

PRESENT STATUS OF THE J-PARC CONTROL SYSTEM

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Abstract

The present status of the J-PARC (Japan Proton Accelerator Research Complex) control system is presented.[1], [2] J-PARC is a high-intensity (1MW of beam power) proton accelerator being constructed jointly by Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK) in JAERI Tokai site.[3] It consists of a 400-MeV linac, a 3-GeV Rapid Cycling Synchrotron (RCS) and a 50-GeV Main Ring synchrotron (MR). The first beam commissioning of Linac and RCS is scheduled in 2006 and MR in 2007. In parallel with it, a part of 60-MeV Drift-Tube Linac (DTL) of the J-PARC accelerator complex is now being constructed at KEK site for R&D purposes. We have decided to use Experimental Physics and Industrial Control System (EPICS) as the control system environment, mainly because it is widely used in this field of accelerator controls and its accumulated software is fully utilizable. [4] One of the special features of our system is maximal use of network technology.

We planned to employ network-based controllers such as Programmable Logic Controllers (PLCs) and measurement instruments instead of using other field-busses such as General Purpose Interface Bus (GPIB) or CAMAC serial highway. The network hardware and software can be easily standardized.

Timing system is one of the important components in accelerator control. It aims at providing trigger signals all over the accelerator with the accuracy of 1 nano second. The design is almost completed and prototypes of electronic modules have been tested. Another important component is an interlock system.[5]

The accelerator interlock system consists of two separate systems; a Personnel Protection System (PPS) [6] and a Machine Protection System (MPS). The detailed design of the PPS at each accelerator and experimental facility is now in progress according to the general guideline of PPS requirements. Very fast response (an order of micro seconds) is required at the upstream of the linac. An electronic module called an MPS unit has been designed and its prototype is now being tested.

INTRODUCTION

J-PARC accelerator complex consists of three stages of accelerators. The first stage is an ion source, RFQ linac, 60 MeV Drift Tube Linac (DTL), and a 200 MeV Separated-type Drift-Tube Linac (SDTL). Energy of the linac will be upgraded with a Annular-Coupled Structure

linac (ACS) to 400 MeV. Linacs will be operated at 50 Hz. The second stage is a 3 GeV Rapid-Cycling Synchrotron (RCS) operated at 25 Hz. The last stage is a 50 GeV Main Ring synchrotron (MR) operated with 3.64-second cycle time. Extracted beam from MR will be transported to an experimental hall for nuclear and particle physics experiments. The beam from MR will also be guided to the neutrino oscillation experiments beam line aimed at Super-Kamiokande located about 300km west of J-PARC site. At the second phase of the J-PARC project, the beam from the linac will be guided to Accelerator Driven nuclear waste transmutation System (ADS) facility after accelerating up to 600 MeV by using Super-Conducting Cavity linac (SCC).

The first and second stages of the accelerator complex, Linac and RCS, are being constructed mainly by JAERI and the last stage, MR, by KEK.

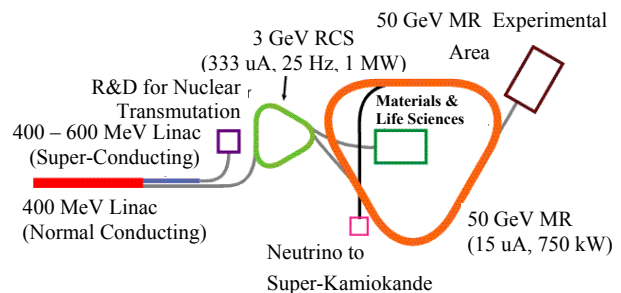


Fig. 1: Configuration of the J-PARC accelerators.

OVERVIEW OF THE CONTROL SYSTEM

The J-PARC control system is designed following so-called standard model architecture based on EPICS. The system consists of three layers, e.g. presentation layer, equipment control layer, and device interface layer as shown in Figure 2.

At the presentation layer, server workstations will be used to make and run application programs for operations. This layer includes high-speed reliable network. The network is based on switched Gigabit Ethernet (GbE) operated in duplex mode.

At the equipment control layer, there are Input/Output Controllers (IOCs) equipped with VMEbus board-computers with VxWorks and a large number of embedded-type computers run linux or micro-iTRON (A

Japanese real-time operating system for the embedded computer such as mobile phones.) as the operating systems.

At the device interface layer, we decided to use TCP/IP protocol on the 10/100 Mbps Ethernet as the common fieldbus. We have been developing common device driver for network devices and device support routines for various network devices[7, 8, 9, 10]. There will be a very large number of PLCs and intelligent equipment used in order to reduce cost and get flexibilities in 10msec ranges. VMEbus modules will be used in order to obtain fast data acquisition and/or quick responses in 10 micro-second to milli-second range.

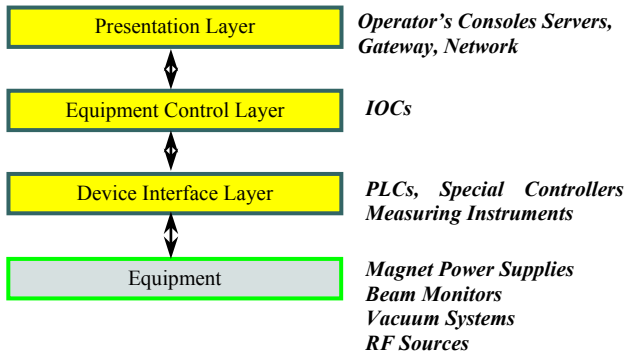


Fig. 2: The standard model configuration.

PRESENTATION LAYER

Servers

The presentation layer consists of X-terminals for man-machine interfaces, application program server, database server, data-archiving server, web server, and gateway to the outside world and the network. We should be careful to design control computer network and keep the control computer system isolated from the outside world to guarantee security and deterministic feature of the accelerator control system. There will be a gateway to the general purpose network for limited users or limited applications.as shown in Fig. 3.

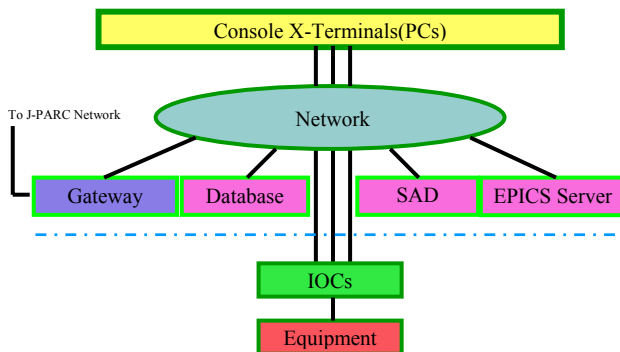


Fig. 3: The Presentation Layer

Network

The main part of the J-PARC accelerator control network constructed using Gigabit Ethernet(GbE) technology with fiber-optic cables. There are 17 local node stations in the network. All local node switches are connected to the central core switches in the star topology. At the central node, there are two core switches connected with each other for fail-over switching capability. At each local node, there are edge-switches connected with each other for the fail-over capability similar to the central node. For each connection between the central node and a local node, there are at least two paths provided for redundancy as shown in Fig. 4.

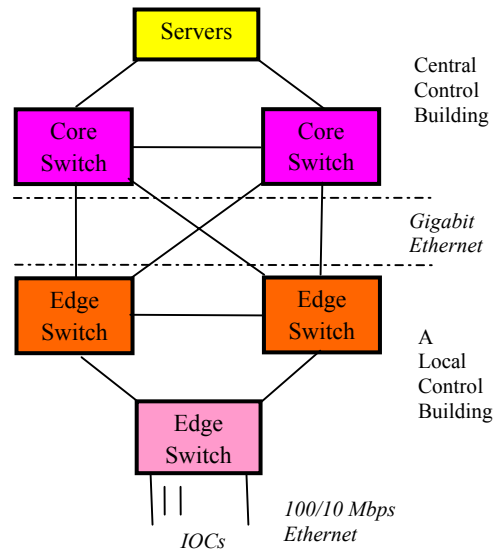


Fig. 4: Schematic view of the network configuration.

Application programs

The application programs for operating J-PARC accelerators will be coded by using resources of this layer by people such as accelerator physicists, accelerator hardware engineer, accelerator operator, technicians, and accelerator users. Therefore, we provide two kinds of high-level application program language system for writing application programs, namely, Structural Accelerator Design (SAD)[3] language system and Python[4] language system (see Fig. 5). These two languages run application programs in interpretive manner so that the programmer can get very short turn-around time in debugging phase of programming. The execution of the application programs would be slower than a compiler language but the advantage of user friendliness is worth being considered.

This scheme of building accelerator control system has been successfully realized in the KEKB accelerator control system at KEK.[5]

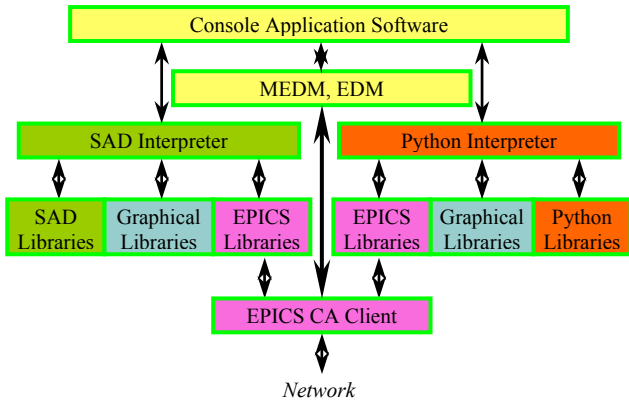


Fig. 5: Configuration of application software.

EQUIPMENT CONTROL LAYER

In the equipment control layer, there are IOCs in VME subracks with Power PC 750 based board-computers or with intel x86 CPUs. They usually run VxWorks operating system. But there will also be other intelligent embedded computers which run Linux operating systems or micro-iTRON real-time operating system which is widely used in mobile phones.

DEVICE INTERFACE LAYER

As stated above, in the device interface layer, we decided to use Ethernet as the fieldbus. A large number of PLCs and measuring instruments are connected to the Ethernet using TCP/IP protocol because it became popular that such equipment has network interface providing high speed data transfer capability. Network based Device Interface Modules (DIMs) are introduced in order to connect power supplies or other equipment to the control system through network. [7, 8, 9, 10, 11]

Network devices

We decided to use devices of this kind with EPICS intensively for stability of the TCP/UDP standard protocol widely used in commercial fields and flexibility in a configuration of the devices.

Table 1 summarizes the PLCs and DIMs to be used in the control systems, where EMB-LAN100 is an interface module for DTL Q magnet power supplies and BPMC is for MR Beam Position Monitors (BPMs)

Table 1: Devices Supported

Device	Type	Maker	Protocol
FA-M3	PLC	Yokogawa	TCP/UDP
MELSEC-Q	PLC	Mitsubishi	TCP/UDP
CV-1/CH-1	PLC	Omron	TCP/UDP
EMB-LAN100	DIM	Custom	UDP
BPMC	DIM	Custom	TCP

TIMING SYSTEM

J-PARC timing control system distributes a highly stabilized reference 12-MHz master clock, a 50-Hz trigger clock and a serially encoded “type” information in every 50-Hz period. [12] There are fan-out and E/O modules used for distributing these three signals through optic fiber cables. A set of O/E, fan-out and E/O modules are used for dividing the signals at the relay-station in each facility, if necessary. This is a star configuration and all facilities receive the same signal / information (master clock, trigger clock and type).

PERSONNEL PROTECTION SYSTEM

Safety issues are very important to handle such high power beam. PPS and MPS are installed for the man and machine protection. The PPS protects personnel from the radiation and other hazards caused by the operation of the accelerators.[13]

Hardware

As the PPS assures the safety of people, it must be highly reliable and fail-safe. The system is constructed by using PLCs. Usual computers are not used in the interlock sequences because their reliability seems still to be insufficient. They are used only in software development and monitoring of PLCs. The PPS is independent from other systems, such as the accelerator control system, to prevent it from being disturbed.

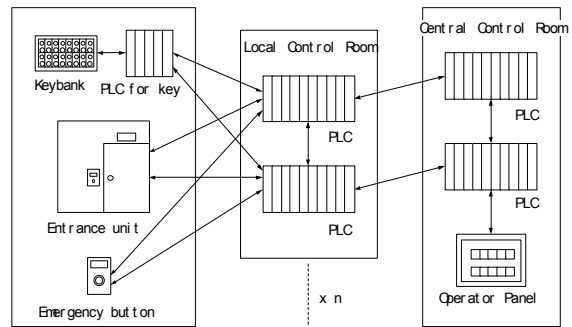


Figure 6: Hardware configuration.

In order to make the system more reliable, PLCs are used redundantly as shown in Fig. 6. The signals from important devices, such as emergency buttons, door switches, etc., are read redundantly.

Copper wires are used to connect these devices to PLCs in the local control room. The connections between equipment in the central and local control rooms are done by using both optical fiber cables and copper wires.

Access Control

For the convenience of the beam operation and access control, the J-PARC beam tunnels are divided into following access control areas as shown in Fig. 7.

- Linac area,
- 3 GeV RCS area,

- 50 GeV MR area, and
- four experimental facility areas.

Any two neighbouring areas are separated by a shielding wall. In each beam transport line that goes through the wall, at least two bending magnets are assigned as safety devices and one beam plug is installed for the safe access. When people access to the downstream area, these safety magnets are turned off and the beam plug is inserted into the beam transport line to prevent the beam from being injected into the area where people are working.

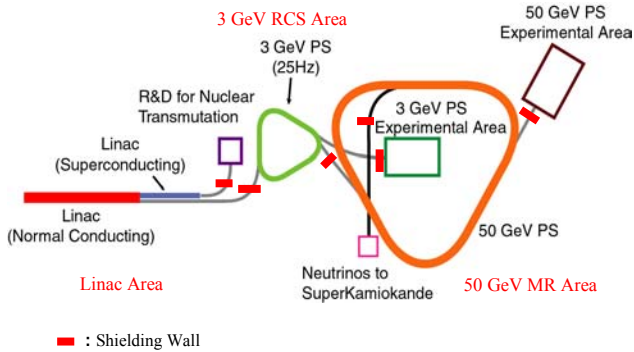


Figure 7: Access control areas.

Access State

Three access states are defined in the present system:

- Limited Access State,
- Controlled Access State, and
- No Access State.

The latter two access states are divided into sub-states. Each access control area takes one of these states independently.

PPS provides facilities for protecting J-PARC personnel from dangerous conditions such as radiation, high voltage, low oxygen content air and so on. The whole accelerator area is managed by dividing into sub-areas, linac, RCS, MR and experimental areas. Accelerator areas are isolated physically from other accelerator or experimental areas by the separation walls. There is another constraint that is called “operation mode”, which defines the working accelerators and active beam-lines. Any person who want to go into the accelerator tunnel must clear following conditions; 1. the sub-area which he wants to go into is not active, 2. he has permission of getting into that sub-area. The entrance to the accelerator sub-area is isolated by a small room in which only a few persons can exist. He should pick up a safety key by asking the operator in the Central Control Room (CCR) to give permission. If the shift leader permits, he will be able to pick up a safety key from the station. In the accelerator tunnel, there are sets of speaker and emergency button switch and any one who hears the announcement of starting operation in the tunnel will push the emergency button switch and the operation will not start.

MACHINE PROTECTION SYSTEM

The beam powers of the J-PARC accelerators are very high and it is very important to protect accelerator components from being hit by the beam. Especially at the early stage of the accelerators, the energy of the proton beam is low enough to deposit all its kinetic energy to the accelerator components. Therefore, beam loss means heating up of the components. We should provide a machine protection system by blocking the linac beam within as quick as a few tens of micro-seconds. Otherwise the component will be permanently damaged. The fastest and the most effective detector of the machine failure is thought to be the beam-loss monitors. The beam-loss monitors are distributed along linacs as shown in Fig. 8. An MPS unit detects the radiation is above the threshold level caused by machine failures, it propagates MPS signal to the upstream unit as shown in Fig. 9. The most upstream-end unit blocks the beam at the RFQ linac by stopping the RF source fed into the tank as shown in Fig. 10. At the same time, it sends a command to insert the beam shutter into the beam-line.

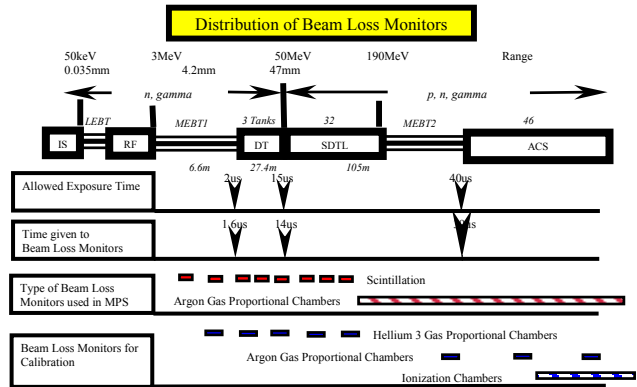


Fig. 8: Distribution of beam-loss monitors along linacs.

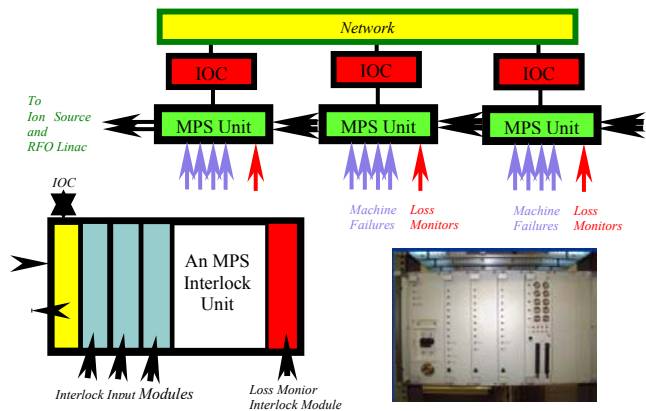


Fig. 9: MPS units and their configuration.

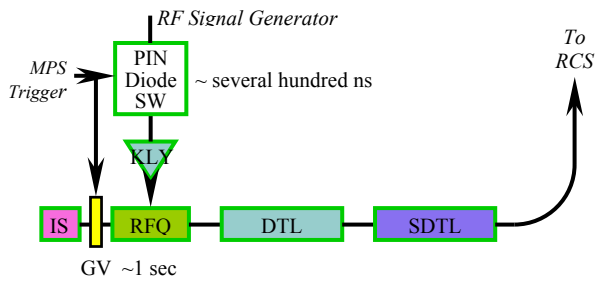


Figure 10: The MPS beam blocking mechanism.

Once RCS starts acceleration after accepting beam from linac, there is no way to dump the beam except completing RCS cycle. Then the beam will be extracted from RCS and dumped into the beam dump on the beam transport line to MLF.

At MR, a beam abort system is provided in addition to MPS and the beam in MR can be kicked out to the beam dump during injection and acceleration phases. But once the extraction phase is started, the beam will be transferred to the experimental hall.

BEAM TEST OF THE DRIFT-TUBE LINAC

Test operation of the first tank of DTL has started and the check of the EPICS based control system has also been done.[14] This test will continue by the end of March 2004. Then all the linac components will be transported to the JAERI site for the final installation. The control system will be tested and optimized and people will have valuable experiences for writing application programs using EPICS utility programs and SAD and Python.

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