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NEXT GENERATION CONTROL SYSTEM USING THE EtherCAT TECHNOLOGY

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Abstract

Toward the SPring-8 upgrade, which we call SPring-8-II, we have adopted EtherCAT with a master/slave topology as a network-based fieldbus. Since the cyclic data transfer time is less than 1 ms, EtherCAT can provide sufficient performance for a fast control and feedback system. Controllers and sensors are set near equipment, and input and output data are sent to/from an EtherCAT master via a LAN cable. This reduces the number of wires and the working time for wiring. In FY2016, we installed EtherCAT into three different equipment control systems. One was a prototype digital LLRF system in the high-power RF test stand at SPring-8. Another was the encoder readout for an undulator at SPring-8. The other was the control system for a kicker magnet power supply at SACLA. An XMC-typed EtherCAT master module was implemented into each of these systems and connected to multiple vendor slaves. In this paper, we report the results of an electrical noise immunity test on LAN cables, the status of the new control systems using EtherCAT technology, and the installation plan of the EtherCAT slaves under development.

INTRODUCTION

As an Ethernet-based open standard protocol, FL-net has been operating well for over 10 years at SPring-8 and SACLA. FL-net is a factory floor network protocol with a masterless topology [1]. Since the token cycle time of FL-net is between ~15 ms and ~180 ms, we are introducing FL-net into slow control such as facility control, the data acquisition of radiation monitors, and high-power supplies for the klystrons. Currently, an upgrade plan of SPring-8 is in progress [2]. High-speed bus access, the transfer of large amounts of data, and synchronization with a timing signal are required in the next-generation control system. As a network fieldbus, we adopted Ethernet for Control Automation Technology (EtherCAT) with a master/slave topology [3]. Since its cyclic data transfer time is less than 1 ms, EtherCAT is suitable for a fast control and feedback system. The introduction of EtherCAT is proceeding at semiconductor and automobile factories, and its market is large. There are many choices of commercial products based on EtherCAT and a stable supply of commercial products is attractive for long-term operation and maintenance. Additionally, it is relatively easy to develop a control unit supporting EtherCAT by using an EtherCAT slave protocol stack.

In this paper, we report the results of an electrical noise immunity test on LAN cables and the installation of the control systems using EtherCAT technology.

ELECTRICAL NOISE IMMUNITY OF LAN CABLES

Since EtherCAT slaves can be installed near control components such as motors and signal sources, EtherCAT can reduce wiring and working time, and it is cost effective. However, in accelerator and synchrotron radiation facilities, slaves may be installed in places with high electrical noise levels, so it is necessary to pay attention to the effect of electrical noise on LAN cables. Therefore, we conducted the electrical fast transient/burst immunity (FTB) test documented in IEC 61000 4-4 [4].

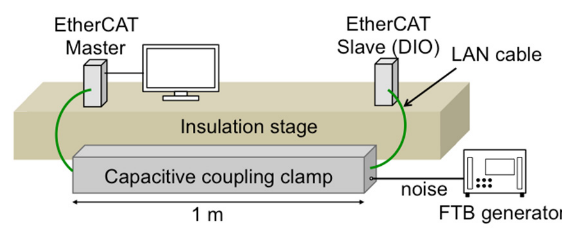

Figure 1: Configuration of the FTB test.

Test Method

We tested 1) CAT5e UTP, 2) CAT5e STP, 3) CAT7, 4) CAT5e using NoiseBEAT tape, which was developed by NTT AT [5] and was employed special magnetic alloy films to provide reliable EMI noise reduction. Figure 1 shows the configuration at the FTB test. A LAN cable was wired through a capacitive coupling clamp of 1 m length. Each LAN cable had a length of 10 m. An EtherCAT master (Beckhoff C6920-0040) [6] and a DIO slave (Hitachi Zosen ECAT-DIO 8) [7] were set on an insulation stage. An FTB generator outputted the test voltage with a pulse wave of 66 kHz or 30 kHz in a burst form with a cycle of 300 ms. The test voltage was varied in increments of 1 kV in the range from +/-0.5 kV to +/-4.5 kV. The test time was 60 s each test. To judge whether a LAN cable was being subjected to noise damage, a judgment program with the following sequence was run:

- The master sends a specified value of a digital output (DO) to the slave.

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- The slave outputs the specified DO value, reads the looped-back digital input (DI) value, and returns the DI value to the master.
- The master judges whether the DI value is equal to the specified DO value. If the DI value is different, it is an error. Also if the master cannot receive the response message, it is an error.

Measurement Results

Table 1 shows the measurement results of the FTB test. The value in the table indicates the error rate. Among the four LAN cables, CAT5e UTP had the lowest noise immunity. For STP and CAT7, the error rate gradually increased with the test voltage. The error rate for CAT5e using NiseBEAT tape suddenly increased at the test voltage of +4.5 kV at 30 kHz. There was no difference upon changing the polarity of the test voltage.

From our test results, in locations with a good electrical noise environment, CAT5e UTP showed reasonable performance. In locations with a poor electrical noise environment, it will be better to use CAT5e STP or CAT7 for the EtherCAT network.

Table 1: Measurement Results

Test voltage	**CAT5e UTP**	**CAT5e STP**	**CAT 7**	**CAT5e NoiseBEAT**
Electric noise of 66 kHz				
+0.5 kV	0.0%	0.0%	0.0%	0.0%
+1.0 kV	59.1%	-	-	-
+1.5 kV	93.1%	0.0%	0.0%	0.0%
Electric noise of 30 kHz				
+2.5 kV	38.3%	0.06%	0.0%	0.0%
+3.5 kV	-	1.5%	0.5%	0.0%
+4.5 kV	-	2.4%	1.3%	90.9%

INSTALLATION OF ETHERCAT SYSTEMS

Cavity Tuner Control for LLRF System at SPring-8 Storage Ring

The renewal of the low-level RF (LLRF) system for SPring-8 is under way. The old-style system using single-function analog modules that have been running for over 20 years will be replaced with a modern digital system using MicroTCA.4 modules. The RF system consists of four RF stations along the SPring-8 storage ring, and comprises a high-power klystron with a high-voltage power supply, eight accelerating cavities, LLRF modules which stabilize the amplitude and phase of the cavity accelerating field, cavity tuners to adjust the resonant frequency with motorized plungers, vacuum pumps for the accelerating cavities, and a cooling system for the cavities at each station. The prototype with a cavity was

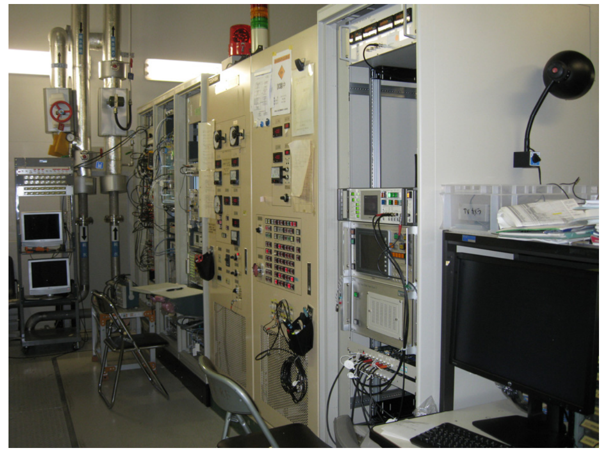

Figure 2: Photograph of the prototype LLRF system at the test stand.

tested at a high-power RF test stand at the SPring-8 storage ring [8, 9]. Figure 2 shows a photograph of the prototype LLRF system at the test stand. An Advanced Mezzanine Card (AMC) digitizer, a signal-conditioning rear transition module (RTM), an EtherCAT master XMC module mounted on a VadaTech AMC105 PMC/XMC carrier module [10], a MicroTCA Carrier HUB (MCH), and a CPU module running Ubuntu 14.04 LTS configured with a low-latency kernel are installed in an MTCA.4 crate.

An Advanet AdXMC1573 [11] EtherCAT master module was adopted. A master protocol stack of an AdXMC1573 was equipped with an acontis technologies EC-Master supporting Class A [12]. The operating system running on the host CPU is not subject to the load of EtherCAT communication processing because EtherCAT communication is processed on the master protocol stack, and the operating system accesses to process data object (PDO) and service data object (SDO) via a shared memory installed in this module. The EtherCAT slaves are the following four nodes: a motor controller (Melec F3200/EC) [13] for cavity tuner control, two digital input modules (CEC ECAT-S-DIO) [14] for the encoder readout of tuner motors, and an analog input module

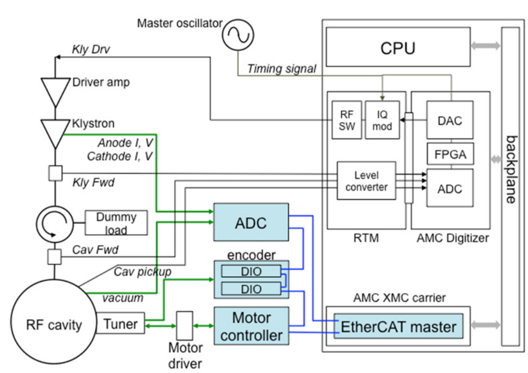

Figure 3: Connection configuration of the EtherCAT system for the prototype LLRF system.

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(Sinfonia Technology AI0816) [15] for the readout of analog signals such as the vacuum pressure and the anode voltage of the klystron. Figure 3 shows the connection configuration of the EtherCAT system for the prototype LLRF system. An AI0816 module has 8 channels of ADC input with 16-bit resolution. ADC sampling is performed in synchronization with the distributed clock (DC) of EtherCAT. The DC is set to 1 ms. The feedback loop for the stabilization of the resonant frequency of the accelerating cavity is set to 200 ms. Data such as the tuner position, pulse rate, vacuum pressure, and anode temperature are collected with a 2 s cycle and the data are stored in a database.

Since the prototype has been successfully operated, one of the four RF stations will be replaced at the end of FY2017.

Undulator Control for SPring-8-II

In the upgrade plan of SPring-8, to achieve bright low emittance, the beam energy is reduced from 8 GeV to 6 GeV and the number of bending magnets is increased. Therefore, the straight sections of the undulator must be about 2 m shorter than their present, and the undulator period length must be shortened. The options for the replacement of the undulator are as follows: the modification and reuse of the conventional standard in-vacuum undulator (IVU), the installation of a new standard in-vacuum undulator (IVU-II) having lightweight compact frame, and the development of a system for fast switching of the polarization by the spectrum-splitting method [16].

The IVU consists of three units of 1.5 m length and is set on a base plate. First of all, the IVU of BL05XU was modified to an undulator of 3 m length in March 2017. One of the three units was removed and the base plate was cut. Main and sub-absolute encoders for readout of the undulator gap position were installed at both ends of the IVU. Previously, the encoder data were read by using a VME digital input board. At the modification of the IVU, the sub-encoder was replaced with an EtherCAT-compatible encoder (Hengstler ACURO AC58) [17]. We adopted an EtherCAT master AdXMC1573 and an AdXMC1573 was implemented in a VME CPU board with a XMC mezzanine slot.

The pulse motor control and the encoder readout of IVU-II will be operated through EtherCAT. IVU-II is under development, and a beam test will be started in cell 34 of SPring-8 from March 2018.

Control for Pattern Power Supply of Kicker Magnet at SACLA

At SACLA, a kicker magnet switches between two beamlines, which are the first central beamline (BL3) and the second beamline (BL2). However, the laser intensity of BL2 was limited compared with that of BL3. To solve this problem, a kicker magnet and a high-precision pattern power supply (PS) were developed [18].

Figure 4 shows a block diagram of the control for the pattern power supply of a kicker magnet. The PS is connected to a programmable logic controller (PLC). The PLC implements a DIO modoule, an ADC module and an EtherCAT slave module featuring a dynamic PDO [19], where a user can define the exchange data structure of the PDO. At the start up of the PS, the PLC sends a preserved reference trapezoidal pattern to the PS via serial lines. The reference pattern is generated pulse by pulse using FPGA and DAC operated in synchronization with trigger signals from the timing system of SACLA. The feedback control of the PS stabilizes the output current based on the reference trapezoidal pattern [18]. The PLC ADC module receives the output voltage and the output current, and the PLC DIO module handles interlock signals. These data are sent to a VME system implementing an EtherCAT master (AdXMC1573), and are stored in a database. To adjust the magnetic field of the kicker magnet, a graphical user interface running on an operational console can change the current value of the flat top of the reference trapezoidal pattern. The current value is sent to the PS via the VME system and the PLC.

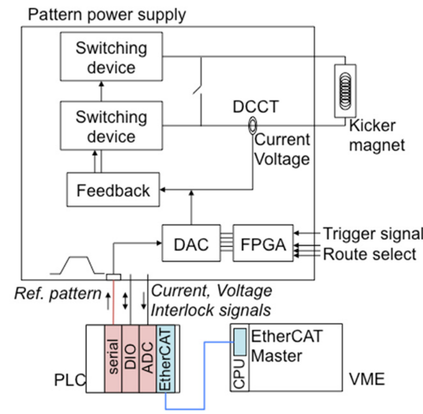

Figure 4: Block diagram of control for the pattern power supply of a kicker magnet.

The beam commissioning of the new beam-switching system was successfully completed, and the beam-switching system started to operate after the summer shutdown of 2017. As an injector of the upgraded SPring-8, the beam switching system will drive the electron beam to the SPring-8 storage ring.

DEVELOPMENT OF ETHERCAT-COMPATIBLE EQUIPMENT

52 beamlines are in operation at SPring-8, and over 200 PM16Cs [20], which are 16-axis pulse motor controllers equipped with a communication port (GP-IB, an RS232C, and RJ45 for a serial Ethernet bridge), have been installed for the control of beamline components such as the monochromator, mirror, and frontend slit. Currently, each PM16C is controlled from a VME system via the communication port. In the upgrade plan for the beamline control, the replacement of the VME system with a PC-based system and the use of EtherCAT are being considered. Therefore, we decided to develop an

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EtherCAT-compatible PM16C (new PM16C). Since an AdXMC1573 can be implemented not only on a VME system but also on a PC, it will be possible to progressively replace the system by the installation of a new PM16C. The PDO data area of the new PM16C consists of two areas. One is an area that constantly updates data, where the current pulse count, limit status, and error status are written. Other is a command communication area. After an EtherCAT master sends a command, the master does not send next command for exclusion control until an EtherCAT slave replies to the command response. The new PM16C will be completed at the end of 2017.

We developed an RTD (Pt100) temperature measurement module (E-069) with 0.001 degree C resolution over 15 years [21]. The E-069 includes a CPU card running the 2.6 kernel of SH-Linux. Currently, the MADOCA data-collecting process is running on SH-Linux. However, it is difficult to keep the development environment for the old operating system. We decided to stop developing with the old operating system and to operate the E-069 as an EtherCAT slave. A new E-069 will start to collect temperature data from spring 2018.

SUMMARY

An upgrade plan for SPring-8 is in progress, and a storage ring injection test from SACLA is scheduled for FY2018. We adopted EtherCAT technology as a network fieldbus for the next-generation control system. We conducted an FTB test on LAN cables. From the test results, it will be better to use CAT5e STP or CAT7 in the locations with poor electrical noise environment. EtherCAT has been installed into the prototype digital LLRF system in the high-power RF test stand at SPring-8, the encoder readout for an undulator at SPring-8, and the control system for a kicker magnet power supply at SACLA. The EtherCAT systems using multiple vendor products have been successfully operated. The development to support EtherCAT on existing equipment such as a pulse motor control unit and an RTD temperature measurement is under way.

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