [8, 9]. From the simulation results, the component alignment goals are set to be a value less than 0.3 mm and 0.1 mm in the standard deviations for the whole linac and each Sector with the length of 100 m, respectively. These values have been almost achieved by using the combination scheme of the laser tracker and a quadrant segmented photodiode with a reference laser system.

The simulation results show that the emittance preservation is feasible by using the fine beam orbit control called the offset injection scheme. The high precision beam position measurement will be carried out by the newly developed readout system based on the VME module [10]. The beam test result shows that the beam position measurement precision is about 3 µm although the present system one is around 25 µm. Four beam position monitor (BPM) readout system based on the VME card have already conducted by using this new module. Around 90 remaining modules will be installed soon.

BEAM COMMISSIONING

Phase I Beam Commissioning

The Phase I beam commissioning successfully started in the February of 2016. During first week, the beam tuning of beam transport line were mainly conducted. The beam orbit, energy, energy spread tunings, and timing adjustment for the monitor systems were carried out without any significant issues. The new event based timing system has launched for the main ring beam injection including the bucket selection function. The typical electron beam orbit and bunch charge from the thermionic electron gun to the end of beam transport is shown in Fig. 3. The electron beam with the bunch charge of around 0.7 nC is successfully delivered to the end of beam transport line. For the positron beam operation, the

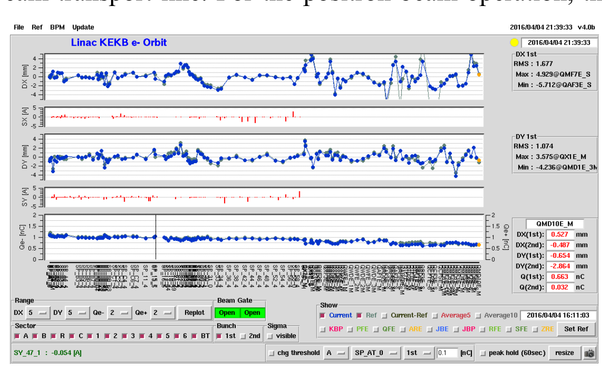

Figure 3: Plots of the electron beam orbit and bunch charge by using the thermionic electron gun. The plots show the horizontal (top), vertical (middle) beam positions in the units of mm, and bunch charge in the unit of nC at each BPM location.

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similar result is obtained, and its performance is enough for the Phase I commissioning.

Towards Phase II and III, the low emittance beam study is also now going on by the newly developed photocathode rf electron gun. By using the rf gun, the electron beam with the bunch charge of 0.4 nC was successfully transported to the end of linac as show in Fig. 4. The stability of the beam position and bunch charge obtained by the first BPM are shown in Fig. 5. The fluctuation of horizontal beam position is relatively larger than vertical one, and it should be improved for the low emittance preservation study. The study of beam injection to the main ring will be conducted very soon.

Towards Phase II and III Beam Commissioning

The Phase I commissioning will last until the end of this June. Phase II and III beam commissionings are going to be started in the October of 2017 and 2018, respectively. Between the end of Phase I and the beginning of Phase II, one year will be devoted to the low emittance beam development. The low emittance preservation with the electron bunch charge of 2 nC and 5 nC are required for the Phase II and III commissionings, respectively. For this purpose, the high precision BPM readout system has already developed since the fine beam orbit control is a crucial beam handling issue. In addition, the mover for the accelerating structure is now tested for the active component alignment as a countermeasure for the ground fluctuation.

The final version of flux concentrator with the work hardening process is now under development, and it will be installed into the beamline and tested in this November. For the simultaneous top-up injection of four rings, the pulsed quads and steering magnets are going to be installed into Sector 3 to 5 during the summer shutdown of 2017.

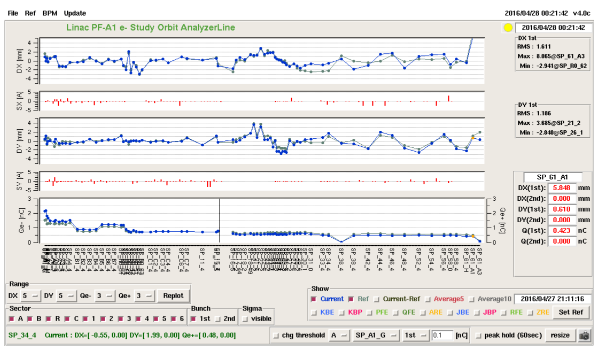

Figure 4: Plots of the electron beam orbit and bunch charge by using the photocathode rf electron gun. The plots show the horizontal (top), vertical (middle) beam positions in the units of mm, and bunch charge in the unit of nC at each BPM location.

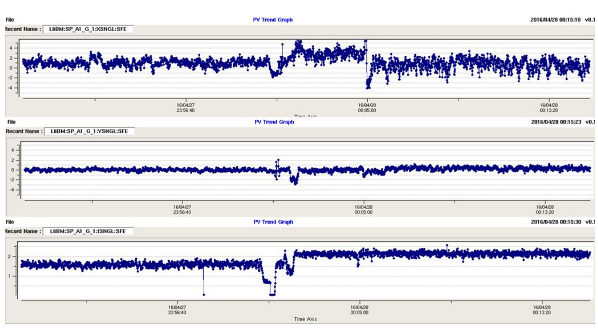

Figure 5: Beam orbit and bunch charge measured by the first BPM with the photocathode rf gun. The top, middle, and bottom plots show the bunch charge in the unit of nC, the horizontal and vertical beam positions in the units of mm, respectively.

CONCLUSIONS

In this February, the Phase I beam commissioning of SuperKEKB main ring started successfully by using the thermionic electron gun. Towards Phase II and III commissioning, the linac low emittance beam study is also now going on by the newly developed photocathode rf electron gun. Before the Phase II commissioning being started in the October of 2017, the required components of the flux concentrator and the pulsed magnets will be ready.

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