

PLC-BASED BEAM CHARGE INTERLOCK SYSTEM FOR RADIATION SAFETY IN THE KEKB INJECTOR LINAC

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Abstract

A new PLC-based beam charge interlock system is under development for radiation safety and machine protection in the KEKB injector linac. This system restricts integrated amounts of beam charges passing through several locations along the linac before they are injected into four different storage rings (KEKB e^+e^- storage rings, PF, PF-AR). The beam charges are measured using wall current monitors and detection electronics controlled by PLCs. This system issues beam abort requests directly to the radiation safety control system through twisted hardwired cables when the integrated amounts of beam charges exceed the threshold level prescribed at each location. In this report, we describe the new design of the PLC-based beam charge interlock system, with particular focus on the development and performance of the PLC controls.

INTRODUCTION

The KEK B-Factor (KEKB) injector linac [1] delivers electron (or positron) beams to four different storage rings in daily operations. One of the purposes is to directly supply 3.5-GeV positron and 8-GeV electron beams to the KEKB storage rings, where a high-energy e^+e^- collider experiment (KEKB project [2]) is in progress. For the KEKB operation, the continuous injection scheme [3] is implemented in order to maintain the stability of beam collision and peak luminosity as high as possible. The other purpose is to supply 2.5 GeV and 3 GeV electron beams to two different photon factories (PF and PF-AR, respectively) [4], where extensive studies on materials science is in progress. The frequency of injection is twice per day for each ring under the nominal user time.

A new sophisticated injection scheme has been investigated in order not to disturb the beam injections to the four storage rings with each other and to keep the stabilization of the storage rings independently. The new injection scheme requires a simultaneous and continuous injection [5, 6] to all the downstream storage rings. Research and development (R&D) studies on the new injection scheme have been conducted since 2004.

The programmable logic controller (PLC)-based beam charge interlock (BCI) system is one of the R&D systems required for the new injection scheme. This system restricts the integrated amount of beam charges passing through the linac, and also that delivered to the beam transport line of each storage ring without any conditions in terms of the beam mode. When the integrated amount exceeds a certain threshold level prescribed at each location along the linac, the BCI system issues a beam abort request directly to the safety control system of the linac for radiation safety and machine protection.

Although the present software-based BCI system is implemented on a UNIX-based host computer by utilizing the beam position monitor (BPM) system [6], it is not a dedicated system for this purpose. It reads beam charges measured by the BPM system and calculates the integrated amount of beam charges. Based on similar interlock conditions, the beam abort request can be sent to the safety control system through the computer network. However, the software-based system has several drawbacks: strong dependence on the BPM system, slow data-acquisition speed, low reliability for the new injection scheme, *etc.* We have developed the new BCI system, overcome these drawbacks, and increased the reliability of radiation safety and machine protection, even in the new injection scheme.

BCI SYSTEM

The PLC-based BCI system has been newly installed along the linac beam line. Maximal integrated amounts of beam charges are restricted at six locations (Locat.) along the beam line in the tunnel, while the detection systems are installed at three stations (St.) in the klystron gallery. The maximum allowable integrated amounts of beam charges are prescribed at each location and they are summarized in Table 1.

Table 1: Maximal integrated amounts of beam charges prescribed at each location along the injector linac.

St.	Locat.	Q [nC] (integrated)	Q [nC/pulse] x Hz (per pulse)	Time int.	
B-8	B-8	2500	50 x 50	s	
		4.5×10^6	25 x 50	h	
2-2	2-2	1250	25 x 50	s	
		2.25×10^6	12.5 x 50	h	
6-A	Linac	2.25×10^5	1.25 x 50	h	
		KEKB	5.76×10^5	3.2 x 50	h
		PF	7.83×10^4	0.87 x 25	h
		PF-AR	2.88×10^4	0.32 x 25	h

Here, the restricted beam charges are defined as the integrated amounts of beam charges measured per second (and/or per hour) depending on the location while the beam charge per pulse refers to the average charges at maximum repetition rates.

The block diagram of the BCI system is shown in Fig. 1. Pulsed beam signals from a wall current monitor (WCM) are transmitted and received pulse-by-pulse by the detection electronics (or BCI module) through a 35-m-long coaxial cable at a detection speed of more than 50 Hz. It measures the integrated amount of signal charges based on a charge integration circuit and transforms the signal charges into beam charges using calibration coefficients. The hardware system of the WCMs and

detection electronics are described elsewhere [7]. Here, the PLC-based control system is described in detail.

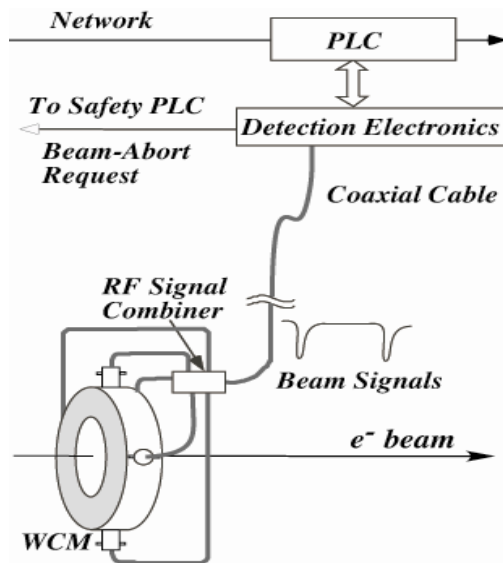


Figure 1: Block diagram of the beam charge interlock system.

The PLCs control the detection electronics and receive the integrated beam charge data every second. When the integrated amount of beam charges exceeds a certain threshold level prescribed at each location (see Table 1), the beam abort request issued by the detection electronics is transmitted directly to the safety PLC installed in the main control room. After receiving the beam abort request, the safety PLC immediately refrains from transmitting a trigger signal to the electron gun. A block diagram of the generation scheme for the beam abort requests is shown in Fig. 2.

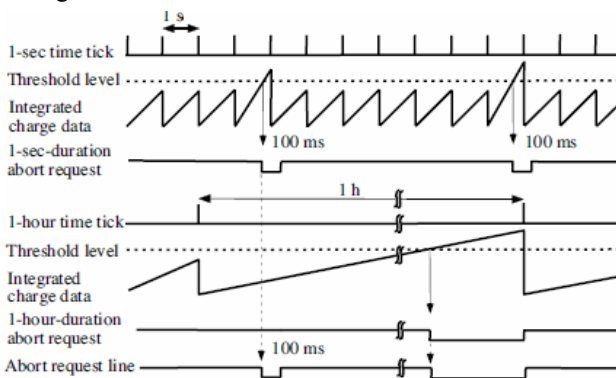


Figure 2: Block diagram of the scheme for issuing beam abort requests.

When the 1-sec (and/or 1-hour) interval of the integrated charge data exceeds the threshold level, a driver circuit of the safety PLC supplying a 24 V DC level switches off a no-voltage contact. Simultaneously, the detection electronics issues a beam abort request with a long pulse of 100 ms (and/or a zero-voltage level) directly to the safety PLC through a twisted hardwired cable. The abort request with an interval of 1 h is reset

every clock hour, while that with an interval of 1 s is reset every second.

This system can automatically restart the measurement of the beam charges, even during a power failure, since the data obtained before the power failure is temporally stored in the EPROM of the detection electronics. These data are reloaded in memories after recovery from the power failure. It should be noted that these functions maximize the reliability of radiation safety in the injector linac.

PLC-BASED CONTROL SYSTEM

The PLC-based control system comprises a main PLC, three slave PLCs, and a sub-PLC, as shown in Fig. 3.

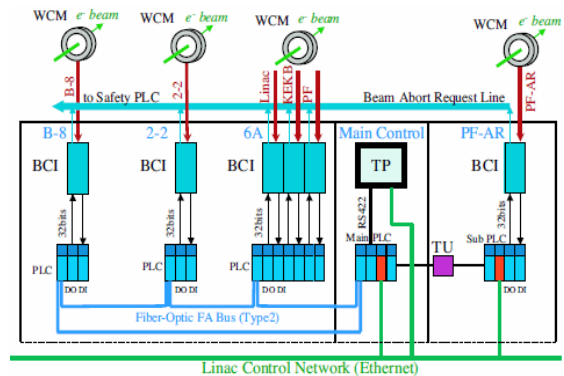


Figure 3: Block diagram of the PLC-based control configuration for the BCI system.

Five BCI modules are controlled by the main PLC (YOKOGAWA, FA-M3) with a CPU module (YOKOGAWA, F3SP66-4S) through the slave PLCs, which are connected in a loop with optical fibers (FA-bus (type2), 10 Mbps) over a total length of 1.3 km. The main PLC controls the digital input/output (DI/O) modules in the slave PLCs. The DI/O modules are connected to the BCI modules with 32-bit parallel communication cables. The main PLC performs several functions for a set of parameters and data acquisitions of the BCI modules. The sub-PLC controls one BCI module. The communication between the main PLC and the sub-PLC is achieved through a 1.1-km-long pair cable with a 128-bit serial two-way communication protocol because such a long distance inhibits the nominal communication protocol using optical fibers.

The TP is connected to the main PC through RS422 with a communication speed of 115 kbps. All functions of the BCI modules are set through the TP. The TP is also connected to the linac control network through ethernet. It also facilitates the development and maintenance of software programming. The main PLC is also connected to a Linux-based archiver, where EPICS Input-Output Controller (IOC) is running, through the linac control network. A data logging system based on the EPICS archiver stores the data from the main PLC.

The power supply of the main PLC is switched on through an on-delay timer in order to communicate with

higher reliability to the slave PLCs at the beginning of the control system. Power is supplied to the entire control system through uninterruptible power systems (UPSs) using batteries in order to avoid any problems due to an unexpected power failure.

DATA COMMUNICATION

Communication overview

The PLCs read the data, integrated amounts of beam charges for the 1-sec interval, detected beam-shot number, alarm status, *etc.*, through the DI modules from the BCI modules. They also store the data along with integrated amounts of beam charges for a 1-hour-interval, 1-day-interval, and 1-week-interval, after the calculations in the memories of the PLCs. These implementations can be processed within 1 ms, where the sampling time interval of the DI module is set to 250 μ s. On the other hand, the time interval for data acquisition of the DO module is less than 1 ms.

The alarm histories and time traces of the integrated amounts of beam charges obtained at each location are displayed on the TP in real time.

Communication between PLC and BCI module

The word-type data with 24 bits and bit-type data, respectively, are mutually transferred between the PLCs and the BCI modules with a handshake procedure by using “Write” and “Read” commands defined by the side of the PLCs. A series of these commands is summarized in Table 2.

Table 2: Protocols for data communication between the PLC and the BCI module using “Write” and “Read” commands.

Command	Data	# of bits
Write (4 bits)	1-sec-duration intergrated Q (presc.)	20
	Calibration coefficient	20
Read (4 bits)	1-sec-duration intergrated Q (meas.)	20
	Integrated beam shot numbers	20
Write (1 bit)	Abort status	0
	Clock time	0
	Data clear	0
Read (1 bit)	Abort status	0
	Beam detect	0

These commands are implemented with the handshake procedure as shown in Fig. 4.

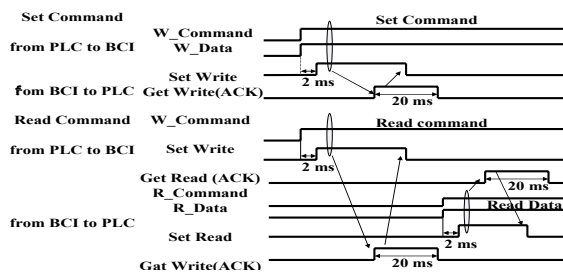


Figure 4: Handshake procedures for data communication between the PLC and the BCI module.

For example, the data are set from the PLC to the BCI module by sending a series of commands, a command (Write Command) to be set (W_Command), data (W_Data) to be written along with a bit command to be set (Write Bit Command). One cycle of the data set based on the “Write Command” is completed by receiving an acknowledge signal (Get Write (ACK)) from the PLC. For reading data, a similar procedure is implemented by using “Read” commands. The TP facilitates the implementation of these commands.

Communication between PLC and EPICS archiver

The main PLC is connected to the Linux-based EPICS archiver via the linac control network. This archiver logs the data stored in the main PLC through an EPICS IOC. A database is created from these logged data. The application software displays time traces of the integrated amounts of beam charges, beam abort status, *etc.*, on any X-terminal by utilizing the database for achieving stable linac operation. Such simple command-based control architectures strongly support the stable operation of the BCI system.

SUMMARY

We have successfully installed a PLC-based BCI system for radiation safety and machine protection in the KEKB injector linac. This control system has good performance and high reliability along with the detection system based on the WCMs. It enables us to reinforce the increase in beam intensities and repetition rates toward the new injection scheme of the linac operation.

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