THE TR30 CONTROL SYSTEM - A CASE FOR OFF-THE-SHELF SOFTWARE

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ABSTRACT

The TR30 is a 30 MeV high intensity H^- cyclotron for medical isotope production. The control system for this machine was implemented using commercial software and hardware wherever possible. An Allen Bradley PLC programmed in ladder logic was used as the control processor. The console supervisory system consisted of two IBM PCs running the Allen Bradley ControlView software. With this approach, a very low software to hardware cost ratio of 1:2 was achieved with no penalty in functionality.

1. INTRODUCTION

The TR30 is a compact cyclotron for production of radionuclides for medical use. The first machine of this type was designed and built on the TRIUMF site under a technology transfer agreement between TRIUMF and Ebco Technologies Inc. of Vancouver, B.C. The machine accelerates H^- ions up to an energy of 30 MeV. Two high intensity proton beams – up to 350 μA total current – of different energies can be extracted simultaneously.

2. REQUIREMENTS

2.1. Control System Scope

The TR30 control system looks after the cyclotron from the ion source to the ends of the beam lines. This includes all aspects of device and machine protection. Independent systems are responsible for the control of the RF feed-back system, the target stations, site services, and the enforcement of personnel safety, especially with respect to high voltage and radiation. These systems are beyond the scope of the control system and this paper.

2.2. Required Features

The control system has to provide operator access for control and diagnostics to all elements of the TR30 vacuum system, to the power supplies of the injection line, to the main magnet, to the two beam lines, to extraction and diagnostic probes, and to all beam diagnostic elements. In addition, control and status information must be exchanged with up to six target stations, the RF feed-back control system, and the radiation safety system. The control system uses 700 digital and 220 analog control channels. All device protection is carried out by the control system thus avoiding hard-wired interlocks. With commercial applications in mind, emphasis was placed on reliability and ease of operation and maintenance.

3. DESIGN AND IMPLEMENTATION

Over the past years, with the increased performance of personal computers, a wide variety of commercial products for process monitoring and control has become available.[1] For various reasons these systems have not been widely used for accelerator control, although the progress in technology makes them more and more attractive.

In the TR30 project, it was decided at an early stage to base the control system on one of these commercially available software/hardware solutions. Expected benefits from this approach were

a) greatly reduced software costs by being able to concentrate on application programming and by avoiding system programming tasks,

b) the industrial ruggedness and quality of the final product, and

c) simplification of documentation and maintenance.

It was felt that these benefits would by far outweigh the limitations of a general-use software package over a tailor-made in-house solution, provided the commercial system was "open", i.e. allowed the addition of user-written code to add missing functionality.

After evaluation of a variety of commercial systems, the TR30 control system was based on an Allen Bradley solution: a programmable logic controller (PLC) and the ControlView * console software package.

*ControlView is a trademark of Allen Bradley Corp.

3.1. Concept

The control system uses three networked processors in a two-layer architecture, a *device control layer* at the lower level and a *supervisory layer* at the higher level.

The device control layer implements the functions for basic device control such as analog and digital device readout, device switching, setpoint change and device interlocks. It provides fast beam trips and vacuum trips, some sequencing and fast closed-loop control, as well as the interface to the safety system, target stations, etc. When this layer is shut down, e.g. for software or hardware servicing, all devices are switched to a safe state. This is necessary because all interlocks are provided by this layer. In general, valves are closed, all other devices are switched off. Exceptions are made for the gate valves to the probe housings and for the five cryo-pumps which do not change state if the control system is brought down. This prevents damage to the probes and maintains the high vacuum in the cyclotron tank and in the beam lines during control system service.

The supervisory layer provides the operator interface through graphics screens a pointing device, and and alphanumeric keyboard. Higher level functions such as alarming, data logging, trend displays, slow closed-loop control and some automation are also provided in this layer.

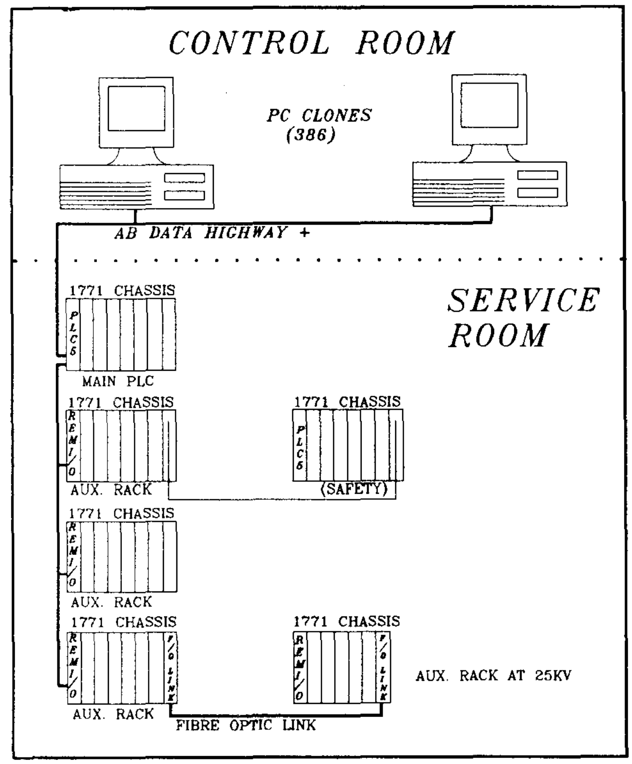

Figure 1. Overview of the Control System Hardware Configuration

3.2. Hardware

The device control layer hardware consists of one PLC 5/25 processor, four crates of 1771 series I/O modules at ground potential, and one I/O crate at the ion source potential of approximately 25 kV. The ion source crate is connected to the rest of the system by a fibre-optics link. There is no redundancy in this layer.

The supervisory layer consists of two IBM compatible PCs (80386), each equipped with 4 MBytes of memory and a 60 MByte hard disk drive. The PCs are located in the operator console. Each drives one colour screen, one monochrome screen, and a printer. Control of the TR30 is possible using only one of the console computers although there is some loss of convenience.

The two layers are networked with the Allen Bradley Data Highway Plus, a serial token-passing bus with a speed of 57.6 kbits/sec. Figure 1 shows a schematic diagram of the hardware setup.

3.3. Software

Reading and writing of the I/O modules and the communication between the PLC and the console processors are all part of the PLC system firmware. The PLC application program for the TR30 device control layer was developed using the Ladder Logistics † package of the AI Series software from ICOM Incorporated. The application is developed on a PC, e.g. one of the console PCs, and downloaded into the PLC5 user memory where it can also be modified on-line. The program is "written" in *ladder logic*, a programming paradigm which is borrowed from drawing relay logic diagrams. This method of programming is highly intuitive for controls engineers and technicians. As a result, software and hardware implementation are closely coupled. The programmer draws the diagrams using the interactive ladder editor of the Ladder Logistics software. The assembling of the diagrams into machine code is taken care of by the programming software. An short example of ladder logic code as it looks to the programmer in the ladder editor is shown in Fig. 2.

The supervisory control layer uses the ControlView software package from Allen Bradley. ControlView consists of a core, a proprietary real-time operating system for the PC and optional application modules. The core maintains a current value data base of user-designated PLC variables ("tags"). Raw values are periodically scanned, i.e. read from the PLC, and scaled according to information which the programmer provides when configuring the data base. The data base and the update rates for different scan classes are configured by filling in forms. The application modules are set up in a similar way. No programming skills are required. The TR30 system uses the ControlView modules for alarming, data logging, trending, derived tags, and event detection.

A special application module is the ControlView

† Ladder Logistics is a trademark of ICOM Inc.

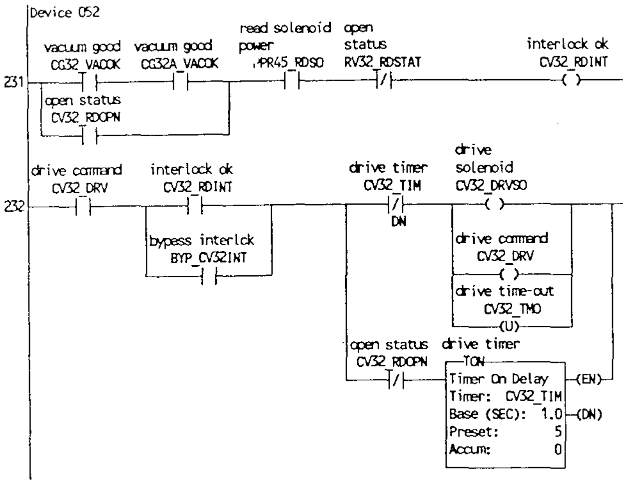

Figure 2. Section of ladder logic code. A processor bit is represented as a relay with an arbitrary number of contacts.

graphics editor which is used to design the graphics pages for the operator interface. One can assign attributes like colour, visibility etc. to the objects on a graphics page. These attributes may depend on and change with tag values in the current value data base. Lists of function key commands can also be attached to graphics objects. Again, these assignments are done interactively. Graphics pages can be modified while the control system is operating.

ControlView is an open system due to the C-Toolkit library option which allows the user to develop custom tasks and easily integrate them into the system.

3.4. Operator Interface

The operator interfaces to the ControlView system using a pointing device such as mouse, trackball or touchscreen, and the PC keyboard.

For the TR30, a mouse was chosen as the pointing device and the user interface was designed so that the operator runs the machine essentially from pictures and menus. This can also be done by using function keys and command line input from the keyboard only. Using the ControlView tools, a set of sub-system pages and device control panels was developed which are accessed through a customized menu system. A sub-system page, e.g. for the vacuum system or a beam line, shows a graphical outline of the sub-system. The operator selects and operates devices with the mouse or function keys. In addition, complete information for each device, including the state of all its interlocks, can be obtained by calling up the device's control panel. Figure 3 shows a hard copy of a beam line page.

3.5. Implementation Experience

Only one of us (DJD) had previous experience with PLC programming. The ControlView package was a newly released product. In both cases the learning curve was very short. Most of the desired functionality was easily achieved with the features available in the ladder logic and ControlView. Custom C code was written to accommodate the non-linear scaling of the vacuum gauges, to generate customizable alphanumeric display pages on the monochrome screens, to provide an on-line diagnostic probe scan, and to develop a command procedure processor with more functionality than provided by the ControlView macro processor.

For a new product, ControlView proved to be quite complete, mature and bug-free. Missed were tools for more tightly integrating the development of the ladder logic and the ControlView application as well as tools for monitoring and optimizing the use of ControlView resources.

As the TR30 was the first machine of its type, the control system implementation was done in two stages: At the start of commissioning, an open loop system was provided. During commissioning and as operating experience was gained on the machine, more operator support was added such as closed loops in the PLC, event driven adjustments in ControlView, and command procedures for routine operational tasks.

The Ladder Logistics package contains extensive online diagnostics features. The actual state of all inputs and outputs and internal program variables as well as the activity of the ladder rungs can be inspected on-line in real-time. This proved invaluable during commissioning of the system.

In ControlView, fixing application bugs and upgrading the system was very easy as it mainly involved interactive changes of screens or configuration form entries. Due to the layered system architecture and the redundancy at the console level, there was very little downtime due to control system work. This was especially important as all interlocks were provided through the device control layer.

Of course there are limits in any off-the-shelf system. On the hardware side, only DACs with 12-bit resolution were available. Therefore higher resolution interfaces to the power supplies for the cyclotron magnet and four beam line dipole magnets had to be developed. The control circuitry of a few other power supplies had to be modified to match the Allen Bradley signal levels. On the software side, the C-Toolkit allowed straightforward work-arounds in the few cases where we encountered difficulties, such as inadequacies in the ControlView expression syntax and in the macro processor. The low Data Highway speed and database update rates created problems for diagnostic probe scans which were solved by data buffering in PLC memory and slightly delayed readout carried out by a C-Toolkit task.

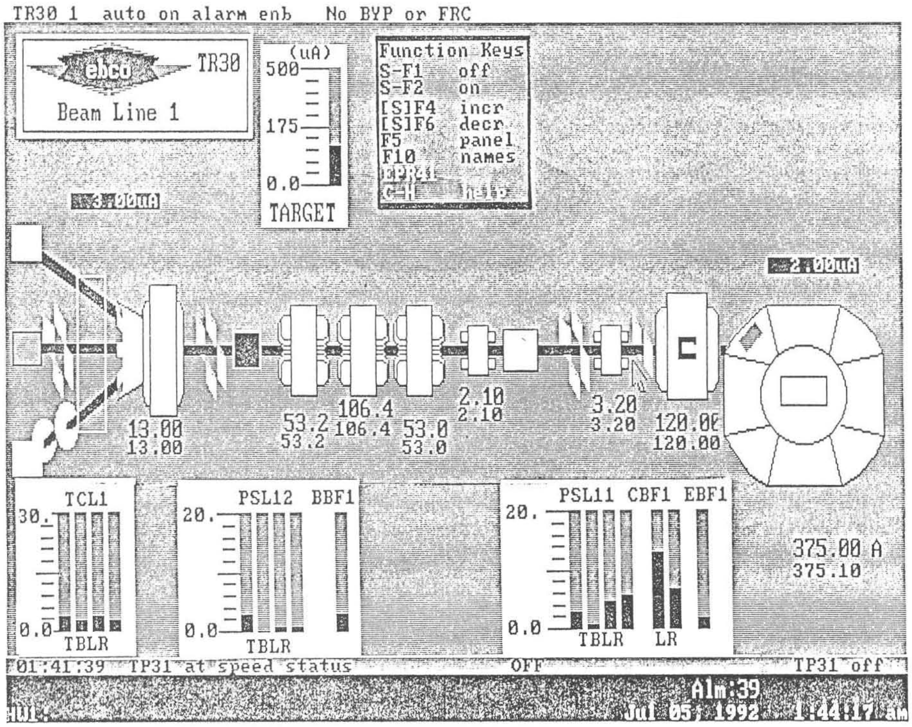

Figure 3. Example of a beam line sub-section page

Although the restriction to EGA resolution in the graphics displays is of mainly aestetic importance, it should be corrected in a future ControlView release.

4. Summary

In summary, the decision to build the TR30 control system based on a PLC and commercial software proved to be very successful. The control system was built on schedule and on budget. An unusually low ratio between overall software and hardware cost was achieved without loss of functionality. This was mainly due to the high "entry level" which both the ControlView and Ladder Logistics packages provide for the system designer. Since the initial commissioning of the system several functionality upgrades have increased the amount spent on software and pushed the ratio from 1:3 closer to 1:2. Figure 4 shows a break-down of the control system costs.

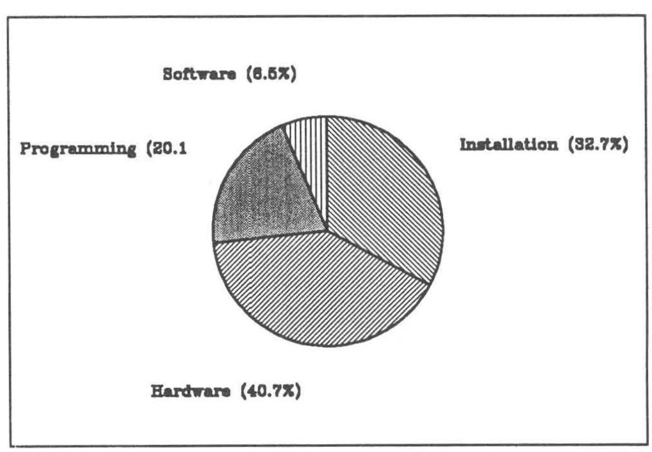

Figure 4. Control system cost breakdown

5. Acknowledgements

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6. REFERENCES

1) "Process Monitoring and Control Software Listings", Control Engineering, **Vol.39 No.3**, 16 (1992).