# Development of beam interlock system driven by change in current of the magnet

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At the RI Beam Factory, the machine time (MT) using SRC (Superconducting Ring Cyclotron) is implemented for about 4 months a year. In recent years, with increase in the beam intensity, the power of the beam at the target has increased to about 13 kW during $^{78}$Kr acceleration. Many electromagnets used in cyclotrons and beam transport lines are individually powered by a DC power supply. When the power supply fails, the trajectory of the beam changes. If the beam strikes the vacuum vessel and melts, the beam operation cannot be continued. To prevent such troubles, when the power supply fails or turns off, the power supply itself detects this and sends a signal to the beam interlock system (BIS),[1)] and stops the beam within a few tens of milliseconds. On the other hand, even when the power supply is in operation, if the current value changes arbitrarily, the beam trajectory will change and cause trouble. Such abnormal events do not occur frequently, but several troubles have occurred. For example, during the $^{70}$Zn-MT on April 18, 2017, the current value of the SRC-SH1 power supply changed from −24 A to −97 A without any operation. The beam struck the vacuum bellows at the SRC injection section, the bellows melted, and the MT was interrupted.

With the increase in beam power, it becomes necessary to have a system that stops the beam by detecting the changes in current due to unknown causes or noises. A simple method is to constantly measure the set current value of the power supply and the actual current through the network, and when the difference between the two values become large, the system issues a signal. However, with the method of monitoring via the network, it is difficult to stop the beam within a few tens of milliseconds after the phenomena, since the repetition rate of the monitor is not sufficiently fast and the monitoring speed cannot be kept constant.

Therefore, we developed a system that can detect changes in the current of the power supply by a relatively simple method and send a signal to the beam interlock system only when it is not due for operation. Figure 1 shows a schematic diagram of the beam interlock system driven by change in current (Curs-BIS). The system consists of an FA-M3 PLC produced by Yokogawa Electric Corp. The main components are a sequence CPU, analog input modules, and a digital output module.

In order to precisely measure the current stability, the signal cables had already been wired from each power supply to the DVM. The signal cables are branched and connected to the 16-bit analog input modules in the Curs-BIS system. The system is programmed to measure the input analog signals of 24 to 48 points at intervals of 8 msec and send a signal to the beam interlock system when the measured value exceeds the preset allowable value. On the other hand, when the current is

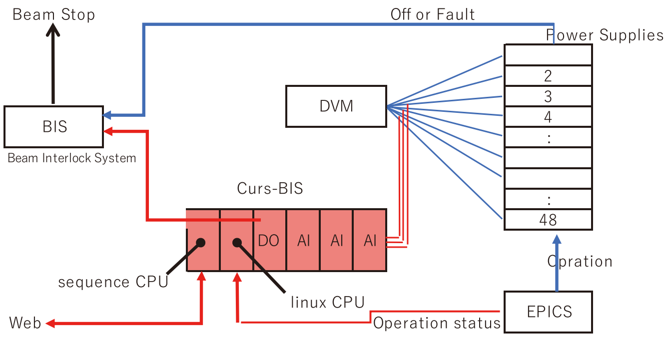


Fig. 1. Schematic diagram of the beam interlock system driven by change in current (Curs-BIS). The parts drawn in red are newly installed.

changed by an operation for the adjustment of the beam trajectory, the signal should not come out. In order to distinguish whether the change in current value is due to the operation or not, a real-time CPU module (F3RP61) that was installed Linux was added.[2)] Since the EPICS CA client runs on the CPU, when the power supply operation is performed on the EPICS network, the information can be detected within several milliseconds and is instantaneously transmitted via the FAM3 bus to the sequence CPU register. Thus, a program is established to judge whether the change in current is due to an operation or some kind of trouble and judge whether to send a beam interlock signal. After the current has been changed by the operation, the allowable range of current is automatically reset again after several tens of seconds.

The time required for one scan of the sequence program was about 0.4 msec during normal operation. All the current values that are being measured and the histories of the beam interlock signal can be monitored on the WEB.

We tested two sets of the Curs-BIS at uranium machine time from October 2018. The number of power supplies monitoring the current was 24 units each. The power supply stopped due to trouble several times, and the change in current was detected and the system worked correctly. The result of the test was almost satisfactory. However, unnecessary interlock signals were sometimes issued when some of the power supplies were largely changed from 0 A to a predetermined current value.

Next time, we will improve the program so that no signal will be issued just after the power supply is turned on. In addition, we will also increase the number of monitors to 48 per units.

References
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2) A. Uchiyama *et al.*, Proc. PCaPAC08, WEX03, (2008).

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