OPERATIONAL PERFORMANCE OF A NEW BEAM-CHARGE INTERLOCK SYSTEM FOR RADIATION SAFETY AT THE KEKB INJECTOR LINAC

T. Suwada*, E. Kadokura, M. Satoh, K. Furukawa, KEK, Tsukuba, Ibaraki 305-0801, Japan

Abstract

A new beam-charge interlock system has been developed for radiation safety and machine protection at the KEKB injector linac. Although the previous software-based interlock system was working, it was replaced with the new hardware-based one to improve its operational performance and reliability. The new interlock system restricts the integrated amount of beam charges delivered to four different storage rings (KEKB e^+, KEKB e^-, PF, PF-AR) at six locations along the linac and the beam transport lines. The full-scale operation of the new interlock system has started in 27 March 2008 after elaborate beam tests. In this report we describe the beam tests, the technical improvements, and the operational performance of the new beam-charge interlock system.

INTRODUCTION

A new injection scheme is under development for simultaneous and continuous injection delivered from the KEKB injector linac [1] to both the downstream storage rings (the KEKB electron/positron rings and the PF ring). The technical review was reported elsewhere in detail [2]. The new beam-charge interlock (BCI) system is one of the R&D subjects pertaining to the new injection scheme. The BCI system restricts the integrated amount of the beam intensity passing through the injector linac and the beam transport line to each storage ring. When it exceeds a certain threshold level prescribed at each location, the BCI system directly generates a beam-abort request to the safety control system of the linac for radiation safety and machine protection. Its technical review was reported in detail elsewhere [3-5].

The new BCI system also supplies a proper environment to advance the present accelerator complex towards the future projects. The following four subjects are underway,

(1) to increase of the injection beam intensity towards the next-generation B-factories,
(2) to perform the stable and continuous injection over an hour to the PF-AR,
(3) to enable easy beam tunings for the PF injection with a new beam dump,
(4) and to perform the new injection scheme for both the KEKB and the PF rings.

These subjects are strongly required for improving the stable and fast injection with higher-brightness (or higher-intensity) electron and positron beams into the downstream storage rings. In order to perform them, the instantaneous and integrated beam intensities must be controlled pulse-by-pulse at both the linac and each transport beam line. Therefore, the hardware-based BCI system with a higher reliability must have been developed for these purposes.

The new interlock system enables to relax the restrictions in the beam intensity for each injection mode. Table 1 shows the comparisons of the old and new beam-charge intensities prescribed at each location along the linac and each beam transport line.

Table 1: Comparisons of the Old and New Beam-charge Intensities Prescribed at Each Location

Location	Old		New	
	[nC/s]	[nC/h]	[nC/s]	[nC/h]
R0-01	1250	-	2500	4.50×10^6
22-44	625	-	1250	2.25×10^6
Linac	62.5	-	-	2.25×10^5
KEKB	-	5.76×10^5	-	5.76×10^5
PF	-	-	-	7.80×10^4
PF-AR	-	0.72×10^4	-	2.32×10^4

Based on this modification, the injection beam intensity can be controlled every an hour and every a second. In particular, the instantaneous beam intensity has been relaxed by two times. Thus, this modification has enabled to test high-intensity beam acceleration studies for the next-generation B-factories. On the other hand, the stable injection to the PF-AR over an hour has been realized. For the PF injection, the beam-intensity control has been available with a new beam dump. Thus, the flexible beam-intensity control has started and the highly reliable environment to advance the new injection scheme has been ready.

The development of the new BCI system has been finished after elaborate system tunings with beam tests during two years. The full-scale operation has started without any significant problems.

FURTHER TECHNICAL IMPROVEMENTS

The designs of the new interlock system started in 2006, and the development of both the hardware and software system finished in October 2007. During two months since then, the operational tests were performed to check the technical functions, the reliability, and the stability in the nominal injection operation. We found several faults during the beam tests. Further the technical improvements have been performed step-by-step in order to increase the system reliability and flexibility. For the hardware system, metal doors were installed to shield a system rack to

*E-mail address: tsuyoshi.suwada@kek.jp.

further reduce electromagnetic noises mainly caused from high-power klystrons. An uninterruptible power supply (UPS) was also installed at each system rack to improve the operational reliability even for an unexpected power failure.

On the other hand, for the software system, the following subjects have been performed

(1) to add a clock time adjustment function for whole the system,
(2) to improve the stability of a serial communication line between the AR and the main control room of the linac,
(3) to connect the alarm system,
(4) and to improve the operational panels and the data transfer speed.

These improvements enabled to implement the flexible functions of the operation panels and to increase the speed of the data transfer and storage. The data transfer and the command controls were also stabilized without any problems. The function that automatically adjusts the clock time differences between the detector modules and the PLCs by communicating the UNIX-based host computer was added. It enabled to quickly let the linac operators know the abnormal system status. Thus, based on the software improvements, the operators can get easily and quickly the proper information and status of the BCI system.

BEAM TESTS

The wall-current monitors are utilized for the beam-charge measurements in the new BCI system. They were calibrated with both bench and beam tests. The calibration system of the test bench was reported in detail elsewhere [4,6]. Here, the results of the beam tests are briefly described. The typical results with the KEKB positron beam are shown in fig. 1.

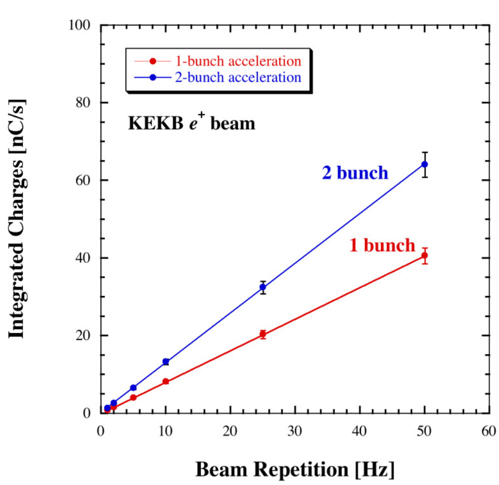

Figure 1: Linear relations of the beam charges integrated every a second interval as a function of the beam repetition rate obtained for one-bunch (red) and two-bunch (blue) acceleration mode.

The results show the linear relations of the beam charges integrated every a second interval depending on the beam repetition rate obtained for one-bunch and two-bunch acceleration mode. The results indicate a good linearity within 1% and with a dynamic range of ~20 dB although the obtained data include tiny beam intensity fluctuations.

Figure 2 shows the time trends of the beam charges integrated every a second interval measured for the nominal KEKB operation during a day. We can clearly see the variations in the differences on the KEKB electron and positron beam intensity, on the number of the accelerated bunches, and the repetition rate. The results also show that the beam charges are stably measured pulse-by-pulse without any significant signal noises.

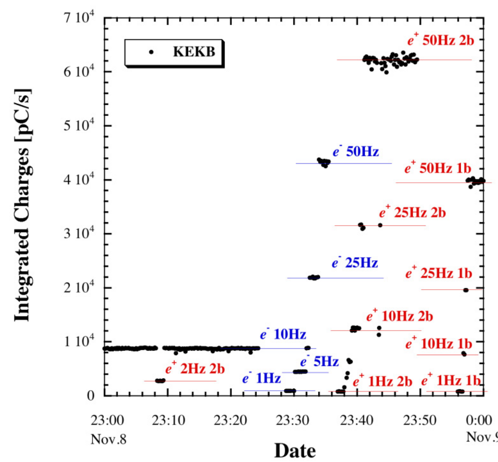

Figure 2: Time trends in the beam charges integrated every a second in the nominal KEKB operation. The repetition rate, the number of accelerated bunches (1b: 1 bunch, 2b: 2 bunches), and the charge sign are indicated at each data point.

Figures 3 (a) and (b) shows the typical time trends of the integrated charges integrated every an hour interval during a week and a day obtained for the nominal KEKB operation, respectively. As shown in fig. 3(a), the typical integrated intensities are ~3% to the prescribed beam charges (CL=5.76x10^5 nC/h) at location KEKB while the maximum of the integrated intensity have attained up to ~10% (or 6x10^4 nC/h) level to it. This level (~3%) corresponds to the integrated beam charges in the stable continuous injection operation, in which the electron and positron injection has alternatively changed every a few minutes. The maximum level (~10%) corresponds to the injection with a maximum repetition rate. Thus, we can see that in the nominal operation condition the measured beam intensity is far enough away from the prescribed beam charges.

As shown in fig. 3(b), we can also see that the BCI system is properly reset every clock hour, and it successively continues the measurement after the reset without any time delay. It is also confirmed that the variations in the linear slope of the measured integrated charges depend on the change of the beam repetition rate.

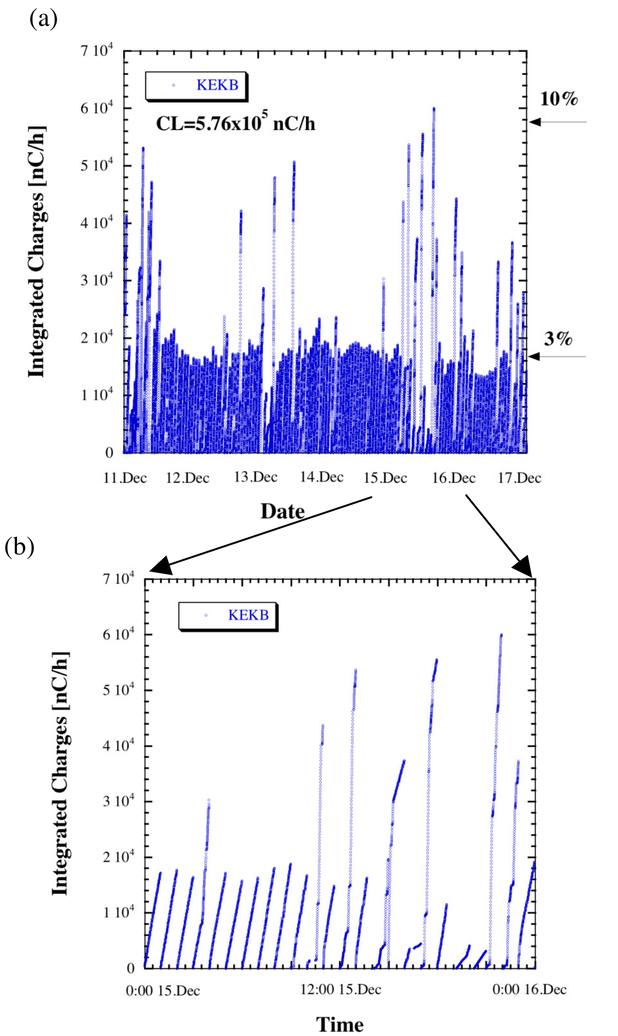

Figure 3: Time trends of the beam charges integrated every an hour during (a) a week and (b) a day in the nominal KEKB operation.

OPERATIONAL PERFORMANCE

The successive full-scale operation of the BCI system has been stably implemented during three months without any significant problems while no abort-signal requests were generated in this operation. The typical charge-intensity levels measured in the nominal operation are summarized in Table 2. It should be noted that the unit is indicated by the ratio of the integrated beam charges to the prescribed ones at each location. The maximum of the beam charges integrated every a second (hour) at R0-01 was ~35% (~13%) for the primary high-intensity electron beam for positron generation.

Thus, it was confirmed that the beam intensity levels were much less than the prescribed beam charges in the nominal operation for each injection mode. The results clearly also show the good reliability and stability of the BCI system without any dangerous excesses on the beam intensity for all the beam modes.

Table 2: Integrated Amounts of the Beam Charges Normalized by Those Prescribed at Each Location Obtained in the Nominal Linac Operation

Location	Beam Charges (1s interval) [%]	Beam Charges (1h interval) [%]
R0-01	8-35	3.5-13
22-44	1.5-5	2-12
KEKB	-	3.5-10
PF	-	0.2-0.6
PF-AR	-	2-5

The BCI system enabled to store other important data, that is, the beam charges and the shot numbers integrated during a day and a week at each location. The 1-week beam-charge data depending on the injection modes are required to radiation-safety records in the linac operation. We have no such kinds of data logging systems until now. It is expected that these data give an important operational history not only for radiation safety but also for the long-term stability and reproducibility of the injector linac operation.

SUMMARY

The full-scale operation of the new beam-charge interlock system has started since 27 March 2008. The new BCI system highly improved its reliability and stability for radiation safety and machine protection for the KEKB injector linac and the downstream beam transport lines. It was confirmed that this new system has stably continued to work during three months until this summer shutdown (the end of June 2008) without any significant problems. An environment to advance several new activities for our future projects is ready now.

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