SELVA Winder Machine Controls Upgrade Proposal

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Rev. 1.0
April 29, 2011

Executive Summary

This document is in response to a request from Giorgio Apollinari on March 25, 2011 to investigate the possibility of devoting T&I Department resources to support the refurbishment of the SELVA winder machine and bring it to ORC in the next 7 to 8 months.

Having this machine operational is on the critical path for the Division magnet programs in FY12, in particular for the fabrication Nb3Sn Dipole prototype for the LHC upgrade.

According to the machine final "customer", Fred Nobrega, the machine is needed to wind Nb3Sn dipole prototypes by February 2012. At the moment the machine is setup to wind long LHC quadrupoles, and the state of the program and very old electronics is unknown. Modifying the program to wind dipoles or any other new magnet is expected to be a very difficult and labor-intensive task, as there are no local experts that can do it. The last time the machine was modified for winding LHC quadrupoles, experts from the machine manufacturer in Italy had to be brought in to reprogram the machine over the course of weeks. Moreover, the very old Allen-Bradley Computer Numerical Controlled (CNC) system is obsolete and can fail at any time.

It is therefore critical to upgrade the old electronics and software to make it easier and more reliable to wind new magnet types with this machine.

Andrzej Makulski has developed a proposal to upgrade the SELVA winder machine controls. This proposal has been reviewed by Ruben Carcagno, Darryl Orris and Jerzy Nogiec from the T&I Department, and then by Fred Nobrega and Luciano Elementi from the MSD Department. The approach outlined in this proposal has been endorsed by everyone, and it is expected to provide a much more flexible, reliable, and easy to use system for winding magnets with the SELVA machine.

The effort has been divided into four phases, each with a clear deliverable, to assure the basic functionality for winding a magnet is ready by February 2012 and still have "hooks" for adding automation layers later.

<u>The estimated direct M&S cost for this upgrade is ~ $30K. The labor to bring the machine to minimum required functionality by February 2012 is ~1.7 FTEs. An additional 1.2 FTEs would be required to add automation layers beyond February 2012</u>.

Control Architecture Proposal

We propose to preserve all machine control devices (motors, encoders, switches, sensors, etc) as well as motor drive electronics, but replace all electronics and computers associated with the old Allen-Bradley CNC system. In addition, we propose to provide a wireless "joystick" type of device for the operator to manually control the system while standing next to the magnet being wound.

Preserving machine control devices and motor drive electronics would substantially reduce the cost and labor of this upgrade. The risk is not too high, because we can purchase an identical (still commercially available) servo motor amplifier spare and for most other control devices (encoders, brakes, switches, transducers) there are commercial alternatives if they were to fail. Approximately 180 signals are required to interface machine control devices to the new control system.

The highest risk is the 20 years old PC AT (80286 processor) computer and associated electronics. Some modules are very difficult to obtain, even used. Logic circuits are often based on CPLD (programmable chips) technology. They are almost impossible to repair without firmware. Because of these reasons, the machine downtime due to electronics failure is unpredictable. Programming this system is very complex and requires expertise not available at Fermilab.

Therefore, we propose to completely replace this layer of obsolete electronics and complex software by a modern solution based on National Instruments CompactRIO system with distributed Input/Output over EtherCAT. This is a high-performance real-time distributed control system in a rugged hardware platform. It includes field-programmable gate array (FPGA) processors for very fast and reliable real-time control and interlocks, and a processor running a Real-time operating system (VxWorks). A wide variety of rugged high-performance I/O modules is available for this architecture, which is easily expandable by adding more slave chassis. This system can be programmed by high-level Labview software. Unlike the old SELVA machine CNC system, the expertise to program and maintain the proposed upgrade system is widely available in the T&I Department and elsewhere at Fermilab.

Figure 1: proposed architecture for the SELVA machine controls upgrade

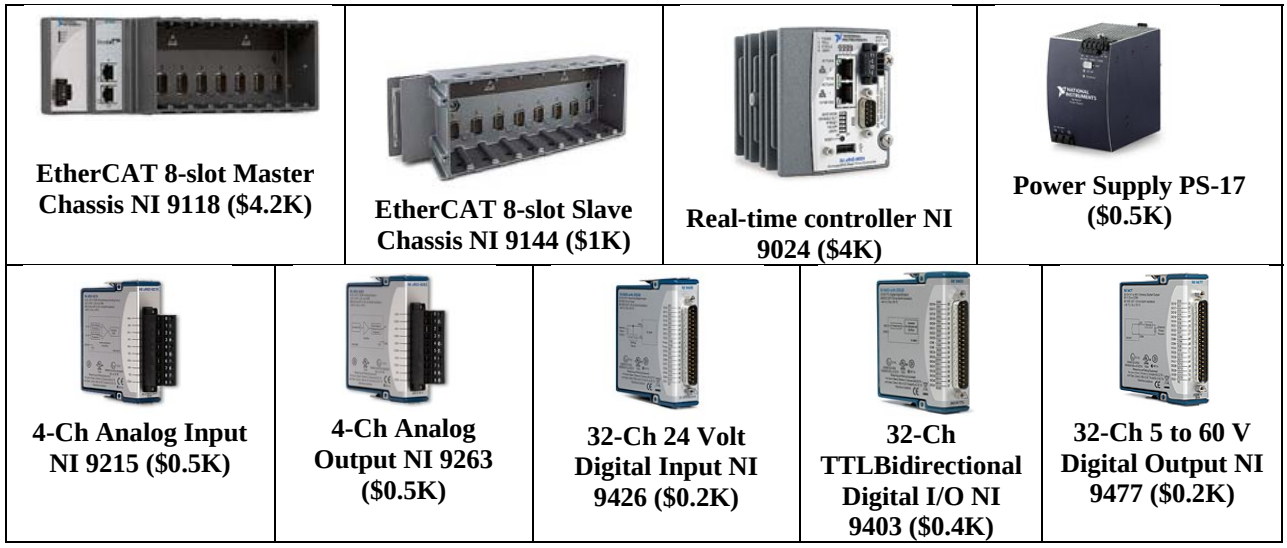

Figure 2: components for the SELVA machine controls upgrade

The NI CompactRIO system has to be interfaced to the ~ 180 machine control device signals. To accomplish this interface, a custom-built electrical box will be needed. The box consists of signal conditioners, optical isolators, and logic level translators. The estimated cost is $5K, plus another $1K for miscellaneous cables and connectors.

Finally, for operator interface to the control system we propose a new wireless remote control transmitter equipped with custom-built joysticks, switches, and buttons. An example of such solution is provided by Kar-Tech

Figure 3: Radio control devices

These radio controls for industrial applications can be ordered with custom control options (E-Stop, dual axis joysticks, paddles, potentiometers, pushbuttons, toggle switches, thumb wheels,

LCD displays, etc). They come with shoulder straps, are made of high impact plastic, and include a battery that provides more than 20 hours of continuous operation with 1 hour fully charge. The operating range is approximately 1,000 feet.

The receiver can handle up to 36 inputs (analog/digital) and 36 outputs (analog/digital). The outputs are a configurable combination of current regulated proportional, PWM, on/off, or other types on request; the inputs are a configurable combination of analog, digital, timer/frequency, quadrature, or other types on request. The radio control can be programmed using LabView software.

With this powerful remotely operated transmitter, the operator can stand next to the coil being wound and easily activate the desired motion.

Project Execution Proposal

We proposed to conduct the execution of this project in 4 phases with clear deliverables associated with each phase. The description of each phase follows:

Phase 1: Demonstrate operation of all motions

The objective of this phase is to demonstrate the capability to read all signals and control all motion axes from the Graphical User Interface and from the Radio Control. This phase will require machine interface reverse engineering, electrical interface box design and fabrication, generate electrical schematics, cabling and wiring, procure and set up the CompactRIO electronics, and basic programming to move motors, acquire signals, and displays.

Phase 2: Support for manual winding

The objective of this phase is to provide the basic functionality to manually wind a coil. **After this phase is complete, it should be possible to manually wind a prototype Nb3Sn LHC dipole coil**. This phase will require additional programming to provide basic SELVA winding machine functions, such as automatically keeping the proper cable tension and elevation and synchronizing mandrel angle and elevation with cable feeder motion. Interlocks to prevent materials or equipment damage should also be programmed in this phase. **This phase must be completed by February 2012**. Completion of Phase 2 on schedule will be a major objective of this project.

Phase 3: Add machine learning mode

The objective of this phase is to add the capability to operate the machine mode in “learn” mode; where manual actions can be recorded by the system and then “played back” with pause and resume options. This capability will help when there is a series of coils to be wound with the machine.

Phase 4: Semi-automatic mode

The objective of this phase is to add semi-automation functions such as automatic mandrel adjustments when the cable feeder travels around the poles. Tentatively, we could also consider embedding a model which given mandrel, coil, and cable parameters it could calculate the proper motion trajectory and automatically program the system to follow that trajectory. This concept can be refined as more experience is gained with operating the machine with the new system, or a different automation idea may develop. The new control system will be powerful enough to be able to accommodate very sophisticated automation strategies, if such ideas exist and would be of benefit to the magnet programs.

Project M&S Estimate

	Unit Price ($K)	Qty	Total ($K)
Master Chassis	4.2	1	4.2
Slave Chassis	1	2	2
Controller	4	1	4
Power Supply	1	1	1
4-Ch Analog Input	0.5	3	1.5
4-Ch Analog Output	0.5	3	1.5
32-Ch Digital Input	0.2	5	1
32-Ch TTL I/O	0.4	2	0.8
32-Ch Digital Output	0.2	5	1
Radio Control Transmitter	3	1	3
Radio Control Receiver	2	1	2
Interface Box	5	1	5
Cables	1	1	1
TOTAL			**28**

Project Labor Estimate

	Labor (man-months)	
Phase 1	4	Engineering, prototyping, testing
	4	Interface box Fabrication, cabling, wiring
	6	Software development and testing
Phase 2	6	Software development and testing
Phase 3	3	Software development and testing
Phase 4	12	Software development and testing
TOTAL	**35**	
FTEs	**2.9**	

<u>Note that between now and February 2012 (completion of Phase 2), the project is expected to require 20 man-months or 1.7 FTEs to be allocated.</u> This is non-trivial amount of effort for the T&I Department to absorb, and it would have to be carefully coordinated and balanced with many other competing activities.