The Slow Control System of the Muon g-2 Experiment

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Abstract

The muon g-2 experiment (AGS E-821) will measure $a_\mu = \frac{1}{2}(g-2)$, the anomalous magnetic dipole moment of the muon, in the world's largest superconducting solenoidal magnet. Since the magnet stores the muons during their lifetime, running the experiment is similar to running an accelerator, though on a much smaller scale and with fewer timing requirements. The slow control system for the experiment will provide real-time monitoring of the experimental parameters by means of industrial subsystems; commercial products comprise both the hardware and its interface. The industrial basis of the control sytem makes it quite easy to install, and provides a simple way of implementing rudimentary controls for most of the variables. Two independent networks isolate critical control functions from bookkeeping functions, yet still provide a degree of redundancy. Since commercial products form the bulk of the slow control software, there is a minimal programming requirement for tool development.

I. Introduction

Experiment 821 at the AGS will measure g-2 of the muon by storing a bunch of them in a magnetic field until they all decay. The magnetic field is a continuous circular dipole field, formed by four superconducting coils embedded in an iron yoke. The muons circulate in the magnetic field, but their decay electrons escape to smaller radii, entering calorimeters spaced radially about the inner circumference of the magnet. The muon precession frequency appears as a modulation of the decay electron spectrum. This implies that the data from the experiment is not a series of events, but rather the modulation impressed upon the energies of thousands of decay electrons. Running an experiment in this fashion almost approximates the running of a tiny accelerator with continuous extraction. There are a few differences, there is no extraction to external beamlines, there is no longitudinal acceleration (the relativistic γ of the muon is constant at a value known as the *magic* γ, to free the measurement from the effects of electrostatic focusing quadrupoles). Thus, there are no rf cavities or ramping magnetic fields. There is, though, weak electrostatic focusing with quadrupole electrodes embedded in the vacuum chamber. Since the experiment looks quite like an accelerator, there is a need for a more automatic presentation of device status, and a more central initiation of control signals, than is usually the case in a beam line. These requirements imply that the data acquisition systems for the hardware status, and the software for display, be fully integrated at the planning stages, rather than separately matched. An efficient way to take advantage of an integrated approach is to buy commercial plant-floor type monitors and their associated software packages. These customize easily to various industrial applications, and they seem to be applicable to the muon storage ring as well, even though it is not quite like a plant floor.

There are architectural considerations in an experiment that one would not confront in industrial applications. These differences make the g-2 control system not quite a plug and play toy, but careful consideration of how various ring subsystems interact should make the continuous operation of the ring fairly painless. The main idea in this architecture is that all hardware subsystems operate in a high-priority, local control loop, but talk to the slow control system when they can. The slow control system then logs status information or trouble reports. The local control loops also have priority over control signals sent down to them from the slow control system. This is to prevent the human operator of a system from helplessly losing control to the slow control system.

At the level of the actual hardware, the slow control system will communicate to modular industrial controllers. These controllers are microcomputers, generally configured to operate scanning analog to digital converters or standard industrial signal conditioners. They exist as self-sufficient processors, and have the ability to run the local control functions easily. The ones that E-821 will use will be Allen-Bradley[1] PLC's (Programmable Local Controller's). They are nearly ubiquitous in plant floor environments, and they have sufficient communications ability to fulfill the reporting requirements for the slow control system. The newest versions also allow ethernet connections, which simplifies their integration into the existing BNL network.

The whole control system will use an ethernet network to communicate among its parts, and to communicate at a higher level to the data acquisition host. It will also have a hidden network strictly for automatic control purposes and free of any monitoring responsibilities. X-terminals will be the primary interface to humans. They will be running graphical applications strictly for control purposes.

II. The Local Controller Hardware

The controllers for the muon g-2 experiment will be Allen-Bradley PLC-5/E industrial controllers. These controllers have a small complement of memory with a battery backup, some communications ports, the ability to scan several hundred to several thousand input or output circuits, and options for EEPROM program backup. Basically, they are scanners that read to or write from a bank of circuits. Separate modules determine the identity of these circuits, and the types of signals they process. The controller simply reads channels and stores them in its memory. It then provides the channel information to a display, which can be just a screen with a display of status indicators, or a highly integrated front end of a control system.

The communications channels that the controllers use come in three types, two quite useful and one less so. There is the proprietary Data Highway, which connects all the PLC's, and which has a reasonably high capacity. There is an ethernet link,

*Work performed under the auspices of the U.S. Dept of Energy, Contract No. DE-AC02-76CH00016.

which exists independently of the Data Highway, and has about twenty times its transmission capacity. And finally, there is an RS-232 port, useful as a debugging tool, on each PLC.

The controller has all the characteristics of a small, dedicated computer. There is some data handling ability, interrupt capability, status flags, and the ability to run multiple control programs. Their use in E-821 will be to run local control loops for the major subsystems, and to pass news reports back up to the slow control host computer.

The controllers themselves do not have the ability to process raw input signals from various devices. Specialized input modules will handle these tasks. As an example, the controls for the liquid helium refrigerator require temperature readings from junction sensors. A specialized module linearizes and buffers these junction signals before passing them on to the processor, which likes to see only well-conditioned, standard industrial inputs (*e.g.* 20 ma. loop signals). Other electronic front ends perform similar conditioning in their respective environments.

This separated function design of the electronics also minimizes confusion in the field wiring to the processors. All wiring from the front end modules to the processors is on terminal strips, and is identical with respect to wire type and termination. The specialized input wiring we will segregate by function onto the appropriate electronics. This input bundling is easier to maintain and repair than just running wires in sequential channel order, heedless of their functions.

III. The Network

Devices and computers in the muon g-2 experiment will communicate with each other via an ethernet network. The PLC-5/E controllers have an internal ethernet interface, requiring, however, an external transceiver. Allen-Bradley software, running on the data acquisition/slow control host computer, will handle the communications between controller and the ethernet. This network should handle easily the data transmissions from ring subsystems and file transfers from the DAQ host.

In addition to the ethernet connections, the PLC's will communicate with each other via the proprietary Allen-Bradley Data Highway (actually, Data Highway+, or DH+), a custom network for their PLC interconnections. This second "shadow network" increases the slow control reliability by isolating the important control loops at the major subsystem level from the pure news-gathering functions of the ethernet. The Data Highway provides a way for automatic controls to function separately from the slow control system, though one could also activate devices through slow control, with the approprate priority and privileges. Since the two networks share nothing, failure of the slow control system or the ethernet does not compromise the operation of the ring subsystems.

The Data Highway transmission rate is 57.6 kbaud, in contrast to the much faster ethernet rate of 10 Mbits/sec. However, the Data Highway carries much less in the way of actual data than the ethernet. The Data Highway interconnection is responsible for carrying the control signals, global flags, and small blocks of data among the PLC's. The detailed description of these transmissions among the PLC's is actually imbedded in the design of the subsystem control loops, which I will describe later. This "hidden" network remains invisible to the ethernet network, so the ethernet must also carry some of the same information. This redundancy is fortuitous, increasing the reliability of the transmissions at no cost, since E-821 requires the ethernet and Allen-Bradley supplies the Data Highway as standard equipment.

IV. The General Architecture

The basic idea of a slow control system is to provide a monitor on the g-2 ring function. It should allow the free transfer of data from ring subsystems, unencumbering the extant automatic controls. These automatic controls and their self-linkages are not properly in the realm of the slow control system. However, there is a connection between automatic and slow control systems. It's probably best to describe the entire ring heirarchically, from the controller, at the base, to the slow control monitor, at the apex.

At the level of the hardware inputs, the PLC controllers share automatic control among themselves on the Data Highway, and they pass news reports up to the slow control host on the ethernet. Note that the only common point between the two networks is at the PLC. From there on, the networks separate permanently. The ethernet network includes the DAQ/slow control computer host, an HP9000.

The host computer runs the proprietary Allen-Bradley Interchange software, which allows the host to communicate directly to the PLC's over the ethernet. At this point, the slow control system has gotten access to data and/or news reports from the controllers. It is a collection of "unedited" data packages from the controllers. At this level, FactoryLink, a comercial software suite, takes over. FactoryLink integrates these reports graphically and stores the raw data in a proprietary database. The host computer monitor will display a picture or schematic of some subsystem, and variables or parameters that are changing will appear in graphical form. For example, the helium level in the cryostat would appear on the screen, if that screen were selected. The cryostat, filled with helium, would appear as part of a cartoon illustrating the refrigeration system.

The central tenet of the slow control system is that it monitor and control the E-821 subsystems without disrupting the local control or feedback of that subsystem. To achieve this non-interference, it is necessary to assign priorities to any operations which may affect the running of a particular subsystem. A local process, for instance, a power supply, has inherent feedback control, and may have setpoints and software controls, as well. These *Local Loops* have the highest priority, being interruptible only under conditions set forth by their designer. Next higher in priority are *Triggers* which represents a way that the slow control operator (*i.e.* an E-821 "Control Room" operator) could trigger a switch to control a device, or process. As a garish example, there could exist a "Crash" button, which would activate an energy dump from the magnet. Since these priorities are lower than the local loop priorities, the triggers are easy to disable intentionally at the hardware level.

At the lowest priority is the passing of reports up to the operator console, which displays them. The requirement here is for an update rate of perhaps once per second for preformatted reports. This should be slow enough that the PLC's have no problem keeping up with requests from the slow control system, even though they are executing their own set of instructions in the local loops. FactoryLink handles the initiation of requests and processes the replies from the PLC's. No request for news ever slows down the automatic control system, since these requests are both of the lowest priority, and are travelling on the ethernet, not the Data Highway. The only mechanism for slowing any control functions will the processing of requests by the PLC's, or the operation of triggers. If the news report from the PLC exists in a predetermined format, of constant length, the delay caused by its transmission becomes a bookkeeping problem. This just means that it becomes part of the local loop, simply another task for the PLC.

V. FactoryLink

FactoryLink is a product of USData Corp.[2] . It is an industrial plant-floor monitoring system made up of several software modules. Not all of the modules are necessary in any particular application, and, in fact, the g-2 experiment uses a subset of the full suite. FactoryLink, running on the host, gathers information from the PLC's and displays it in several ways. The primary mode is animation, whereby cartoon representations of subsytems respond to underlying tag values, which themselves are simply the readback signals from the hardware. A simple form of animation is a thermometer, for example, whose "mercury" rises and falls with the readback from a given thermocouple. FactoryLink also provides canned versions of strip chart recorders, linear scales, and color or gray-scale displays. There is a drawing tool for generating the screens that become animate, and a run manager that operates the screens once they are drawn.

FactoryLink also provides a database which is, in fact, central to its operation. This database is proprietary, though they do provide tools for accession and storage in standard formats (*e.g.*Sybase, dBaseIV, etc.).

References

[1] Allen-Bradley, 100 Crossways Park West-Suite 202, Woodbury, NY 11797.

[2] FactoryLink, USDATA Corporation, Industrial Products Division, 138 River Road, Andover, MA