# LHC COLLIMATOR ALIGNMENT OPERATIONAL TOOL[*]

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## Abstract

Beam-based LHC collimator alignment is necessary to determine the beam centers and beam sizes at the collimator locations for various machine configurations. Fast and automatic alignment is provided through an operational tool has been developed for use in the CERN Control Center, which is described in this paper. The tool is implemented as a Java application, and acquires beam loss and collimator position data from the hardware through a middleware layer. The user interface is designed to allow for a quick transition from application start up, to selecting the required collimators for alignment and configuring the alignment parameters. The measured beam centers and sizes are then logged and displayed in different forms to help the user set up the system.

## INTRODUCTION

Proton beams circulate in the CERN Large Hadron Collider (LHC) at a nominal momentum of 7 TeV/c and a total stored energy of 362 MJ [1]. The protons can be lost in the machine aperture as a result of equipment failures, operational errors, or beam dynamics processes such as intrabeam scattering. Deposition of the high-energy particles in the superconducting magnets could cause quenches and produce a dangerous accident scenario. For these reasons, the LHC is protected from particle losses by a multi-stage, multi-turn beam collimation system [2]. The collimation system scatters and absorbs halo particles before they can reach the machine aperture, and is designed to provide a cleaning efficiency of 99.998%.

An LHC collimator consists of two parallel blocks, or jaws, of carbon, tungsten or copper material. Each collimator is oriented azimuthally to clean in the horizontal, vertical or skew planes. Each of the four jaw corners can be moved individually by transmitting requests to the Motor Drive Control (MDC) which in turn controls dedicated stepping motors [3]. Linear Variable Differential Transformers (LVDTs) provide an independent measurement of the motor settings, as well as the upstream and downstream jaw gap. This data is transmitted back to the client via the Position Readout Survey (PRS) module.

The cleaning efficiency of the collimation system depends on the correct positioning of the collimator jaws with respect to the beam axis. The beam trajectory is not known precisely due to misalignments of the collimator tanks housing the jaws and other equipment such as quadrupole magnets and Beam Position Monitors (BPMs). The actual beam orbit may deviate from the design orbit over several months of operation due to ground motion and thermal effects [4]. Hence, all collimators are periodically aligned to the beam to determine these parameters. A jaw is aligned when a sharp increase followed by a slow exponential decrease appears in the signal read out from a Beam Loss Monitoring (BLM) detector [5] placed downstream of the collimator.

## OPERATIONAL TOOL

### Main Display

A screenshot of the main display of the collimator application is shown in Fig. 1. The B1 and B2 collimator names are displayed in blue and red respectively. The collimators are displayed in 8 categories, divided by beam and plane. The MDC and PRS state is shown for each collimator, with the color coding described in detail in Table 1 and Table 2. From this screen, the user can launch the user interface for an individual collimator.

Apart from opening windows for individual collimators, the user may decide to start an alignment of several collimators by clicking on the *Setup* drop-down menu in the top-left hand corner. The user then has the option to create a new setup or load an existing setup. The second option is useful if the alignment needs to be resumed after a beam dump, so that all previously measured and saved values are loaded.

If a new setup is created, the user is presented with a collimator selection interface, to be able to select the collimators for alignment. The names are color-coded in red, blue and green for horizontal, vertical and skew respectively. The user is then directed to the next screen, which involves selection of the hierarchy settings for each collimator family. Pre-defined default settings for a selected machine mode are loaded from a configuration file, and can be modified directly from the window if necessary.

### Collimator Controller

Once all the alignment parameters are defined, the collimator controller window is launched (see screenshot in Fig. 2). The BLM signal is displayed in the top right panel, with the collimator left and right jaw positions in the panel below it. In the top left corner, three tabs allow the user to input the individual jaw corner positions, set both corners of each jaw to the same position, or apply increments to the jaw positions. All the inputs are transmitted to the MDC.

Figure 1: Screenshot of the main application GUI. Only B1 collimators are shown for clarity.

The bottom left panel displays the PRS data, and allows the user to add or remove data shown in the collimator position plot. On the right is the list of collimators selected for setup.

The collimators are ordered by their longitudinal position in the LHC in an anti-clockwise fashion. In this manner, crosstalk between BLM signals within the same insertion region during the simultaneous alignment of collimators in the two beams is minimized. The smaller boxes on either side of the names represent the primary collimator in the same plane, which needs to be re-aligned as part of the procedure to create a reference cut in the beam halo [6], before each regular collimator is aligned. The collimators highlighted in turquoise have already been aligned. Table 3 lists the various color codes, as well as the state they represent.

The applied BLM threshold (seen in green in the BLM plot) is also displayed, as well as the jaw position, energy and $\beta^*$ (the amplitude of the $\beta$-function at the interaction points) limits, which help the user to select the pre-defined parameters. The limits are opened at the start of the align-

Table 1: Color Codes for the Collimator Statuses

| Color | Description |
|---|---|
| Green | WAITING_COMMANDS |
| Yellow | MOTION_EXECUTION |
| Red | UNCONFIGURED |
| Purple | ARMED |

Table 2: Color Codes for the MDC/PRS Warning and Errors

| Color | Description |
|---|---|
| Green | No PRS/MDC Warnings or Errors |
| Yellow | PRS and/or MDC Warnings |
| Red | PRS and/or MDC Errors |

ment, and would automatically trigger a beam dump if they are exceeded. A tab for beam-based alignment (BBA) allows the operator to align a collimator individually, by inputting the left and right jaw step sizes as well as the loss
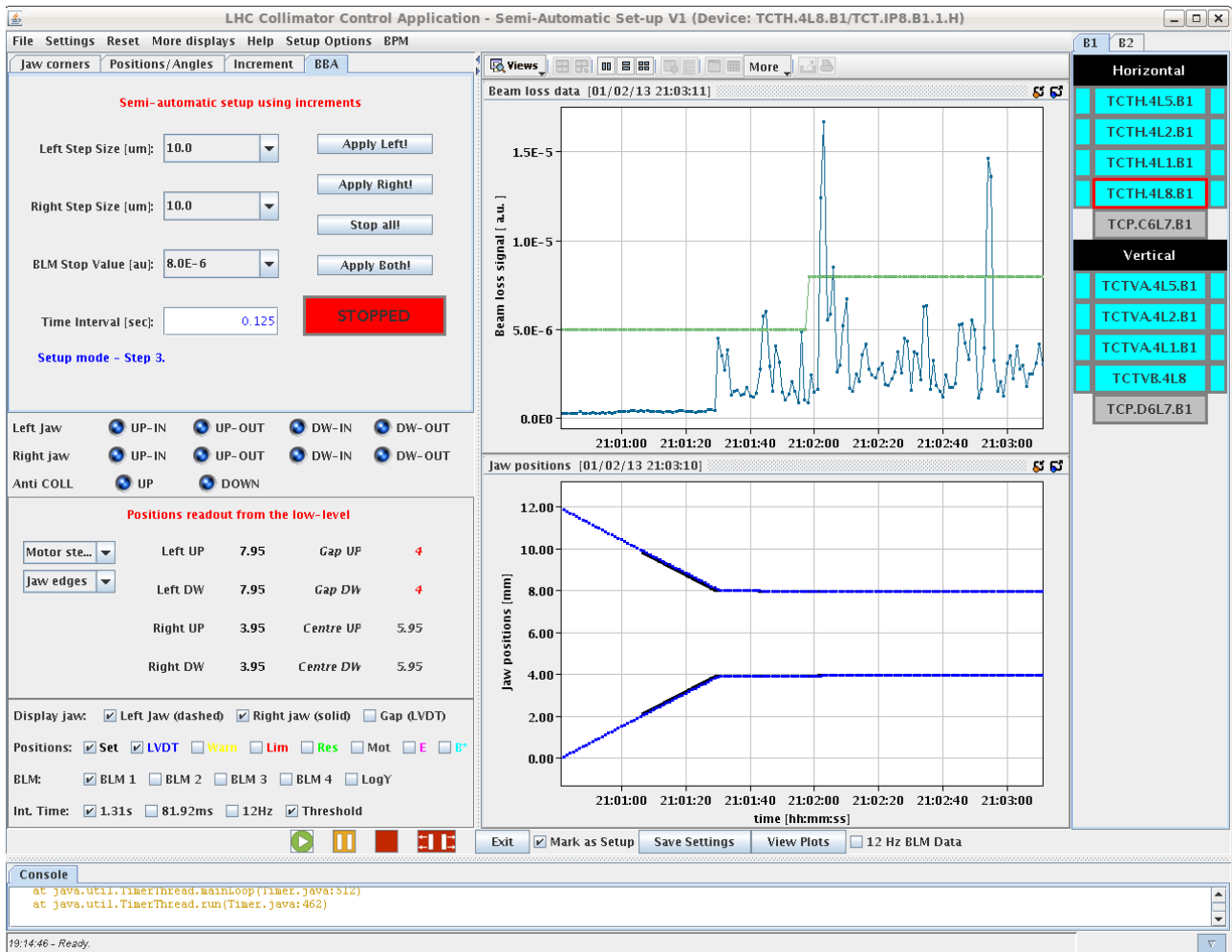
Figure 2: Screenshot of the collimator controller window.

Table 3: Color Coding used to Identify the Different Alignment States of an Individual Collimator

| Color | State |
|-------|-------|
| Gray | Not moved yet |
| Green | Collimator jaw(s) moving |
| Red | Collimator jaw has just stopped moving, decision in process |
| Yellow | One or both jaws have touched the beam, collimator not aligned |
| Turquoise | Collimator is declared to be aligned |

threshold and the time interval in the top left panel and then clicking one of the "Apply" buttons.

At the start of the alignment, the collimators can be moved to tighter settings around the BPM-interpolated settings by clicking on *BPM* in the menu at the top. The alignment sequencer can then be launched by clicking on the green *play* icon at the bottom of Fig. 2. The sequencer performs the various stages of the alignment, starting off with parallel alignment of all collimators, and then sequen-

tially fine-tuning each one to get the beam centers and beam sizes. For a full description of the alignment algorithms developed, see [6]. The sequencer can be paused or stopped at any time by clicking on the appropriate buttons in the bottom panel.

One disadvantage of the GUI in Fig. 2 is that only one BLM-jaw position plot can be viewed at any one time. To view the same plot for other collimators, the user can click on the collimator names shown in the list on the right-hand side. In case the user would like to have a global view of the alignment (especially during parallel alignment), clicking on the *View Plots* button opens a separate window (see Fig. 3), which displays the BLM signal, jaw positions and alignment status for each collimator.

The beam-based data measured during the alignment can be viewed by clicking on *Display* in the main application window. A typical example of a setup sheet with data from an alignment of all tertiary collimators (TCTs) is given in Fig. 4. The alignment sequencer automatically populates the sheet, but nevertheless it remains fully editable. Depending on whether the alignment is carried out at injection or top energy, the user can choose whether the equa-
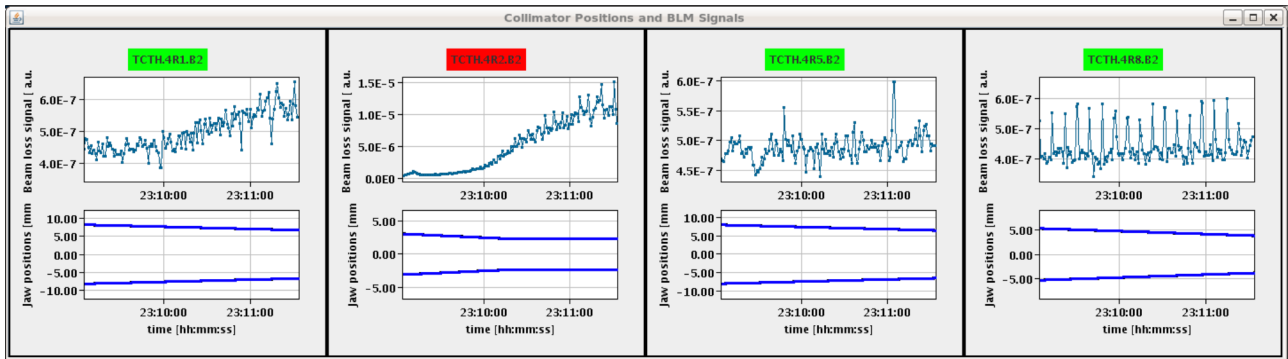
Figure 3: The multi-view window, showing the BLM signals, jaw positions and alignment status for each collimator.

Figure 4: Screenshot of the collimator setup sheet after a TCT alignment.

tions that calculate the positions to open the jaws to after alignment (step 4 in the alignment procedure) rely on the measured or the nominal beam size. All data generated by the collimator application are logged for offline analysis.

## SUMMARY

The LHC is equipped with a beam cleaning system comprising of 86 ring collimators, which prevent high energy circulating particles from impacting the superconducting magnets and sensitive equipment. The cleaning efficiency and protection capability of the system depend on an accurate positioning of the collimator jaws with respect to the beam axis. The beam centers and beam sizes at the collimator locations are measured via beam-based alignment. In this paper, the software application used to perform the alignment was reviewed. The tool is designed to exploit several algorithms which speed up the alignment time [6], but also allows the flexibility for the operator to make manual movements and changes.

## REFERENCES

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Geometric Emittance: 8.21E-10
Setup N Sigma: 4.5
RMS Momentum Deviation: 3.06E-4

| Number | Status | Collimator Name | Angle (deg) | JAW L Calib (mm) | JAW R Calib (mm) | LVDT gap | Gap Offset (mm) | Half Gap Meas (mm) | Eff sigma in coll plane | JAW L Setting (mm) | JAW R Setting (mm) | Target HALF GAP sigma | Pos |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Horizontal** | | | | | | | | | | | | | |
| 9 | True | TCP.C6L7.B1 | 0.00 | 1.020 | -1.525 | 2.474 | -0.252 | 1.272 | n/a | n/a | n/a | 3.62 | 197 |
| 10 | True | TCTH.4L5.B1 | 0.00 | -1.895 | -7.975 | 6.067 | -4.935 | 3.040 | 0.942 | 4.482 | -14.352 | 10.00 | 131 |
| 11 | True | TCP.C6L7.B1 | 0.00 | 0.895 | -1.425 | 2.249 | -0.265 | 1.160 | n/a | n/a | n/a | 3.30 | 197 |
| 36 | True | TCP.C6L7.B1 | 0.00 | 0.895 | -1.425 | 2.250 | -0.265 | 1.160 | 0.352 | 0.895 | -1.425 | 3.30 | 197 |
| 37 | True | TCTH.4L2.B1 | 0.00 | 2.950 | -2.275 | 5.191 | 0.338 | 2.612 | 0.791 | 8.249 | -7.574 | 10.00 | 321 |
| 38 | True | TCP.C6L7.B1 | 0.00 | 0.855 | -1.405 | 2.190 | -0.275 | 1.130 | n/a | n/a | n/a | 3.21 | 197 |
| 42 | True | TCP.C6L7.B1 | 0.00 | 0.855 | -1.405 | 2.189 | -0.275 | 1.130 | 0.352 | 0.855 | -1.405 | 3.21 | 197 |
| 43 | True | TCTH.4L1.B1 | 0.00 | 3.500 | -2.115 | 5.569 | 0.692 | 2.808 | 0.942 | 10.110 | -8.725 | 10.00 | 265 |
| 44 | True | TCP.C6L7.B1 | 0.00 | 0.815 | -1.365 | 2.109 | -0.275 | 1.090 | n/a | n/a | n/a | 3.10 | 197 |
| 45 | True | TCP.C6L7.B1 | 0.00 | 0.815 | -1.365 | 2.109 | -0.275 | 1.090 | 0.352 | 0.815 | -1.365 | 3.10 | 197 |
| 46 | True | TCTH.4L8.B1 | 0.00 | 7.680 | 4.260 | 3.400 | 5.970 | 1.710 | 0.551 | 12.579 | -0.639 | 12.000 | 231 |
| 47 | True | TCP.C6L7.B1 | 0.00 | 0.785 | -1.325 | 2.038 | -0.270 | 1.055 | n/a | -0.270 | -0.270 | 3.00 | 197 |
| **Vertical** | | | | | | | | | | | | | |
| 0 | True | TCP.D6L7.B1 | 90.01 | 1.035 | -0.585 | 1.596 | 0.225 | 0.810 | n/a | n/a | n/a | 3.20 | 197 |
| 1 | True | TCTVA.4L5.B1 | 90.01 | 2.505 | -1.355 | 3.852 | 0.575 | 1.930 | 0.600 | 6.572 | -5.422 | 10.00 | 131 |
| 2 | True | TCP.D6L7.B1 | 90.01 | 0.980 | -0.540 | 1.496 | 0.220 | 0.760 | n/a | n/a | n/a | 3.00 | 197 |
| 12 | True | TCP.D6L7.B1 | 90.01 | 0.980 | -0.540 | 1.487 | 0.220 | 0.760 | n/a | n/a | n/a | 3.00 | 197 |
| 13 | True | TCTVA.4L2.B1 | 90.01 | 0.620 | -4.760 | 5.343 | -2.070 | 2.690 | 0.840 | 6.332 | -10.472 | 10.00 | 325 |
| 14 | True | TCP.D6L7.B1 | 90.01 | 0.965 | -0.530 | 1.464 | 0.217 | 0.748 | n/a | n/a | n/a | 2.95 | 197 |
| 18 | True | TCP.D6L7.B1 | 90.01 | 0.965 | -0.530 | 1.464 | 0.217 | 0.748 | n/a | n/a | n/a | 2.95 | 197 |
| 19 | True | TCTVA.4L1.B1 | 90.01 | 4.460 | 0.450 | 3.977 | 2.455 | 2.005 | 0.600 | 8.452 | -3.542 | 10.00 | 265 |
| 20 | True | TCP.D6L7.B1 | 90.01 | 0.955 | -0.520 | 1.445 | 0.217 | 0.738 | n/a | n/a | n/a | 2.91 | 197 |
| 21 | True | TCP.D6L7.B1 | 90.01 | 0.955 | -0.520 | 1.445 | 0.217 | 0.738 | n/a | n/a | n/a | 2.91 | 197 |
| 22 | True | TCTVB.4L8 | 90.01 | 2.025 | -1.895 | 3.883 | 0.065 | 1.960 | 0.650 | 7.862 | -7.732 | 12.000 | 232 |
| 23 | True | TCP.D6L7.B1 | 90.01 | 0.940 | -0.500 | 1.405 | 0.220 | 0.720 | n/a | 0.220 | 0.220 | 2.84 | 197 |
| **Skew** | | | | | | | | | | | | | |