THE FIRST 1 1/2 YEARS OF TOTEM ROMAN POT OPERATION AT LHC

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Abstract

Since the LHC running season 2010, the TOTEM Roman Pots (RPs) are fully operational and serve for collecting elastic and diffractive proton-proton scattering data. Like for other moveable devices approaching the high intensity LHC beams, a reliable and precise control of the RP position is critical to machine protection. After a review of the RP movement control and position interlock system, the crucial task of alignment will be discussed.

INTRODUCTION

The TOTEM Roman Pot system [1] has been designed for measuring very forward protons originating from elastic or diffractive scattering processes. With different beam optics, four-momentum transfers down to $\sim 10^{-3}\,\mathrm{GeV}^2$ can be reached, corresponding to scattering angles of a few μrad. The proton detection is accomplished by stacks of 10 silicon sensors placed in movable beam-pipe insertions – so-called “Roman Pots” (RPs) – that can approach the beam. In some special runs the distance from the beam centre has been smaller than 1 mm. The system consists of 24 RPs arranged in 4 stations at 147 m and 220 m on either side of LHC’s IP5. Each station is composed of 2 units separated by a distance of 2 – 5 m. A unit consists of 3 RPs, two approaching the outgoing beam vertically and one horizontally, allowing for a partial overlap between horizontal and vertical detectors, which is useful for the alignment.

THE ROMAN POT MOVEMENT CONTROL SYSTEM

System Architecture

The RP movement control system [2] has been derived from the one of the LHC collimators. The top level user interface, a modified version of the Central Collimation Application [3], is operated from the CCC. It allows the operator to send RP position requests and critical position limits to the middle level control (see below) and to read back the measured positions. A graphical display shows the time evolution of requested and measured RP positions, the position limits, and the dose rates measured by Beam Loss Monitors downstream of the RPs (see example screenshot in Fig. 2). The middle level is the FESA-based [4] Collimator Supervisor System [5], providing the link between the Collimation Application and the low level motor control running on a PXI [6] crate. The PXI CPU controls the stepping motors of the individual RPs and manages the position read-outs from the stepping motor encoder (step counter) and from the independent LVDT system (see next subsection). The PXI computer also interfaces to FPGA cards which independently from the CPU accomplish the interlock-relevant comparison between actual RP positions and their critical limits (see later subsection). The FPGA cards have direct connections from the microswitches and the LVDTs and to the beam interlock logic card.

Note that from the TOTEM control room no RP movements can be triggered, except emergency retractions via mechanical springs. This policy enforces centralisation of controls in the CCC and enhances communication between TOTEM and the LHC operators. However, the TOTEM Detector Control System monitors passively all operations.

Microswitches and Position Measurements

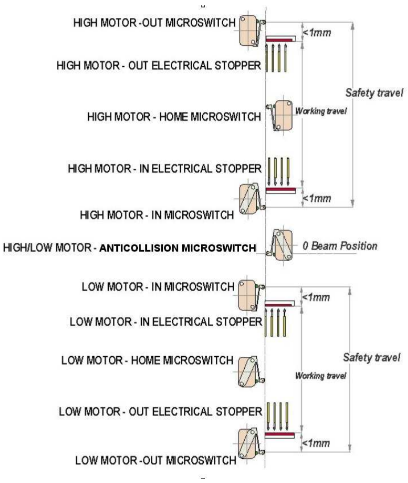


Figure 1: Schematic overview of the RP microswitches tagging some particular pot positions and defining the travel range.

The RP mechanics has a series of microswitches [7] (Fig. 1) tagging certain positions in the RPs’ movement range and triggering appropriate responses. The IN and OUT electrical stoppers define the range of motion and stop the pot at its first point of electrical contact with their spring test probes. These probes have an elastic travel of 3.18 mm beyond the first point of contact. The OUT microswitch beyond the electrical stopper acts as a redundant motor stopper. The OUT stopper also serves as absolute position reference; its on-off transition point has been surveyed by laser calibration. The HOME switch is relevant for interlock purposes. The HOME flag is active in all retracted pot positions beyond the first contact point with the HOME switch. The ANTICOLLISION switch stops the motors if a top and a bottom pot come too close to each other.

The RP system has two redundant position measurements: 1. The motor encoders, i.e. step counters, are used for active movement control. Each step of the stepping motor corresponds to about 5 μm. Due to a small position dependence of the step size, step calibration curves are measured for each RP at least once per year. The encoder measures the position relative to the OUT electrical stopper; it has no absolute position memory. In a fast extraction of a pot with the springs, the mechanical coupling between the pot and its motor is removed, leading to a loss of the absolute position information. Hence, to ensure a correct calibration, each RP insertion is preceded by an encoder reset at the OUT stopper. 2. The LVDTs [8] provide an absolute position measurement but are subject to small drifts and need to be periodically recalibrated. These measurements are used for the position interlock and as an independent cross-check of the encoders.

TOTEM Beam Interlock Logic

Like all LHC experiments and many machine components, the TOTEM RP system has an input to the LHC beam interlock system to avoid beam operation when a RP is in a position where it would represent a danger.

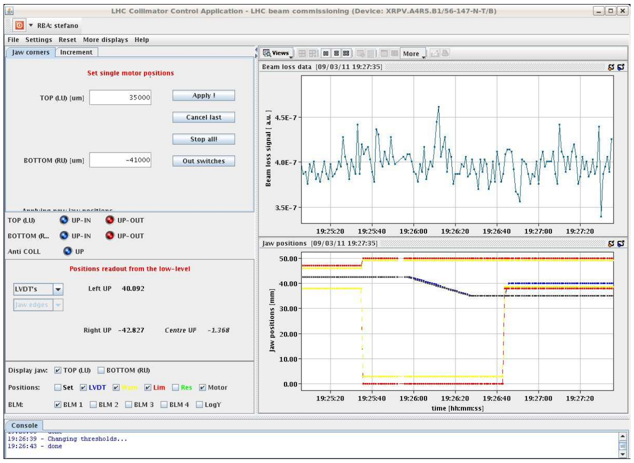
This logic is implemented in the programmable TOTEM interlock card that receives beam mode information (SMP parameters) from the General Machine Timing (GMT), RP position validity information from the FPGA cards comparing each RP's LVDT position with its beam-mode dependent critical limits, and simple electrical contact information from the RP Home microswitches. The output signals, INJECTION_PERMIT and USER_PERMIT are transmitted by hardware links to the beam user interfaces ("CIBF" and "CIBU"); copies are sent to the Detector Control System. The key functions of the interlock logic [2, 9] are the following: 1. Withdrawal of INJECTION_PERMIT: Prevention of any beam injection when at least one RP does not touch its HOME microswitch. 2. Withdrawal of USER_PERMIT: Beam dump and automatic RP extraction if either (a) at least one RP is away from its HOME switch in a beam mode where RP operation is not allowed, or (b) at least one RP is outside the position range defined by beam-mode dependent critical limits.

An example sequence of an interlock test performed with the Collimation Application in the CCC is shown in Fig. 2.

ROMAN POT ALIGNMENT

Beam-Based Alignment

The beam-based alignment of the RPs is performed with a technique established for the collimators [10]: a reference beam edge is produced by closing the horizontal and vertical primary collimators (TCPs) until they scrape the beam halo at an aperture $n_{\mathrm{TCP}}\sigma_{\mathrm{TCP}}$, where σ_{TCP} is the beam size at the collimator, calculated for nominal optics functions and for a given normalised emittance. This beam edge is then used as a reference for the RPs: the pot approaches the circulating beam in steps as small as 10 μm. When it reaches the edge, a beam loss is measured in a Beam Loss Monitor (BLM) downstream (Fig. 3). In this condition, the RP and the primary collimator are at the same normalised distance n_{TCP} from the beam orbit with an accuracy given by the step size. At the contact position, the RP scrapes slightly into the beam. To refine the scraped beam edge, the primary collimator in the appropriate plane is moved further towards the beam until it becomes again the aperture bottleneck. The average of the two normalised reference distances n_{TCP} of the primary collimators is used to compute the normalised distance n_{RP} of the RP.



TOP (LU) [um] 35000

BOTTOM (RU) [um] -41000

TOP (LU) ● UP-IN ● UP-OUT

BOTTOM (R... ● UP-IN ● UP-OUT

Anti COLL ● UP

LVDT's

Left UP 40.092

Right UP -42.827 Centre UP -1.368

Display jaw: ☑ TOP (LU) ☐ BOTTOM (RU)

Positions: ☐ Set ☑ LVDT ☑ Warn ☑ Lim ☐ Res ☑ Motor

BLM: ☑ BLM 1 ☐ BLM 2 ☐ BLM 3 ☐ BLM 4 ☐ LogY

```
19:26:39 - Changing thresholds...
19:26:43 - done
```

Figure 2: RP movement sequence during the interlock tests 2011: black = motor step counter position, blue = LVDT position, red = outer and inner dump limits, yellow = outer and inner warning limits. At 19:26:40 the inner limits are changed such that the RP position becomes illegal. Consequently the pot is automatically retracted. The LVDT correctly indicates the new position (~39.7 mm). The step counter, however, stays at 37 mm because in the emergency extraction with the springs the motor coupling is lost. A reset at the mechanical reference point (OUT stopper) is needed.

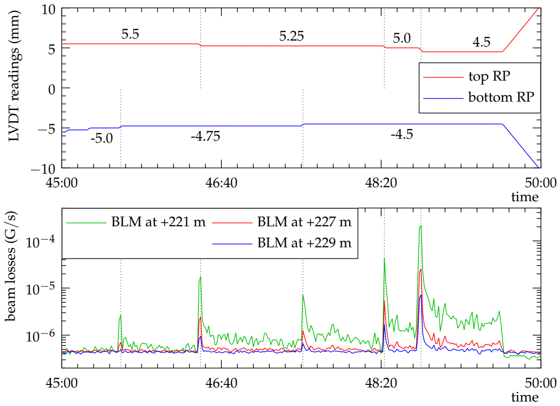


Figure 3: Beam-based alignment sequence for a vertical RP pair in 2010. In this early alignment exercise the step size was large (250 μm). Nowadays, 10 μm are used for better precision. The integrated dose in the BLM spikes was also used to calibrate the BLM response [11].

Note that this procedure only establishes the distance between the *thin window* of the RP and the beam centre. The alignment of the different *silicon detector planes*, both relative to each other and to the beam, is determined by software, using real particle data.

Software Alignment

A detailed discussion of the software alignment methods is given in [12]. Most degrees of freedom of the relative alignment between the RP sensors can be obtained from the reconstructed tracks. The underlying idea is that sensor misalignments give raise to residuals, i.e. the distances of the measured hit positions from the fitted tracks. This technique is sensitive to shifts (along the sensor read-out direction, i.e. perpendicular to the microstrips) and rotations of individual detector planes relative to each other, but not to global shifts or rotations. The transverse overlap between vertical and horizontal detectors (Fig. 4) establishes the alignment between the mechanically independent 3 pots of a RP unit. Fig. 5 shows a comparison of the track-based alignment results for an example RP with the optical metrology data.

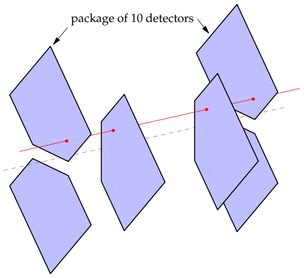


Figure 4: Schematic view of a RP station with a track traversing the overlap zone between top and horizontal detectors.

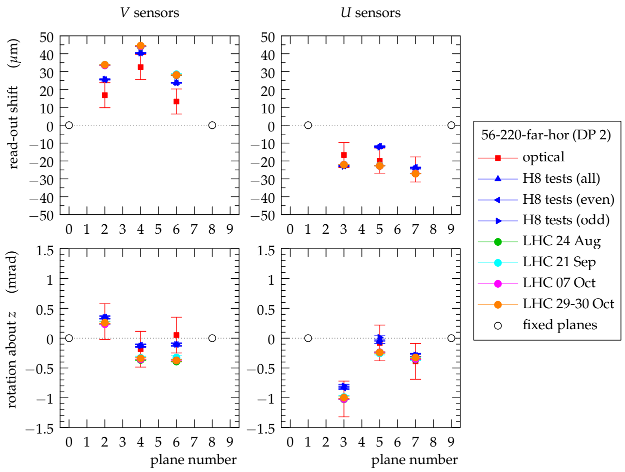


Figure 5: Comparison of different alignment result for one example detector package. “H8” refers to a test beam alignment before installation, “LHC” to an alignment with LHC physics data in 2010, “optical” to the metrology measurement during assembly.

The global misalignment modes (e.g. common shifts or rotations of entire stations w.r.t. the beam) are inaccessible to the track-based techniques but can be constrained by exploiting known symmetries of certain physics processes. A prominent example is elastic scattering with its clean hit distribution in the vertical detectors (Fig. 6). The horizontal and vertical symmetries of the distribution lead to an alignment precision of better than 10 μm horizontally and about 20 μm vertically.

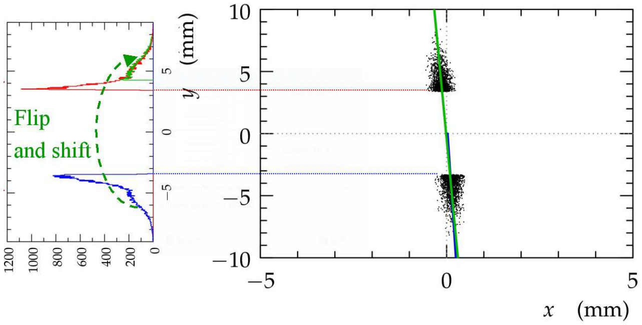


Figure 6: Illustration of RP station alignment based on the symmetry of the elastic scattering hit distribution. Right: distribution of track intercepts in a scoring plane between the near and far units of a RP station. Note that the tilt of the vertical band is mainly caused by optics imperfections. Left: projection of (right) onto y. The symmetry line of the vertical distribution (indicating the position of the beam centre) is found by inverting the sign of the $y < 0$ part (excluding the region near the acceptance cut) and shifting it until it coincides with the $y > 0$ part.

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