SuperKEKB POSITRON SOURCE CONSTRUCTION STATUS

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Abstract

The KEKB electron/positron injector linac is under the upgrade for SuperKEKB. A new positron source with a target, a beam spoiler, a flux-concentrator and large-aperture S-band accelerating structures inside DC solenoids and an electron/positron separator have been installed. Preliminary positron beam commissioning has been started. The first positron beam has been observed after the upgrade. A construction status of the new positron source and a recent positron beam performance are reported.

INTRODUCTION

A positron source upgrade is one of the major challenges for the SuperKEKB injector linac [1]. In the upgrade, the positron bunch intensity is boosted from 1 nC to 4 nC by increasing the positron capture efficiency and the positron beam emittance is shrunk from 2100 μm to 92, 7 μm in the horizontal and vertical planes by introducing a damping ring. More concretely, we have been introducing or upgrading the following items, (1) a flux concentrator (FC) as a positron focusing solenoid with a larger energy acceptance, (2) a positron production target which fits in the FC geometry and a beam spoiler for target protection, (3) bridge coils to make smooth solenoid field distribution between the FC and downstream DC solenoids, (4) large aperture accelerating structures for the positron capture section and a subsequent accelerator module for enlarging transverse phase space acceptance, (5) an electron/positron separator chicane and a beam stopper for eliminating secondary electrons, (6) a focusing system of quadrupole magnets which matches to the enlarged acceptance of the capture section, (7) beam collimators to eliminate positron beam halo, (8) a damping ring (DR), (9) beam transfer lines to/from DR including an energy-spread compression system at the injection line and a bunch compression system at the extraction line, (10) an upgrade of the another energy-spread compression system and the switchyard beam lines at the end of the linac corresponding to the change of the electron/positron beam energy asymmetry from 8.0/3.5 GeV to 7.0/4.0 GeV. The components (1) to (6) have already been installed in the beam line as shown in Fig. 1 and a preliminary positron beam commissioning has been started. A status of these components and a preliminary positron beam performance are described in the following sections.

Figure 1: SuperKEKB positron capture section.

PRIMARY ELECTRON, TARGET AND BEAM SPOILER

Primary electron beams are accelerated up to 1.5 GeV before the 180 degree J-arc by the eleven accelerator modules of 160 MeV energy gain per module (effectively nine modules for reserving two modules for a stand-by and for an energy adjustment margin) and further up to 3.3 GeV by another eleven modules. Because one of the module is not operated because a klystron modulator has been converted to a temporary pulse power supply for the flux concentrator, primary electron beam energy at the stage of June 2014 is 3.1 GeV.

Positrons are produced with a 14 mm thick amorphous tungsten. If a primary electron beam pulse of the designed intensity (two bunches of 10 nC each) is focused in a spot size (σ_x, σ_y) smaller than 0.4 mm, the peak energy deposition density (as an index of the target destruction condition) can exceed the limit 35 J/g obtained from the SLAC operation experience. To robustly prevent the target from this situation, a beam spoiler is introduced at 3 meters in front of the target for enlarging the spot size more than 0.7 mm by multiple scattering in a thin plate. Details of the beam spoiler is described in Ref [2] and [3].

For a pulse-by-pulse switching of the electron and positron injections, we have adopted a scheme to switch an electron orbit by pulsed steering magnets to hit the target to produce positrons or to pass through small holes beside the target and in the beam spoiler. The orbit of the electron for injection is

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set on the axis of the beam line to avoid an emittance growth. Meanwhile, the target is set with a 3.5 mm offset from the axis. Degradation of a positron yield by the target offset amounts to 50 %, however, it is shown to be reduced to 20 % by proper optimization of an electron incident position and of flux concentrator orientation with respect to the target as described in Ref [4].

FLUX CONCENTRATOR

We have developed a flux concentrator (FC) based on the SLAC-IHEP model design [5]. A temporary pulse power supply has been constructed by modifying an existing klystron modulator to supply pulse current of 6 μs width to the FC. A snubber circuit is connected to the pulse feeding line for a pulse wave form shaping. The maximum current is limited to 6 kA that is half of the design specification 12 kA, since this temporary power supply uses only single thyratron instead of two in the complete power supply. Thus, the available FC field strength at this stage is 1.8 T instead of the specified 3.5 T. The bridge coils outside the FC generate an additional 0.5 T field at 600 A current. After successful operation tests of two prototype FCs up to 6 kA, we have manufactured a FC assembly for operation in the beam line. It is composed of a FC in a vacuum chamber with pumping ports and two ion pumps, a positron production target in front of the FC with 2 mm gap, two bridge coils and horizontal/vertical steering coils of DC current operation outside the chamber, magnetic flux return yoke, a girder to support the assembly components, a multi-coupling plates for quick connection/disconnection of the various connectors for the DC power cables, the interlock signal cables and the cooling water pipes. The FC is set with 2 mm offset from the beam line axis. Thus, the target and the beam hole are placed within the aperture diameter of 7 mm keeping the hole on the axis as shown in the Fig. 2.

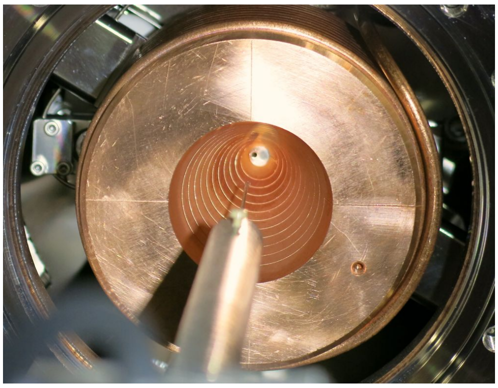

Figure 2: Flux Concentrator viewed from downstream.

The pulse current from the power supply is fed through ten parallel coaxial cables of 18 m long to reduce the inductance of the power line. To avoid the radiation damage in the insulation material at the cable terminals, the cables are connected to a power line of parallel copper plates at a position 3 m from the FC. The plates are connected through short removable copper bars to the electrodes at the end-plate of the FC chamber. After the operation in a test stand, the FC assembly has been installed in the beam line. In a high-voltage processing of the FC, the solenoid field by the bridge coil induced gas bursts. Thus, we have performed a careful processing by scanning the FC voltage and the bridge coil field strength. After the processing, we still have some bursts in the beam operation, however, the frequency is less than a few per day.

LARGE APERTURE CAPTURE SECTION

We use the large aperture S-band (LAS) accelerating structures in the positron capture section since their aperture diameter (30 mm) enlarge the transverse phase space acceptance twice compared to that with the conventional S-band structures (21 mm). Details of the LAS structure is described in Ref [6]. In the capture section for SuperKEKB, six LAS structures are installed inside the DC solenoid modules as shown in Fig. 3.

Figure 3: LAS structure insertion into DC solenoid.

While the first two structures are connected to a set of a klystron and a SLED cavity for higher field gradient as 14 MV/m, the following four structures to an another set for 10 MV/m. The high gradient in the first two structures is essential in reducing the satellite particles that can make radiation problem during the damping ring injection. The LAS structures are also used in the subsequent accelerator module in a quadrupole focusing region. Four structures were installed there. Acceleration length in the capture section is increased from 6 m for the KEKB capture section to 12 m for SuperKEKB. As a result, the positron beam energy from the capture section is boosted to 110 MeV compared with that of KEKB as 70 MeV even with the initial deceleration. This boost improves the beam transmission efficiency in the matching section after the capture section. As described in Ref [6], accelerating structures immersed in a magnetic field by DC solenoids or quadrupole magnets, can suffer from breakdown and multipacting problems. Since all the LAS structures are still in an rf processing stage, the operation for the preliminary positron beam commissioning has been performed with the SLED cavity detuned. The achieved field gradient are 10 MV/m for the first two structures and 7 MV/m for the others. Due to the limited power available at this stage, the DC solenoids are operated at half of the design current. Thus the DC solenoid field strength is 0.2 T instead of the specified 0.4 T.

ELECTRON/POSITRON SEPARATOR

A particle tracking simulation study has shown that a capture efficiency of the secondary electrons from the target is comparable to that of the positrons. The electron bunch comes 175 ps (a half of an rf wave length) apart from the positron bunch as a result of phase slipping in the capture section. The BPMs used in the SuperKEKB linac cannot separate signals by the electrons and the positrons. Precise beam position and intensity cannot be measured due to the cancellation of these signals. In order to obtain pure positrons after the capture section, we have installed an electron/positron separator chicane as shown in the Fig.4. In the middle of the chicane, positrons pass 30 mm aside from the beam line axis and electrons pass approximately the same distance on the other side. These beam spots are well separately considering the spot sizes and the energy spreads. The secondary electrons are absorbed by a 60 mm thick tungsten-copper alloy (W 70% + Cu 30%) block. While, the high energy electrons from the rf-gun propagate on the axis slightly aside from the stopper block. We have a positron stopper block as well, on the other side of the separator. These blocks can be moved separately by pulse motors with a position resolution of 50 μm. By measuring beam transmission with changing the beam stopper block positions, energy distributions of the positrons and of the secondary electron can be measured.

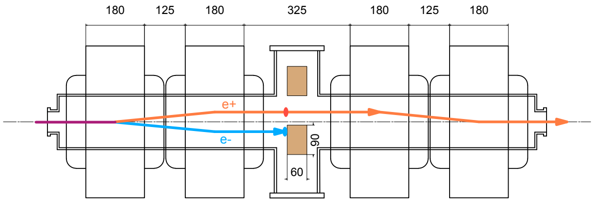

Figure 4: Electron/positron separator chicane.

PRELIMINARY POSITRON BEAM PERFORMANCE

An operation of the upgraded positron source has been started in May 2014. At this stage of the beam commissioning, some components were operated at parameters lower than the design specifications. Due to a limitation of the temporary power supply, the FC was operated at a half current of the specification. The DC solenoids in the capture section were also operated at a half current due to a power station limit. The LAS accelerating structure were operated at 70 % of the design field gradient. The electron bunch intensity from the photo-cathode rf gun was still low as 1 nC compared with the design intensity of 10 nC. Due to the beam loss in the beam bunching section and the limited energy acceptance of the J-arc, the primary electron beam intensity on the positron production target was 0.5 nC. With this low intensity primary beam, we started to search for a positron beam signal. In the beginning of the beam tuning, two independent rf phases of accelerating structures in the capture section have been adjusted to change synchronously by measuring crest phases with beam passing through the target hole reaching to the energy analyzing station a the end of the linac. By proper adjustment of the common rf phase, primary electron incident position on the target and other parameters, we observed a faint large spot on the screen monitor after the capture section. To identify it to be the positrons, we observed the BPM signal wave form with inserting the electron stopper block in the electron/positron separator chicane. Finally, we observed a signal induced by positively charged particles. The positron bunch intensity was 0.02 nC at the entrance of the beam transfer line to the damping ring. The observed conversion efficiency was 4 %. It will be improved to the design capture efficiency (40 %) by boosting the FC pulse current, the DC solenoid currents, the LAS structure field gradient and the positron beam transmission efficiency in the quadrupole focusing region.

SUMMARY

The positron source of KEKB injector linac has been upgraded for SuperKEKB. The components of the new positron source have been installed in the beam line. Though the operation parameters of some components are significantly lower than the design specification, a preliminary positron beam commissioning has been started. We have observed the first positron beam in the upgraded system. With the primary electron bunch intensity 0.5 nC at the positron production target, the positron bunch intensity was 0.02 nC at the entrance of the beam transfer line to the damping ring. The conversion efficiency was low at this stage, however, it will be improved by boosting the component operation conditions to the design values.

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