OPERATION STATUS AND STATISTICS OF THE KEK ELECTRON/POSITRON LINAC

Y. Ogawa#, A. Enomoto, K. Furukawa, T. Kamitani, M. Satoh, T. Sugimura, T. Suwada, Y. Yano, K. Yokoyama, M. Yoshida, KEK, Tsukuba 305-0801, Japan
Y. Imai, T. Kudou, S. Kusano, K. Suzuki, T. Toufuku, MELCO SC, Tsukuba 305-0801, Japan

Abstract

The KEK electron/positron linac has been operated since 1982, surpassing the total operation time of more than 120,000 hours. It presently delivers four different beams to four different rings quite stably, even frequently switching beam modes. Operation status and statistics is reported with the emphasis on continuing efforts in various kinds of machine improvements, which have ensured the stable operation. Recent on-going upgrade programs are also presented.

INTRODUCTION

The total operation time at the KEK electron/positron linac has reached more than 120,000 hours in FY2005 since FY1982, when the first 2.5-GeV electron beam of about 30 mA was injected into the photon factory (PF) ring. The linac has so far experienced extensive renovations twice: one for TRISTAN and the other for KEKB [1]. The required beam characteristics such as energy, intensity and time structures have become quite diverse as well as the operation time per year was drastically increased at each project. Fig. 1 shows the linac history in operation time and machine failures, which will be analyzed in this report, relying on statistics and our continuing efforts in machine improvements. Table I lists the present properties of the beams delivered to different rings, indicating that the linac operation mode is quite complicated. In Table I, KEKB LER has two parameters in each cell, since those of a primary high-intensity electron beam are also shown. The recent requirements of the continuous injection mode (CIM) for KEKB and the top-up injection mode for PF have pushed further the linac to take an unprecedented operation mode: a quasi-simultaneous injection to all rings [2].

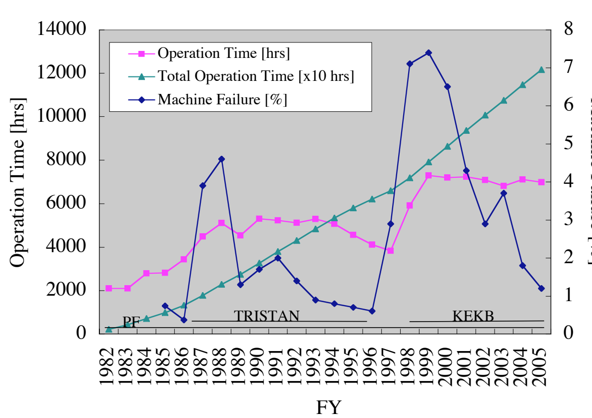

Figure 1: Operation history.

Table 1: Present beam characteristics.

Ring Name	KEKB HER	KEKB LER	PF	PF AR
Particle	e^-	e^- / e^+	e^-	e^-
Energy [GeV]	8.0	4.0 /3.5	2.5	3.0
Intensity [nC]	1 x 2	10 / 1 x 2	0.1	0.1
# of Bunch	1 x 2	1 x 2	3 - 4	3 - 4
Repetition [Hz]	10 - 50	10 - 50	25	25
Injection /Day	> 250	> 500	1 - 2	2

OPERATION STATUS

The typical daily operation status of KEKB is shown in Fig. 2, indicating that the beam currents of HER and LER are kept almost constant (CIM) by frequent injections, while small decays of the currents seen four times per day reveal injection periods for PF and PF_AR. The linac eventually undergoes full-time injections to four rings. Presently four beam modes are switched so that all settings of magnets, rf phases and beam timings are changed according to the beam properties listed in Table I. As a consequence, the minimization of a beam-mode switching time and the realization of its reproducibility have been among the most demanding issues for the linac to assure a stable and reliable operation. Fig. 1 shows that the machine-failure rate significantly rose at the beginning of the KEKB, but afterwards it has dropped quite steadily. More detailed operation statistics are presented in the following section together with some brief interpretations, manifesting a good performance of the linac.

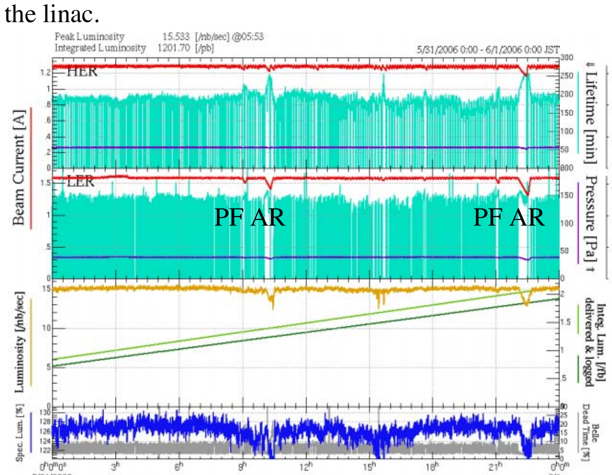

Figure 2: Typical KEKB daily status.

#yujiro.ogawa@kek.jp

OPERATION STATISTICS

Fig. 3 shows a detailed operation history with time breakdown structures, indicating a sudden increase of the KEKB injection time in FY2004 when CIM started. The beam mode switching time, however, still accounts for more than 30 % of the yearly operation time because of frequent mode switching, which is a major issue for our linac as mentioned in the previous section.

Seven-years statistics on failure rates are shown in Fig. 4; the failure includes all kinds of machine troubles, while the injection-delayed time is a part of the failure time, causing a real injection delay, and the rf trip rate is particularly quoted here to give a hint about the stability of the rf system and the accelerator sections. Failure rates have satisfactorily diminished, indicating that the machine availability is reaching about 98 % in FY2005.

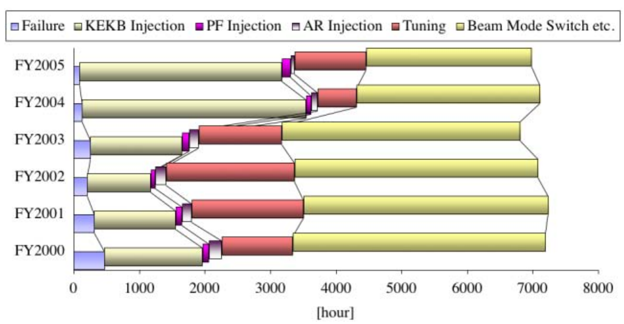

Figure 3: Detailed operation history.

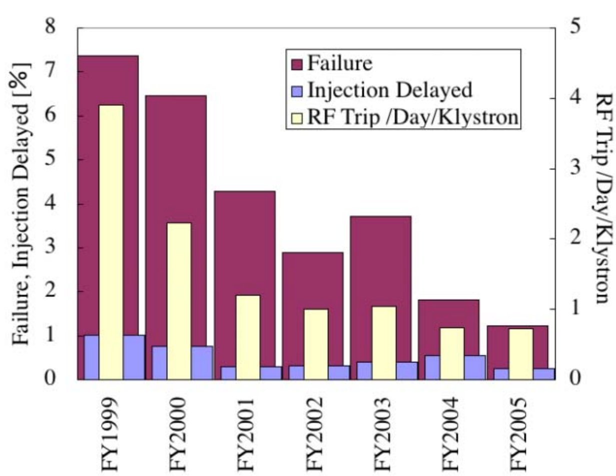

Figure 4: History of failure rates.

Although categorization of machine failures should be a delicate issue, a tentative classification into several items is attempted and a recent example of # of failures in subsystems (FY2005) is shown in Fig. 5. A history of MTTR (Mean Time To Repair = Downtime / # of Failures) in subsystems is given in Fig. 6, showing satisfactory improvements over the last few years. Some typical examples that have considerably contributed to this amelioration are discussed in the following.

RF system

Since the reliability of an rf system is directly linked to the linac availability, a good deal of effort has been made especially since KEKB started. Performances of the rf system, comprising 60 klystrons and modulators with low-level rf and timing systems, have been maintained in various aspects:

- Improve the robustness of the system itself.
- Prepare every spare, which should be easily exchangeable when broken down.
- Predict the component failure so as to repair or exchange in a more organized or scheduled manner.

A typical and outstanding example of the last one, which has been utilized on a routine base, is a klystron dip test [3]. This is one of the most rapid diagnostic methods developed at our linac for checking klystron emission performances in only several minutes. The dip test is usually carried out for stand-by klystrons even during operation and for non stand-by ones in the short period of maintenance scheduled every other week so that any signs of klystron deterioration could be easily found. For the suspected klystron, a usual emission measurement (>1 hr) is conducted and the time line of the klystron exchange is determined looking over the whole machine operation schedule. This maintenance criterion has greatly helped the reduction of MTTR in the rf system.

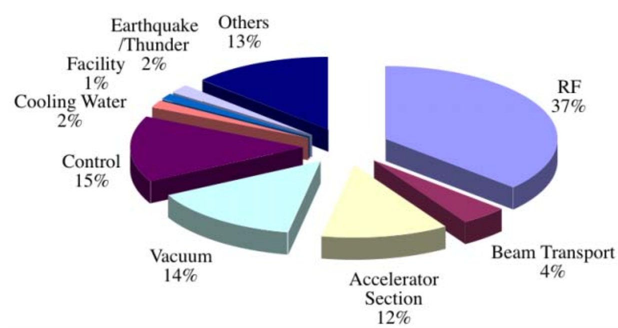

Figure 5: # of failures in subsystems (FY2005).

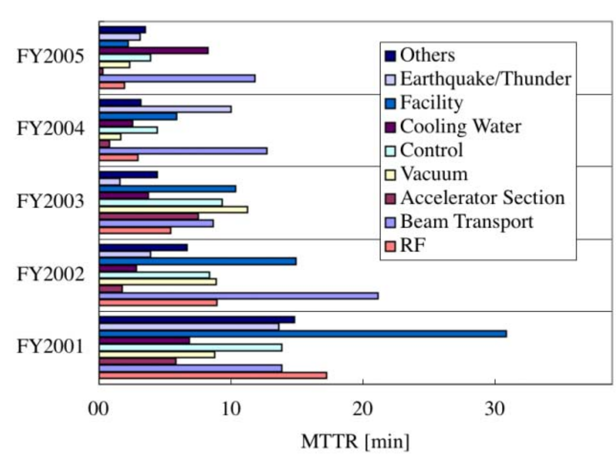

Figure 6: History of MTTR in subsystems.

Accelerator Section

The accelerator sections used in high-energy linacs, which are usually exposed by high electromagnetic fields, sometimes suffer unexpected rf breakdowns so that the linac operation might be stopped. Although it is obvious in this case that an appropriate treatment is essential for efficient recovery, practical procedures had not been optimized for recent severe operation conditions such as CIM in KEKB; for instance, the rf recovery must be carried out quite steadily without any serious operation interruptions even during injections. Various kinds of sophisticated auto-recovering systems have been developed for this purpose, and the number of the rf breakdown rate (rf trip rate) has decreased year by year (Fig. 4), indicating the fact that the optimal care for rf breakdowns is particularly crucial to a stable operation of high-availability machines.

Control System

The linac control system covers a broad range of items: those directly influencing on the beam operation such as feedback systems, and those indirectly sustaining a reliable operation as well, which, for instance, comprise the system redundancy.

A large number of feedback systems have been implemented to stabilize not just the beam orbit and energy but also the rf phases and timings; for example, a feedback of electron-gun timings is essential for stable operation of a high-intensity electron beam for positron production. The feedback systems, which must work differently depending on various kinds of beams listed in Table I, are also the keys to assuring good reproducibility of the beam mode switching.

The system redundancy is usually introduced within limited resources of money and manpower after having reached a certain level of reliability for each component constituting the control system. Various kinds of redundant systems including file servers and networks have been accommodated in our control system. The emphasis of the linac, however, has been especially on not excessively depending upon the manpower: even if no control experts are present at control-system troubles, the system should almost automatically recover without serious disturbances to the machine operation. The improvement in MTTR for the control system shown in Fig. 5 could represent the fruit of these efforts.

UPGRADE AND R&D

SuperKEKB, a major upgrade of KEKB was proposed in 2004 and many relevant R&Ds have been carried out. Main requirements for the injector linac are positron beam upgrades of energy, intensity and emittance: the energy from 3.5 to 8.0 GeV, the intensity twice as high and the emittance reduction equivalent to the present electron beam, while items indispensable for realization of these requirements are the system renovation of beam diagnosis and operations. Several issues related to these items are briefly described in the following.

Positron Energy

Since the length of the positron acceleration is limited in space, it was decided that an acceleration gradient be doubled by introducing C-band accelerator sections with appropriate rf sources and power supplies in place of the present S-band system. The basic R&D and the beam acceleration test have been finished, accomplishing an acceleration gradient of about 40 MV/m [4]. System integration and rf aging are currently being pursued in order to get sufficient reliability for stable operation.

Positron Intensity

In the design of positron production system, a flux concentrator would be implemented just after the positron target and the R&D has already started in collaboration with a Russian group. A multi-bunch scheme has recently been proposed to increase the total positron charge and a preliminary experiment was conducted in the case of three-bunch acceleration by applying a waveform flattening technique to SLED input signals so as to equalize the energy of three bunches. The principle of the new scheme was experimentally verified by accelerating a beam of a few nano Coulomb to the positron target [5].

Operation Mode

In SuperKEKB, a quasi-simultaneous injection is essential for efficient operation, in which, in principle, all kinds of beams must be accelerated with the same optics: common magnet settings but different acceleration phases for different energy. This multi-energy scheme [6] has been designed and the beam test was successfully carried out, though still requiring further machine studies such as those concerning a common-orbit correction method.

CONCLUSIONS

Operation status and statistics of KEKB is presented, verifying good machine availability. Recent on-going linac upgrade programs for SuperKEKB are outlined.

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