IMPROVEMENTS IN THE T2K PRIMARY BEAMLINE CONTROL SYSTEM

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Abstract

The T2K experiment is a long-baseline neutrino oscillation experiment in Japan. We report recent improvements in the T2K primary beamline control system. The first improvement is a new interlock system for current fluctuations of the normal-conducting (NC) magnet power supplies. To prevent the intense beam from hitting the beamline equipment due to a current fluctuation in a magnet power supply, we continuously monitor the power supply output current using digital-panel-meters. The second improvement is a new PLC-based control system for the NC magnet power supplies. We will also discuss the actual implementation of these improvements.

INTRODUCTION

The T2K (Tokai-to-Kamioka) experiment [1] is a long-baseline neutrino oscillation experiment at J-PARC (Japan Proton Accelerator Research Complex). A high intensity beam of muon neutrinos is produced and allowed to propagate 295 km, from J-PARC to Super-Kamiokande. Based on the analysis of all data collected by the T2K experiment between January 2010, when it began full operation, and March 11, 2011, when it was interrupted due to the Great East Japan Earthquake, 88 neutrino events were detected by the Super-Kamiokande, with six clearly identifiable as electron neutrino interactions [2]. After temporary recovery from damage due to the earthquake, T2K resumed data acquisition in March 2012. In July 2013, with 3.5 times more data, muon neutrino to electron neutrino transformation has been firmly established [3].

Figure 1 shows a layout of the T2K neutrino experimental facility. The high intensity proton beam is extracted from the Main Ring synchrotron (MR), guided through the neutrino primary beamline to the target station. The proton beam hits a graphite target, producing pions. These pions decay into muons and muon neutrinos in a decay volume. All the muon neutrinos escape from the facility, whereas all the other particles are absorbed by a beam dump. A near detectors (ND280) located 280 m downstream of the target.

Figure 2 shows the T2K primary beamline, consisting of the preparation, arc and final focusing sections. In the preparation section, the extracted proton beam is tuned with a series of 11 normal-conducting (NC) magnets. In the arc section, 14 doublets of super-conducting combined function magnets [4] are located and bend the beam toward Kamioka direction. In the final focusing section, 10 NC magnets guide and focus the beam onto the target. There are 22 power supplies for the NC magnets. These power supplies and their control system have a maintenance problem due to antiquated equipment. We plan to replace all the power supplies for NC magnets and modernize its control system. In April 2013, the beam power of the MR was 230 kW. This beam power is planned to increase to 750 kW within five years.

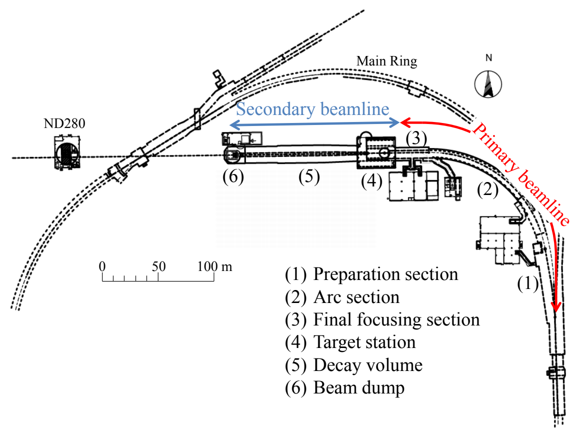

Figure 1: Layout of the T2K experimental facility.

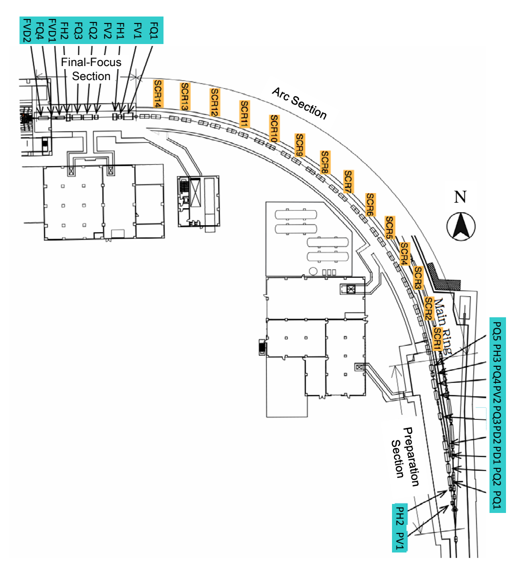

Figure 2: T2K primary beamline. The preparation and final focusing sections contain 21 normal-conducting magnets, whereas the arc section contains 14 doublets of super-conducting magnets.

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CURRENT STATUS AND ISSUES

J-PARC includes two independent interlock systems, the PPS (Personnel Protection System) and the MPS (Machine Protection System). The PPS is a statutory interlock to protect personnel from radiation, whereas the MPS is an interlock designed to protect beamline equipment from high intensity beams. In T2K, the healthiness of extracted beams and beamline equipment is assessed spill by spill. If beam-loss alarms are activated or beamline equipment experiences trouble, MPS is activated and the next beam spill is aborted. In February 2011, the output current of one of the power supplies for the NC magnets decreased suddenly. The beam could not be aborted under the existing interlock system and activated the MPS alarm at the beam-loss monitors. We need a new interlock system for such conditions.

INTERLOCK SYSTEM FOR CURRENT FLUCTUATIONS

System Concept

The key device of this interlock system is a digital-panel-meter (DPM), containing an analog-to-digital converter and a numeric display that also includes alarm options.Table 1 shows the specifications of the DPM (Watanabe Electric Industry Co., Ltd. [5]). The DPM continuously samples and digitizes the DCCT (DC Current Transformers) output voltage of the power supplies. The DPM allows four warning thresholds, HH, HI, LO and LL, which are output by the photocoupler. We use HI and LO outputs as MPS sources.

System Configuration

Figure 3 shows configuration of the interlock system. Figure 4 shows a SysML diagram of a DPM and PLC, shown as the dashed line box in Figure3. The DPMs continuously sample and digitize the DCCT output voltage of the power supplies, and they determine whether it falls within a preset range. HI/LO outputs of DPM are connected to PLC input-modules. The input-modules aggregate the HI/LO signals from all DPMs and the output-module outputs MPS signals. Each DPM is controlled by a RS485 communication module of the PLC. Data communication between DPMs and the RS485 module is performed by a ladder program on PLC CPU. Figure 5 shows the interlock system for the preparation section of the primary beamline.

Interlock Monitoring Panel

Figure 6 shows a monitor panel for interlock of NC magnet power supplies. EDM (Extensible Display Manager), one example of an EPICS display manager, was used to build the monitor panel. The panel indicates the status of interlocks for NC magnet power supplies.

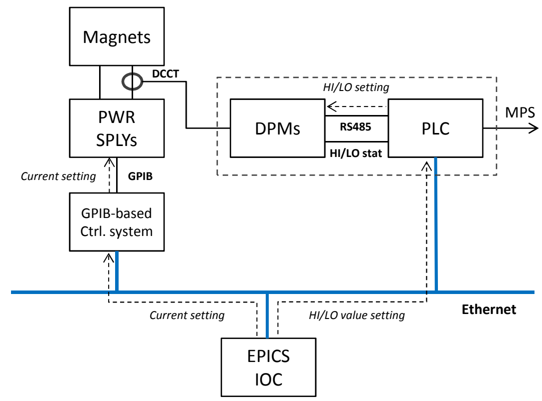

Figure 3: Configuration of the interlock system for current fluctuations. Dashed arrows show instructions/commands.

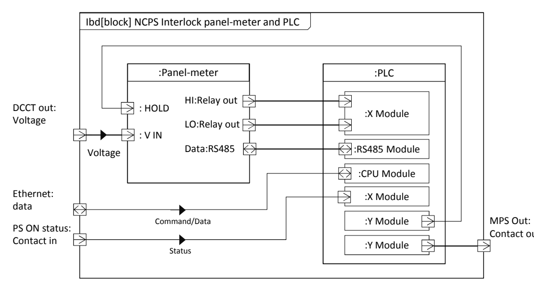

Figure 4: SysML diagrams of a digital panel meter and PLC.

Table 1: Digital Panel Meter Specifications

Item	**Specification**
Model / Type	A7711C / DC voltage meas.
Outer dimensions (mm)	72 (W) × 36 (H) × 118 (D)
Sampling rate (Hz)	1000
Input range (V)	±0.1, ±1, ±10, ±100, ±700
Input impedance (Ω)	1 M
Display range	-9999 to 9999
Communication	RS485

Operation Result

Table 2 shows a history of MPS after implementation. There were three MPSs issued by this system from March 2012 to the present.

PLC-BASED CONTROL SYSTEM FOR POWER SUPPLIES

System Concept

We plan to replace the power supplies of NC magnets. As a new candidate, we built a PLC-based control system with compact and high performance ready-made power

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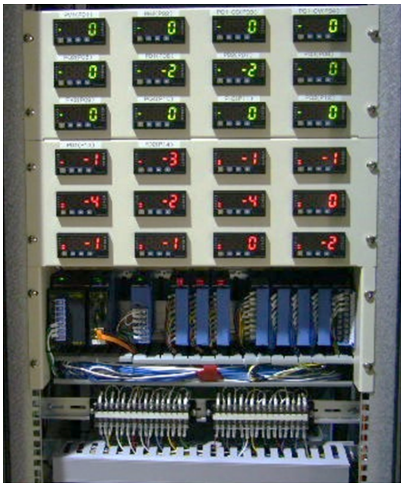

Figure 5: Digital panel meters and PLC of the interlock system for current fluctuations.

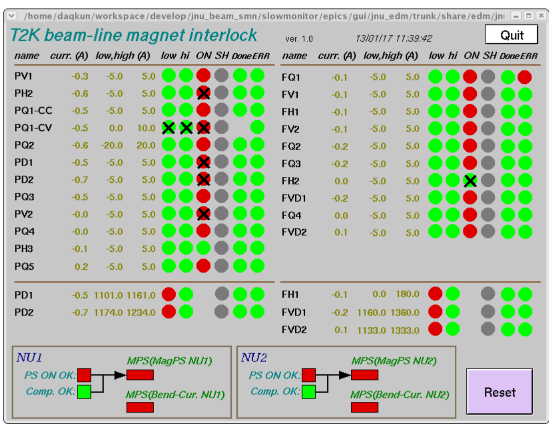

Figure 6: Monitor panel for the interlock system for NC magnet power supplies.

supplies (Danfysik SYSTEM9100 [6]). Table 3 shows the specifications of SYSTEM9100. We have used the power supply for the steering magnet in the primary beamline. The present power supply control system for NC magnets is not designed to support EPICS. It uses RDB as an interface to EPICS [7]. A new control system has been designed by application of EPICS, with PLC adopted as an EPICS interface. Using the PLC for interface of EPICS, we consider that the robustness and real-time performance of the system have been improved.

System Configuration

Figure 7 shows configuration of the new power supply control system (Dashed arrows show commands/status). The hardware consists of a PLC CPU, a PLC RS485 communication module, PLC I/O modules and a digital multimeter. The commands to the power supply are sent from EPICS IOC via the RS485 module. Except for during command processing, the status of the power supply is retrieved by the RS485 module at one second intervals and the IOC updates the EPICS database. The power supply and RS485 module communicate via ladder programs. Two DCCTs are installed at the current output lines of the power supply. One is connected to the DPM interlock system, while the other is connected to a digital multi-meter for monitoring

Table 2: MPS History

Date	Magnet	Operation (HI / LO)	Fluctuation
18 May 2012	PQ2	485.0 (490.0 / 480.0)	485.0→462.0 A
24 Nov. 2012	PV2	-2.0 (3.0 / -5.0)	-2.0 → 14.6 A
21 Jan. 2013	PD2	1206.9 (1211.9/1201.9)	1206.9→60.5 A

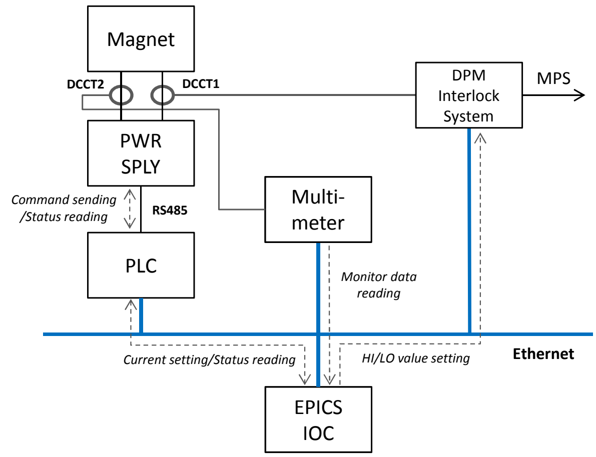

Figure 7: Configuration of the power supply control system.

Figure 8: The power supply and PLC.

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Table 3: SYSTEM9100 Specifications

Item	Specification
Max. output current	200 A
Max. output Voltage	60 V
Max. output power	12 kW
Drift (long term 8 hours)	±10 ppm
Remote control	RS232, RS422, RS485

and archiving data by EPICS.

Commands

Table 4 shows commands supported by the system. Ten of the commands installed in SYSTEM9100 can be implemented.

Table 4: Supported Commands

Command	Description
N	Power ON
F	Power OFF
RS	Reset Interlocks
AD	Read Monitor Channel
DA	Set Output Current
REM	Set Remote mode
LOC	Set Local mode
ASW	Set Answer mode
CMD	Read Command mode
S1	Read Status

Operation Result

In October 2012, the new power supply and control system were installed for a steering magnet in the preparation section. In December 2012, the same system was installed for a steering magnet in the final focusing section. At present, the two power supplies for the steering magnets and control system work well without any failure. The power supply control system for NC magnets is a mixture of the old and the new right now. But the old and new will merge in 2014.

SUMMARY

We made two improvements in the T2K primary beamline control system. The first was the development of a DPM-based interlock system for the current fluctuation of the power supplies of NC magnets. This system, first applied in March 2012, should decrease the risk of an intense beam hitting beamline equipment due to the current fluctuation of a magnet power supply. The second improvement was the development of a PLC-based control system of ready-made power supplies for steering magnets. The old power supplies of the steering magnets and control system were replaced by new power supplies. They have been used since October 2012.

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