

# A MOVEMENT CONTROL SYSTEM FOR ROMAN POTS AT THE LHC

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## Abstract

This paper describes the movement control system for detector positioning based on the Roman Pot design used by the ATLAS-ALFA and TOTEM experiments at the LHC. A key system requirement is that LHC machine protection rules are obeyed: the position is surveyed every 20ms with an accuracy of  $15\mu\text{m}$ . If the detectors move too close to the beam (outside limits set by LHC Operators) the LHC interlock system is triggered to dump the beam. LHC Operators in the CERN Control Centre (CCC) drive the system via an HMI provided by a custom built Java application which uses Common Middleware (CMW) to interact with lower level components. Low-level motorization control is executed using National Instruments PXI devices. The DIM protocol provides the software interface to the PXI layer. A FESA gateway server provides a communication bridge between CMW and DIM. A cut down laboratory version of the system was built to provide a platform for verifying the integrity of the full chain, with respect to user and machine protection requirements, and validating new functionality before deploying to the LHC. The paper contains a detailed system description, test bench results and foreseen system improvements.

## OVERVIEW

The Roman Pot movement control system is used at CERN by two LHC experiments; ATLAS-ALFA [1] and TOTEM [2]. To gather experimental data, ATLAS-ALFA and TOTEM must position their detectors close (down to  $\sim 800\mu\text{m}$ ) to the LHC beams. In order to maintain the beam vacuum conditions, the detectors are sealed inside a movable section of vacuum chamber; this movable section is called a Roman Pot.

## SYSTEM REQUIREMENTS AND OPERATING CONSTRAINTS

TOTEM's 24 detectors are arranged in groups of three: A pair of Roman Pots in the vertical axis and a single Roman Pot in the horizontal axis as shown in figure 1. ATLAS-ALFA's 8 detectors are arranged in vertical pairs only, with no horizontal component. Each pot is moved using a step counting motor and position information is provided by means of stopper switches (with on/off transition points at known, fixed, locations) and an LVDT (Linear Variable Differential Transformer). A tensioned spring attached to each Roman Pot and compensation bellows connected to the beam vacuum provide a simple means of pot retraction: When power to the stepper motor is cut, these pull the pots back to the safe position.

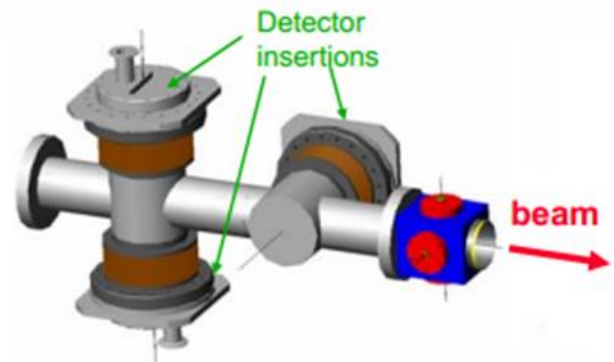


Figure 1: 2 Vertical and 1 Horizontal Roman Pot on the LHC beam pipe.

The LHC beam collimation system [3] is responsible for beam halo cleaning and various aspects of the LHC machine protection. Collimation is carried out by moving mechanical jaws close to the LHC beams, respecting a tight settings hierarchy, to ensure the safe disposal of energy from large amplitude beam halo particles. From a control perspective, operating TOTEM and ATLAS-ALFA's Roman Pots can be broadly considered a subset of collimation control [8]; both require moving hardware with a high degree of accuracy close to the high energy LHC beams, but with more degrees of freedom involved in collimation movement.

Movement of the Roman Pots is carried out by the LHC operations team (to positions requested by the experiment shift crew). Taking this and the similarities (control-wise) of collimation and pot movement into account it was decided that the Roman Pots movement control system should, as far as possible, clone the movement control system used by the LHC collimation system, providing the dual benefits of reducing risk, by reusing a proven stack, and providing a homogenous interface to operators and operations software. From the viewpoint of the CCC operations software, Roman Pots are treated as a special family of collimators.

Some Roman Pot specific requirements:

1. In case of power failure the Roman Pots must be automatically retracted from the beam.
2. In the case of conflicting position readouts the Roman Pots retract from the beam.
3. When there is beam in the machine, the Roman Pots should be limited to their retracted position for all machine modes except for **StableBeams**.

- Stepper motor power is disabled when the pots are extracted and waiting for a valid beam mode.
- Beam injection is prohibited unless the Roman Pots are in the retracted position.
  - Slower LVDT readout (~50Hz, compared with collimation systems ~100Hz).

### MOTOR CONTROL FRONT END

Step counting motors move the Roman Pots housing the detectors, the position of the pots is available from an LVDT connected to the (movable) pot and the surrounding (static) frame. The status of a series of microswitches (see the box expanded out - the right hand half of Figure 2) is fed into the control system to provide coarse-grained information about pot position.

The IN and OUT stoppers stop the pot when the central test probe reaches either, the IN and OUT switches provide redundant support for this movement constraint. The HOME switch shows when the pot is in a 'safe' position (in the shadow of the beam pipe, ~4cm), relevant for interlock purposes (all pots should be in this position for beam injection for example), and the ANTI-COLLISION switch prevents paired pots colliding.

FPGA cards housed in a PXI crate handle interlock decisions based on the readout from the switches and LVDT. Software running on a PXI Real Time (RT) controller controls the stepper motor and communicates with the FPGA cards to feed back position and status information to the upper control system layers. Note that the FPGA cards make interlock decisions and execute corresponding actions autonomously; they have no dependency on the software running in the RT controller.

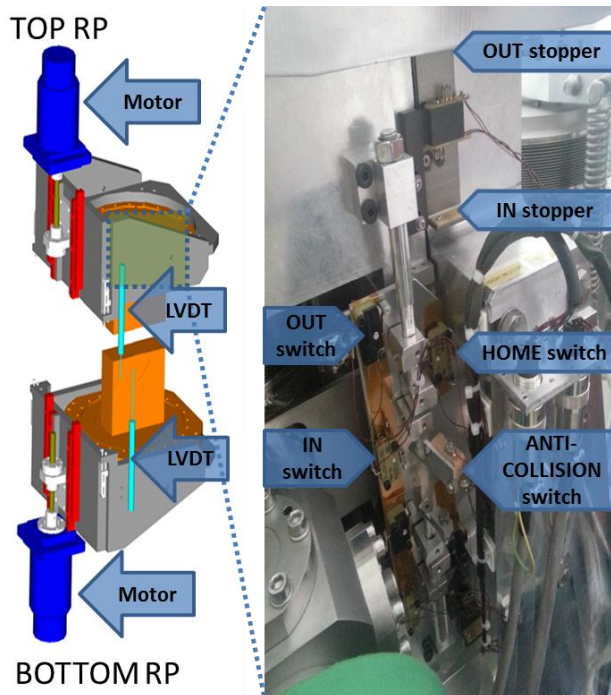


Figure 2: The Roman Pot Front End, sensors and actuators.

### LOGICAL STRUCTURE OF THE CONTROL SYSTEM

The Roman Pots control system uses a 3-tier architecture. Collimation experts in the CCC monitor and remotely control the Roman Pots using a graphical Java (Swing) application. The CCC's high level control applications use a middleware abstraction, the FESA framework [4], to provide a homogeneous means of accessing the heterogeneous variety of devices lower down the control chain.

The control system uses a FESA server implementation specific to Roman Pot movement, with two key purposes: Exposing a command and control FESA interface to high level client applications and translating and passing (bi-directional) data between this interface and the low level, PXI facing, DIM [5] interface. As noted earlier in the requirements section, to avoid introducing complexity in the top level control layer applications the Roman Pots FESA server implementation exposes the same interface as the LHC collimation FESA server. FESA servers and their clients communicate using the (CERN proprietary) RDA protocol [6] and access to this interface is controlled on a property by property basis with RBAC [7]. This middleware layer is physically hosted on a computer (running Scientific Linux), which is commonly referred to as a 'FEC'.

As with collimation, data exchange between the FESA server and PXI is over an asynchronous publish/subscribe mechanism, provided by the DIM runtime. Since DIM uses a proprietary (to CERN) protocol to exchange data, a further data mapping layer (named 'DIM DLL' in figure 3) is needed to make the data translation between the DIM layer and gateway API to the business logic controlling the front end which runs in the Labview RT on the PXI.

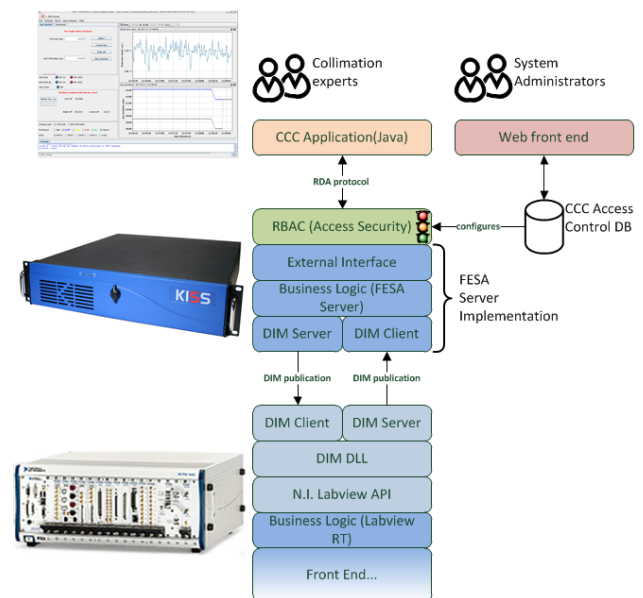


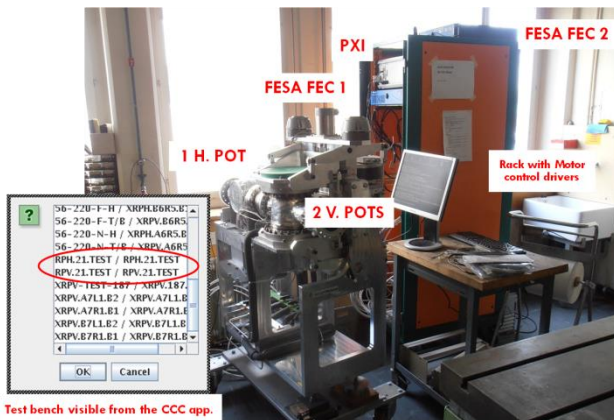
Figure 3: The control system back-end and middleware.

## USAGE AND SYSTEM IMPROVEMENTS

Generally the Roman Pots have been successfully operated, however, whilst using the system during the course of data taking some problems were identified and had to be addressed. As the Roman Pots are deployed in the LHC, access for investigating problems and validating candidate solutions is limited. This is an extremely inconvenient situation, impeding efforts to improve the system. To overcome this, a clone of the production system, a testbench, was built.

### The Testbench

To permit recreating and investigating problems reported on the production equipment, the testbench is a faithful reproduction of the entire control chain used in the production systems, albeit on a reduced scale. The testbench uses exactly the same system components from the top level Java HMI down to the sensors and actuators connected to the (empty) Roman Pots situated on a section of beam pipe, but has only 1 horizontal and 2 vertical pots.



**Figure 4: The testbench – a clone of the production system.**

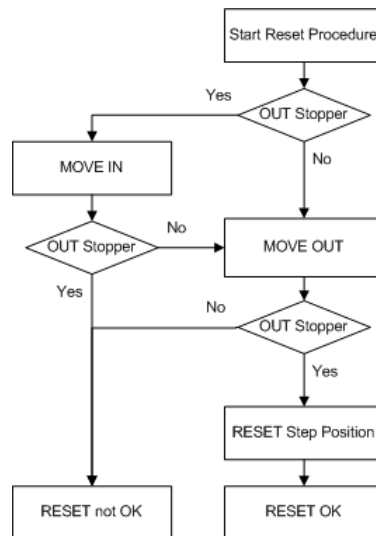
The problems described below were reproduced and investigated using the testbench, solutions were deployed to and validated on the testbench before deployment to the production environment.

1. Sometimes, pot movements stopped prematurely, a few 100s of microns before the required position.

*Resolution:* Using a LASER survey, it was observed that all steps were slightly less than the assumed  $5\mu\text{m}$  and furthermore, that the size of the motor steps is not uniform over the range of motion. Calculating the number of steps to move to realize a specific displacement had previously been calculated simplistically; dividing displacement by the assumed step size. The LASER survey was used for each pot to create its own calibration curve to detail its position dependent step size – now, step count is calculated using the pot position and calibration curve.

2. Absolute pot position data came solely from LVDT readouts. Independently of the Roman Pots control system, the collimation group had observed LVDT drifts of up to a few 100s of microns over time.

*Resolution:* A new absolute position reference for each pot was introduced by means of a mechanical OUT stopper; the on-off transition point having been accurately surveyed. A new (Boolean) property was added to the FESA interface, which, on being set to TRUE (from the CCC control application) requests the PXI to drive the pot back to the transition point of the OUT stopper, thereby arriving at a known absolute position, at which point the motor step counter is reset to 0. Figure 5 shows the reset procedure logic, note the pots can move slightly further out than the OUT stopper transition point. In order to execute a valid reset the pot is moved incrementally towards the beam until the OUT stopper is no longer depressed, and then the pot moved away from the beam until the transition point is reached.

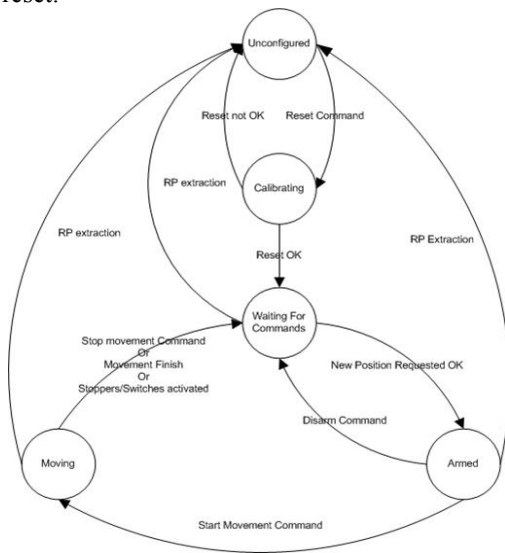


**Figure 5: The improved reset procedure.**

3. Following the deployment of the resolution for problem 2 (above) to the production system, further operational issues were observed, stemming from the fact that under certain conditions it was still possible to introduce a discrepancy between the actual pot positions and the position as reported by the motor step counters. When a pot is retracted by the springs, the motor step counter does not reflect this passive movement and stays unchanged; now indicating the wrong position. Furthermore, the spring tension retracts the pots further out than the reset point, into an undefined position. The old controls logic allowed an active movement from that undefined position, without enforcing a prior step counter reset.

*Resolution:* The finite state machine of the movement system was augmented (see Figure 6) such that, following a spring extraction or system restart all pots enter an **Unconfigured** state, in order to exit this state and enter the **Waiting For Commands** state (i.e. receptive to

positioning commands) the pot must perform a successful reset.



**Figure 6: The enhanced state machine, as prototyped and validated on the testbench.**

4. Each pot had two limits: Warning - breaching this triggers pot extraction; Dump – breaching this triggers a beam dump and a pot extraction. It was noticed that under certain LHC operational sequences, these limits could be relaxed to the “parked” pot position, an action which could be carried out by non-collimation experts.

*Resolution:* A new redundant dump limit was added, this limit is set from the CCC via a new property on the FESA interface which is access controlled to collimation experts only.

5. An RP movement control system interlock is (as with all experiment interlocks) unmaskable, operating the LHC requires an OK flag from the RP movement control system to indicate that the FPGA cards in the PXI crate calculate that no pots currently breach any critical limits. This can cause the situation whereby a malfunctioning FPGA (or a malfunctioning LVDT supplying invalid position information to the FPGA interlock logic) can block LHC operation.

*Resolution:* The central resolution was to bridge the FPGA interlock connection with a bypass mechanism (protected by a key kept in the CCC); with the bypass activated, the FPGA interlock signal is blocked and power is cut to the movement motors.

6. A failure in the power supply for the FESA host computer meant that the Roman Pots control system could not be operated.

*Resolution:* To improve availability of the movement control system, a backup FESA host computer was introduced (for TOTEM only) with a dedicated box for switching power and Ethernet to the standby computer in the event of the primary failing.



**Figure 7: Redundant FESA (KISS) computers.**

## FUTURE WORK

- The FESA team recently released a new FESA version (v3), FESA users are encouraged to update to this version. There is no automated means of updating the Roman Pot FESA server codebase to this new version, this presents an ideal opportunity to review and refactor the code with the aim of reducing future maintenance effort.
- Labview supports OPC-UA (an industry standard integration protocol). Replacing DIM with OPC-UA as the means of FESA/PXI communication removes the need to maintain the custom data translation layer (the DIM DLL in Figure 3).
- The Roman Pot front ends are equipped with resolvers, devices which record the angular displacement of the motor spindle. Their output is currently unused, but will be integrated into the control system (subject to validation on the testbench).

## CONCLUSIONS

Basing the Roman Pot movement control system on the established LHC collimation control system has proved expedient in building and deploying the system. The system has been used successfully since 2010 to collect experimental data for the TOTEM and ATLAS-ALFA experiments but not without some problems. The creation of the testbench has been vitally important in providing an accessible clone of the production environment for recreating and diagnosing problems and providing a safe environment in which to trial prototypes and validate final modifications before they are applied to the experiment hardware on the LHC beam.

## REFERENCES

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- [2] The TOTEM collaboration “The TOTEM Experiment at the CERN Large Hadron Collider”, JINST 3 (2008) S08007.
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