CONTROL SYSTEM FOR A LIMITATION OF AN INTEGRATED AMOUNT OF BEAM CHARGES DELIVERED FROM THE KEKB INJECTOR LINAC

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Abstract

A new beam-charge limit system is under development for radiation safety of the KEK B-Factory (KEKB) injector linac. This system restricts an integrated amount of beam charges, which are delivered to four different storage rings. The beam charges are measured with wall-current monitors basically at three locations of the linac. Instead of the present software-based system, the new hardware-based system generates and sends beam abort signals directly to the radiation safety control system of the linac with hard-wire cables when the amount of the detected beam charges is beyond a certain prescribed threshold level. In this report we describe the new design of the beam-charge limit system in detail, along with the detector circuits and their characteristics.

INTRODUCTION

The KEKB project[1] is progressing in order to test CP violation in the decay of B mesons. KEKB is an asymmetric electron-positron collider comprising 3.5-GeV positron and 8-GeV electron rings. The KEKB injector linac[2] was upgraded in order to inject single-bunch positron and electron beams directly into the KEKB storage rings. The beam charges are designed to be 0.64 nC/bunch and 1.3 nC/bunch with a maximum repetition rate of 50 Hz for the positron and electron beams, respectively. High-current primary electron beams (~10 nC/bunch) are required in order to generate a sufficient number of positrons. Since the KEKB is a factory machine, a well-controlled operation of the injector linac is required for minimizing the tuning time and for maximizing stable operation in order to increase the integrated luminosity.

For this purpose, two kinds of the new injection schemes have been performed for this purpose. One is the simultaneous injection of two bunches[3], which has been carried out since September 2002 and April 2006 for positron and electron beams, respectively. The other is the continuous injection[4], which has been also carried out since January 2004. The former scheme means that the simultaneous acceleration and injection of two bunches separated by 96 ns in an rf pulse in order to inject the electron and positron beams to the KEKB rings. The dedicated beam-feedback control systems make stabilization of the two bunches possible well[5]. The two-bunch injection scheme has enabled us to boost the injection rate of both the electron and positron beams by a factor two. The latter scheme is the continuous injection in which experimental data of the collider can be taken even during the injection except for time interval for switching the injection of the electrons (positrons) to that of positrons (electrons). Thus, the new schemes contribute to keeping the stability of the beam collision and the peak luminosity as high as possible in the colliding experiment.

On the other hand, the injector linac is also responsible for the injection of the pulsed electron beams into the PF and the PF-AR storage rings[6]. The injection rate is two times per day for each ring during a nominal user time. When the beam injection to these rings is required, the continuous injection to the KEKB needs to stop temporarily during the injection after switching the injection mode. Such injection disturbance for the KEKB often not only reduces the peak luminosity but also deteriorates the collision stability. Thus, the new injection schemes have been investigated in order to carry out the simultaneous and continuous injections to both the KEKB and PF except for the PF-AR. The R&D works have started since 2004, and a new beam transport line between the linac and the PF was constructed as the first step in summer shutdown of 2005[7].

A development of a new control system restricting beam charges for radiation safety is one of several R&D issues for the new injection schemes. This control system restricts an integrated amount of beam charges passing through the linac and also being delivered from the linac to the beam transport line to each storage ring. Although the present control system for this purpose is working, it is specialized not with a hardware-based control system but a software-based control system utilizing the beam-position monitor (BPM) system[8]. The software-based control system runs on the UNIX-based host computer. It reads the beam charges measured by the BPM system and calculates the integrated amount of beam charges. When the integrated amount of the beam charges is beyond a certain threshold level at several locations prescribed along the linac, the control system generates a beam abort signal and send it directly to the electron gun (or the safety control system). However, the present control system has several drawbacks: strong dependence on the BPM system, slow data-acquisition speed, impossible control for the new injection schemes, etc. The new control system is now under development in order to overcome these drawbacks and to increase the reliability of the radiation safety of the linac in the new injection schemes for both the KEKB and PF.

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BEAM-CHARGE LIMIT SYSTEM

System Overview

Locations of the beam-charge limit system installed along the linac are shown in Fig. 1. The beam charges are restricted basically at three locations of the beam line. The solid circle indicates a beam-charge instrumentation, which comprises a wall-current monitor (WCM) and a detection electronics. They are installed at the location B-8 in sector B, the location 2-2 in sector 2, and the beam switchyard (6-A). The location B-8 restricts mainly a maximum amount of the beam charges for the primary electron beam for positron production. The location 2-2 limits the maximum charges after the positron target. The location 6-A restricts the maximum amount of the beam charges at an entrance of the beam transport line corresponding to each storage ring. The maximum allowable beam charge prescribed at each location is summarized in Table 1. The prescribed beam charge is defined not by a beam charge of one pulse but by an integrated amount of the beam charges per second (or hour) depending on the locations.

Hardware Overview

The hardware of the beam-charge limit system using the WCMs is shown in Fig. 2. When a bunched beam passes through a vacuum pipe, image charges (wall currents) are induced on the inner surface of the vacuum pipe. The WCM measures a voltage drop induced by the image charges through a resistor connected between both ends of the vacuum pipe. The picked-up pulsed signal is sent to a detection electronics installed at a klystron gallery through a coaxial cable (35-60 m). The detection electronics measures the beam charges pulse-by-pulse. When the integrated amount of the beam charges is beyond a certain threshold level prescribed at each location, the beam-abort signal is generated and fed directly to a programmable-logic controller (PLC) for radiation safety installed at the main control room. After receiving the abort signal, the PLC of the radiation safety inhibits immediately a trigger signal to be supplied to the electron gun. On the other hand, the main PLC receives the beam-charge data measured by the detection electronics through the daughter PLCs, and displays the data in real time on a terminal with a time stamp.

Detection Electronics

The detection electronics based on a charge-integrating analog circuit is now under development. Figure 3 shows the block diagram of the detection circuit. The pulse signal with the width of 1 ns from the WCM is fed directly into the detection electronics which can be received the pulsed signals with the different polarity corresponding to the electron and positron beam. These two signals are combined by an rf combiner. The combined signal is divided by two signals with 50-Ω strip-lines printed on a circuit board. One is for the charge integrating of the main pulse, and the other is for the trigger-timing generation for switching of the main pulse signal with a fast rf switch (MACOM, SW-283-PIN) and for the analog-to-digital conversion. The rise time of the main pulse signal is elongated with a gaussian filter (rise time~5 ns, Picosecond Pulse Labs, Model 5915) with keeping its pulse shape. Then, the main pulse is cut off with a 30-ns-long gate pulse generated by the fast rf switch. The gate pulse is generated with a fast window comparator (MAXIM MAX9600) and a pulse stretcher circuit generates a pulse gate of 30 ns. The main pulse is amplified with three consecutive operational amplifiers with a function of a low-pass filter, and it is fed to the charge-integrating circuit through an analog switch in which the signal is again cut off with the pulse width of 30 μs. The charge–integrating circuit integrates the area of the main pulse which is proportional to the beam charges. An analog-to-digital converter (A/D) converts the pulse area to a digital data. The digital data is stored and also added up in a memory in order to calculate the integrated amount of the beam charges. Figure 4 shows the linear input-output relation with a test pulse of 1-ns width. The preliminary result indicates a good linearity in an input charge range over 23 nC. The minimum detectable charge was less than 100 pC, which was restricted by the threshold voltage of the window comparator.

SUMMARY

The new beam-charge limit system is under development for radiation safety of the KEKB injector linac in order to carry out the new injection schemes for the KEKB and the PF. The preliminary test of the detection electronics gives a good result (detection limit of the beam charge~50 pC/bunch and the dynamic range of the detection electronics~46dB at maximum) satisfied well for this purpose.

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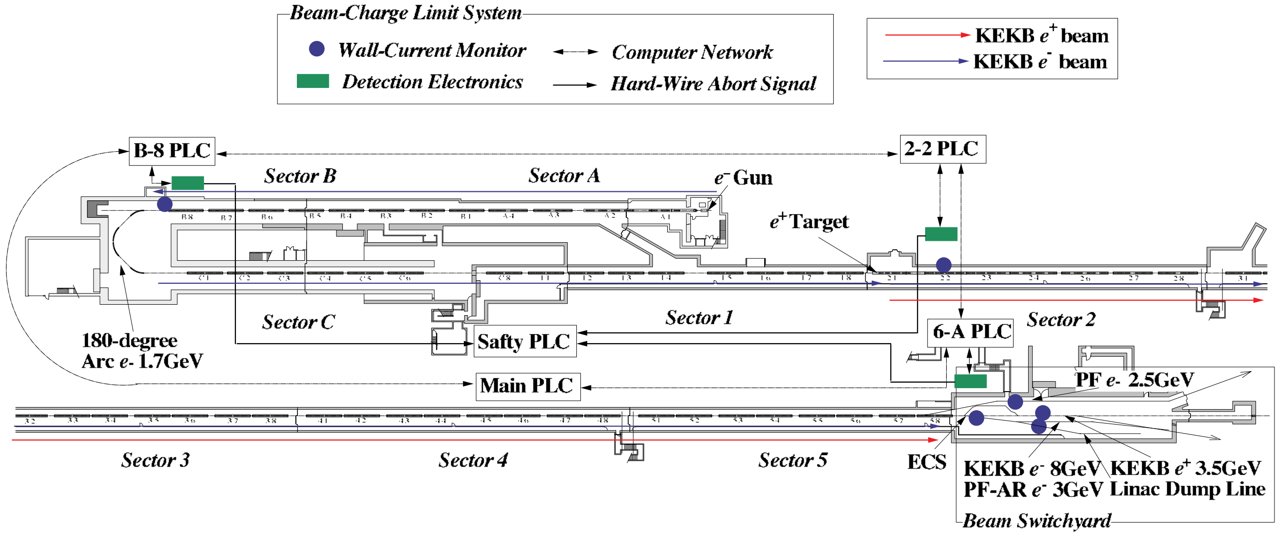

Figure 1: Locations of the beam-charge limit system for radiation safety at the KEKB injector linac.

Table 1: Integrated amount of the beam charges prescribed at each location of the injector linac

Locati-ons	Beam Charge (Integrated) [nC]	Time	Beam Charge (Pulse*) [nC/pulse]xHz
B-8	1250	sec	25 x 50
2-2	625	sec	12.5 x 50
Linac	62.5	sec	1.25 x 50
KEKB	5.76×10^5	hour	3.2 x 50
PF	2.25×10^5	hour	1.04 x 25
AR	7.2×10^3	hour	0.08 x 25

The symbol (*) indicates an average beam charges in a pulse.

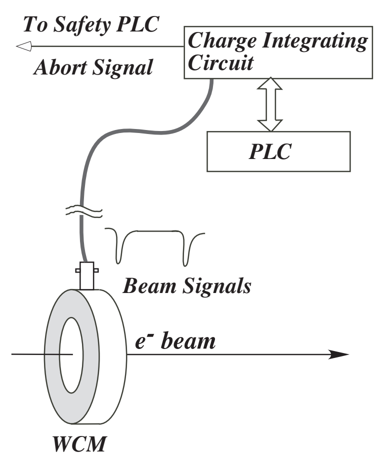

Figure 2: Block diagram of the beam-charge limit system using a wall-current monitor.

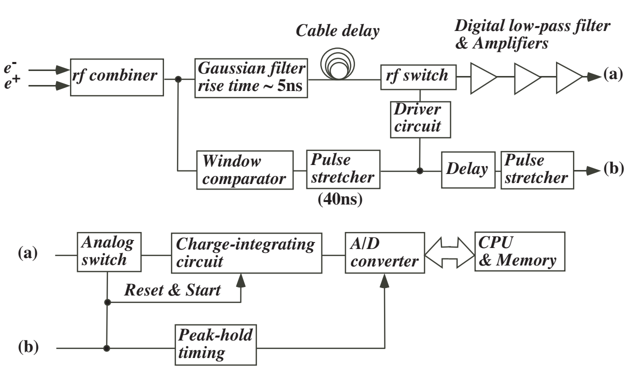

Figure 3: Block diagram of the detection electronics.

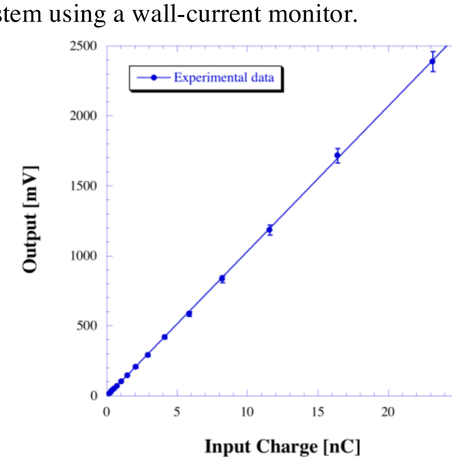

Figure 4: Linear relation of the input test charge to the output voltage. The input charge to the detection electronics is normalized by a beam charge.