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| Motion Control System for the Dump Line Beam Imagining Chambers |
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|  | Name | Title |
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# Scope

This document describes the electromechanical motion control hardware used in the beam imaging chambers in the dump line. It also outlines ideas for how an ESS motion control engineer might write their motion control software to control this hardware.

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# INTRODUCTION

The purpose of a beam imaging chamber in the dump line is to hold one of two scintillating screens in the beam path so that its photon emission can be imaged by a camera installed in the wall next to the chamber. The images captured by this camera will be used by the operators to tune the beam during commissioning. Later, the system may be used to characterize new scintillating materials. The operator will have three choices with regards to the position of the screens relative to the beam:

1. Screen A centred on the beam path
2. Screen B centred on the beam path

Or

1. Both screens completely removed from the beam pipe

The two screens are several centimetres larger (TODO: quantify. possibly adding a diagram here) than the camera’s view of them, and so micron-level positioning accuracy of the screens is not required or helpful. Positioning accuracy to within +/- 3.0mm is sufficient here. The purpose of the motion control system described in this document is to safely position the screens in one of the three valid positions described above.

# motion System Overview

This motion control system is driven by one stepper motor mounted outside the vacuum chamber. The stepper motor turns the leadscrew of a 600mm vacuum compatible linear positioner mounted vertically on the top flange of the dump imaging chamber. This linear actuator moves a 114mm CF-style vacuum flange upwards and downwards. The flange has bellows attached to it which maintain the dump line’s vacuum during motion. The metal frame holding the scintillating screens is also attached to the moving flange and so movement of the flange results in vertical movement of the screens inside the chamber.

As the linear actuator moves upwards or downwards, a plunger can strike one of three position switches attached to a rail system on the linear actuator. These three position switches signal to the control software that the screens are in one of the three valid positions as described in the introduction section above. The actuator also has two limit switches which are mounted directly on the mechanical stops which are clamped to the linear actuator’s guide rail. These two switches signal to the motion control software that the system has moved outside its intended limits. These five switches are the only direct position feedback the motion hardware can give to its control system, there is no encoder.

# Hardware

There is no encoder to read back the position of the stepper motor.

1. Stepper motor with gearbox

**Manufacturer**: Phytron

**Part Number**: VSS57.200.2,5-VGPL 52/16-UHVG with 4 lead bipolar wiring [1]

The motor is fitted with a 16:1 reduction ratio gear box.

The motor accepts 2.5A/phase, which are nominally 0.8 Ω and 2.9mH. The motor winding insulation has a 70V rating.

The maximum motor spin speed is 600RPM (for a step frequency of 128kHz in 1/64 microstep mode) so that the leadscrew turns at a maximum of 600/16 = 37.5 RPM and so the screens travel at a maximum 2.54 \* 37.5 = 95.25 mm/min.

1. Linear actuator

**Manufacturer**: UHV Design

**Part Number**: Custom HLSML64 with 600mm stroke [2]

The actuator’s leadscrew has a 2.54mm thread pitch.

The linear actuator has a plunger with an adjustable height. This plunger is the piece that strikes the three position switches. This height controls the “dead zone” of these switches, that is the length the stage travels between the open-closed switch transition to the closed-open transition. It’s recommended to adjust the plunger’s height such that there is approximately 3mm of dead zone.

1. Switches

**Manufacturer**: Crouzet

**Part Number**: 83160154 [3]

* 1. Two limit switches

These two switches are mounted on the mechanical end stops and will become closed approximately 2mm before the endstop is hit. They will remain closed when the endstop is hit, they cannot be driven past.

* 1. Three position switches

These three switches are mounted on the railing system along the linear actuator in positions that correspond to the three valid positions that the screens can take. Their dead zone is adjustable based on the limit switch striker’s configurable height (see Linear actuator above).

# Electrical Connections

The motion control hardware provides 21 electrical connection points, including 2 which are optional for a K-Type thermocouple for monitoring the stepper motor’s internal temperature.

15 of these 21 are switch signals. Each of the five switches provides three signals: Common, Normally Open and Normally Closed (COM, NO, NC).

4 of these 21 are stepper motor control signals: Phase A winding +, Phase A winding -, Phase B winding + and Phase B winding –

The remaining 2 of these 21 signals are for a K-Type thermocouple which can optionally be used to monitor the internal temperature of the stepper motor, which may be used to detect an over temperature event in the motor so that it can be shut off to prevent damage.

TODO: add a table?

# Suggested Software Design/Control LogiC

Delivery and design of motion control software for the system is outside the scope of U. of Oslo’s delivery. Ultimately the design of the motion control software is of course up to the ESS motion control team. This section is intended to serve as a reference for how U. of Oslo expects the ESS motion control engineer to write their software.

Switch Interface

The motion control software must continuously monitor the signals from the five switches in the system. Very high frequency polling or monitoring of these switch states is not needed since the system does not move very fast, 100ms response time to a change in switch state should be enough.

Motor Interface

The motion control software must command the motor to take steps in either the forward or reverse direction. The direction of movement for steps taken in the “forward” depends on how the stepper motor is wired to its driver, but for the purpose of this document, we’ll assume that “forward” moves the screens upwards and “reverse” moves the screens downwards. The motor should always be driven at its maximum speed (although its assumed the driver hardware has a ramp generator that will provide appropriate acceleration and deceleration phases in the motion profile that is actually delivered to the stepper, appropriate values for the driver hardware’s ramp generator configuration is left up to the ESS engineer), which results in the screens moving at approximately 95.25 mm/minute. See the Hardware section for details on the maximum speed for the motor.

Operator Interface

The interface that the operator uses to control the system must allow them to command the motion system to drive the screens to one of three possible positions:

1. Screen A (the top screen) is centred on the beam path (Position 1)
2. Screen B (the bottom screen) is centred on the beam path (Position 2)

Or

1. Both screens are completely removed from the beam pipe (Position 3)

The interface should always show the operator the state of all the switches in the system so that they can verify the screens are in the expected location. When the system is in motion, potentially none of the switches is closed. In this case, the operator should use the camera to learn the position of the screens.

The ability of the operator to command the system to move to a new position should be disabled while the system is in motion.

The interface should not allow the operator to command the system to move to a position that the system is already in, thus at any given time, the operator has either two or zero (if currently in motion) choices of where to command the system to move to.

Control Logic

During normal use, the two limit switches should never become closed. They are only reached if the control system somehow fails, causing the motor to drive past the position switches which represent the three valid positions the system can take. If the system ever senses a transition of one of the limit switches from open to closed, the motor direction should be immediately reversed, and the motor should be driven until one of the valid position switches is reached. After a limit switch has been hit, the system should be disabled, and the cause of the failure diagnosed.

During normal use, the system should never idle in a state where none of the switches is closed, the system should always drive the motor until one of the valid position switches is closed. This prevents the system from idling in a state where the operator cannot quickly and easily determine the location of the screens.

If the screens are in Position 3 and the operator commands a new position, the system should drive the motor in reverse until the goal position switch becomes closed.

If the screens are in Position 1 and the operator commands a new position, the system should drive the motor forward until the foal position switch becomes closed.

If the screens are in Position 2 and the operator commands movement to Position 3, the software should drive the motor forward until the Position 3 switch is reached.

If the screens are in Position 2 and the operator commands movement to Position 1, the software should drive the motor reverse until the Position 1 switch is reached.

On power up, the control software should inspect the state of the switches. If one of the position switches is closed, it should do nothing. If the top limit switch is closed, it should drive the motor in reverse until a position switch is reached. If the bottom limit switch is closed, it should drive the motor forward until a position switch is reached. If no switch is closed, it should drive the system forward until a switch is closed.

Control System Offline Health Check

It may be useful to include a health check mode to verify the functionality of the motor, the two limit switches and the three position switches. When this mode is activated, the control software should drive the motor forward until the top limit switch is closed. The software should then begin to drive the system in reverse. When the top limit switch transitions from closed to open, the step counter should be reset to zero. As the actuator travels downward, the plunger will actuate all three position switches. The software should record the step counter’s value at each of the open-closed and closed-open transitions of each position switch. When the bottom limit switch closes, the step counter value should be saved and motion should be halted. To determine if the system is healthy, the step counter values associated with each of the switches open-closed and closed-open transitions should be compared with values recorded during commissioning.

Movement Timeouts

To protect against the case of a faulty limit switch or other motion system failure, all movement commands should have a timeout. It is expected that the screens will travel at approximately 95.25 mm/minute. The spacing between each valid position is approximately 230mm, thus any movement between adjacent positions is expected to take about 2 minutes, 28.8 seconds (and a movement between position 1 and 3 is expected to last for 5 minutes). Movement events lasting longer than ~ 5% beyond these expected times should result in the system being disabled and the failure diagnosed.

# Machine Protection System Interface

The system has been designed to be intrinsically safe to the machine so that it does not require any interface to the Machine Protection System. The motion system is prevented from taking any position that may result in damage to the beamline. All possible positions the linear actuator can take are safe because the only components that may ever enter the beam pipe are the two scintillating screens. All hardware used to mount and hold the screens will always remain outside the pipe. Travel beyond its intended design limits is prevented in two ways: first by limit switches that will signal to the motion control software that the linear actuator is moving outside of the intended range and second by mechanical stops clamped onto the linear actuator’s guide rail which prevent motion beyond the limits in the case that the control software malfunctions and ignores the limit switch signals. Although the wider linear accelerator will remain undamaged in the case the system malfunctions, the stepper motor and/or gearbox here may become damaged or degraded if the system is driven into its mechanical endstops for prolonged periods.

# Maintenance

The linear actuator’s leadscrew and bearings should be greased with NUCLEOL G121 grease.

# references

1. Attached stepper motor datasheet: ds-vacuum-en.pdf
2. Attached linear actuator datasheet: HLSML64-20895-001-FOR-APPROVAL.pdf
3. Attached switch datasheet: SF133210\_B 83160154.pdf

Document Revision history

| Revision | Reason for and description of change | Author | Date |
| --- | --- | --- | --- |
| 1 | First issue | Greyson Christoforo | 24 August, 2020 |
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