LINAC UPGRADE IN INTENSITY AND EMITTANCE FOR SUPERKEKB*

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Abstract

The SuperKEKB is now in a construction stage. The injector linac should be upgraded for realizing the 40-times higher luminosity than that of KEKB. This requires both bunch charge increase and reduction of beam emittance. All of the relevant hardware designs for the injector system are being finalized now to meet the commissioning of the ring by the end of 2014. In the present paper is briefly reviewed the overall progress of such design decisions and hardware developments in the last two years. A perspective towards the commissioning is also presented.

INTRODUCTION

In order to realize much higher luminosity in SuperKEKB [1] than that of KEKB, the injector linac should be upgraded both in its intensity and the beam emittance. The relevant parameters are shown in the Table 1. As shown in the table, the electron and positron beam charge should be increased by about 4-5 times than KEKB, while the emittance should be reduced by more than an order of magnitude. The status as of the year 2010 was described in [2] and [3]. In the present paper, we review the advancement after then.

The intensity and emittance of the electron beam are realized directly by adopting a photo-cathode RF gun [4]. In contrast, the positron intensity is increased by adopting a higher capture efficiency system with a flux concentrator (FC) [5] followed by the large-aperture accelerators [6], while its emittance is reduced by a damping ring (DR). For preserving such a low emittance of both beams through the linac [7], the suppression of the emittance growth is crucial. To this end, the alignment of the accelerator components should be improved to be within a sigma of a hundred microns, where we need an improvement by about a factor 10. In addition to this improvement, the beam based alignment (BBA) is definitely needed with higher-resolution BPM's [8].

The upgraded linac will serve a 1 nC beam for the initial commissioning of the rings by the end of 2014. The low emittance beam will be injected to the rings for collision run by the end of 2015. Continuously and even later than 2015, we will make efforts to increase the bunch charge. We are planning this staged development of the beam characteristics depending on the budgetary and civil engineering limitation.

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Table 1: Injector Linac Requirements
KEKB → SuperKEKB

Item	Electron	Positron
Energy (GeV)	8 → 7	3.5 → 4
Bunch charge (nC)	1 → 5	1 → 4
Number of bunches	2	2
Emittance (micron)	~100 → 20	~2100 → 10
Rep. Rate	50	50

OVERALL DESIGN

Basic Configuration

We are upgrading the injector linac for SuperKEKB with fully utilizing the existing linac for KEKB so that the schematic of the linac becomes that as shown in Figure 1. The J-type linac shape should be adopted to assure the electron energy, even though the energy is reduced from 8 to 7 GeV. In order to install a DR at 1.1 GeV, we shifted the positron production target from the unit 2-1 (beginning of sector 2) to the unit 1-4 (middle of sector 1). The reduction of the drive electron energy from 4 to 3.5 GeV is compensated by the higher efficiency in the new positron capture system.

Mission of the Linac

In addition to serving the beams into the two rings of SuperKEKB, the linac should serve for other two rings at the same time, PF (Photon Factor) in top-up mode and PF-AR (PF Advance Ring) taking an injection period. This requires the acceleration and transmission of different beams, in energy and intensity, simultaneously. More pulse magnets are installed to improve the optical characteristics for each beam.

Recovery from Earthquake to SuperKEKB

The linac suffered from a mess due to the earthquake in 11 March, 2011 [9]. The supports for the accelerator girders were bent, many of Q magnets were fallen and bellows with BPM's were ruptured. These should be replaced, reinforced and realigned. The alignment requirement for SuperKEKB is much stringent so that the alignment method is also being refined.

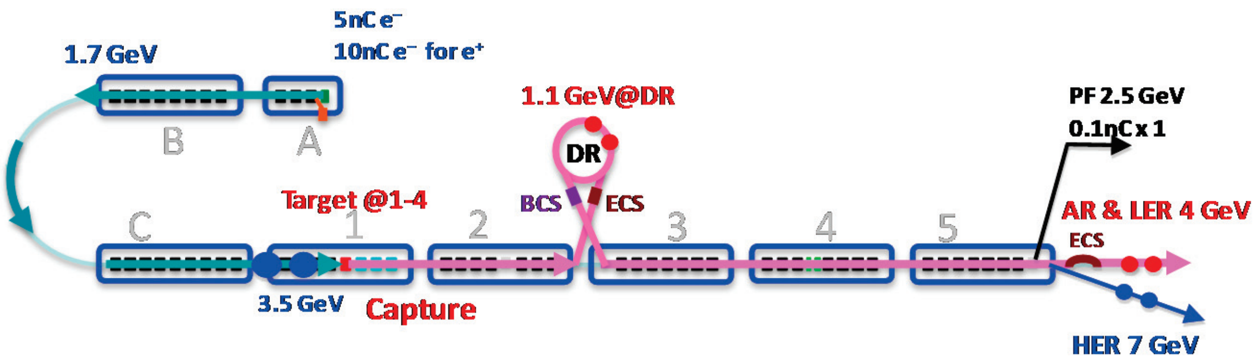

Figure 1: Schematic for injector linac for SuperKEKB.

ELECTRON PRODUCTION

The electron bunch of 5nC bunch charge with low emittance is generated by a photo-cathode RF gun [7]. The candidate cathode materials are such as LaB_6 or Ir_5Ce. These will be illuminated by a laser of 266 nm with a few mJ per pulse [10] to get 5 nC without heating. If Qe is not high enough by some reason, we consider the introduction of the heating. The RF cavity for extraction and acceleration of the electrons is performed by a DAW cavity with curved cathode shape [4]. It allows the high charge and the low emittance with relatively low cavity gradient.

Due to the earthquake, the test system was located at the sector 3 and the preliminary test has been performed as shown in Figure 2. Now a bunch charge of 1 nC was extracted and the emittance will be estimated in near future.

Figure 2: RF gun system installed at 3-2 section.

POSITRON PRODUCTION

The positron bunch is produced by a W target with the electron bunch of 10 nC at 3.5 GeV energy. The capture efficiency should be improved by a factor 5 than KEKB. To realize this high capture efficiency, the FC [5] is used instead of the pulse coil. It is followed by a large aperture RF system with the negative RF phase [6].

A flux concentrator has been developed under the collaboration with BINP Novosibirsk [3]. Even if this design opens the possibility to a very high field as 10 Tesla, we decided to start with the type developed by SLAC [11] to meet the requirement to operate from late 2013. The detailed information of the type was given from IHEP China [12]. The shaping and the field measurement of the prototypes are ongoing. We may use a special copper material which is supposed to keep the hardness even after silver brazing cycle.

The capture section is composed of two L-band travelling-wave accelerator structures with the beam hole diameter of larger than 35 mm. The RF power is terminated by the collinear load section to get rid of the outer wave guide and minimize the solenoid bore to be 260 mm in diameter. Load material is atmospheric plasma-sprayed Kanthal. The first L-band accelerator structure is shown in Figure 3. This is the one used for bunch compression after DR as shown in Figure 1, but the main part of it will be reproduced in a collinear design for positron capture. This structure in Figure 3 is soon high-power tested. It produced 10 MV/m with 15 MW input.

The choice of 5/11 times S-band linac frequency offers two features, larger longitudinal acceptance and the reduction of the injection loss at the damping ring by suppressing the S-band satellite [13].

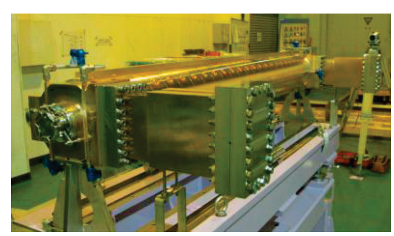

Figure 3: Prototype L-band accelerator structure for BCS.

EMITTANCE PRESERVATION

The emittance preservation is one of the big upgrade items for the injector linac, because the requirement for the KEKB was much looser than the present one. Most basic strategy for suppressing emittance growth is to realize the better alignment. From the beam simulation, such a tolerance as 100 microns over a hundred meters or so is required. We will firstly realign the whole linac components which were heavily moved by the earthquake [9]. The first step of this realignment, equivalent to the initial installation, will be done with respect to the laser beam monitored by quadrant photo detectors. The transmission of the small-aperture laser beam over 500 meters was confirmed and it will be used for the initial setting. The actual position of each component with respect to the reference line is measured by a laser tracker system. The alignment will be gradually refined by introducing the beam-based alignment. The resolution of the BPM's will be improved from 50 microns to 10-20 microns by applying the better signal processing [8].

The emittance growth due to the short-range wake field will be reduced by shortening of the bunch length and also by introducing the beam offset [14]. We will prepare such tuning knob by adding pulse steering magnets.

In order to evaluate the low emittance along the linac, the wire scammers are used for the beam emittance measurement. We found that the beam loss monitor by detecting Cerenkov light emitted in the optical fiber can be used for the detection of the beam intersection with the wires with better S/N ratio than the case with PMT [15]. The vertical emittance as a function of position along a bunch will be measured by introducing a deflector cavity at the end of linac. This activity is ongoing under collaboration with SLAC.

STAGED UPGRADE SCENARIO

The upgrade scenario of the injector linac has been redefined reflecting various boundary conditions, not only the technical perspective on the readiness of the hardware but also the budgetary profile and the civil engineering schedule. Our rough idea on the staged goal for the beam is listed in the Table 2. By the end of 2013, both electron and positron with a bunch charge of 1 nC will be commissioned even in a low rep. rate mode and in a reduced intensity as required from the radiation safety. The electron will be produced by the RF gun from the beginning. From the end of the year 2014, 1 nC beam will be injected to the rings to serve for initial commissioning and vacuum scrabbling of the rings. Finally with the introduction of the damping ring by the end of 2015, 1 nC bunch with the emittance for the SuperKEKB will be injected for collision run. Then later on, the intensity of the positron will be increased by gradually increasing the axial magnetic field of the flux concentrator and the following DC solenoid field. Note that the latter is the case that we cannot prepare enough cooling and electric power for magnets before this time.

PERSPECTIVE

The quadrant photo diode suffers from the radiation. Therefore, the laser alignment cannot be a method of monitoring the reference line in a longer period, especially after establishing a high current operation for SuperKEKB. During the long-term operation of collision run, the monitoring of the reference line will be done with a different laser system for Fresnel lens [16], which does not suffer from the radiation. However, it can be replaced by beam based alignment, once the alignment is established and the misalignment does not develop so big in a short period.

The synchrotron injection scheme to the high energy ring has being studied as a possible better injection scheme [17]. This requires lower bunch energy spread from the linac and sophisticated septum design.

Table 2: Staged Upgrade Scenario

Q (bunch charge), PRF (Rep. rate), ε (emittance)
nC Hz micron

Stage	**Electron**			**Positron**		
year	Q	PRF	ε	Q	PRF	ε
KEKB	1	50	~100	1	50	~2000
2013/E	1	~5	Study	~1	~5	↑
2014/E	1	50	↑	1	50	↑
2015/E	1	↑	20	1	↑	10
SuperKEKB	5	50	20	4	50	10

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