THE LINAC UPGRADE PLAN FOR SUPERKEKB

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Abstract

The next generation B-factory "SuperKEKB" project [1], whose target luminosity is 8×10^{35} $cm^{-2}s^{-1}$, has just started. A "nano-beam scheme" is introduced to the SuperKEKB. In the scheme, required beam energy, charge and normalized emittance at the end of the injector linac are 7 GeV, 5 nC/bunch and 20 x 10^{-6} m for electron and 4 GeV, 4 nC/bunch and 10 x 10^{-6} m for positron, respectively. They are quite challenging targets for the present linac. In order to meet the requirements, we will introduce new components to the linac. They are a photo-cathode RF gun for an electron beam, a positron capture section using L-band cavities, a newly designed positron-matching device and a damping ring for a positron beam. This paper shows a strategy of our injector upgrade.

PRESENT INJECTOR LINAC

The present injector linac provides four beams to four rings. They are KEKB High Energy Ring (HER), KEKB Low Energy Ring (LER), Photon Factory ring (PF) and Photon Factory Advanced Ring (PF-AR). Table 1 shows the beam parameters for four rings. All rings except for the PF-AR normally operate in "Top-up" mode, so linac injects three kinds of beam to them simultaneously [2].

The linac is in the shape of 'J' and an electron gun is located at the end of the shorter side of 'J' (see Fig. 1). This electron gun has a thermionic cathode grid assembly (Y796, EIMAC division, CPI) and an electron beam extracted by pulsed electric potential of 200 kV from the cathode-grid assembly is bunched and accelerated by a sub harmonic buncher 1 (SHB1, 114 MHz), a sub harmonic buncher 2 (SHB2, 571 MHz), a pre buncher (2856 MHz) and a buncher (2856 MHz). This electron gun is called "A1-gun". The A1- gun has four pulsed charge settings and can change the settings at the maximum injection repetition of 50 Hz. As for the HER beam, two electron bunches, each of which has a charge of 1 nC, are accelerated in the same RF pulse and attain energy of 8 GeV at the end of the linac. As for the LER beam, two bunches of 10 nC beam are accelerated to 4 GeV and irradiate a tungsten (W) target. An electron beam generates an electromagnetic shower in the target and emerged positrons are captured by a quarter-wave-transformer type of matching section with an air-core pulse coil whose magnetic field is 2 T and an RF field of an S-band accelerating section. Conversion efficiency from electrons to positrons is approximately 10 %. In other words, an electron beam of 10 nC is converted into a positron beam of 1 nC. Converted positrons are accelerated to energy of 3.5 GeV and injected into the LER. Normalized beam emittances at the end of the linac are 3.0 x 10^{-4} m for the HER and 2.1 x 10^{-3} m for the LER. As for the PF-AR, the beam generated at the "3T-Gun" in the middle of the linac is accelerated in the linac and injected to the PF-AR ring every 12 hours. It takes a few minutes and during the injection, simultaneous injection to other rings is suspended.

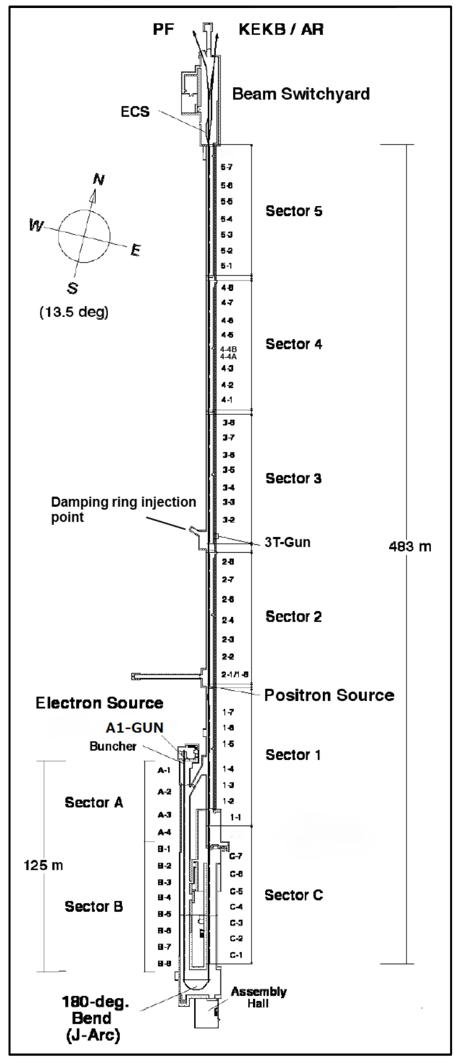

Figure 1: A plane view of the injector linac

Table 1: Present Beam Specifications

	Particle	Energy (GeV)	Charge (nC)	Bunch (bunch/RF-pulse)	Top-up
HER	e^-	8.0	1.0	2	Yes
LER	e^+	3.5	1.0	2	Yes
PF	e^-	2.7	0.1	1	Yes
PF-AR	e^-	3.2	0.1	1	No

BEAM REQUIREMENT FOR SUPERKEKB

The KEKB team has been proposing an upgrade plan multiplying the luminosity by factor of about 40 for several years [1]; however, a base design of the SuperKEKB has changed radically in 2009 [3, 4]. Since the luminosity is proportional to the product of beam currents and inversely proportional to the beam size, there are cursory two choices to upgrade luminosity, i.e. to multiply the beam current or to reduce the beam emittance. Contrastively the previous luminosity upgrade plan depended mainly upon the beam current upgrade; a new upgrade plan will have been achieved by the beam size reduction with an assist of beam current increase of merely about factor of two. Table 2 summarizes required injection beam parameters at present. Compared to the present linac parameters, the bunch charge increases by a factor of 4 to 5, while the beam emittance reduced by one order of magnitude.

We are also considering a simultaneous injection to all four rings in order to maintain the currents of the SuperKEKB rings. Without this simultaneous injection scheme, the SuperKEKB rings will lose their beam currents rapidly during the PF-AR injection due to their short life time; roughly about 10 minutes. In this scheme, we are proposing to change the beam particle of the PF-AR from electron to positron.

Table 2: Required Beam Parameters

	HER	LER
Energy (GeV)	7.0 (- 8.0)	4.0
Charge (nC/bunch)	5	4
Bunch/pulse	2	2
Normalized Emittance ($x10^{-6}$ m)	20	10
Repetition (Hz)	50	
Energy Spread $\delta E/E$ (%)	0.08	0.07

LINAC UPGRADE PLAN

Electron Beam

An upgrade plan for the electron beam has a very simple strategy. We will install an additional electron gun next to the present "A1-gun". The new electron gun is a laser driven photo cathode RF gun. An RF gun cavity and a 1m-long accelerator section will be installed in an accelerator room and a laser system will be installed in the A1-gun room. Both of the accelerator room and the A1-gun room locate on the underground level. A present pulsed power supply for the A1-gun will be moved to an extended ground floor and an RF source for the RF gun will be installed also on the same floor. The A1-gun and the power supply will be connected with a high-voltage coaxial cable.

As for the cathode material, we are considering to take advantage of Cu with a longer operating life. Assuredly it is often said that quantum efficiency of Cu is about two orders of magnitude less than that of Cs_2Te. It is noted that the quantum efficiency of Cu for the laser wavelength of 193 nm is about two orders of magnitude lager than that for 266 nm [5]. A laser wavelength near 200 nm will bring Cu favorable quantum efficiency comparable to Cs_2Te. A rough estimate, using the quantum efficiency near 200nm measured at CERN, gives necessary laser pulse energy of 0.1 mJ/pulse for 5 nC electrons at the Cu cathode.

As for the cavity design, we use Kim's method [6, 7] assuming practical parameters. Kim's equations show that accelerating field strength in a cavity has a strong influence on total beam emittance, so that we will use a single cell cavity with shorter filling time with an expectation of higher accelerating field strength. In order to reduce production costs, we will utilize the present RF sources, thus, the RF gun cavity will be operated at frequency of 2856 MHz.

Positron Beam

In order to increase positron-beam charge, we will improve capture efficiency four times [8, 9] by introducing a new adiabatic matching device and new L-band accelerator structures [10] in the capture section locating at the downstream of a positron generation target.

We have two candidates for the matching device. One is a flux concentrator and the other is a superconducting solenoid. Generally, a flux concentrator consists of two coils. A pulse current in the primary coil induces eddy current in the secondary coil and eddy current gives off a strongly concentrated magnetic field near the centre of the coil just after the positron generation target. The magnetic field will be 3-5 times stronger than that of the present matching solenoid. A prototype flux concentrator, which can achieve a magnetic field of 10 T, has been developed in collaboration with BINP, Russia. The primary and the secondly coils of the prototype has combined into a single conductor, which properly acts as the primary and the secondly coils by carrying the primary and secondary currents in different paths in the same conductor. A preliminary operation test at BINP was successfully finished with results of no mechanical failure. The prototype flux concentrator will be shipped from BINP and will be installed in a test stand at KEK in June, 2010. An operation test will be started soon.

The superconducting coil is another idea to apply a strong magnetic field as the matching device. It is a main issue to understand whether the superconductive coil can maintain superconductivity or not in the electromagnetic shower near the target. Quench limit measurement under environment near electromagnetic shower has just started using the present electron beam at the end of the linac. Preliminary result shows that quenching is not sensitive to peak heat density by pulsed irradiation. After more detailed irradiation studies with a test solenoid, we will start designing a prototype solenoid taking into account the irradiated average heat density and field strength in the solenoid wire.

The final decision for the matching device will be made after performance studies of the flux concentrator and the superconducting solenoid.

The S-band capture sections will be replaced by L-band capture sections, whose first disk's aperture diameter is more than 30 mm. Fabrication of the first prototype L-band section has just started at Hitachi, Ltd. Table 3 shows specifications of the capture sections.

Table 3: Capture Section Specification

	Present	New
Accelerating field (MV/m)	14	10
aperture diameter of structure (mm)	20	30
RF frequency (MHz)	2856	1298
Structures configuration	1 m x 2 + 2 m x2	2 m x 6

As for an RF source of L-band, a new 40 MW class klystron will be developed. The present modulator power supply for S-band klystron will be utilized for the L-band klystron.

As for an emittance reduction of positron beam, we will introduce a damping ring in the middle of the linac, where positron beam with energy of 1 GeV is available. The beam emittance of 2×10^{-6} m at the injection point will be reduced to 17×10^{-9} m in horizontal and 5×10^{-9} m in vertical at exit of the damping ring. For the details of the damping ring, please refer to the reference [11, 12].

The positron generation target will be moved to the position where the primary electron beam energy becomes 3.5 GeV, while the present target locates at the position of 4.0 GeV. This relocation is required in order to have sufficient energy margin of the positron beam for 1 GeV injection to the damping ring. Though, the conversion efficiency from electron beam to positron beam will be reduced by lowering the primary electron beam energy, a new matching device and new capture sections will eventually increase positron yield.

SUMMARY

In order to achieve the luminosity of 8×10^{35} $cm^{-2}s^{-1}$ in the SuperKEKB, the injector linac needs to provide higher charge and lower emittance beams for the SuperKEKB rings. As for the electron beam upgrade, we will introduce a photo-cathode RF gun with a Cu cathode illuminated by laser with wavelength of near 200 nm. With respect to the positron beam upgrade, we will prepare a new matching device with much higher magnetic field and new capture sections with much larger aperture. There are two candidates for the matching device, one is a flux concentrator and the other is a superconducting solenoid. Both of them will provide several times stronger magnetic field than that of the present matching device. The development of these new devices has been just started or will be started soon. It may take a certain amount of time to complete the studies.

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