CUSTOMIZABLE MOTION CONTROL SOLUTION SUPPORTING LARGE DISTANCES

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Abstract

Motion control solutions for controlling a movement of motorized mechanical subsystems for accelerators, telescopes or similar spatially distributed systems require high degree of flexibility regarding the use and connectivity. One platform should fit different applications and provide cost effective solutions. A connection to the control system (CS) is required on one side, while on the other side a connection to a variety of motors, position encoders and other feedback devices must be provided. In case of more complex mechanics, an advanced kinematics control is essential to provide features such as motion tuning, interpolation and controlled acceleration. An embedded computer is used for SW-flexibility and CS-support. Motion control capabilities are provided by separate HW; programmable multi axis controller. Signal adaptation for a direct connection of the equipment is managed by an interface board. Easy installation and debugging is provided by low-level local control; front panel switches and indicators, RS232 or direct keyboard and monitor access. An advanced approach is required in case of a larger distance between the motor controller and the motors with position encoders.

INTRODUCTION

Every accelerator facility features several hundreds motion mechanical systems that need to be precisely moved in/out or along the path of the beam. These are ranging from straightforward single-axis devices (e.g. slits), extending over more complex devices requiring parallel movement (e.g. septum, undulators) to fairly complex multi-axis systems like hexapods.

Different motors must be utilized to suite the motion dynamics and torque requirements; different types, sizes and phases (e.g. servos, steppers, brushless, etc.). Besides just controlling motors, special care must be taken for protecting the mechanics and system; this requires the use of limit switches, inclinometers, interlock signals, etc. To have trustworthy control over the position of the mechanics, additional position read-back systems are employed; either incremental or absolute or combination of both. Motion control system must be capable of reading them.

Last but not least, the motion control system should be flexible enough to provide flexible control system integration and for debugging-purposes independent standalone operation.

To lower the development and commissioning effort for a newly constructed insertion device, a scalable and robust motion control platform addressing all previous aspects is required.

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MOTION CONTROLLER REQUIREMENTS AT GSI

At the GSI the mechanics is moved using 5-phase stepper motors that connect to drive spindle using drive belt with system-dependant transmission ratio. Mechanics to be moved is fixated to drive spindle that has a position increment of 5mm/rev. Most of the systems is equipped with inner on outer limit switch and, where applicable, with touching switch (i.e. in the case of opposite moving mechanics).

GSI is accelerator for heavy ions [1]; all the equipment used inside the tunnel must be resistant to heavy ion radiation. Although there are places that are partially shielded from radiation, only robust electronics can be placed inside the tunnel. For the position feedback the sliding potentiometers have proven to be robust enough to survive in such radiation intensive area. Additionally, tunnel construction requires that maximum distance between motion controller and motors can be extended up to 250 m.

Some of the systems feature multi-axes motion, which could be driven in such a way that could cause mechanics of different axes to crash into each-other. These systems require interlock scheme where the movement of particular axis is allowed only when the others axes are out of the way, i.e. parked in its home position.

Injection septum control

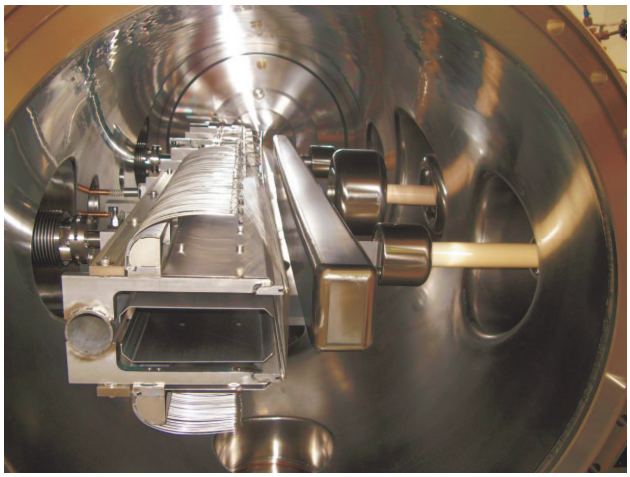

Figure 1: Electrostatic injection septum as seen from inside. Anode and cathode plate are being moved towards each other by the means of two parallel spindles per plate (plate holders extensions). Plates must be moved parallel and must never touch.

GSI and Cosylab have decided to jointly address the requirements for this motion control project for the control of the electrostatic injection septum. GSI provided the know-how of their already existing systems and Cosylab provided expertise in motion controllers and control system integration.

SYSTEM OVERVIEW

Figure 2 presents a quick *layered* overview of a motion control solution, sliced in layers from the stepper motors to the support for the CS integration.

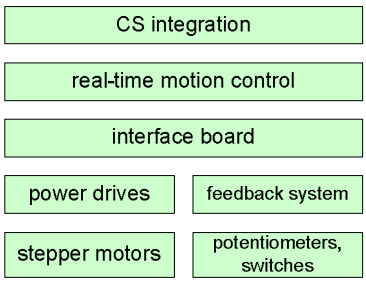

Figure 2: Motion control overview.

Figure 3 depicts hardware and software layers based on their physical existence. microIOC integrates single board computer (SBC), programmable multi-axes controller (PMAC), PMAC interface board, RS-485 serial interface, and LCD/LEDs. microIOC extension box (mEB) integrates parts that must be close to the mechanics: stepper-motor drives, analogue voltage acquisition module and input/output module.

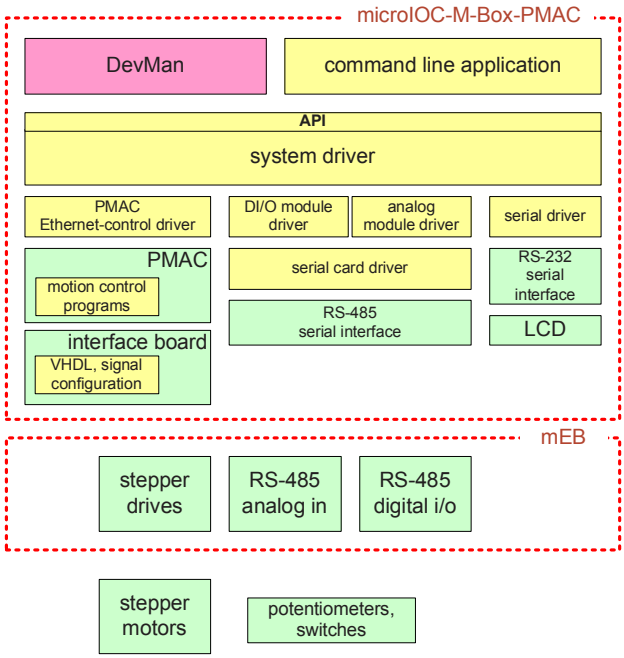

Figure 3: The entire solution is split into two boxes; the controller and power part. The former is placed outside of the tunnel the latter is placed inside. The distance between them is up to 250 m.

Integration into the control system

Starting from the top, the support for the control system integration is provided using microIOC platform [2]. This platform is based around SBC, especially designed for use in stressed and rough environments. It provides the complete functionality of the personal computer, but sized down to the quarter of letter-paper size.

microIOC runs Linux operating system, Debian distribution, which is booted from the compact flash card. This represents a host platform for a system-driver, providing communication to PMAC and position feedback system. On top of this device manager was developed – as a server application – providing device a CS access. In parallel to device manager a low-level command line application was written that provides direct low-level control. This is useful for testing and debugging purposes and can be employed by either connecting to microIOC through SSH connection or by simply attaching VGA monitor and keyboard.

SBC is equipped with two Ethernet connections; one is used for CS connection and the other is used for configuring and controlling PMAC.

Real-time motion control

The core of the motion control is based on the independently running DSP-based Delta Tau's PMAC [3]. PMAC is highly versatile motion controller providing synchronous control of up to 8 axes. Each axis can have defined its acceleration and deceleration curve, maximum speed, limit switches, etc. It can handle reverse kinematics motion, multiple coordinate transformations and much more. PMAC handles motion control by executing motion control programs that are downloaded and permanently stored in its memory. Configuration download and runtime control is done over Ethernet (from SBC). PMAC is responsible solely for executing motion programs, requested by SBC. CS integration is handled by SBC, thus providing failure-safe standalone motion control.

Interface board

PMAC provides standard pulse-and-direction 5 V interface for stepper drive and limit switches inputs. Incompatibilities arise when different types of motor drives are used. In some cases this is just the matter of signal polarity (e.g. amplifier enable vs. winding off signal) and could be easily solved using simple additional logic. Some other times additionally required signals can not so be easily generated (e.g. handling brake signal if it is not supported by stepper driver itself).

This is the reason that drove as to the decision to use a programmable circuitry, Xilinx CPLD [4], that provides easy signal-path reconfiguration, suited to particular use case example. Based on the experiences we have with different use-case scenarios we decided to map specific PMAC signals through CPLD. This provides a very important input/output extension, greatly complementing advanced motion control features of the PMAC. We

added per-axis custom input/outputs that are memory mapped into PMAC's extension port. This way we can easily provide signals for controlling a stepper-motor brake or any other interlock signals, change the polarity of particular signals or add additional HW protection layer.

Taking into account noisy operating condition inside the tunnel the signals coming out of- and going into PMAC must have its voltage level shifted to provide noise immune communication. To protect the electronics itself we added an optical isolation of all the output/input signals from/to PMAC.

Feedback system

Mechanics for the septum control can return two types of position feedback; analogue voltage from sliding potentiometers, relating to position, and digital signals from end limit switches.

Normally, limit switches should not be used; their function is to protect the mechanics being moved outside of the allowable range. Limit switches are of type fail-safe, i.e. closed contact is required for normal operation – if for example cable gets disconnected this causes an erroneous condition and the movement is prohibited. However, in the case of a septum control there is peculiarity that moving septum plates into the path of the beam must not rely on the inner limit switches as anode and cathode could come into contact. This has to be handled in software.

Position feedback is obtained using sliding potentiometer. It is mounted along the spindle, having its middle contact attached to the mechanics being moved. If constant voltage is applied to potentiometer end contacts, middle tap voltage readout is proportional to the position. Support for long distances required we installed analogue to digital conversion (ADC) module closer to the mechanics, inside of the tunnel. We have chosen 16-bit standalone ADC module I-7017 with serial interface [5]. ADC module and microIOC communicate using robust RS-485 communication. As a precaution for noisy environment microIOC provides optically isolated RS-485 port.

This kind of position feedback enables open-loop position control. I.e. the mechanics is first moved for the desired number of steps and after that the potentiometer voltage can be read out to check if the desired position was reached. When calibrating the mechanics the visual feedback of the system is first required to compensate misalignments of potentiometers and spindles.

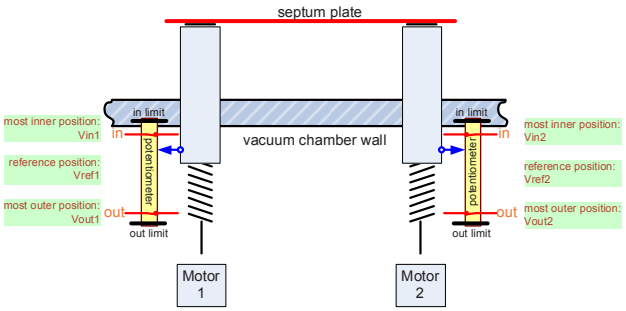

Figure 4: Schematic overview for half of the septum.

Power part – mEB

As already mentioned, the distance requires the solution to be split into two boxes – microIOC is placed outside of the tunnel and extension box is placed inside the tunnel near the mechanics.

Extension box integrates only parts that could not be placed 250 m away from the mechanics; Vexta stepper-motor drives, ADC module, power supply and some input/outputs for interlocking. Stepper-motor drives operate in a current mode and the line inductance prohibits having a distance larger than approximately 60 m (even here the pulse frequency must be severely lowered to 500-2.000 Hz).

All the communication between microIOC and extension box is done using either optically isolated RS-485 line or optically isolated 24V low-power signal (driving optocoupler inputs) – this permits robust communication over 250 m distance.

SUMMARY

This paper presented an overview of the motion control platform solution. We exposed important issues that have to be addressed when a flexible platform needs to be built. A stress was put on a motion controller that could be easily customized for used in different scenarios. Support for large distances and noisy environment is also laid.

REFERENCES

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