INJECTOR LINAC UPGRADE FOR SuperKEKB

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Abstract

In the forthcoming upgrade of the KEK-B factory to SuperKEKB, beam currents in the storage rings will be doubled and beam lifetimes will be ten times shorter. To make up for rapid decrease of the stored currents, several times higher linac beam intensities are required both in electrons and positrons. To achieve extremely high luminosity in the SuperKEKB, beam emittance has to be very low. Emittance of injected beams from the linac should be reduced to be five times smaller for electrons and two hundred times smaller for positrons compared to those of KEKB. To realize these low-emittance and high intensity beams from the linac, the electron pre-injector will be upgraded with a new electron-gun, the positron capture section will be upgraded for higher positron intensity and a positron damping ring will be introduced to make a positron emittance sufficiently small. This paper reports on design considerations in the linac upgrade for SuperKEKB.

INTRODUCTION

SuperKEKB is a next generation B-factory aiming a peak luminosity of $8 \times 10^{35} cm^{-2} s^{-1}$ which is forty times higher than that of the present KEKB. Table 1 shows a beam-parameter comparison of KEKB and SuperKEKB concerning beam injection. Design of the SuperKEKB is described in the references [1, 2]. SuperKEKB adopted nano-beam scheme for higher luminosity and it requires a significant upgrade of the injector linac in beam intensity and emittance. An overview of the present injector linac and the upgraded linac is shown in Fig. 1. To achieve five times higher intensity and five time smaller emittance of an electron beam for HER injection, a photo-cathode RF gun will be added in the pre-injector. For a positron beam, two hundred times smaller emittance is required, a damping ring will be introduced at the end of the Sector-2 of the linac. To increase positron intensity in four times, positron capture efficiency will be improved by a stronger focusing solenoid after a converter target and by accelerating structures of larger-aperture size. The new positron capture section will be placed 40 m upstream in the linac to have sufficient energy margin for injection to the damping ring. Previous design considerations on these key components in the linac upgrade are described in the reference [3] and more recent status is described in this paper.

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Table 1: KEKB/SuperKEKB Linac Beam Parameters

	KEKB		SuperKEKB	
parameters	e^+	e^-	e^+	e^-
beam energy [GeV]	3.5	8.0	4.0	7.0
stored current [A]	1.6	1.2	3.6	2.6
beam lifetime [min]	150	200	10	10
bunch charge [nC]	(10)*, 1	1	(10)*, 4	5
number of bunch	2	2	2	2
emittance [μm]	2100	100	10	20
Energy spread [%]	0.125	0.05	0.07	0.08
bunch length σ_z [mm]	2.6	1.3	0.7	1.3

(*) for primary electrons

LOW EMITTANCE ELECTRON SOURCE

In the electron pre-injector of the KEKB linac, electron beam pulse is generated from a thermionic gun with a Barium-impregnated tungsten cathode by a 200 kV accelerating voltage. A beam pulse of 1 ns length from the gun is compressed into a single bunch of 10 ps (FWHM) by an RF bunching section with two sub-harmonic bunchers of 114 MHz and 571 MHz and S-band (2856 MHz) pre-buncher and buncher cavities. To double an injection beam charge to the KEKB rings, another bunch is generated 96 ns after the first bunch and these two bunches are accelerated in a same RF pulse. Typical bunch charge of electrons for injection to HER is 1 nC and that of primary electron beam for positron production is 10 nC. A positron bunch charge for injection to LER is 1 nC. An electron bunch charge for Photon Factory ring injection is 0.1 nC. These different intensity electron beams are generated from the same gun by changing grid bias and grid-pulser voltages.

While electron beam emittance for HER injection is required to be less than 20 μm for SuperKEKB as shown in the Table 1, typical emittance of a 1 nC electron bunch is more than 100 μm in the present linac. Bunch charge for SuperKEKB HER injection is five times larger and emittance in this beam intensity will be much larger if we use the present gun and the bunching section.

To achieve the high-intensity and low-emittance beam generation, we are considering photo-cathode RF-gun type

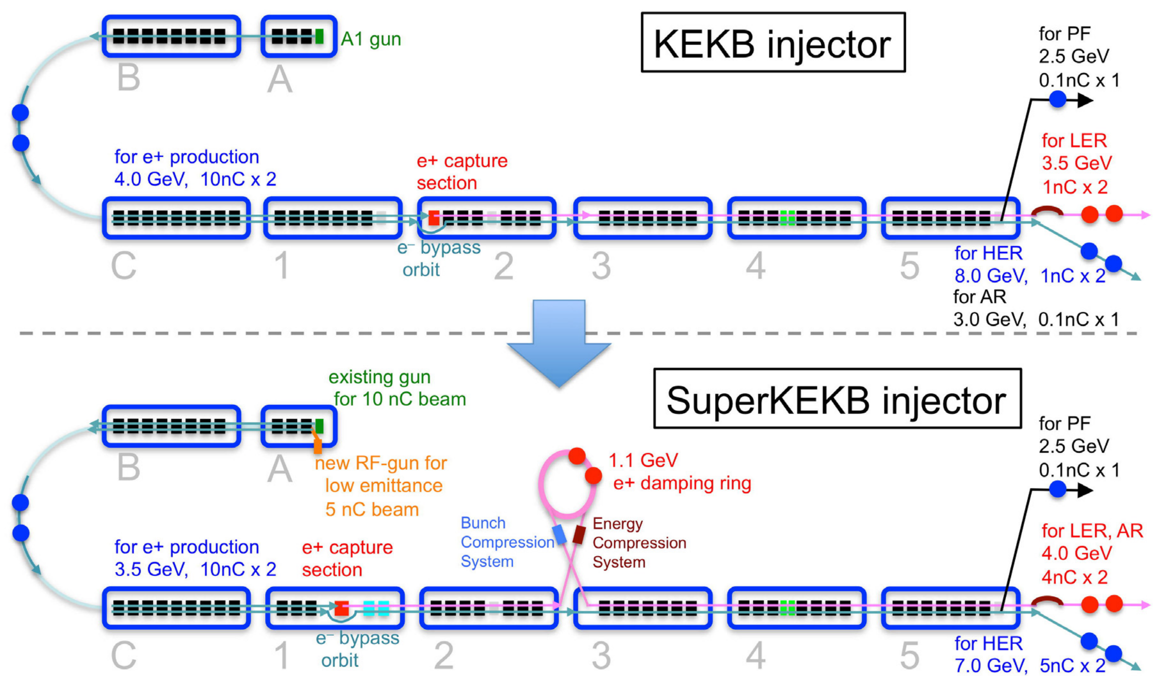

Figure 1: Layouts of KEK and SuperKEKB injectors.

of electron source. With a high acceleration field in an RF cavity, space charge effect is suppressed. Direct short bunch generation by a laser photon pulse eliminates an emittance growth in the RF bunching section.

Various types of cathodes are in consideration as candidates, which include a low QE material like copper, a high QE material like CsTe and LaB6. Specification of a laser system for this photo-cathode is quite dependent on a choice of the cathode material. Design considerations on these candidates are underway and prototype studies will be performed.

It is supposed that a 10 nC electron beam for positron production will be generated from the existing pre-injector, a low-emittance beam will be generated from the new RF-gun and these two electron sources will be switched pulse by pulse. If we can achieve 10 nC beam charge from the RF-gun and pulse by pulse beam intensity switching in future development, we will unite the electron source.

POSITRON CAPTURE SECTION

Positrons emerged from a converter target are captured in a focusing system with a combination of a short strong solenoidal field and a long weak field for phase-space matching and are accelerated in accelerating structures covered by this solenoidal field. The KEKB positron capture section uses air-core pulse solenoid coil to generate 45 mm long 2 Tesla field and DC solenoids of 8 m long 0.4 Tesla field. This matching system characterized by a rapid change of the field strength is called as QWT (Quarter Wave Transformer) and has relatively narrow positron energy acceptance (10 ± 2 MeV). We will replace this matching system by which is called as AMD (Adiabatic Matching Device) to increase positron yield. An AMD is characterized by a high peak field (6 Tesla) and a gradual change in a solenoidal field strength (in 200 mm) and it has a wider energy acceptance as 2 ∼ 20 MeV. We have two candidates in consideration for a solenoid which can generate 6 Tesla field.

One of the candidates is a flux-concentrator (FLC) type of pulse solenoid which can generate strong field with an induced current in a copper conductor. We are collaborating with BINP in this FLC development. A prototype we are going to perform an operation test is developed on a design made for a linear collider positron source. In this prototype, a single half-sine pulse current (30 kA at peak) of 25 µm pulse width is applied to the magnet and a 10 Tesla solenoidal field is generated inside an 8 mm aperture diameter of the copper conductor. A FLC has a thin radial slit in principle to induce a current inside the conductor. It makes significant magnitude of transverse field component and degrades a positron capture efficiency. To precisely evaluate a positron yield with the FLC, detailed particle tracking simulation with three dimensional field distribution information will be necessary. We are preparing a field mapping measurement system of a pick-up coil and a movable stage to obtain a detailed field distribution data. Operation test of the prototype FLC and the power supply will start in October 2010. The prototype will be installed in the KEKB positron capture section and a positron generation beam study will be performed in February 2011.

Another candidate is a super-conducting solenoid (SCS). We can design a field distribution flexibly with a SCS compared with the FLC and it has a good axial field symmetry. The biggest problem in using a SCS as a positron focusing magnet is the quenching by intense radiation from a converter target. Temperature, magnetic field strength and current density should be below certain critical limit curve defined for each super-conducting material. We have worried of a possibility that quenching can be more sensitive for a case of a pulsed heating by short beam pulse from the linac. We have performed beam irradiation tests of a sample SCS to quantitatively evaluate the quench limit for a pulsed heating. Preliminary result shows that quenching is not sensitive to a pulsed heating and a normal critical curve can be applied considering an average heating from beam radiation. In designing SCS for positron focusing, a thickness of a radiation shield and coil dimension should be optimized for positron yield and temperature rise. To obtain detailed design limits of the SCS, we will perform a beam irradiation tests with a prototype solenoid and a cryostat which can contain a realistic converter target inside. The beam test will start in October 2010.

To increase positron capture efficiency by enlarging a transverse acceptance, it is effective to use larger aperture accelerating structures in the capture section because the acceptance is proportional to a square of an aperture size of the structures. Natural selection is a lower frequency accelerating structure (L-band 1298 MHz) which has larger aperture (35 mm dia.) compared with the present S-band structures (2856 MHz, 20 mm dia.). Nevertheless, we are considering also larger aperture S-band structures (30 mm dia.) as another alternative because of cost effectiveness. L-band RF sources and magnets (solenoids and quadrupoles) placed around the L-band structures are costly. Simulation studies to compare positron yields and design consideration for cost estimation are underway. Final selection will be made on results of these considerations. In any cases, larger aperture accelerating structures will be adopted only in a few accelerator modules including the capture section and existing normal S-band structures will be used in a downstream positron acceleration linac. Recent simulation study show that a combination of different RF frequencies is effective in eliminating satellite bunches generated in phase slips in the capture section. Thus, minimum numbers of L-band structures will be used.

POSITRON LINAC AND DAMPING RING

Emittance of positrons is inherently large because they are produced as secondary particles. It is far beyond the requirement for SuperKEKB injection. We will introduce a damping ring (DR) at the end of the Sector-2 of the linac as shown in Fig. 1 to reduce the positron emittance by radiation damping. Details of the DR design and the beam transfer line are found in the references [4, 5]. The extracted vertical beam emittance is expected to be 7 μm and it satisfies the requirement 10 μm. The design beam energy is increased from an original design value 1.0 to 1.1 GeV to avoid a beam instability due to coherent synchrotron radiation. To compensate for low acceleration field in the large-aperture accelerating structures and have sufficient energy margin of positrons for DR injection, the positron converter target and the capture section will be moved 40 m upstream in the linac. As a result, number of accelerator modules for positron acceleration before the DR will increase from six to nine and the primary electron beam energy at the target will decrease from 4.0 to 3.5 GeV.

To improve beam injection efficiency to the DR, an energy compression system (ECS) is introduced in the beam transfer line from the linac to the DR. An energy spread of positrons from the linac is compressed by a momentum dependent path difference and a energy adjustment by an RF acceleration in S-band structures. In beam extraction from the DR, an bunch compression system (BCS) is introduced in the beam transfer line to the linac. A bunch length of positrons from the DR is compressed by an RF acceleration in L-band structures and a momentum dependent path difference, which results in smaller energy spread at the end of the linac.

SUMMARY

In the upgrade to SuperKEKB, several times higher beam intensities and one order of magnitude smaller beam emittances are required to electron and positron beams from the injector linac. A photo-cathode RF gun will be used to generate low-emittance electron beams. A stronger positron focusing solenoid of 6 Tesla field and larger-aperture accelerating structures will be used to improve positron capture efficiency. A damping ring will be introduced to reduce positron emittance. Design consideration and comparison between candidates for these new components are ongoing.

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