KEKB INJECTOR LINAC STATUS AND FUTURE UPGRADE

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Abstract

This paper reports on recent status of the KEK B-factory Injector Linac. The double-bunch injection of positrons has been used for three weeks KEKB operation in May 2002. The injection rate has almost doubled compared with the previous single-bunch injection mode. Careful tuning to equalize the beam characteristics of the two bunches has been done for a sufficient beam transmission efficiency of both of them. Though the double-bunch injection is promising, there is still a problem of lower peak luminosity in this mode and the single-bunch injection is used for ordinary operation. Preliminary studies of continuous beam injection while keeping the detectors of the collision experiment turned on, were successful. They showed that the beam background of the injected beam was acceptable for the detectors of the experiment.

This paper also describes the design study of the injector upgrade for a future project of the ten-times higher luminosity machine, SuperKEKB. In this upgrade, the positron injection energy will be raised from 3.5 GeV to 8.0 GeV and the beam intensities of the electrons and the positrons will be increased five times and twice, respectively.

1 LINAC STATUS

The KEK electron/positron linac has been operating for injection to the KEKB collider rings [1] (8.0-GeV e- for the High Energy Ring (HER) and 3.5-GeV e+ for the Low Energy Ring (LER), to the Photon Factory (PF) storage ring (2.5-GeV e-) and to the AR SOR ring (2.5-GeV e-). Details of the linac layout and its components are described elsewhere [2]. Recently, the KEKB has achieved a peak luminosity of 7.2×10^{33} /cm^2/sec and a daily integrated luminosity of 387 /pb/day. Both of them improved the world records. Stable and efficient beam injection from the linac greatly contributes to minimize the dead time and to improve the time-integrated luminosity. In the following sections, the routine operation status of KEKB injection and the two beam studies to improve injection performance are described. The one of the studies is double-bunch injection to increase positron beam intensity and the other is continuous injection without interrupting the collision experiment.

1.1 Linac Performance

Fig. 1 shows the typical daily performance of KEKB. The red lines show the beam currents in HER (upper) and in LER (lower) and the yellow line shows the luminosity. The maximum currents are 940 mA (e-) and 1460 mA (e+). Every 80 to 90 minutes, the beams are refilled. Refill injection typically takes 12 to 13 minutes in the positron single-bunch injection mode. The details are 1 minute for the detector turning off and changing the tunes for the injection, 1.5 minutes for electron injection (710 $\rightarrow$ 940 mA), 0.5 minute for the linac mode change, 8.5 minutes for positron injection (800 $\rightarrow$ 1460 mA) and 1 minute for the detector turning on and changing the tunes for the collision. Most of the time during injection is spent for the positrons. In addition to these periodic injections, the beams are injected after sudden aborts which occur a few times a day. After the aborts, injection takes a longer times to fill the maximum currents from zero.

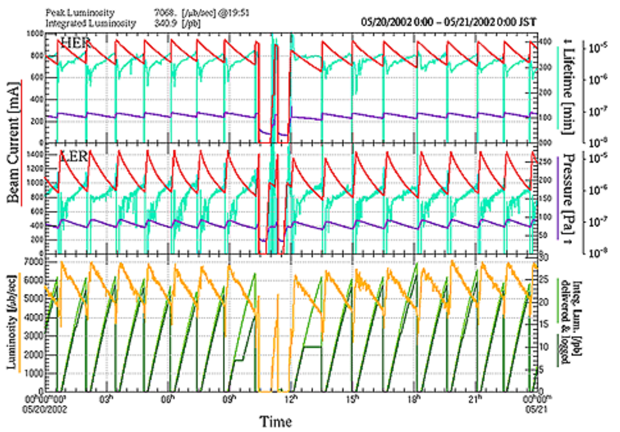

Figure 1: KEKB Daily Performance

The linac beam specifications and the performance are listed in Tab.1. The values referred to in the parentheses for the positron charges and its injection rates are those for the double-bunch injection described in the next section.

Table 1: Linac Performance

items	**KEKB e-**	**KEKB e+**
Beam Energy	8.0 GeV	3.5 GeV
Beam Intensity	1.0 nC	0.6 (1.2) nC
Emittance (normalized)	0.8 μm	2.5 μm
Energy spread	0.5 %	0.5 %
Injection rate	3.0 mA/s	1.5 (3.0) mA/s

1.2 Double-bunch Injection

Since positron injection takes about six-times longer than electrons, the poor positron intensity is a bottleneck for the integrated luminosity. It is difficult to increase the bunch charge of the primary electron (10 nC), because it is the maximum as for a tolerance to the wake-field effect. To increase the positron collection efficiency, large upgrade of the positron focusing system will be necessary.

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As a cost-effective way to increase the positron intensity, we have studied the possibility to increase the number of bunches in one beam shot [3]. Due to the RF frequencies of the linac (2856.000 MHz) and the KEKB rings (508.887 MHz), the bunches have to go in 96.289-nsec intervals. For efficient beam transport of the two bunches, careful tuning is required. Especially, the energies of the two bunches should be equal to fit for the limited energy acceptance. This is mainly done by appropriate tuning of the SLED RF pulse timing, as described in the ref [3]. It can deal with two bunches, but not for three bunches or more. Fig. 2 shows the orbits and the charges of the first (blue) and second (green) bunches along the linac until the end of the beam-transfer line. The intensity of the second bunch is slightly less, but the total intensity is almost doubled and the injection rate is increased from 1.5 → 3.0 mA/sec.

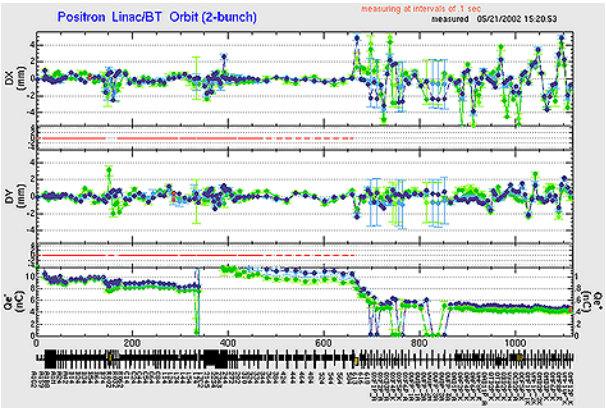

Figure 2: Double-bunch Injection

Although the positron injection rate is almost doubled, the peak luminosity is 10% less in this mode of operation due to the irregular bunch spacing in the storage rings. Further investigation is necessary to improve the peak luminosity.

1.3 Continuous Injection Study

Even if the injection time is very short, the luminosity degradation during the collision experiment is a large inefficiency factor for the time-integrated luminosity. It is inevitable because of a gradual beam loss by the beam-beam and the beam-gas collisions. One of the ideas for improving this situation is to inject the beam while keeping the detectors of the experiment turned on. If it is achieved, the time-integrated luminosity is improved by 20 to 30%. However, there is a large possibility of detector trip-off by the beam background during injection. We studied the endurance of the detectors during beam injection. The result was fine, and no detectors were tripped. Fig. 3 shows the run-status in this study. It is clear that the LER positron current is almost constant due to continuous injection, and the luminosity degradation is less. There is still some problems concerning the data quality of the detectors, also the continuous injection mode is premature to use for routine operation. However, these the problems are supposed to be fixed by small modifications of the data-taking components.

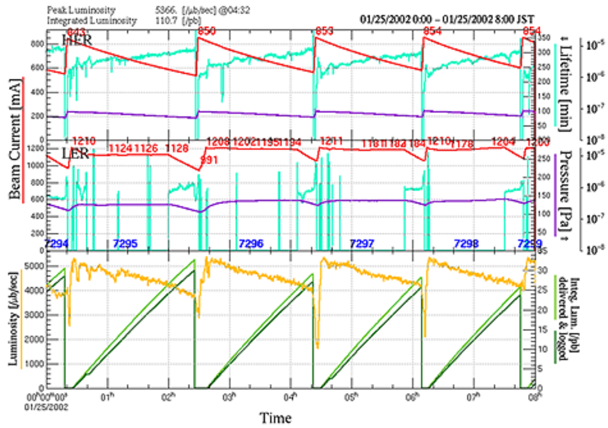

Figure 3: Continuous Injection Study

2 FUTURE UPGRADE

As one of the possible future projects of KEK, a feasibility study to upgrade of the present KEKB to a 10^{35} luminosity machine, SuperKEKB, has been started. The beam specifications of the SuperKEKB are listed in Tab. 2.

Table 2: SuperKEKB parameters

items	**KEKB**	**SuperKEKB**
Beam (HER)	8.0 GeV e-	8.0 GeV e+
Beam (LER)	3.5 GeV e+	3.5 GeV e-
Stored current (HER)	1.1 A e-	4.1 A e+
Stored current (LER)	2.6 A e+	9.4 A e-

As can be seen in the Tab. 2, the beam charge will be switched at SuperKEKB in order to avoid the electron-cloud effect in the positron storage ring, which will be crucial at low energy. Hence, although the linac will have to inject 8.0-GeV positrons, the maximum energy gain by the accelerator units after the positron production target is not sufficient (4.8 GeV). We are considering two possible schemes to increase the positron injection energy. The first scheme is to double the acceleration field by using the C-band accelerating structures. The other scheme is to accelerate the positrons twice by beam re-circulation. Not only the beam energy, but also the beam intensities should be greatly increased. Details of these issues are described in the following sections.

2.1 Energy Upgrade (High gradient scheme)

In this scheme, the acceleration field gradient is increased (21 → 42 MV/m) by replacing the present S-band (2856 MHz) accelerating structures by the C-band (5712 MHz) counterpart. Consequently, the RF sources also must be replaced. A schematic view is shown in Fig. 4.

Three fourths of the positron-accelerating units are replaced by the C-band components. A positron damping ring is added to reduce the emittance and to avoid beam loss

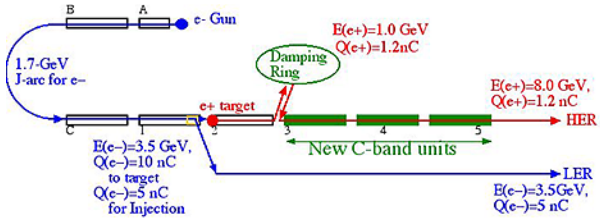

Figure 4: High gradient Scheme

in the C-band structures with smaller apertures. The Japan Linear Collider C-band group has been working to develop the C-band components, the klystron, the pulse modulator, the RF compressor, the accelerating structure and so on [4]. For example, a 50-MW class C-band klystron is already commercially available. However, their component designs are optimized for the specification of the linear collider. Thus, we have started designing the components optimized for the SuperKEKB injector. The design of the pulse modulator is in progress to fit for the limited space in the klystron gallery. The design of the prototype C-band accelerating structure will be based on the presently used S-band $2\pi/3$-mode traveling-wave structure, except that the dimensions will be scaled according to the frequency. Concerning the RF compressor, we first thought about a scaled-down version of the present S-band SLED type TE015 cavity, but found that the Q value is not sufficiently high at the C-band. We are considering to adopt the TE038-mode cavity, used for CERN LEP injector linac (LIPS cavity) [5], which has higher Q. Prototypes of the components will be fabricated this year and high-power tests of them will be performed next spring.

2.2 Energy Upgrade (Recirculation scheme)

In this scheme, the positron beam is re-circulated to upstream through a damping ring in synchronous to the next RF pulse to arise, as shown in Fig. 5. The beam-line layout and the beam operation are rather complicated. The re-circulated positrons and the newly arrived electrons are set in a certain bunch-spacing which gives the optimum acceleration phase for both of them.

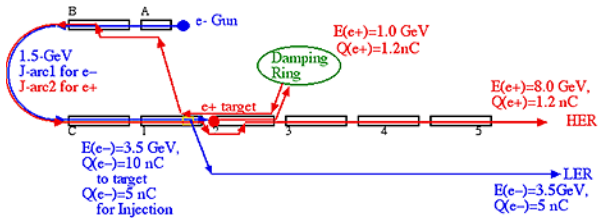

Figure 5: Beam Recirculation Scheme

The positrons and electrons are separated before the 180-degree beam turn, since they go through different bending lines because of their opposite charges. They are recombined after the beam turn and further accelerated up to the positron production target. Just before the target, they are again separated. The electrons hit the target to produce the next positron beam, and the positrons bypass the target. The positrons are combined with the newly produced low-energy positrons after a few acceleration units. Further, after a few units, the low-energy positrons are extracted by the fast kicker and sent into the damping ring, and the high-energy positrons are accelerated up to the end of the linac. In this scheme, upgrades of the accelerating structures and the RF sources are not necessary. However, the operation is complicated and careful tuning will be required for beam separation and combination, as well as for the acceleration of two positron beams with different energies in a common beam-transport line.

2.3 Beam-Intensity Upgrade

The second issue in the upgrade is to increase the beam intensities. As shown in Tab. 2, the electron stored current will be increased by 8.5 times and the positron current by 1.6 times. This unbalance comes from the charge switch and it release the requirement for the positron intensity. Double-bunch injection is supposed not to be compatible with use of the damping ring. Instead, we are considering an upgrade of the positron focusing system. Provided, the present 2.3-Tesla pulsed solenoid coil is replaced with a 6.0-Tesla flux-concentrator type of tapered solenoid, similarly to the SLC positron source, the positron yield is expected to be almost doubled. The design of the flux concentrator and the prototype fabrication will be performed later. Concerning the large increase of the electron intensity, there is no problem to produce such a high-intensity beam. Already, 10-nC electron beam is produced from the electron-gun as a primary beam to produce positrons. However, the worse beam quality of the high-intensity will be a problem for injection. The 5-nC intensity is a good compromise of the beam quality and the injection rate. An injection study of high-intensity electrons will be performed to investigate the level of the beam background.

3 REFERENCES

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