UPGRADE PROGRAM OF THE PSI CYCLOTRON CONTROL SYSTEM

T. Korhonen, D. Anicic, A. Mezger, D. Vermeulen, Paul Scherrer Institute, Villigen, Switzerland

Abstract

The PSI 590-MeV Cyclotron is already more than 30 years in operation. However, it still holds the world record in continuous beam power. There is an active experiment program being pursued, and new experiments are planned and being built. In addition, the beam intensity is being upgraded by 50%. The control system has been through several incremental upgrades. However, the new requirements and other developments at PSI (other accelerator facilities) force again an upgrade. This time the whole architecture of the system is to be changed. The controls hardware architecture will be changed and the underlying software will move to EPICS. All this has to happen without compromising the operation schedule. In the upgrade program we are planning to benefit from several new developments, both in-house and together with the community. The central technologies to be used will be presented. The issue of how to tackle the somewhat contradictory goals of upgrading on the fly will be discussed.

INTRODUCTION

The PSI 590 MeV Proton Cyclotron was built in the 1970's as a meson factory for particle physics research. It has ever since been continuously evolving, reaching record levels of beam intensity. At the same time, the user community of the machine has largely changed, now the machine is mainly serving other physics areas with a spallation neutron source (SINQ) or uSR (muon spin resonance) facilities, and the particle physics is now only one of the user groups of the machine. This evolution is of course one of the reasons for the machine's longevity and drives the development further.

At the moment, the machine produces a continuous beam of 2 mA. Several improvements in the last years have taken place and will enable the machine to go to even higher currents. This autumn (2007) the machine can already, at least part of the time, deliver currents up to 2.2 mA. The target in the next years would be stable delivery of 3 mA beam.[1]

A further addition to the machine is a source of ultracold neutrons (UCN) [2], planned for operation in a couple of years from now. This facility comes in addition to the existing SINQ source, and both of them will be operated simultaneously. However, the beam will not be split but switched. That is, the UCN source will get beam in pulses with the full beam intensity but with a duty cycle of approximately 1%. The rest of the time the beam goes to the meson and SINQ targets.

CHALLENGES

As can naturally be expected for a machine of this age, many of the components have been designed and implement by people who have retired or are going to retire soon. With the retirements a certain amount of know-how is inevitably lost. Another problem, although every effort has been taken to care for this, is the aging of the components. We have tried to keep stock of the critical components so that the electronics could be maintained. However, this works only as long as the people who have the required know-how are around. In addition, the old standards do not have enough potential for performance increase.

The other constraints are related to the performance of the machine and the operation schedule. As far as possible, the operation of the facility cannot be compromised. During its life the machine has evolved and a large amount of know-how in handling beams with high power has accumulated. That know-how should be preserved, and if possible, better documented so that it can be better maintained and carried over to the new generation of people who work with the machine. This knowledge includes many safety aspects. The accelerator has been equipped with a lot of logic to ensure safe operation and prevention of damage to the machine through hardware failures or mishandling of the beam.

Yet another challenge ahead of us is the new mode of operation where the beam is not anymore statically being directed in one direction but will be switched, and thus appears macro-pulsed to the users. This has an influence on how the extensions and new features are to be optimally implemented.

HARDWARE SOLUTIONS

The control system of the cyclotron is based on CAMAC, with most of the I/O-modules being in-house developments. Although the electronics itself is still working very reliably, the other infrastructure (CAMAC power supplies and fan units) are approaching the end of their lifetime and require quite a lot of maintenance to keep them running. Another problem is the limited amount of spare modules, which makes it difficult to cope with changes in the machine setup (even if the running systems could be kept alive.) In this area, an upgrade has been inevitable for a long time already. Although a complicated task, upgrade solutions for most of the device controls have already been developed and deployed.

The most abundant devices to be controlled are the power supplies of which there are hundreds. They are of various ages, ranging from more than 30-year old ones to relatively recent. With the SLS project, the digitally controlled power supplies were introduced and are now used in all our facilities. The old analogue-controlled power supplies are eventually to be replaced with the new ones, however the replacement process will take a very long time (certainly more than 10 years), and cannot happen in the same time frame as the control system hardware replacement.

In the cyclotron controls, the power supplies have been equipped with a local controller that is interfaced to the power supply and to the control system. To make the replacement process as flexible and simple as possible, we designed a new intermediate controller ('MultiIO') that has on the control system side an identical control interface to the digital power supplies but can be connected to the old power supplies without requiring any changes in the cabling. This enables us to more or less fully decouple the power supply upgrade program from the controls upgrade. If we equip the power supplies with a MultiIO interface, all we need to do when the old power supply is replaced is to change the connection from the control system unit to the new power supply.

In addition, the MultiIO is implemented with an FPGA, a very flexible configuration of IO and several plug-in modules for different functions. If necessary, it could also be used as a feedback controller to improve the stability of the power supplies, used to collect performance data at a high rate and so on.

The beam diagnostics electronics has been originally developed with CAMAC and is now being gradually replaced with a FPGA-based solution (VPC) plus the required signal conditioning boards. This replacement process is also slow and will take several years until the functionality of the old modules is ported to the new FPGA-based modules[3].

There are also several other subsystems that need to be upgraded. For example, the RF plants are moving towards digital control and would have to be considered anyway. However, this upgrade path fits into the overall scheme and do not pose problems other than those that we need to solve anyway.

As already mentioned, a large and complicated system is the interlock and machine protection system. It was originally developed in CAMAC but has been fairly recently re-implemented using FPGA technology [4]. The new implementation provides essentially the same functionality as the old system, but with several new features. The complexity of the system however makes the replacement a big challenge, as logic has to be re-implemented in the new system, verified and tested. This work is however well underway and the new modules have already been extensively applied, as replacements and also in a new project.

Introducing synchronization is a new need driven by the new UCN source and the need to switch the beam between it and the other facilities. In this area we are able to benefit from developments that have been done for another PSI project (the Swiss Light Source) and then carried on by other projects, most notably the Diamond Light Source and LCLS at SLAC.. Just to mention two significant recent developments, the addition of time-deterministic data transfer and the addition of plug-in modules enable us to implement several things better than with the original modules. The hardware development is done by a company (Micro-Research Finland) so the new hardware can simply be bought [5]. The development however has been with close collaboration with the community, so that the continuity and compatibility between the developments is guaranteed and the flow of ideas has been bidirectional.

SOFTWARE

The current control system software of the PSI cyclotron (internally called "ACS", not to be confused with other software packages with similar names) is based on a thick client architecture where practically all the application logic resides in the server level. EPICS on the other hand is more oriented towards thin clients, and provides facilities for implementing much of the functionality directly in the IOC level. This has an impact on how the implementation should proceed. For instance, in a thick client application, a lot of manipulation on the register level is done in the clients, whereas in EPICS this manipulation is typically done in the device support layer in the IOC. Implementing the device support in the ACS way makes it possible to use the ACS applications with minor modifications, but on the other hand it would prohibit us from using effectively the EPICS facility of record linking, which in turn is essential for implementing intelligence at the low level.

The first goal is to be able to reproduce at least the same level of functionality and features of the ACS-based system in the EPICS implementation. There are a few issues to be solved before we can reach this goal.

One of the most distinctive features of the ACS software is that all the I/O channels, and associated applications are configured through a database. There is no readily available solution to have this feature in EPICS, so we have to build a facility like this, and prepare porting the data to the EPICS-based system. At the same time, other PSI facilities can benefit from this feature, so the effort is not only for the single purpose of this upgrade project.

An issue related to what is written above is that use of the modern technologies like FPGAs has, so to say, moved the engineer's workbench from the soldering bank to the computer. In other terms, this means that the tuning and development often happens in the real system. The system parameters are defined in a large number of registers. If each register (most of them are only required in the development phase) had to be defined in a database, this can slow down the development cycle. A compromise has thus to be found.

ACS software also has its own method of converting between physical, engineering and device units (for example, magnet field values, magnet current and D/A converter values). This is integrated into many of the applications, and a method to do this is required.

Level conversion can be implemented with a combination of EPICS records, or could also be achieved with the help of a few custom records. Finally, looking at this issue it was decided to use a number of soft channels to achieve the conversion, the main reasons being that there will then be no need to generate dedicated record types and the management and parameterization of the conversion will be easier this way.

PHASES OF THE UPGRADE

As the machine is rather big and complicated and the time to do development is limited, our plan is to replace at least most of the hardware before we start to change the hardware. The reason to do this mainly that we do not find it worth the effort to write all the required device support for modules that would soon be replaced anyway. In addition, it will be easier to verify the correct operation when we already know that the hardware works.

This is clearly not an approach that would be universally applicable. In our case this is feasible because for most of the new hardware we have already support written for the ACS system (for the PROSCAN project.)

When most of the hardware has been replaced, we plan to replace the old device/attribute pairs with EPICS channels. For this purpose a utility that is able to produce the EPICS channels from a database, similar to the old system is required.

This step would reproduce the structure without the business logic in low level, but enable using the old client applications with minimal changes. This does not yet enable utilization of the low-level intelligence in EPICS, although it would already allow some useful features to be taken into operation, for instance monitoring alarms and values from the IOC level. For that in ACS, one would need an application that polls the channels and monitors them for alarm limits.

IMPACTS

As always in a situation like this, things will change. However, what changes do we expect, and what do we want to have? Naturally, one would not like to lose good features, and finally have more possibilities in the end. Otherwise the change would be just a lot of work for nothing. One must see what we cannot afford to lose and what would be the most beneficial things in the long term.

The obvious things are facilities or functions in the old system that the new one does not have. For instance, the advantages of being able to maintain the hardware configuration through a database and associated applications are so obvious that one would not like to lose that. This and a number of other features need to be implemented.

On a more philosophical, or organisatory level, what we will inevitably lose is the possibility to compare the behaviour of two different systems. This is often beneficial to one or other side when a good feature from the competing system can be added to the other. However, at one point one will anyway reach a point where the differences would become insignificant.

We naturally hope to see much more things on the winning side. The most obvious thing is the possibility to share applications and know-how between projects and facilities. The same group of people needs to maintain the systems anyway and it is also more interesting and motivating for people to participate in different projects. When everybody is familiar with the tools it is easier to move from one project to another, and to develop applications and components that can be deployed in more than one facility.

We also expect to benefit from the fact that we can move at least a part of the applications to the low (=IOC) level. This gives us new possibilities like implementing local feedback loops or state changes based on the status of some other components.

Addition of the timing system will improve our capability to do measurements synchronously without being limited by the capabilities of the network. It also gives a possibility to implement the (foreseen) first fault detection in the interlock system, by providing a global clock for the modules. The synchronous data transfer capability of the recent event system cards can also bring us some very interesting capabilities, in particular with the new switched operation. For instance, one can tell in advance to the diagnostic systems what the expected current will be in the next minutes, which could increase the reliability of transmission measurements in the case when the beam is not purely continuous anymore.

SUMMARY

The upgrade program is planned to take the PSI cyclotron controls forward for the next 10-15 years, and hopefully beyond that. The investment is large but should pay it back with the fact that the system has a chance of being (re) documented, the knowledge of the underlying components will be refreshed and for the PSI staff it is easier to share knowledge and to participate in projects in the different facilities. The major part of the work is already defined, but still many technical solutions have to be found to carry this project to the end.

ACKNOWLEDGEMENTS

The upgrade program is only possible to implement with the collaboration of many people, in- and outside PSI. Of people outside PSI we would like to specifically thank the fruitful discussions with Bob Dalesio concerning the possible upgrade paths.

REFERENCES

[1] Information about the PSI Proton Accelerator: http://abe.web.psi.ch/facilities/facilities.php
[2] F. Atchison *et al.*, "The Ultracold Neutron Facility at PSI",. http://ucn.web.psi.ch
[3] B. Keil *et al.*, The "Generic VME PMC Carrier Board": A Common Digital Hardware Platform for Beam Diagnostics and Feedbacks at PSI", EPAC04, Lucerne, Switzerland
[4] G. Dzieglewski, A. Mezger, "Protection Mechanisms For A High Power Accelerator", ICALEPCS'05, Geneva, Switzerland
[5] Information about the event system under http:://www.mrf.fi