UPGRADE OF THE CONTROL AND INTERLOCK SYSTEMS FOR THE MAGNET POWER SUPPLIES IN THE T2K PRIMARY BEAMLINE

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Abstract

T2K is a long-baseline neutrino oscillation experiment at J-PARC in Japan. A high intensity neutrino/antineutrino beam is generated and propagates 295km to Super-Kamiokande. The high intensity proton beam which reached 350 kW in May 2015, is extracted from the Main Ring synchrotron and guided through a primary proton beamline to a graphite target using normal-conducting (NC) magnets and super-conducting combined-function magnets. In October 2014, we replaced all of the power supplies (PSs) for the NC magnets with newly developed PSs. We also developed a new control system based on the Experimental Physics and Industrial Control System (EPICS) and PLC, putting emphasis on the safe operation of power supplies, and integrated it into the existing interlock system. Consequently the latency time for the interlock system was improved. We report the actual implementation and operation results of these developments.

INTRODUCTION

The T2K (Tokai-to-Kamioka) experiment [1] is a long-baseline neutrino oscillation experiment at J-PARC (Japan Proton Accelerator Research Complex) in Japan. A high intensity neutrinos/anti-neutrino beam is produced, and propagates 295 km from J-PARC to Super-Kamiokande.

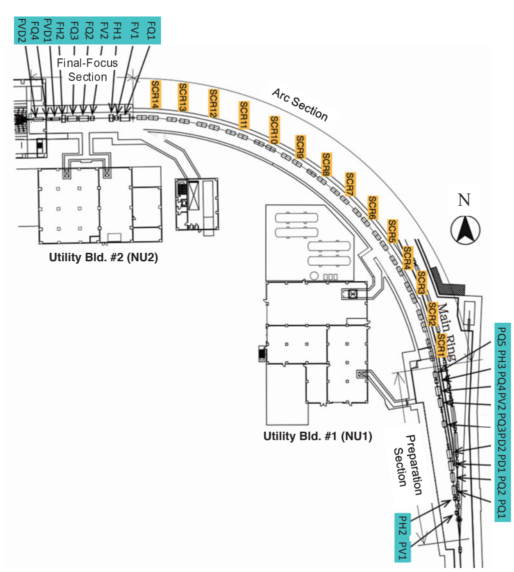

Figure 1: T2K primary beamline.

The T2K neutrino experimental facility is composed of primary/secondary beamlines and a near detector (ND280). The high intensity proton beam which reached 350 kW in May 2015, is extracted from the Main Ring synchrotron (MR) and guided through the neutrino primary beamline to a graphite target. Figure 1 shows the T2K primary beamline, consisting of the preparation (PREP), arc and the final focusing (FF) sections. Fourteen doublets of super-conducting combined function magnets [2] are located in the ARC section and bend the beam towards Kamioka. In the PREP section, the extracted proton beam is tuned with a series of 11 normal-conducting (NC) magnets. Ten NC magnets in the FF section guide and focus the beam onto the target. The power supplies (PSs) for the PREP section are located at the utility building-1 (NU1) and those for the FF section are located at the utility building-2 (NU2).

Some critical primary beamline issues are:

- A single failed beam shot, caused by a trip of the NC PSs, for example, results in serious damage of beamline equipments.
- The NC magnet power supplies were made mostly in 80's and required increasing effort for maintenance.

In order to solve these problems, we developed new power supplies for the NC magnets with a power supply company, and replaced all of the PSs in the summer of 2014.

NEW POWER SUPPLIES

The requirements for the new PSs for the NC magnets were (1) improvement of the safety interlock, (2) precise and stable operation, (3) improvement of maintenance, (4) upgrade of the control system and (5) downsizing. We report on each requirement and its actual implementation.

Table 1 shows the types of PS, corresponding to each magnet, its rated current, and its unit count. Figure 3 shows pictures of the new PSs.

Table 1: New power supplies for the normal conducting magnets in the T2K primary beamline.

Magnet type	DC OUT (A) / (V)	Converter type	Current stability(A)	# of units
Dipole	1500 / 100	chopper	0.1	4
Quadrupole	1000 / 100	chopper	0.1	9
Steering I	± 400 / ± 40	chopper	0.05	1
Steering II	± 200 / ± 20	switching	0.05	2
Steering III	± 100 / ± 10	switching	0.05	5

The output current stability is 0.1 A for the dipole and quadrupole magnet PSs and 0.05 A for the steering magnet PSs. The stability is superior to the previous PSs and the

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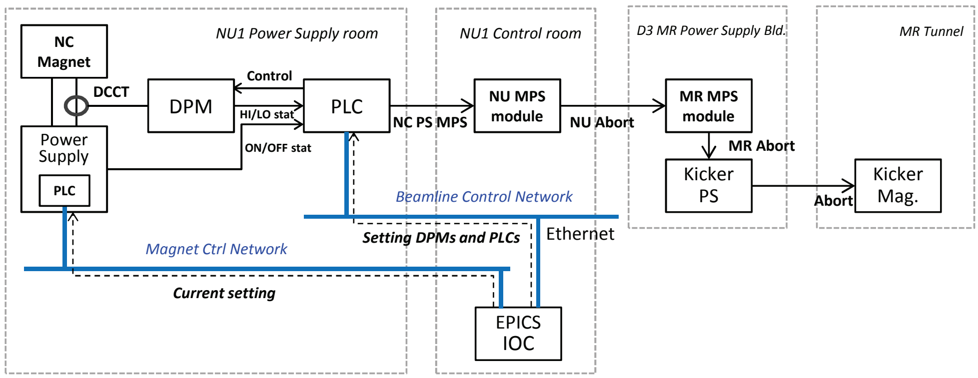

Figure 2: Schematic of the control system for the new power supplies for the normal-conducting magnets.

Figure 3: Pictures of the new power supplies for the normal-conducting magnets. The left photo shows a power supply for a dipole magnet and the right shows four steering magnet power supplies installed in a rack.

output current ripple is reduced. There are two DCCTs in each PS; one is for feedback control and the other is for current monitoring used in an interlock system. Each PS has a LCD touch panel on the front for local operation. For safer operation, control of the PS is password-protected. We succeeded in saving space (about -67%) by installing four steering magnet PSs in a single rack (see Figure 3).

IMPROVEMENT OF THE CONTROL SYSTEM

The control system for the old PSs was not designed to support EPICS [3]. Therefore, we chose to use a relational database as an interface between the old control system and EPICS. A relational database (MySQL) that includes the status of each magnet was prepared. We could access the magnet data via MySQL tables. For the new PSs, we changed the framework of the control system to a less complex configuration: we got rid of our unique control system and adopted standard Programmable Logic Controllers(PLCs) with EPICS. We built two EPICS IOCs, one for PSs at NU1 and another for those at NU2. Figure 2 shows a schematic of the control system for the new PSs at NU1. The IOC communicates with a PLC [4] built into each PS over Ethernet. We separated the new PS's control network from the existing beamline control network in order to separate it from EPICS broadcasts. The new NC PS's output current is monitored by the existing interlock system for current fluctuations as described in the next section.

IMPROVEMENT OF THE INTERLOCK LATENCY TIME

We developed a current-fluctuation interlock system for old NC PSs using digital panel meters (DPMs) in 2012 [5]. The DPMs continuously sample and digitize the DCCT output voltage of the PSs and determine whether it has stayed within a preset range. HI/LO status outputs of the DPM are connected to PLC input-modules. The input-modules aggregate the HI/LO status from all DPMs and an output-module outputs MPS (Machine Protection System) signals. The MPS is an interlock to stop the MR beam and protect beamline equipment from the high intensity beam or a cascade of equipment failures. The DPM is able to change the number of input voltages used in a moving average to remove the fast component of electrical noise.

Latency Time of the Old PSs

We measured the latency time of the DPM and PLC for the old PSs while changing the number of voltages used in the moving average. Figure 4 shows the results of the measurement. The latency of the PLC was measured to be 14 msec, which was nearly constant, as expected. The total latency of the DPM increases in proportion to the number of every used in the moving average. The ripple on the output current of the old PSs was large. Therefore we increased the number of voltages used in the to use as a digital filter. For 100 samples used in the moving average latency time of ~100 ms was expected at the DPM. In order to reduce the latency time, a smaller number of samples was required.

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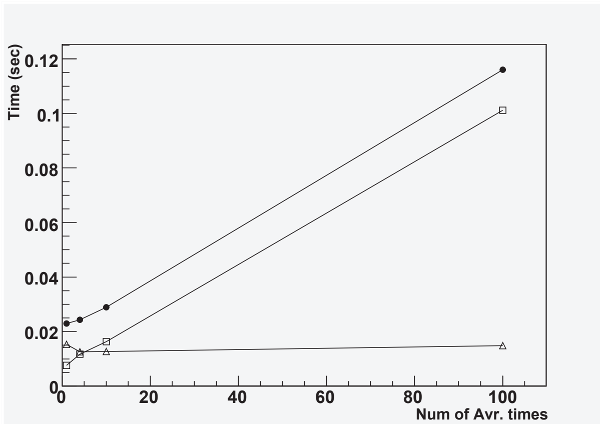

Figure 4: The interlock latency time vs. number of averaged voltage samples times on a digital panel meter (DPM). The open triangle shows the latency time of the PLC. The open square shows the latency time of the DPM. The closed circle shows the sum of the PLC and DPM latency times.

Latency Time of New PSs

In the new PS, we use one of two DCCTs in each PS for the interlock system. The ripple on the output current of the new PSs was small so that only one sample was required in the DMP moving average for each new PS. We measured the interlock latency time of the DPM and PLC while changing the threshold current value of the DPM for the PS for PD1, one of the dipole magnets.

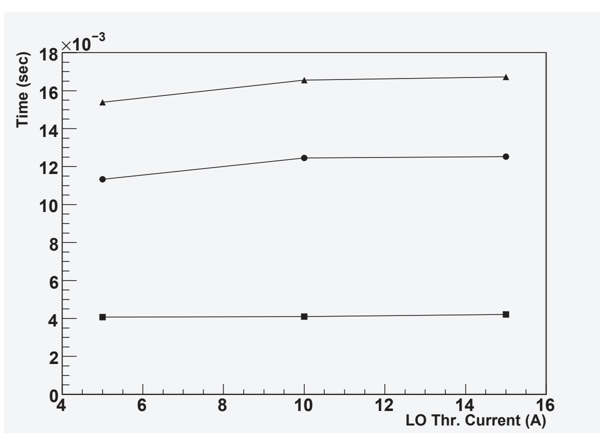

Figure 5: The interlock latency time vs. LO threshold current on a digital panel meter (DPM). The closed square shows the latency time of the DPM. The closed circle shows the latency time of the PLC. The closed triangle shows the sum of the PLC and DPM latency times.

Figure 5 shows the results of the measurement. The results show that the latency time of the PLC is almost the same as the previous measurement. The latency time of the DPM was about 4 ms due to no averaging required at the DPM. The total latency time of the DPM and PLC is about 16 ms with a ±5 A threshold window, the settings used during beam operation. An additional latency time from the PLC to the fast extraction kicker magnet in the MR of 0̃.07ms was measured, but time is negligibly small compared to the latency of the DPM and PLC. We drastically reduced the latency time of the interlock system of the NC PSs, reducing the risk for damage of beamline equipment by high intensity beam.

SUMMARY

We have developed new NC PSs in collaboration with a power supply company, and upgraded the control system for safety and stable operation of a high intensity proton beam. We integrated the new NC PSs into the existing interlock system which checks for NC PS current fluctuation. The latency time of the interlock system was drastically reduced. We developed an EPICS-based control system for the new NC PSs which is simpler and less complicated than old one.

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