Development of a machine protection beam interlock system for the RIBF

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Since 2021, we have been developing a successor system to the current machine protection beam interlock system (BIS) (hereafter, new BIS). During the development phase of the new BIS, we installed the new BIS in parallel with the current BIS to ensure safety. Until 2023, new BIS I/O stations were installed in parallel with two of the ten I/O stations of the current BIS (RIBF-BIS station-1 and station-2), and a chopper station, which combines output signals from the new BIS I/O stations and other systems, such as a user's system, to a beam chopper, was installed in the control room in the Nishina building. The new BIS responds to an alert signal by immediately activating a beam chopper to deflect a beam (the time required for this is called the system response time) and simultaneously inserts a specified Faraday cup (hereinafter, FC). The system response time is 120–130 μs and approximately 470 μs for digital input (DI) and analog input (AI) signals, respectively.[1)] In March 2024, we installed a new BIS I/O station in parallel with the RIBF-BIS station-4.

In the first high-intensity beam experiment using the BigRIPS after the start of test operations of the new BIS in May, there were frequent issues in which FCs were inserted without an error status. After more than a month of investigation, a logic error when the new BIS was signal reset turned out to be the source of the problem. To identify an instantaneous error, most input signals of the new BIS are set to retain the error status until the operator checks them; however, this setting was disabled due to a logic mistake. In addition, the system, which records errors via Ethernet, could not detect error events that are reset instantly. The problem was solved by modifying the logic of the system, and subsequently, the new BIS operated as expected.

During the summer maintenance period, the following tasks were carried out.

- Three new BIS I/O stations were installed in parallel with RIBF-BIS station-3, fRC-BIS station-2, and station-3. In addition, a new BIS I/O station was installed to manage the input signals of both RIBF-BIS station-5 and fRC-BIS station-5 because of their fewer input signals.
- The chopper station was reorganized by installing a dedicated rack next to the original rack.
- The original logic of the new BIS had been designed to output signals to both a beam chopper and FC after the system detects an alert signal; however, it was changed to allow signals to be output to a beam chopper alone.
- To reduce the communication rate in the system, communication among the I/O stations, chopper station, and EPICS applications (interlock condition setting and status monitoring) has been changed from routine periodic sampling to responding only upon change.
- FCs to be registered in the new BIS were reorganized. All FCs on the beamline are registered in the BIS. However, after the 18 years of RIBF operation, only certain FCs are used in daily operation. Therefore, the new BIS picked up FCs that were installed around each cyclotron and key areas for beam transport. Following the changes, the FC settings of the existing BIS were also changed to match the new BIS.

After completing the above, the new BIS was operated stably in the beam service time performed in the second half of FY2024. During this period, large power consumption demonstrated that the pull-up circuit board, which was installed in parallel at each DI signal contact to reduce the system response time, was becoming hotter than expected (cooling fans have been installed). Circuit design that generates large amounts of heat are not suitable for long-term stable operation. Therefore, we are modifying the circuit design to reduce power consumption to less than half. The new low-power prototype achieved equivalent system response time. Detailed design is underway with the aim to introduce the improved board to the system by 2025.

The BIS function for determining the conditions required to inject the primary beam into the BigRIPS is also being redesigned. For safe operation, the beam intensity must be reduced to a sufficiently low level. This reduction is achieved by inserting beam attenuators (ATTs) of various attenuation ratios upstream the RIBF accelerator complex. When the BIS detects a signal indicating the use of the primary beam at the BigRIPS, it takes the signal summarizing the ATT insertion status from the EPICS control system. Further, when the beam attenuation ratio is smaller than the set value, it inserts the FC at the SRC exit to prevent the primary beam from being injected into the BigRIPS. This function has been working stably but

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signals that are not alert signals are input to the BIS and the ATT insertion status is obtained via the network, which is not a reliable method. We are attempting to improve these specifications to be more reliable and simpler in the new BIS by changing the ATT control method.

Reference

1) M. Komiyama *et al.*, RIKEN Accel. Prog. Rep. **57**, S28 (2023).