EXPERIENCES WITH MOTION CONTROL SYSTEMS AT THE CANADIAN LIGHT SOURCE

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Abstract

Devices requiring a motion control system are ubiquitous at a Synchrotron. At the Canadian Light Source (CLS), the highest density and most demanding are devices associated with beamlines. The requirements vary from the simple operation of slits to the more complex and unique end stations. To tackle the diverse requirements we have developed a framework for motion control with a general interface, but standardized on commercial components.

SYSTEM OVERVIEW

Software

EPICS is the standard control system at the CLS and is used for most control and data acquisition needs. It consists of a network of IOCs that are connected directly to devices, in this case motor controllers. The Channel Access protocol is used to read or write to any PV in the network.

The software is used to control approximately 480 stepper motors. EPICS devices drivers have been locally written for each type of motor card in use. The driver encapsulates standard to complex motion control functionality and interfaces to the controller. Encoder and step position can be read at ~ 100 Hz if necessary. Functions that are implemented in the driver also include but are not limited to:

- Closed loop control
- Brake activation
- Backlash correction
- Calibration routines
- Motion profiling
- Homing routines

The device drivers provide a common abstraction of the underlying hardware and map these capabilities into a common set of process variables (regardless of the underlying controller card). From the higher level software viewpoint all of the different types of motors appear identical

Legacy Driver/Controller

CLS initially standardized on an in-house developed stepper motor driver and controller. The drivers were capable of delivering 0.2A to 3A in 0.2A steps and could reach 125 microsteps/full-step. Each motor winding was controlled by a bipolar, chopped, constant current driver. The design accommodated a brake output, relative encoders, and limit switches. The controller was designed for fixed velocity and acceleration but could be modified by changing the ratio of microsteps/full-steps.

Present Design

As requirements changed it was decided to standardize on the OMS Pro-dex VME58 controller and later upgraded to the MaxV VME64-X [1]. They are typically installed in a Weiner VME64 crate [2]. Communication with the crate and the EPICS IOC is furnished by a SIS3100 VME to PCI [3] card over a GBit fibre optic connection.

The controllers are capable of controlling both servos and steppers and may run in open or closed loop, but until recently have been limited to relative encoders. Each card allows for independent or synchronized operation of 8 motor channels.

Figure 1: Control card and break out board.

The motor channels on a MaxV have their signals routed to a corresponding breakout card (see Fig 1.) at the rear of the crate. RJ45 connectors with CAT5 cabling, chosen for their low cost and ease of assembly, distribute the signals to the motion systems. Limit switch and motor enable LEDs, incorporated into the break out board, have proven invaluable during commissioning of a system.

The Cat5 cables terminate at a CLS designed interface box (see Fig 2). The interface is a PCB that has pins for probing and jumpering of signals. All customization is done at this point. Step, direction, and enable signals are passed straight through to the motor driver but encoder and limit switch signals are routed on-board. It is setup to be easily accessible to the designer to probe control

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signals, to change direction and phasing, and avoid time consuming rewiring during commissioning.

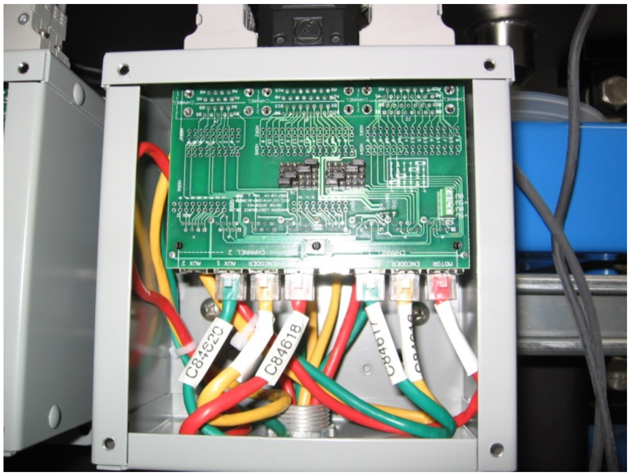

Figure 2: CLS motor control interface board.

After the interface box the control signals are terminated on a motor driver sized for the particular motion system. The distance between the driver and the controller can be quite long as the control signals are low voltage and the Cat5 is twisted pair cable. The maximum length is limited by the communication rate/protocol of the encoders. We opt to install the motor drivers close to the motion system to reduce the EMI generated by high voltage switching signals. CLS has standardized on commercial stepper and servo drivers from Parker Automation [4] but in the case of turn-key systems or special applications we have easily accommodated drivers from a variety of other sources. The wiring between the motor and its respective driver consists of standardized cables and connectors for ease of assembly and reduced cost.

Position Feedback

The control system supports relative encoders with quadrature output from mechanical length gauges, laser interferometers, mechanical slides etc... Absolute encoders have support for EnDat 2.1 protocol with optical rulers and absolute angular encoders. In a few cases there are analog signals from potentiometers are used.

In the case of the EnDat 2.1 protocol the encoder feedback is routed to MMI200-PC104 (24MHz) Interface board [5] that is mounted onto a PC-104 to VME Interface card and installed in the VME64 crate with their respective MaxV control card.

INSTRUMENT PROTECTION

Two different levels of instrument protection are supported based on the user assessment of component cost and downtime. Instruments that are low cost and easily replaced, such as a slit motor, have minimal protection whereas a protein crystallography image detector has a high cost and long lead time and therefore more protection is required. If the mechanical design permits, a more complex scheme may be used.

Redundant Protection on Beamline Optics

Often, in beamlines, optical elements have mirrors or gratings operating in physical proximity to each other (monochromaters, parallel displacement optics, KB mirror systems, shared mirror tanks, etc…) and risk a mutual clash or an independent crash. To prevent such events we use the following devices:

- Micron sensitivity limit switches
- Primary and secondary limit switches
- Relative and absolute encoders
- Hard stops

Example of Potential System Failure & Solution

Systems that are high risk may use a secondary protection scheme. Recently, stepper motors, mistakenly rated for 2A by the vendor, were installed in a parallel beam displacement optical system. During commissioning the motors were being driven at 2A but were in fact rated for 4A. In full-step mode a motor went through a third order resonance [6] and was driven at a high velocity in the direction opposite to the command direction. The limit switches, by design, were step direction dependent and by this convention do not activate if the stage motion is opposite to the stage command direction. Although, a clash did not occur, the potential for a clash was possible.

The issue was resolved by the introduction of low cost potentiometers and interlocked limit switches. The potentiometers serve as course absolute encoders with respect to the high precision incremental encoders. The analog signal from the potentiometer is input to a PLC that is independent of the MaxV controller. The PLC calculates the position, velocity, and direction, based on the voltage to position calibration and its rate of change. They have the advantage in that they do not lose their position information in the event of power loss. The limit switches are in an AND configuration and the PLC output drives a 24 V relay that cuts the power to one or more stepper motors (see Fig 3). Once tripped must be reset manually. This mode of operation exchanges convenience for safety but we assume that the limit switches are rarely activated and outside of commissioning or beamline calibration.

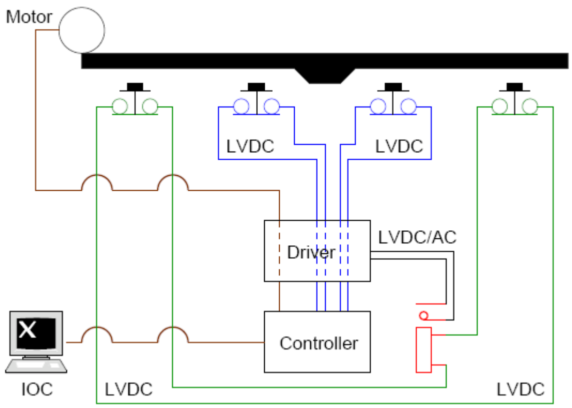

Figure 3: Independent limit switch scheme.

Unintentional direction changes are also possible in closed loop systems if there is a misalignment of an encoder read head on an optical scale. The misalignment can cause the phases of encoder read out to be reversed and force the stage to move in the opposite direction.

In the case of in-vacuum stages in end-stations and mirrors tanks there is the possibility for motor failure due to over-heating. Causes of over-heating can come from driving the motor outside of electrical specification or a failed control process that drives the stage against a physical stop that is outside its range of motion. Replacement of the motor can result in unacceptable downtime for a beamline. The motors can be monitored by a temperature sensor (ie RTD) and monitored by a PLC. If an over-temperature limit is reached the PLC can drive a relay that cuts power to the motors.

Example of Mirror Mount Motion Protection

Recently, the CLS Far-IR beamline upgraded the mechanics and motion control of its optical mirror mounts. The system is a 3-axis kinematic system which changes mirror pitch, yaw, and translation (see Fig 4). Mirror motion is adjusted in 0.5 um steps over a range of +/- 6000 um. The motors used are Haydon 43000 series linear actuators 2 phase stepper motors rated for 5V at 0.7A. Each motor has an RTD glued to its surface to act as a temperature interlock sensor for overheating. The RTDs are routed to a PLC that reads the temperatures. If one or more motors reaches an over temperature limit the PLC applies 24V to a relay that cuts the power to all motors on that mirror. The stepper motor drivers are Parker OFS350-DRI single axis stepper motor drivers controlled by a MAXV card. The encoders Heidenhain ST3000 and ST1200 length gauges, with 0.5 um resolution, to measure the position of the axes.

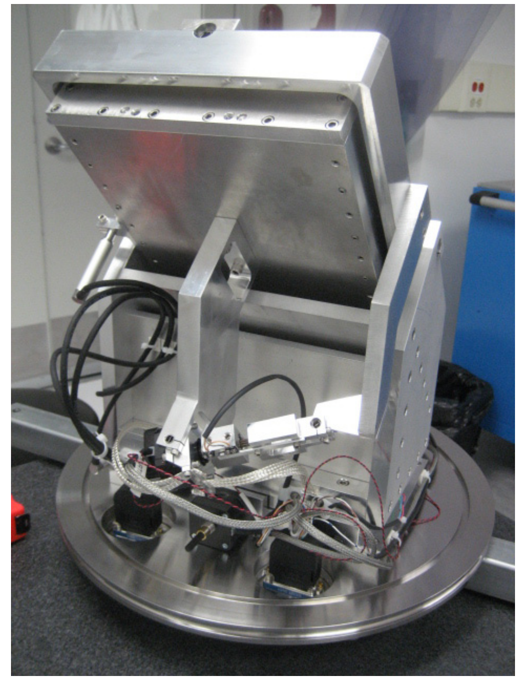

Figure 4: Far-IR mirror mount with motors.

REFERENCES

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[6] M. Bodson, J.S. Sato, S. R. Silver, “Spontaneous Speed Reversals in Stepper Motors”, IEEE Transactions On Control Systems Technology, Vol. 14, No. 2, March 2006.