PERFORMANCE OF THE CONTROL SYSTEM FOR THE J-PARC LINAC

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Abstract

LINAC of J-PARC began to operate in November, 2006, and a achieved an initial performance in January, 2007. Afterwards, the beam supply to RCS begins, and it is operating extremely with stability up to now[1]. The fundamental condition of the control system design is to defend the beam loss detecting it as early as possible because it controls the radiation by the large strength beam to the minimum. This requirement influences from the level of the basic function of high-speed interlock to the level of an advanced application that needs the predictive control. It describes what work distribution, how much man power were necessary for the control system construction.

CONCEPT OF DESIGN

The requirement to minimize the beam loss and to reduce the residual radiation makes large difference from the control system of a past experimental accelerator in the point that operating the trial and error is not permitted. This control system protects LINAC from miss-operation, but flexibility of operation absolutely must be kept for the development of 1MW operation[2]. We set the robustness of protection in the middle-ware, and set the free-stage enclosed that middle-ware for the application.

Basic policies of the strategy are :

- Middle-ware (process communication tools, device drivers, database libraries) gives the perfection as much as possible.
- Least making and maximum recycling by OOP is used.
- End user presents a necessary function of th program, and doesn't make the program itself.

At the debugging, it is severe to find bugs of middle-ware. It takes most of the debugging time that finding the reason of unexpected behaviour of poor libraries or cheep drivers. There is an idea with driver's structure simply to avoid this, too. However, it gives origin to an excessive complexity of a high-level application. We were initially given using EPICS. To make the best use of the advantage of the flat scope of EPICS records, we limited the use of record-link. The use of the record-link is a rapier, and it is necessary to use it under the total management. Even the record file should not be individually described. (Sometimes, the file written at the device test survives still.) The database application that confirmed parsing, matching and grammar was developed. End user, who are the expert of device or equipment, are not always good programmer, and don't know the detail of our function hierarchy. If sharing an individual application by the common device model is attempted, the quiet sleep at the term of all-day operation can be secured. We concentrated on the competent understanding of the function of the application that the user requested.

LINAC components are categorized into :

- Vacuum system (several kind of pumps, vacuum gauge, rough pumping system, gate valve, fast closing valve)
- RF cavity system (cavity, tuner, cooling water, temp meas.,)
- High-power RF source (klystron, HV-PS, LLRF, wave-guide, tuner)
- Magnet system (bend, q-singlet, doublet, steer)
- Monitor system (position, profile, current)

And, each device communicates with :

- Timing System (TS)
- Machine Protection System (MPS)
- Personnel Protection System (PPS)
- Parameter Data Base (DB1)
- Measurement Data Base (DB2)

We described all function of each cell in the matrix that is made of device column and sub-system line. On the result of this detailed examination, we aimed at sharing software by adapting low-level application of each device to common skeleton based on the machine model.

MPS and PPS was required very complicated function because J-PARC is a multi-purpose facility. Though it is preferable to achieve it by hardware logic, it is impossible to achieve it only by the relay logic. We decided using PLC for PPS, and FPGA is used for MPS to realize the required response time.

MAN POWER AND STRATEGY

The control system design started in 2002. It had 4 years to beam operation, but we aimed to use the actual application for factory test of individual equipment after three years. Requested man power was ;

- Five experts those who can develop device driver, process communication.
- Five programmers those who have a experience of medium scale application.

At the beginning, we started 8 members. Fortunately, 4 of us are ex-colleague of SPring-8 LINAC. Machine model, OOP driver and special needs of J-PARC LINAC became our common recognition at once. To cancel the lack of man power, the detailed design of network system was done in outsourcing. And the coverage of the machine model had been expanded to Rapid Cycle Synchrotron, long BT-line and muon magnets.

At the initial phase, new comer tried to adaption of machine model to vacuum component or simple magnet, supervised by the experts. 4 experts, 1 system manager of development system and 3 new programmers changed into 6 experts 2 high-level application developer and 3 OPI programmers.

It worries whether the software by a different method can achieve a necessary function because the person in charge of the devices has an original control specification demand. Especially, the person who takes charge of the device of simple function might see excessive estimation the machine model application for the software sharing. This conflict disappeared when the application in this method showed robustness for the function change in the acceptance test at factory on the devices. The person in charge of the control should make an effort about the device of controlled object to become detailed equally to the person in charge of the device. About the software specification presentation, they are not necessarily the skill people. Even the control people might not describe the software design.

PERFORMANCE OF CONTROL SYSTEM

At the beginning of LINAC commissioning, we were not able to exclude a local operation completely though we aimed at the achievement of the full remote control.

- All devices of the vacuum system are controlled in remote operation. Changing of gauge values from reference value range signs to operator for attention. Exceeding of the gauge value is signed to operator for attention. Beam line gate-valve are controlled as a device of MPS.
- All interlock and tuner position of RF cavity system are shown and controlled in remote.
- All information of the high-power RF source are monitored and controlled in remote. But Start up sequence after the discharge fault was not fixed yet. Then a RF staff started it up manually. Now, auto-recovery sequence is working well.
- All magnets are controlled in remote at the first operation.
- Data of each monitors acquired in remote, but data processing sequence were not fixed. Some new algorithm are developed to determine the beam energy for the phase scan of every cavity[3]. These data processing are done by high level application.

A part of high-power RF system and the ion-source was left in local control at the first operation. This is caused of the difficulty of treating of discharge event. It is another reason of taking time that many PLC are used. Some PLC were brought in with black-box ladder which made by factory. The cost must be estimated by not only hardware but software including the maintenance.

The subsystem of the whole control system operated from the commissioning beginning well.

- TS worked well. Single shot and arbitral train of pulse repetition was able to be set. This was contributed to effective study to avoid residual radiation. This timing system is operated with scheduled type train. But the delay tables can be written synchronously by using reflective memories, and synchronous delay trimming is enable[4].
- MPS has independent communication bus. Two kind of input modules are developed, and the beam loss monitor signal triggers fast response line to avoid a damage of beam bombardment at the low energy region. Less than 5-micro seconds response is achieved and the noise error is less than 1% of unscheduled downtime(~5% of operation time)[2].
- PPS has dual network, dual CPU, dual power supply and dual limit switches. PPS is the safety grounds of legal permission of this accelerator.
- DB1 deal with device information and operation parameters. DB1 also works as a record-file generator.
- DB2 is the collector of monitor data, and the data archiver. Data viewer is continuously modified by users request. Now we meet tread off between reducing the size of storage and quick response of viewer cause of data format.

The number of device driver, which is originally developed, is 21.

- 9 kinds of VME IO boards.
- 2 kinds of TS sender/receiver
- 2 kinds of PLC
- 5 kinds of oscilloscope
- 2 kinds of spectrum analyser
- 1 kind of AWG
- Soft IOC

These drivers are working with no bug for two years. Oscilloscope and spectrum analyser for the monitor device are rather complicated, and necessary function is added on fly when it is required. To identify the behaviour of each shot, we brought the shot ID in. The combination of the shot counter, wave-endless recorder (event recorder) and reflective memory network enable to correct shot number between the many measurement devices. This function is prepared to collect data to which the cause of the beam fluctuation was not treated as the statistical data but the causal relation was able to be presumed.

At the initial operation, ideal parameters were calculated by offline simulation code. But XAL and JCE began to run including SAD script interpreter at the second term of the beam operation. Our application is written in JAVA excluding OPI of pilot version. The integrated OPI has so many record connections, and performance tuning is needed. Handling of multi-processing requires high level skill and knowledge of OS behaviour. We control people are shifting high-level application development. The experience of coding primitive software effects quick debagging of the application. Of course most of bugs are found in high-level description.

Feed back of RF amplitude and phase for long time range is started, and its result shows the effect of temperature of klystron gallery. The macro perturbation, caused by atmosphere temperature, cooling water temperature or voltage of electric power station, is quantitatively analysed by a self-regression model. Accelerator control is fundamentally required to stabilize the beam. High precision stability of each devices are inevitable, but achieving the extra-high current beam needs dynamic control for long time span based on the identifying multivariate analysis. The more specialist of the control theory is requested.

SUMMARY

The control system of J-PARC LINAC successfully established initial requirement. For three to five years from now, this LINAC should aim the 1MW beam power. This control system works as a platform of high-level application. We prepared JCE to merge the components of XAL and other simulation codes. Total analysis of beam behaviour can be done by unified description through LINAC to the ring.

The large scale accelerator is constructed as a project, and keeping the schedule is required. The number of the kind of component of accelerators is not so many, and the state change of each device is not so complex (excluding special destructive monitor).

Experimental Accelerator

If you construct a experimental accelerator of mono-purpose and the life of the accelerator is several years, the control system can be constructed by out-sourcing or by 5 experts of programming. It will take one and half years to make the control system. The middle-ware may make it without sticking to the function hierarchy. Rapid application development must be the first priority. First half year is spent for the design of whole function of the control system. If the number of klystron is greater than 5, the number of control people should be increased. Especially, the variation of monitor device expands quickly. Accessibility of that device has high dependency on bender spec (sometimes it is not opened). There will be many monolithic program described and it is maintained by the author himself. It is not necessary to read the other person's code. When reading is required, it is ok to write another code.

Facility Accelerator

It is necessary to design the accelerator that operation for users is obligated to integrate the whole in the control system. It doesn't depend on the scale to construct the control system of this kind of accelerator, and about ten of control people and four years are required. The member must be contained some persons who are expert of :

- OS, compiler and driver design
- Signal, semaphore and Que
- Event driven message procedure

At the beginning of construction, the detail of the specification of each device is not fixed. That is the chance to involve every device to be defined the state flow and machine model in common. It is necessary to spend the first one year on the optimization of a hierarchical distribution of the software function. Do not let the work of the programmer with low skill level be limited to easy application development. The concept can be shared by the initial entire design, the driver design and the function distribution.

Contributing from the development phase of an individual device is indispensable to come to an agreement about the control specification as the person in charge of the device. Finally integrating a lot of machines by which of each produced the control part in an original idea becomes big dangerous for the normal operation securing. The control system can be constructed with the same man power even if it is a LINAC of 100 klystrons scale if succeeding in sharing machine model and the negotiation with the person in charge of the device.

The emphasis is put on the hardware selection, and the importance of the software structure is not recognized enough still. A cheap control equipment is selected, and excessive load is put on the software production, and a lot of examples decreased the entire performance are seen especially in a small-scale accelerator.

The estimation of the performance of the control system is difficult, because that quantitative description of total balance is impossible. Keeping the schedule, suppressing resources and achieving efficiency of operation show that.

REFERENCES

[1] K.Hasegawa. Other, "Operating experience of the J-PARC LINAC", MOP004 in this conference.

[2] M.Ikegami, "Progress in the beam commissioning of the J-PARC Linc and its upgrade path", MO201 in this conference.

[3] H.Sako, Other, "Transverse beam matching and orbit corrections at J-PARC LINAC", MOP078 in this conference.

[4] A.Ueno, "Unique features of the J-PARC LINAC and its performance – lessons learnt", TU101 in this conference.