KEKB INJECTOR LINAC AND UPGRADE FOR SUPERKEKB

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Abstract

The KEB injector linac delivers electrons and positrons to four rings (KEKB LER, KEK HER, PF and PF-AR). The operational status of the KEKB injector linac is summarized. The R&D work concerning diagnostics of the klystrons and the beam-quality are also described. An upgrade plan of the injector linac using a C-band rf system is under consideration for SuperKEKB. A C-band acceleration structure was installed in the KEKB linac after rf conditioning at more than 40 MW. An energy gain of more than 40 MV/m was confirmed by the beam acceleration. The C-band acceleration unit has been operated continuously for a stability test.

INTRODUCTION

The KEKB Injector linac has provided 8 GeV electrons to KEKB HER and 3.5 GeV positrons to KEKB LER [1]. KEKB has recorded the highest luminosity to which the linac contributes with an advanced operational stability for about 7,000 hours per year. Double bunch injection and continuous injection (CI) schemes have been adopted.

The SuperKEKB project [2], aiming for a ten-times higher luminosity, is under consideration as an upgrade of KEKB. In this upgrade, the injector linac has to increase the positron acceleration energy from 3.5 GeV to 8 GeV [3]. One of the plans for this upgrade is to double the acceleration field (from 20 to 40 MV/m) with a C-band (5712 MHz) rf system. The newly developed components are summarized.

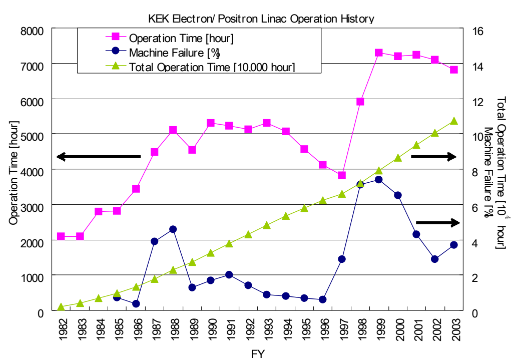

Figure 1: Operation history of the KEKB linac.

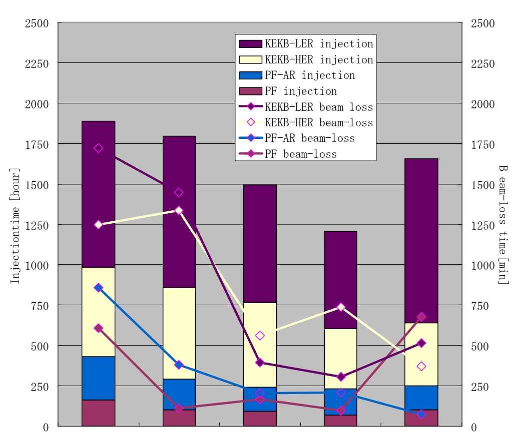

Figure 2: Injection time and beam-loss time to PF, PF-AR, KEKB LER and KEKB HER.

OPERATION STAUS OF KEKB LINAC

Operation History and Statistics

Construction of the linac started in 1978, and operation started in 1982. Electron/positron beams were injected to Tristan from 1986 to 1994. The KEKB rings started their operations from 1998. The operation time is presently about 7,000 hours per year. The history of the operation time is shown in Figure 1. The accumulating operation time reached 100,000 hours on Mar. 3, 2003. The failure ratio has been about 5%. Figure 2 shows the injection time delivered to 4 kinds of rings. The KEKB injection time is more than 80% of the total injection time. The beam-loss time is shorter than the value obtained from the machine failure in Figure 1 because many of failed modules can be replaced by one of the stand-by modules before beam operation. The larger beam-loss time at PF in FY 2003 was caused by a problem of old modules in the trigger system. It was replaced last spring.

Continuous Injection (CI) Scheme

From January, 2004, the CI scheme to KEKB started for higher luminosity operation. CI operation enables us to increase the accumulation luminosity by about 20-

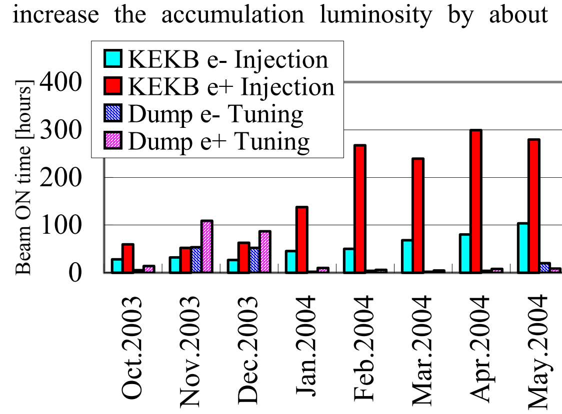

Figure 3: Status of the beam on time. The CI scheme started from Jan, 2004, the beam on time for LER (e+) increased and the tuning time (Dump) decreased.

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30%, and it reaches about 1/fb/day. The positron and electron beams are switched about every 10 minutes. The injection rates at CI are 1.0 mA/s for electrons at 10 Hz and 0.5 mA/s for positrons at 10 Hz, respectively. Figure 3 shows the beam-injection time this year. Since the accumulated current is larger and the lifetime of the positrons in LER is shorter than that of HER, the beam on time is longer compared with that of electrons (HER). After CI started, it became difficult to have time for "tuning", including beam-optics correction and/or rf phase optimization. This tuning is now carried out on demand.

Dip Test of the Klystrons

Figure 4 shows the operation time of the klystron-assemblies. Many assemblies have been used for more than 40,000 hours. These were installed during the KEKB construction and failures caused by the emission decrease can become a serious problem in the near future.

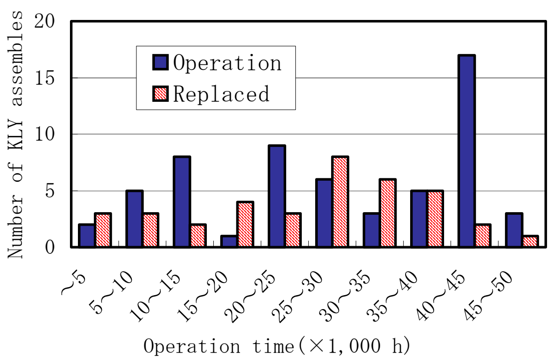

Figure 4: Operation and replaced time of the klystron assemblies. The assemblies installed at the beginning of the KEKB were used for more than 40,000 hours.

In order to catch a slight indication of the emission decrease with a limited diagnostic time (less than 10 minutes), dip tests [4] have been applied to all of the klystrons periodically [5]. Figure 5 shows an example of a dip test. The heater of the klystron is cut for 60 seconds and the emission decrease is monitored. A gradual increase in the dips with operation time is observed, which corresponds to the emission decrease. Such a klystron is replaced during the shutdown time or maintenance time.

Strip Line-Type BPM with Eight Electrodes

Non-destructive procedures are required to diagnose of the beam quality, especially at the CI scheme. The important parameters of the beam quality are the beam energy, beam position, energy spread and emittance. Feedback systems for the beam energy and the beam position are successfully operated at the KEK linac [6]. As for the beam emittance, wire-scanner measurements have been made during injection [7]. The energy spread had been measured using a screen monitor during the beam dump time for linac tuning.

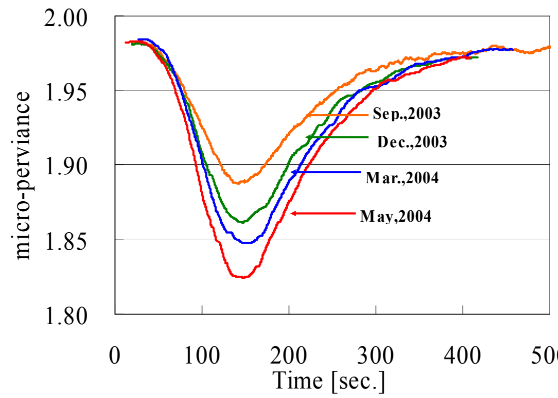

Figure 5: Result of the dip test. This example shows the decrease in emission with time. Such a klystron is replaced prior to a serious emission decrease.

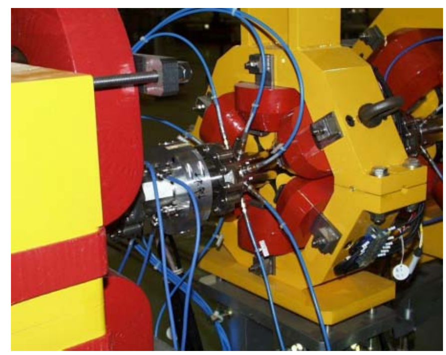

Figure 6: Photograph of the eight-electrodes BPM.

In order to measure the energy spread during injection, a stripline-type BPM with eight electrodes (Figure 6) is utilized [8,9]. This BPM has also been tested as the energy spread feedback for the electron beam and will be tested for the positron beam in this year.

UPGRADE FOR SUPER-KEKB

Upgrade Plan

Figure 7 shows one of the upgrade plans of the KEKB injector for SuperKEKB. Positrons with 8 GeV energy and electron with 3.5 GeV energy are required in this plan. The positron energy is boosted by the C-band accelerator modules. Electron/positron injections are switched by the kicker before the target, and both beams go through independent beam lines. The emittance of the positron beam is reduced with a damping ring. Both of the 2 bunches are used for positron and electron beams.

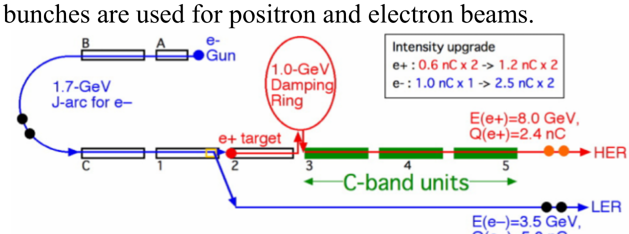

Figure 7: Layout of the linac upgrade for SuperKEKB.

In this plan, twice the number of modulators should be installed in the C-band units. Compact modulators with inverter power supplies are adopted. Figure 8 shows a schematic layout of the rf modules.

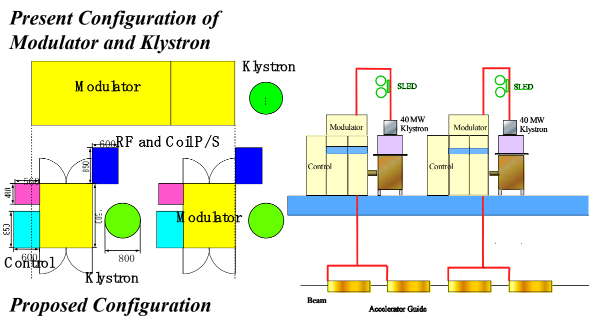

Figure 8: Schematic of the configuration of modulators and klystrons.

A C-band unit will consist of a compact modulator, a klystron, a waveguide window, a pulse compressor (SKIP) and two acceleration structures. In order to develop this upgrade, the C-band components are being examined. The layout of the rf system is shown in Figure 9.

RF Source

A driver klystron (100 kW) will drive eight high-power klystrons. The existing C-band 200 kW klystron for a weather observation station (Mitsubishi Electric Company) is being examined by retuning. The driver klystron (SB) can deliver more than 100 kW (at the applied voltage of 35 kV). The same modulator and high-voltage supply as that to the existing S-band system is used.

A high-power klystron (Toshiba E3726, 50 MW, 50 pps [10]) is used to examine the rf components and to test the beam acceleration. The existing pulse transformer (1:15) and oil tank are reused in this experiment. The operation conditions of a high-power klystron are compared with the existing S-band unit in Table 1.

Table 1: Operation parameters of the C-band klystron

	S-band	C-band
RF output	41 MW	40 MW
Typical charging voltage	42 kV	41 kV
Typical applied voltage	290 kV	325 kV
Pulse duration	4 μs	2μs

Inverter Power Supply

An inverter power supply is a key device for a compact modulator. A photograph of the inverter power supply is shown in Figure 10. The maximum output voltage is 50 kV with a voltage regulation of ±0.1%. Several problems, such as IGBT breakdowns, were found during operation. Improvements of the IGBT circuits and adoption of the durable IGBT have been applied and it runs in the klystron gallery.

Figure 10: Photograph of the inverter power supply. The size is 449mm(H)x 480mm(W)x 630mm(D).

Pulse Compressor (SKIP)

A C-band pulse compressor (SKIP: SuperKEKB Injector Pulse Compressor) was designed and tested this summer. The specifications of the pulse compressor are summarized in Table 2. Since the Q value decrease at high frequency, the TE_{038} mode (same mode to LIPS in CERN [11]) was chosen instead of the present TE_{015} mode at the C-band pulse compressor. The dimensions of

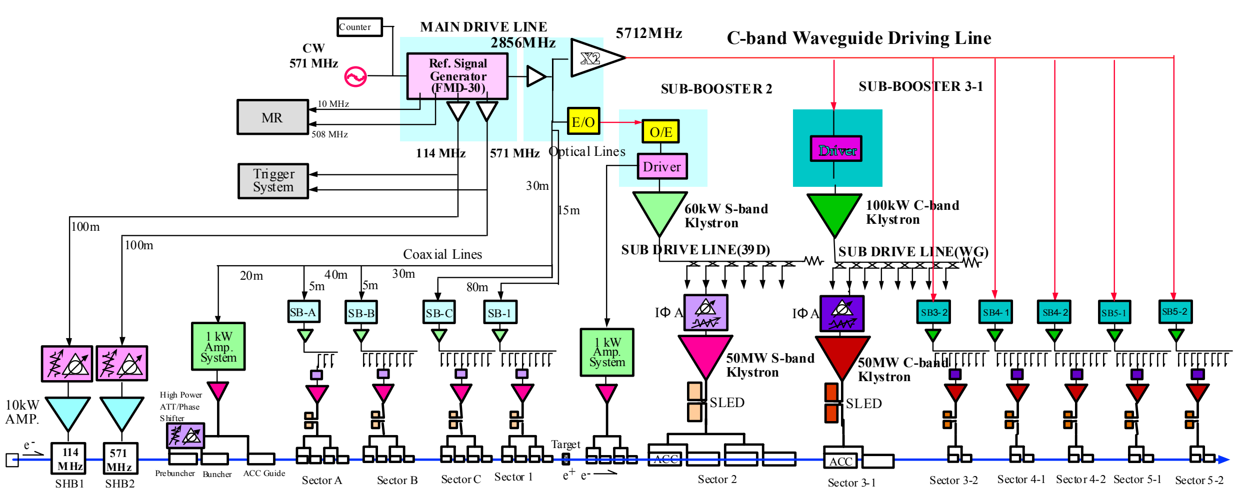

Figure 9: Rf system planned for the linac upgrade.

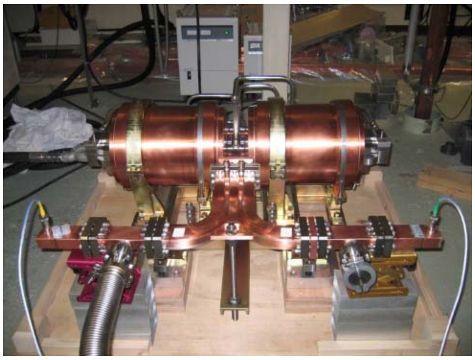

Figure 11: Photograph of SKIP.

the cavity become almost the same as that of the present KEKB-SLED.

Figure 11 shows a photograph of the SKIP. The maximum output power of 200 MW is obtained and the power magnification factor is 4.7 [12]. It will be installed in the klystron gallery for long-time operation with beam acceleration.

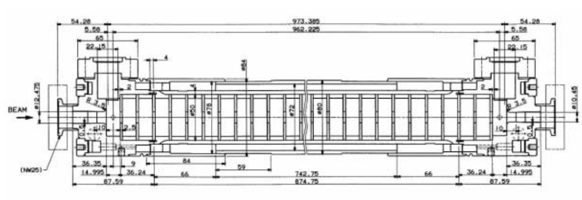

Figure 12: C-band acceleration structure.

Acceleration Structure

The acceleration structure is designed based on the present S-band acceleration structure (Figure12). High-power tests were carried out up to more than 43 MW at the test stand [13]. During the high-power test, an analysis of the breakdown location was carried out by rf signals and acoustic sensors. It revealed that the input coupler was one of the sources of the breakdown, probably due to the thin and sharp-edged coupler iris [13]. At the second model, the coupler structure has been re-designed. A high-power test of the second model is scheduled for this September.

RF Window

An rf window is utilized in a waveguide system in order to isolate the vacuum and pass rf power. A mix-mode window [14] has been designed [15]. The calculated electric fields at the center and the edge of the ceramics are 20% and 50% less, respectively, compared with the present S-band window. The window has a sufficient band-width of more than 200 MHz (<VSWR 1.2). Figure 13 shows a photograph of the window.

In order to examine the rf window, a resonant ring has also been designed. The resonance condition of the ring is controlled by the operation frequency after adjusting the total length roughly by spacers. The window has been tested up to 300 MW [15]. The window after operation

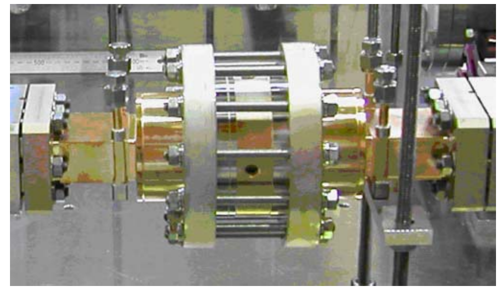

Figure 13: Photograph of the mix-mode window.

showed no damage, and it was installed in the klystron test stand.

Dummy Load

A dummy load is designed based on the present dummy load at the S-band linac. A photograph of the

Table 2: Comparison between KEKB-SLED and C-band SKIP

	KEKB-SLED	C-band SKIP
Frequency	2856 MHz	5712 MHz
Resonance mode	TE_{015}	TE_{038}
Length	33.59 cm	30.72 cm
Cavity diameter	20.51 cm	23.28 cm
Qvalue (Q_0)	90,000	130,000
Coupling	6.4	6.6

dummy load is shown in Figure 14 The load is used at the C-band acceleration structure, and as a load of the pulse compressor. It has been tested up to a 100 MW peak (at the test of SKIP) and a 2 kW average.

Figure 14: Photograph of the dummy load.

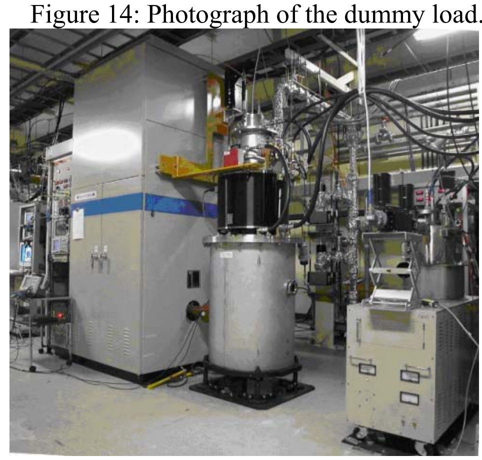

Figure 15: Photograph of the C-band unit installed in the klystron gallery.

Figure 16: Photograph of the C-band acceleration unit installed in the beam-line.

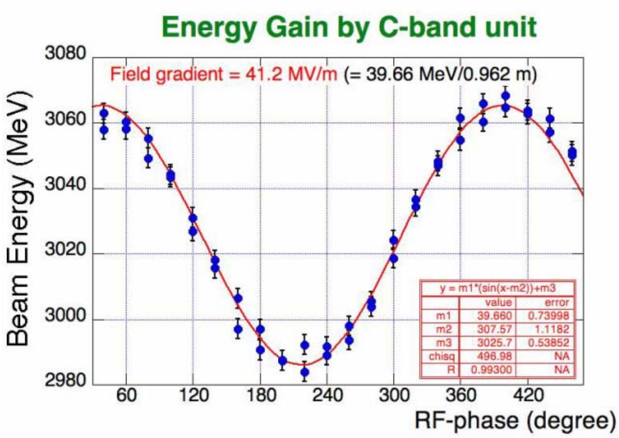

Figure 17: Result of beam-acceleration.

Operation Status at Klystron Gallery

A C-band unit (a driver klystron, a high-power klystron with a compact modulator, an rf window and an acceleration structure) was installed in the klystron gallery and beam line of the linac in Aug., 2003. The first model was installed into the beam line of the KEKB linac (Figures 15 and 16) in August, 2003. An acceleration gradient of more than 40 MV/m has been achieved as shown in Figure 17. The acceleration structure has been operated in the beam line, and it has also been confirmed that the smaller aperture of the C-band structure does not induce any beam characteristics. The unit has been operated for about 6,000 hours, and breakdown statistics of the acceleration structure and a long-time test of the components have been carried out [16]. SKIP was installed in the klystron gallery this summer, and beam acceleration tests with SKIP and a acceleration structure will be examined this Autumn.

SUMMARY

The KEKB linac delivers electron/positron-beams to 4 kinds of rings. The stability of the linac, where the failure rate is less than 5%, supports an efficient operation of the rings. The continuous-injection mode of the KEKB rings requires high-quality managements of the components. Dip tests of the klystrons are helpful to diagnose the klystrons. The eight-electrodes BPM has been tested concerning the feedback of the beam energy spread.

An upgrade for the Super KEKB is under consideration, and the C-band components have been tested. The acceleration structure, a pulse compressor (SKIP), has showed the good performance at a high-power test. Other components, such as the inverter power supply, rf window and dummy load have also been examined, and satisfy our specifications. Beam acceleration tests using SKIP, and high-power tests of the second acceleration structure are scheduled for this Autumn.

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