Microwave Control and Measurement System at the KEKB Linac

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Abstract

The Microwave System for the KEK electron/positron linac is being rejuvenated for the KEKB project. Klystrons are being upgraded and pulse compressors are also being employed to accelerate electrons up to 8 GeV. Because of the beam current and emittance requirements in the KEKB accelerator complex, very stable operation of the microwave source is indispensable.

Thirty VXI-based microwave-monitoring stations have been installed to maintain in a better operation condition. PLC's for basic controls are being adopted for new klystron modulators and sub-boosters. A redundant optical switching network is employed to accommodate a higher bandwidth and to eliminate noise from the modulators.

Upper-layer software for device controls is being upgraded to enable transparent access to both old and new controllers. Not only the current values, but also statistical values, such as averages and standard deviations, will be served for client programs. Advanced application programs, such as feedback loops, are being developed to accomplish improved operation.

Although the simple RPC protocol is used for linac internal communication, an EPICS CA-server will be also prepared for global operation.

1 Introduction

In the KEKB project the stability of the linac beam is crucial to achieve a higher experiment efficiency. Each component of the linac accelerator should be monitored and controlled to operate robustly.

Especially, the microwave system plays an essential and most active role in linac-beam acceleration. The microwave system consists of several sub-systems, and has many control parameters. Some of them are controlled in hardware feedback loops, and should be routinely monitored.

In this paper, an overview of the KEKB linac controls is given first; then, the microwave control and measurement system is described.

2 Linac control system and its network

The control system of the linac was rejuvenated in 1994 [1, 2]. In the new control system, international and de facto standards, such as Unix, VME and TCP/IP, were employed, while many of the old local device controllers should be continued to be supported. The control software was rewritten so as to build layered equipment services utilizing a home-made remote procedure call (RPC) scheme.

2.1 Field controls

The computer network for controls comprises a FDDI and about 50 Ethernet network segments, which are isolated from the laboratory-wide network by a firewall. Although the FDDI and Ethernet networks around the main control room use twisted-pair cables, the connections to local field controllers are now based on fiber-optic cables (10Base-FL Ethernet) in order to eliminate noise from the high-power klystron modulators in pulsed operation. A star-like topology was employed to localize any problems and to ease trouble-shooting.

Currently, the number of 10Base-FL nodes is just above 100, and may soon be doubled if the old controllers are replaced. They are connected with one of 33 10Base-FL repeater stations, which are spread along the 600-meter linac building, and then concentrated into FDDI-10BaseFL switches at the main control room. Although the 10Base-FL connection between the field controllers and repeater stations are single, those between the repeater stations and the central switches are made fault-tolerant by adopting redundant switches and transceivers, since any problem at this level is severe.

For local device controllers, no standard was defined. Once it was considered to have VME computers as standard device controllers. However, we are using many old controllers which are already over 15 years old, and every year new technologies are revealed. Thus, from our experience, it's not practical to decide on a standard. Actually, it costs much manpower to maintain a standard for 20 years.

Instead, we defined criteria, which require that each local device controller should at least speak UDP protocol and be diskless, if possible. If the controller is intelligent, the UDP version of our RPC protocol is installed on it. Old controllers are indirectly connected to the RPC network environment through VME's.

2.2 Central-control architecture

Unix computers consist of a computer cluster and isolated computers, which are also operated to be fault-tolerant. They are mainly DEC Alpha architectures, and a cluster software called True Cluster is installed.

They carry most of the upper layer control tasks. Besides running control-process software, they also support many network services, such as file services (NFS, NetBIOS, AppleShare), a network firewall, name resolutions (DNS, NIS), remote booting (BOOTP, DHCP, TFTP), time synchronization (NTP), failure reports (SNMP, SMTP), routine reports (HTTP), printer services (lpd, AppleTalk) and office mail (SMTP, POP3). Those services are utilized from a number of control computers.

Control services on Unix computers are designed to be accelerator-equipment oriented. Upper layer software serves logical equipment controls hiding physical details. Since several different controllers were developed over a period of 15 years for a kind of equipment, every effort was made to carry hardware-dependent processes in the lower layer software. Most lower and upper layers communicate through the UDP version of the RPC in order to recover failures reliably, while the TCP version is used between the upper layers and the application clients.

Each layer uses a simple memory-resident hashed database to process controls. Depending on the response time of the underlying layer, a layer may cache information, while commands to bypass the cache are also provided.

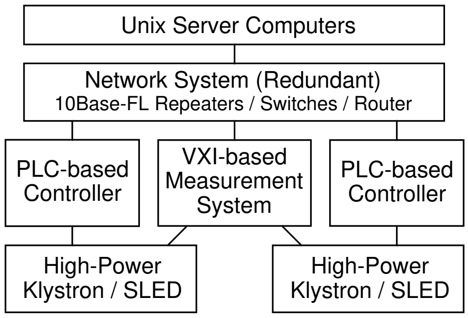

Figure. 1. New PLC-based controller attached to each of 20 new high-power microwave sub-systems. Two sub-systems are grouped and a VXI measurement station is installed. For 40 old sub-systems 20 new measurement stations are also installed, but old controllers continue to be utilized instead of PLC's.

3 Linac upgrade and controls

For the KEKB project, the linac beam energy is being upgraded from 2.5 GeV up to 8 GeV, and 3.5 GeV positrons are also to be generated [3]. In order to accomplish this, energy doublers (SLED) are employed and the length of linac is extended by 50 percent; the number of devices is also to be increased by roughly 50 percent.

Many old controllers for them, which were designed about 20 years ago, could not be reproduced any more, mainly because of the production discontinuance of their components and the company closures. New functionalities are also eagerly required. Thus, new controllers are designed based on the criteria of a UDP connection and hard-disk-less.

New controllers are designed utilizing VME, VXI, CAMAC, PC and PLC technologies, depending on the needs specific to the corresponding devices.

Most of newly designed simple controllers employ PLC's (Programmable Logic Controller). Until recently, its performance and remote connectivity did not meet our requirements. Now, however, it just satisfies our needs for simple controllers; further, its cost-performance is appealing. For example, the response time of a remote control of several input/output ports over a network is about 20 milliseconds. Although this is 10-times slower than modern VME processors, if large data processing is not necessary, a PLC is adequate for simple controllers [4].

Upper layer software had been designed to be independent of the lower layers. It was, thus, relatively easy to integrate new lower layer software for new controllers. At least the RPC interfaces between the upper layer software and clients are kept unchanged, although extensions of the protocol is independently planned to accommodate new needs.

4 RF system upgrade and its controls

In order to accomplish the energy upgrade, the rf system is being improved in both quality and quantity. The output powers of the high-power klystrons are being raised, and SLED's are being attached. Also, the number of high-power klystrons are being increased from 40 to 60. At the same time, related sub-systems, such as the low-power rf system, vacuum system, and trigger system are being improved.

Old controllers for the klystrons [5] are connected with VME's through homemade fiber-optic networks. However, because of the energy upgrade, they have suffered from noise disturbance, and the failure rate of the communication has become several percent. Although most of the errors are recovered by lower and upper layer software, clients see the performance degradation.

The main reason for the noise perturbation seems to be the absence of a grand plane in the circuit boards. Since they were produced more than 15 years ago, multi-layer circuit boards were not chosen. It is also known that the noise depends on the operation points of the klystron modulators.

In order to fulfill the requirements from the beam quality for KEKB, extremely stable operation for the rf system is indispensable. Also, many automatic functions and fast measurement capabilities are necessary, although the budget is very limited.

In consequence, it was decided to install new PLC-based controllers for new klystron modulators and new VXI-based measurement stations for all klystron modulators, while keeping the old controllers for old modulators. Communication between the upper and lower layer software was redesigned to hide the differences between the old and new controllers.

5 New controls for rf system

5.1 Basic controls with PLC

As already pointed out, PLC controllers are suitable for simple tasks. The control of a rf system, however, is not a simple task, and the programming environment of the ladder programs of the PLC's is not ideal. However, if the fast data acquisition is separated, the hardware becomes relatively simple. Also, a simple architecture is often good for complicated tasks.

PLC is a kind of an industry standard, and robustly designed modules are commercially available. Also, recently the programming environment and the connectivity to other systems are much better. PLC-based controllers were, thus, chosen.

It is required for PLC's to have (1) a good TCP/UDP implementation on Ethernet, (2) a remote software installation capability, and (3) a proper user interface for local operators. To meet (1) and (2), an FA-M3 (Factory ACE) series PLC of Yokogawa was chosen. Also, for (3) a V4 type panel of Hakko Electronics was deployed.

The FA-M3 is small sized, and can fit into a space in the rack where an old controller resided. Modules for digital inputs, digital outputs, analog inputs, Ethernet and RS232C have been installed. They are connected with local switches, indicators, interlock signals, slow analog signals, as well as sub-controllers of an isolator/phase-shifter/attenuator (IΦA) and a De-Q'ing trigger through RS232C.

The V4 (V4-t110j) is equipped with a 10.4-inch liquid-crystal display and a touch panel, and is linked with a PLC through the RS232C. It can be easily configured to display variables on the PLC in one of many formats. Also, a number of pages can be defined, which can be selected via a touch panel. Even a strip chart of PLC variables can be drawn without any programs, which is very efficient to monitor the analog values.

An FA-M3 PLC and a V4 panel are programmed visually on a personal computer. A program module for the PLC can be downloaded either via Ethernet remotely or locally via the RS232C. That for the panel can only be downloaded via the RS232C at present. Since it is not convenient to update software at many stations, we are asking the company to develop firmware to transfer programs over the Ethernet through the PLC.

The combination of an FA-M3 PLC and a V4 panel became a smart controller. It is three times as cost-effective [1] compared with the former controllers.

5.2 Measurement system with VXI

At the rf system, signal monitoring is also important. Such a function was designed separately to be implemented on VXI systems. One VXI system covers two high-power klystrons, and 30 systems will be installed in total to provide measurement facilities.

Several pieces of microwave measurement equipment will be utilized, although the budget is not enough at the beginning. Before they were installed, it was not possible to measure the precise microwave power that is introduced for beam acceleration. It was calculated by other means, while those values are very important to transport linac beams.

Each VXI system contains a V743 controller and a waveform digitizer of 1 G sample/s from HP, and other modules, like a digital I/O module. It also has a GPIB bus to other measurement instruments, such as a microwave power meter. Since the processor does not have a hard disk to avoid problems, it uses an Ethernet connection to the boot servers as well as control servers.

Its operating system is a HP-UX, which is capable of running the HP's VEE (Visual Engineering Environment). The VEE is used to prototype the measurement application programs. Actually, all applications are programmed on the VEE presently, because its performance satisfies our current needs. For example, 50 waveforms from the oscilloscope can be transferred on to an X-terminal display over the network. [2]

The programming environment of the VEE is well designed and new functionalities can be added visually. It is very flexible to link with the existing facilities, such as the linac control service. Even compared to other visual environments, like Labview, its feature seems to be mature and appropriate for our purposes.

However, this system consumes much network traffic by nature. Thus, the rf systems were moved to a separate subnet. Currently, the network bandwidth is consumed about 20 percent at most on a few segments. Network monitoring tools survey the network, and no communication degradation has been observed up to now. [3]

5.3 Interface to related systems

The rf system depends on other systems, such as the vacuum and timing systems. Interlock signals from the vacuum system are connected in the hardware. The vacuum-pressure values are also necessary in order to adjust the operating point well. Thus, the pressure values are transferred every second from the upper layer software of the vacuum system on to PLC controllers. Each panel of a klystron controller has a logarithmic strip chart which graphs the pressure at three nearby ion pumps.

The new timing system, installed at the newly extended part of the linac, consists of CAMAC digital delay modules and time-to-digital converters. The ECC-1365 crate controllers of Hytec are attached to the UDP network directly. Precise timing information is important, especially for SLED operation, and is transferred to the PLC controllers through upper layer software of the timing system, including the information from the old timing systems.

Since the KEKB ring where the linac beams are transported will be controlled by the EPICS system [7], informa-

[1] It costs about 8,000 dollars including the chassis and cable assemblies.

[2] The VXI access is not normal message-based but register-based.

[3] Several free SNMP software tools such as Scotty and MRTG are used on Unix servers.

tion and control exchange is necessary between the ring and the linac. For this purpose the EPICS channel access server (CA-server) has been developed [6]. The part for magnet controls is almost completed, and now the part for klystrons is under development. Using this link, the EPICS client sees linac microwave controls as a group of EPICS process variables emulated on the CA-server. For example, a slow, but global, feedback system will be easily build for beam injection.

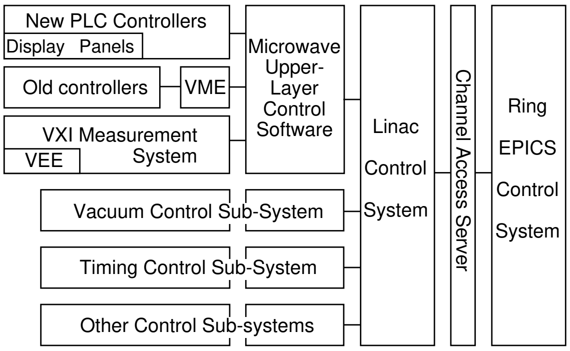

Figure. 2. Layered microwave control sub-system exchanges control information with other sub-systems, especially with the vacuum and timing sub-systems, through linac upper-layer control software. They can be reached from the ring EPICS control system as well as through the channel access server.

6 Applications

Many application programs are planned to be installed, but not all of them are finished. Here, some of them are described.

In order to condition the klystron, SLED, wave guides and accelerating structures, an automatic conditioning software was developed at the central operator's console system. This time, a simplified version of the software was implemented at each PLC controller, which was found to be efficient. It seems that operators found it comfortable to manipulate the system locally while viewing strip charts and other information.

If a fluctuation is found in the microwave measurements, it may be due to a system disorder, and must be stabilized so as not to affect the beams. It often has a connection with the lifetimes of the microwave components as well. At the PLC controllers, standard deviations of several analog points are calculated internally. [4] Although the values are not yet being utilized much, it will soon help to produce stable system operation.

Although fast measurements are carried on VXI's, and results are displayed on X-terminals, sometimes it's useful to view it locally. Thus, waveforms made possible to be transferred from a XVI station to the corresponding PLC panel. Although the speed is as slow as once a second, it provides good information for the local operators.

[4] Modern PLC's are powerful enough to carry such scientific calculations.

7 Conclusion

The communication to the new controllers is fast and reliable, although we had problems on old ones because of the noise caused by the microwave system upgrade.

At the time of this writing, October 1997, about 20 PLC controllers and 10 VXI systems had been installed, and effectively utilized. Actually, a part of a new linac section is under commissioning, and almost every day the software for the PLC's, the display panels and the VXI systems are being improved. A few klystron systems are used for test beams, conditioning of the energy doubler cavities is carried out at other systems, and the remaining systems are under conditioning of klystron themselves. In such multi-operation modes, the system works without any large problems.

Using a well-designed software development environment, the cycle time of the new software to meet a new requirement is very quick both on the PLC's and VXI's. At the same time, it shows its robust features, and the operators of rf systems are almost satisfied.

The features available on old controllers are included on the new one, and also are improved. The upper layer software hide the differences between them. Thus, clients can access the equipment transparently. Although new features implemented on the new controllers should also be implemented on the upper layer to help the old ones, it's under development.

Soon, more applications such as the automatic phase-adjustment system (phasing) and feedback system of the microwave power and phase may be implemented with some improvements of the measurement instruments. This system is expected to provide a firm and stable operation of the rf system and the whole KEKB linac.

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