UPGRADE OF THE SPRING-8 LINAC CONTROL BY RE-ENGINEERING THE VME SYSTEMS FOR MAXMIZING AVAILABILITY

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Abstract

Control system re-engineering of a mission-critical working accelerator is a problem, but it is possible with well-defined procedures and methodology. We have finished an upgrade of control system of a 1GeV electron linac in SPring-8.

The upgrade was divided into two phases, taking into consideration the availability of the linac. In the first phase, we mainly replaced software part with SPring-8 standard framework. In the second phase, we re-engineered the VME systems to maximize availability of the linac operation considering reliability, usability, expandability and flexibility. We newly developed an optically linked remote I/O system and intelligent motor control units. By adopting these systems, we could re-allocate the VME controllers away from known noise sources and also reduce the number of the controllers. All interface connector boxes were re-designed and replaced to achieve easy maintenance and expandability.

We report the upgrade of the linac control system by focusing on the methodology with introducing the new remote I/O system and the motor control unit.

INTRODUCTION

A 1 GeV electron linac of the SPring-8 is a mission-critical accelerator to work as an injector both for an 8 GeV storage ring and 1.5 GeV NewSUBARU. Since September 1999, we had started upgrading the linac control system in order to realize a seamless operation of the SPring-8 accelerator complex and maximize availability of the linac operation. We separated the upgrade into two phases to avoid downtime of the linac due to the upgrade procedure. In the first phase, we mainly replaced software part with SPring-8 standard framework MADOCA (Message And Database Oriented Control Architecture)[1], and minimized hardware replacement as much as possible. Hardware part such as VME I/O system was left for the second phase because the whole I/O part was complicated to upgrade quickly within an available time period. We finished the first phase in September 2000, and the result was already reported in the ICALEPCS'01 [2].

In October 2001, we started the second phase in order to maximize availability of the linac operation. At the beginning, we discussed how the hardware part of the linac control system should be upgraded.

METHODOLOGY

In old linac control system, 27 VME controllers were distributed around the linac and were placed near accelerator components such as electromagnet power supplies, klystron modulators and RF phase shifters. The VME controllers had 5 kinds of direct I/O boards, digital-input (DI), digital-output (DO), analogue-input (AI), analogue-output (AO) and pulse motor controller (PMC) boards. These boards were connected to the equipment through a connector-box coupled with the VME chassis.

Requirements for the upgrade of the control hardware to enhance availability of linac control were as follows.

- Keep CPU boards apart from noise source and isolate I/O parts from VMEbus for the system reliability.
- Provide local control ability of motor controllers for the linac experts.
- Recondition I/O-signals properly for stable monitoring.
- Improve maintainability and expandability of the connector-boxes.

In order to satisfy these requirements, we decided to introduce an optically linked remote I/O system called OPT-VME system [3], and a network-attached pulse motor control unit (MCU). We also decided to reconstruct all the connector-boxes. Figure 1 shows our design architecture of the upgraded control system. We can reduce the number of the VME CPU boards to ten and can use them in a better environment.

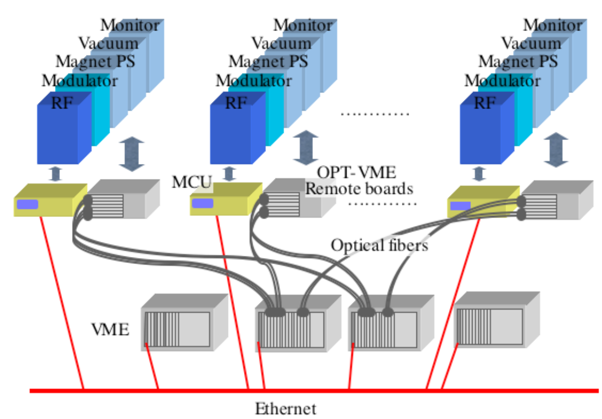

Figure 1: The design architecture of the upgraded control system.

Since the SPring-8 linac is a continuously working accelerator, the biggest problem of the upgrade was that we have to finish the actual installation work within the limited time. Moreover, because of big change of the hardware, we were not allowed to turn back to the old system once we started the work. Therefore, we planned to upgrade the linac control system at the summer shutdown period which was the longest shutdown in the SPring-8. In 2003, a maximum of 7 weeks were available for our upgrade work.

We knew that even the summer shutdown period could not provide us with enough time to put the upgraded control system to the sufficient test, so we had to examine the components of the new control system before the summer shutdown as much as possible.

DEVELOPMENT

OPT-VME system

Instead of direct I/O modules on the VMEbus, we applied the OPT-VME system to the new linac control. The OPT-VME system was already developed and adopted for data acquisition of beam position monitors (BPMs) of the linac [4]. The system consists of master VME boards (HIMV-658) and remote DI boards (HIMV-615) and they are linked with H-PCF optical fiber cables. One master board can connect four remote boards. The system provides high-speed communication of a 64 bits data within 20 microseconds.

For applying to new linac control system, we newly developed three types of remote boards, combo boards (HIMV-731), DI/DO boards (HIMV-616) and AI-16 boards (HIMV-714). The HIMV-731 was developed especially for electromagnet power supplies. It has two channels of AO/AI with 16-bit resolution and 32 bits of DI/DO with photo-coupler isolation. The HIMV-616 provides 64 bits of DI/DO with photo-coupler isolation. The HIMV-714 has 16 channels of AI with 16-bit resolution. In order to introduce these new remote boards, we upgraded FPGA logic of OPT-VME to support input-output transfer mode as well as input-only mode. In the input-output mode, one communication is performed within 40 microseconds which are twice the time in input-only mode. Figure 2 shows the remote boards of the OPT-VME.

Figure 2: The remote boards of OPT-VME.

Taking the availability of the linac operations into account, we designed that the remote boards can hold output signals of AO and DO even though the VME controller involving OPT-VME master boards is reset or powered off. Furthermore we could read back the actual output value on the remote board. Because of these features, we can continue the linac operation without any reconfigurations after the VME systems start up.

Motor Control Unit (MCU)

In order to meet a demand of local controllability of motor drivers, we decided to develop new pulse motor controller with Ethernet connectivity instead of the motor control boards on the VMEbus. To cut down the development cost, we adopted an industrial controller (ND-MCU), and a commercial available motor control board (PCI-7414V) which can control four axes individually. The controller is 4U height, and is fanless and diskless system with three PCIbus slots. The CPU is 200MHz SH-4 (SH7751R), and real-time operating system, μiTRON, is used. For a local operation, a 4-inch LCD with touch panel is attached to the front of the MCU, as shown in Figure 3.

Figure 3: The MCU for pulse motor control.

When the MCU is controlled via a network, it works as a socket server. Fixed operation sequences such as “initialization”, “extraction” and “insertion” are embedded in the MCU so that we can reduce the number of communications between the MCU and client applications. Because these sequences are executed as concurrent tasks, a maximum of twelve axes can be operated from one MCU at the same time. The MCU carries out conversion between pulse counts and physical value, and displays them on the local LCD. These features can offer easy operation not only for remote control but also for local control.

For usual operation of the MCUs via a network, we introduced new software framework called Device Masquerade [5]. By adopting this framework, we can handle network-connected devices as local devices on a computer on which a client process is running.

Even though the client computer is down, the MCU doesn’t lose the original position, so that we need not to initialize the MCUs again after the client computer starts.

For the upgrade of the linac control system, we introduced twenty MCUs, and we used three VME CPU boards in one VME chassis to control all the MCUs via a network.

Connector-Box

In accordance with introducing the OPT-VME system, we decided to reconstruct connector-boxes in 19” racks. They played roles to receive external signal cables with connectors, to marshal the cables, and to condition the I/O signals. The main purpose of the re-engineering was to improve flexibility, expandability and maintainability of the connector-boxes. We needed to recondition the I/O signals properly to fit the OPT-VME remote boards.

For the purpose of the signal conditioning and the signal probing, we installed three kinds of signal terminals in the connector box. The front door of the connector-box can be opened for easy access to the terminals. And the rear connector panel has reserve space for the additional signals. The shielded cables were used in the connector box for noise protection.

We reconstructed 24 sets of connector-boxes after test of a prototype.

PREPARATION

As a first step, we individually tested the developed components like the OPT-VME, the MCU and the new connector-box since July 2002 by connecting to actual equipment of the linac. If there were some problems, then we fixed them until the next test. We raised the completeness of the developed components by repeating this process. Through these examinations, we almost defined the final specification of the OPT-VME, the MCU and the connector box by January 2003. Only for the connector-box, we had to greatly improve the usability and the expandability.

As the next step, we put the new control system to the test of long-term stability under the actual operation condition of the linac. For this purpose, we replaced the control system of the standby section of the linac with the new one in May 2003 after production of the first two connector-boxes for actual use. In the standby section, we could test the control to almost all kinds of the components in the linac. We developed equipment control software during this period. Although we could not have enough time for this period, we found and fixed some software errors of the OPT-VME and the MCU. As the result of this examination, we made a final decision to perform the upgrade.

For the new connector-box, a full check of cable connection was performed in a factory. This check enabled us to reduce the examination time for the equipment control software.

INSTALLATION AND RESULT

We could start the replacement of the control hardware from the second week of the summer shutdown and finish it by the end of the fourth week. From the fourth week, the equipment control software was examined with the replaced hardware. And by the middle of the sixth week, we could operate the linac from the operator consoles by using the upgraded control hardware and the developed software. After some developed software and database modification, the installation of linac control system was finished within a summer shutdown period.

During the period of the accelerator tuning, we needed to tune up the software for the MCU controls in order to improve throughput of the operation software and the data acquisition software on the operator consoles. Then, the linac operation for the experimental users was started without any trouble. The new control system worked well and was stable enough under the actual operation conditions. As we expected, the linac operation could be continued without re-loading the operation parameters after the VME system was rebooted. This shows one of the facts that we succeeded in enhancing the availability of the linac control.

We planned to adopt embedded Linux PCs for the control of the modulator PLCs by RS-232C. But in the summer shutdown tests, we found that unexpected system-down sometimes happened. This event was too rare to find in the previous tests unfortunately. Consequently, we used old workstations for the PLC control as a temporary solution. We have to resolve the problem or find better solution in near future.

SUMMARY

We succeeded in upgrade of the linac control system by re-engineering the equipment control hardware. Since the linac was a mission-critical accelerator, the methodology for the upgrade had to be well defined. The sufficient preliminary tests greatly contributed to reducing much time for the actual replacement. Furthermore, it was very helpful to us that the upgrade of the linac control system was divided into two phases which were the software phase and the hardware phase. As the result, the problem to be resolved in the upgrade process was simplified.

We almost didn't need to modify the operation software running on the operator console, and the databases for the linac. That was because we had taken into account the idea of the device abstraction and the message-oriented operation in the MADOCA framework.

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