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APPLICATIONS OF TIMING READ-BACK SYSTEM IN J-PARC MAIN RING

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Abstract

Japan Proton Accelerator Research Complex (J-PARC) timing system has been in operation since 2006. Over the past 16 years, there were trigger-failure events, and some of which seriously affected the operation of J-PARC accelerator, especially at Main Ring. To troubleshoot the source of such events more quickly, we decided to develop a timing read-back system to read back distributed timing signals at the device side. A PLC-type triggered scaler module was developed as a key of the system. It can count number of pulses in an accelerator cycle and store the counts in a momentary array. Using the module, customized read-back applications for various timing-related signals have been developed: (a) read-back a 25-Hz trigger clock, (b) read-back a pulsed bending magnet trigger, (c) read-back a magnet power-supply trigger. These applications were implemented successfully in J-PARC Main Ring, and demonstrated as countermeasure against past trigger-failure events. More details will be given in the paper.

INTRODUCTION

J-PARC (Japan Proton Accelerator Research Complex) is a high-intensity proton accelerator complex. It consists of three accelerators: a 400-MeV Linac (LI), a 3-GeV Rapid Cycling Synchrotron (RCS), and a 30-GeV slow cycling Main Ring Synchrotron (MR) [1, 2]. Since the initial beam in 2006, J-PARC has been improving beam power. Concerning MR, recent beam power is about 500-kW (50-kW) by fast (slow) extraction, respectively [3].

There are two time cycles used in J-PARC. A rapid cycle, 25 Hz is used at LI and RCS, and a slow cycle is used at MR. When MR delivers proton beams to Neutrino (NU) and Hadron (HD) Facilities, 2.48-s (fast extraction mode (FX)) and 5.20-s (slow extraction mode (SX)) cycles are used, respectively. Because the slow cycle determines the overall time behaviour of the accelerators, it is also called a "machine cycle."

The control system for J-PARC accelerators was developed using the Experimental Physics and Industrial Control System (EPICS) framework [4]. In addition, a dedicated timing system has been developed and operated since 2006 [5, 6]. It consists of one VME transmitter module and approximately 200 VME receiver modules. Event codes, which correspond to the information on beam destinations and on beam parameters, are distributed from the transmitter module to all the receiver modules. A fiber-optic cable network is used for event-code distribution using several optical-to-electrical (O/E) or electrical-to-optical (E/O) modules. According to the received event code, each receiver module generates eight independent delayed-trigger signals.

Since the first beam use began in 2006, the J-PARC timing system has contributed to a stable operation of the accelerators [6]. Nevertheless, some timing trigger-failure events have occurred during beam operation. During each recovery process against a failure, it was often difficult to find a definite module among many modules suspected. Such experiences have prompted us to develop a new module, triggered scaler module, which can read back signals generated by the J-PARC timing system [7, 8].

In this paper, three trigger-failure events occurred in J-PARC MR are introduced briefly. The applications of timing read-back system are described in details, followed by a future plan of new power-supply with embedded timing modules.

PAST TRIGGER-FAILURE EVENTS

There have been some unexpected trigger-failure events in the past 16 years [8, 9]. Herein, three events are briefly given.

- In November to December 2016, the accelerator operation was suspended several times a day, because of the faults of a beam diagnostic system. The investigation showed that an O/E module used for 25-Hz trigger clock produced irregular signals. After replacing the module, the problem was solved.
- In January 2018, a delayed trigger which excites the pulsed bending magnet was stopped. Thereby, few miss-controlled beams went to an undesirable destination, Material and Life Science Experimental Facility (MLF). Soon we found that a fuse in a trigger-fanout module was broken. After replacing the module, the problem was solved.
- In November 2015, a bad quality beam appeared during stable beam delivery to HD. Such beams appeared a few times per month [7]. After about six months troubleshooting, we finally found that a timing receiver module for one of the MR steering magnets showed momentary errors by external common-mode noises. The problem was solved by adding ferrite cores to metal cables.

The first two events showed that a single failure of one module causes a critical problem in an accelerator. It showed no alert from neither the timing system nor the control system. Thus, it was unable to find the problems remotely. The third event was a very low-rate error, a few

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times per month. It was very difficult to search for the trouble source.

These events led us to realize that it was necessary to develop a new system. The system is expected to read back timing signals at suspicious points, and raises an alert when a fault is detected.

TIMING READ-BACK SYSTEM

Introduction

The timing read-back system has been developed as an independent system from the existing timing system. It observes and confirms the delayed-trigger signals, which are provided from the timing system. A unique device, triggered scaler module, is used in the read-back system.

Triggered Scaler Module

Triggered scaler (hereafter TS) module, designed by J-PARC control group, is the key device for developing the timing read-back system. It is a scaler to count number of pulses with respect to the machine cycle. The module stores observed counts in a momentary array. One TS module has four independent input channels. The details of the hardware design, the working principle, and the performance can be found in [8-10].

In 2020, the firmware of the TS was updated [9, 10]. The customized applications were developed based on the updated TS module.

Prototype System

Based on early measurement of the TS module in 2018 [7], a prototype timing read-back system was developed in 2020. The hardware of the prototype system is shown in Fig. 1. It consists of a CPU module, a TS module, and a power supply module. All of them are standard Yokogawa PLC modules. Linux and EPICS are running on the CPU module.

In June, 2020, the prototype system was tested for three types of trigger-failure events, using a dummy injection-kicker signal. As shown in Fig. 2, the system successfully detected the dummy signal and identified all kinds of failures. The details of the system development and discussion on possible types of signal failures are given in elsewhere [8].

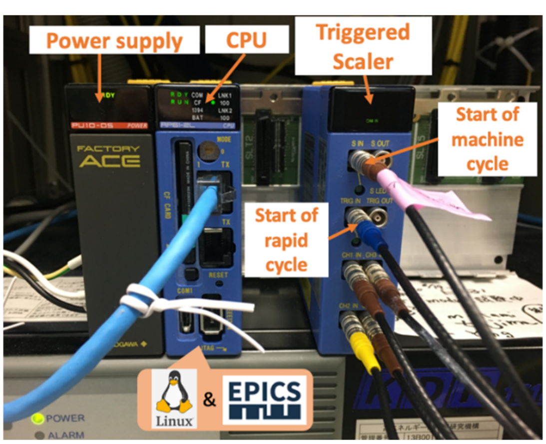

Figure 1: Hardware setup of the prototype system.

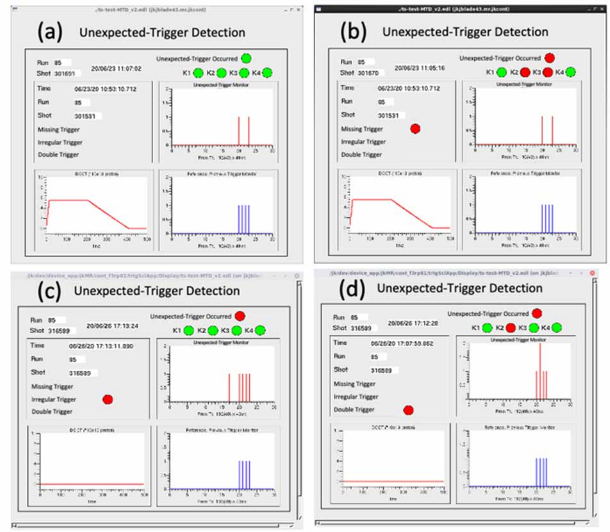

Figure 2: Test results of the prototype system using a dummy injection-kicker signal. Red means an observed signal, blue means a reference signal. Screenshots for (a) normal event with the saved information of the last fault event, (b) a missing-trigger event, (c) an irregular-trigger event, and (d) a double-trigger event.

CUSTOMIZED APPLICATIONS OF TIMING READ-BACK SYSTEM

After the prototype system, some customized applications of timing read-back system were developed toward stable operation of J-PARC MR [9, 10]. Here shows three applications.

Read-Back System of 25-Hz Trigger Clock

The read-back system of 25-Hz trigger clock was developed and tested at one power-supply building of MR in 2021 [10]. Afterwards, the system was upgraded to cover three power-supply buildings. Figure 3 shows the GUI for one of three buildings. Since June, 2022, the status indications of all the three buildings are shown together with those of magnet power supply trigger (Fig. 5).

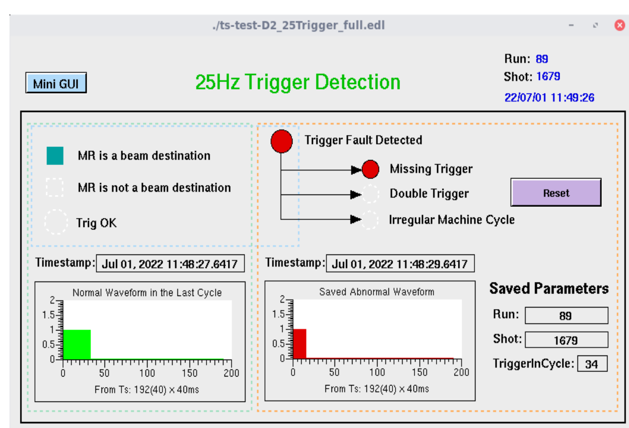

Figure 3: The GUI screenshot of 25-Hz trigger clock for one of power-supply buildings. The indicated error is caused by a simulated missing-trigger signal. Red means an observed signal, green means a reference signal.

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Read-Back System of Pulsed Bending Magnet Trigger

The read-back system of pulsed bending magnet trigger was developed in 2021 [9]. Since then, it has been operational during the beam operation of J-PARC MR. Fig. 4 shows the screenshot of the GUI.

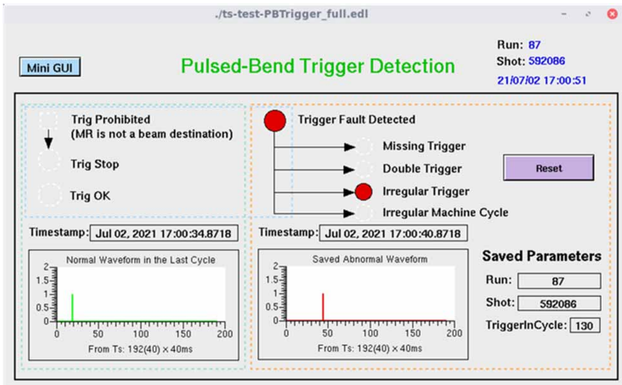

Figure 4: The GUI screenshot of pulsed bending magnet trigger with a simulated irregular-trigger event.

Read-Back System of Magnet Power-Supply Trigger

The read-back system of magnet power-supply trigger was developed in 2022. The hardware consists of three PLC-based setups to cover three power-supply buildings. Each of the setups supervises both 25-Hz trigger clock and magnet power-supply trigger. The system has been operated during the J-PARC beam operation in June and July, 2022. Fig. 5 shows the main GUI.

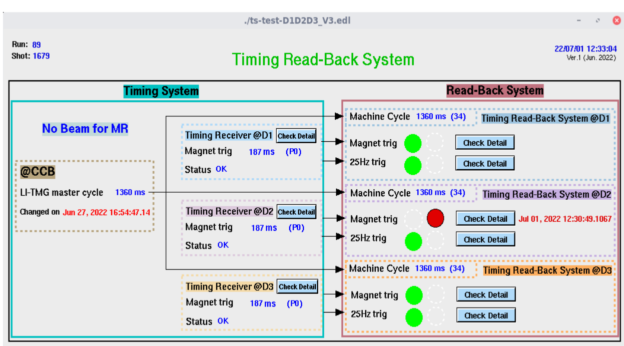

Figure 5: The GUI screenshot of 25-Hz trigger clock and magnet power-supply trigger. The “Timing System” part shows timing system related information. The “Read-Back System” part shows the observed signal status of three power-supply buildings. The indicated error is caused by a simulated missing-trigger signal.

Discussion

After June, 2022, all the three applications of timing read-back system have been operational. They are actually countermeasures against past trigger-failure events given in the above section. With the applications, it becomes possible to find a trigger-failure event remotely. So far, no trigger-failure event was observed.

READ-BACK SYSTEM FOR OTHER SIGNAL

Besides three read-back applications, a read-back application for other signals was also developed, an LLRF pattern monitoring system. In 2018, it was developed to visualize LLRF signals for J-PARC MR [7], and implemented for beam operation in 2021. Figure 6 shows the observed LLRF patterns in different MR energies during May and June 2021.

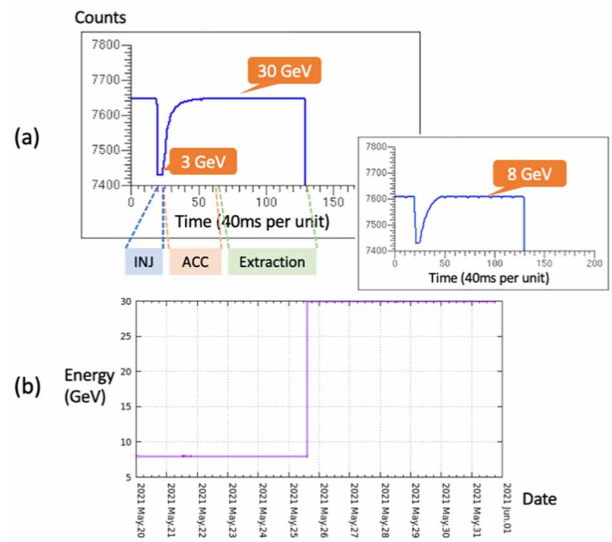

Figure 6: (a) The frequency shift of the LLRF signal is observed by the read-back system. In every machine cycle, 3-GeV protons are injected into MR, then accelerated up to 30-GeV or 8-GeV. (b) 10-day history of the MR energy, which is deduced from the observed LLRF patterns. The energy was changed from 8-GeV to 30-GeV on May 25, 2022.

FUTURE PLAN FOR PULSED BENDING MAGNET

Experienced past trigger-failure events showed that the aging of timing modules has been major sources of failures. To proceed scheduled replacement of old modules with new ones, a next-generation timing system for J-PARC has been discussed [11]. The new timing receiver for MR was developed as a PLC-type module. It is still in test phase and not in use so far.

Besides, a new pulsed bending magnet power supply is under construction along the MR’s 1.3-MW power-upgrade program [12]. It will be installed to J-PARC in 2023. The first PLC-type receiver is planned to be used.

Figure 7 shows the picture of the read-back system with a new PLC-type receiver. Both a receiver module and a TS module are mounted in the same PLC-based EPICS setup, which will be embedded in the frame of the new power supply. In addition, a digitizer module will supervise the output current of the power supply.

As shown in Fig. 8, compared with the current system, there will be no O/E and E/O module. We expect that this scheme will reduce the failure rate drastically.

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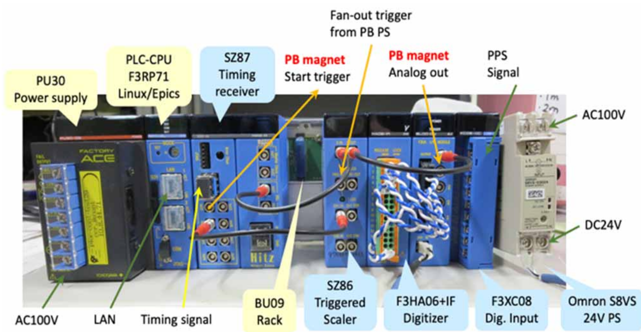

Figure 7: The picture of the read-back system with a new PLC-type timing receiver.

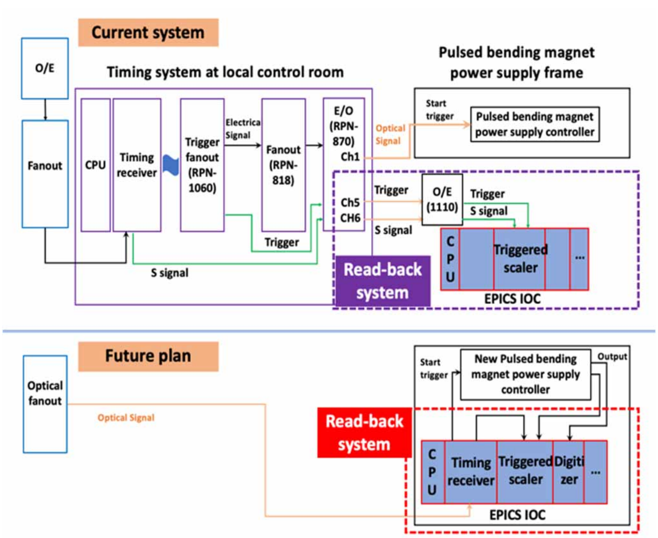

Figure 8: Comparison of current and future timing read-back systems for pulsed bending magnet trigger.

CONCLUSION

Three customized applications of timing read-back system, (a) a read-back system of 25-Hz trigger clock, (b) a read-back system of pulsed bending magnet trigger, and (c) a read-back system of magnet power-supply trigger, have been developed in J-PARC MR. These applications are demonstrated as countermeasure against past trigger-failure events, and are in operation since 2021 and 2022. If the same trigger-failure event as before occurs again, the applications will detect it immediately. It is expected to reduce the time to find the source of failure.

Another read-back application, an LLRF pattern monitoring system, was also developed and started supervising an LLRF signal since 2021. The system is helpful for accelerator operation to confirm the MR energies. It is worth noting that the triggered scaler module can be applied to non-timing field.

A future plan of new power supply for pulsed bending magnet is described. A new PLC-type receiver module and a triggered scaler module will be embedded in the frame of the power supply.

We expect that these works will contribute more reliable operation of J-PARC MR.

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