A Tool based on the BPM-Interpolated Orbit for speeding up LHC Collimator Alignment

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Abstract

Beam-based alignment of the LHC collimators is required in order to measure the orbit center and beam size at the collimator locations. During an alignment campaign in March 2012, 80 collimators were aligned at injection energy (450 GeV) using automatic alignment algorithms in 7.5 hours, the fastest setup time achieved since the start of LHC operation in 2008. Reducing the alignment time even further would allow for more frequent alignments, providing more time for physics operation. The proposed tool makes use of the BPM-interpolated orbit to obtain an estimation of the beam centers at the collimators, which can be exploited to quickly move the collimator jaws from the initial parking positions to tighter settings before beam-based alignment commences.

Motivation

In automatic beam-based alignment, the LHC collimator jaws are moved separately towards the beam from their initial hierarchy settings in step sizes of 5 μm to 20 μm until a loss spike in the Beam Loss Monitor (BLM) signal exceeds a pre-defined threshold [1]. The beam center at each collimator location is calculated as the average of the two aligned jaw positions. An approximation to the beam centers at the collimators can be obtained from an interpolation of the orbit measured at specific locations by Beam Position Monitors (BPMs). A BPM consists of four button electrode feedthroughs mounted orthogonally in the beam pipe. In a future implementation of the alignment software, the interpolated orbit could be acquired and exploited to speed up the alignment process.

BPM-Interpolated Orbit

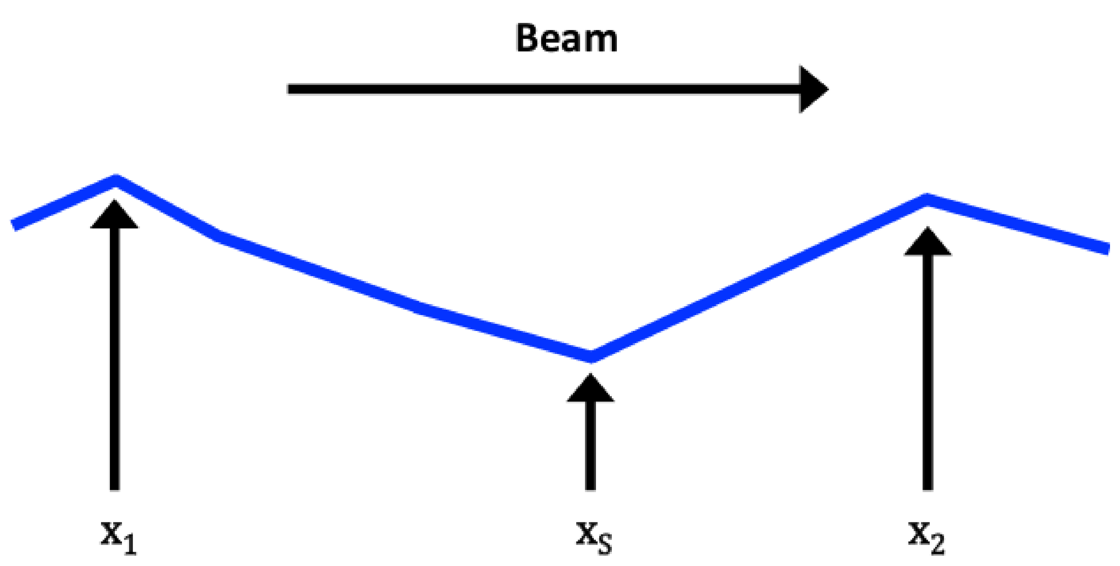


Fig 1. Beam orbit through points 1, S and 2 from [2]

The orbit at point 2 in Fig. 1 can be established from point 1 using a transfer matrix:

$$\begin{pmatrix} x_2 \\ x_2' \end{pmatrix} = M_{12} \begin{pmatrix} x_1 \\ x_1' \end{pmatrix} = \begin{pmatrix} C_{12} & S_{12} \\ C_{12}' & S_{12}' \end{pmatrix} \begin{pmatrix} x_1 \\ x_1' \end{pmatrix}$$

The elements of the transfer matrix are:

$$C_{12} = \sqrt{\frac{\beta_2}{\beta_1}}(\cos\psi_{12} + \alpha_1 \sin\psi_{12}) \qquad C_{12}' = \frac{\alpha_1 - \alpha_2}{\sqrt{\beta_1\beta_2}}\cos\psi_{12} - \frac{1 + \alpha_1\alpha_2}{\sqrt{\beta_1\beta_2}}\sin\psi_{12}$$

$$S_{12} = \sqrt{\beta_1\beta_2}\sin\psi_{12} \qquad S_{12}' = \sqrt{\frac{\beta_1}{\beta_2}}(\cos\psi_{12} - \alpha_2 \sin\psi_{12})$$

Similarly for the orbit from point 1 to S:

$$\begin{pmatrix} x_S \\ x_S' \end{pmatrix} = M_{1S} \begin{pmatrix} x_1 \\ x_1' \end{pmatrix}$$

The interpolated orbit at point S can hence be expressed as:

$$x_S = C_{1S}x_1 + S_{1S}\frac{x_2 - C_{12}x_1}{S_{12}}$$

Finally, the interpolated orbit is transformed to the collimator coordinate system:

$$\Delta_i^{int} = x_S^{hor}\cos\theta + x_S^{ver}\sin\theta$$

BPM-Interpolation Guided Collimator Alignment Tool

The software tool was written in Java, and was integrated into the top-level collimator control application. When the user starts the tool, a query is made to the LHC Aperture Meter, which returns the interpolated beam centers. Once a safety margin is selected, the tool calculates the new tighter settings which will be sent to the hardware. A flowchart of the operation is available in Fig. 2.

A screenshot of the GUI used to move in the collimators based on these values is shown in Fig. 3. The checkboxes on the right-hand side allow the user to prevent the tool from moving in the jaws if they are not selected. The jaws are moved to the settings:

Left: $x_i^L = x_i^{int.} + (N_{TCP} + N_{margin}) \times \sigma_i^n + \frac{\Delta_i^{m,int.}}{2}$, Right: $x_i^R = x_i^{int.} - (N_{TCP} + N_{margin}) \times \sigma_i^n - \frac{\Delta_i^{m,int.}}{2}$

where: $x_i^{int.}$ is the interpolated beam center at collimator *i*

σ_i^n is the 1-sigma nominal beam size at collimator *i*

N_{TCP} is the half gap of the IR7 TCP

N_{margin} is a further safety margin

$\frac{\Delta_i^{m,int.}}{2}$ is the expected average offset between the interpolated and measured center per collimator

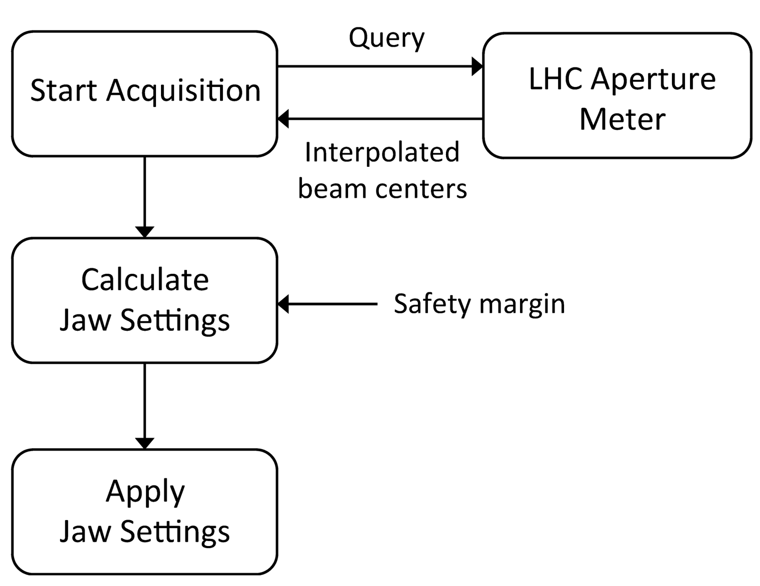


Fig 2. Flowchart of how the tool acquires the interpolated BPM readings and applies the tighter jaw settings based on a safety margin defined by the user.

Fig 3. Screenshot of the GUI used to set the collimator jaws around the BPM-interpolated orbit.

Summary

This paper presents a software tool used to speed up the alignment of the LHC collimators. The similarity between the BPM-interpolated orbit and the measured beam centers at the collimator positions is exploited by the tool to quickly move in the collimator jaws from the initial parking positions to tighter settings before the start of beam-based alignment. It was tested during a LHC beam study, where 23 collimators were moved in to 6.2 σ, after which beam-based alignment was performed. The collimators were aligned in 1.75 hours, which can be extrapolated to 5.5 hours for an alignment of all LHC collimators, a gain of 2 hours over the previous best setup time.

Data Analysis and Interpolation Accuracy

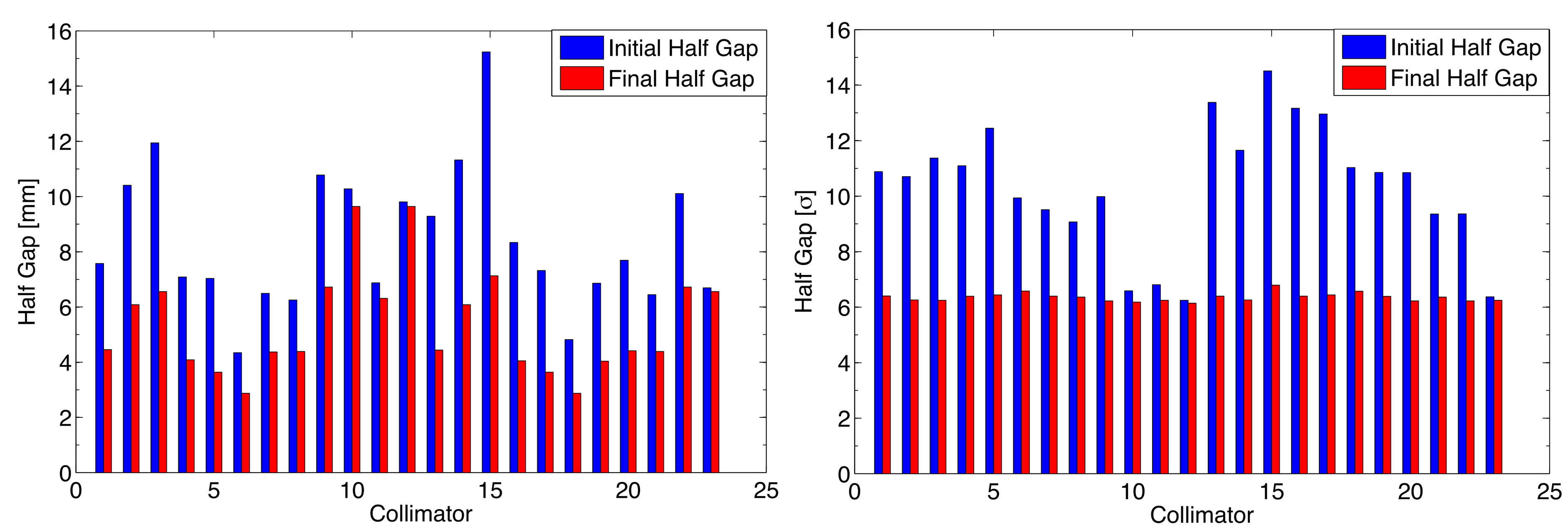
The interpolation is highly dependent on the BPMs selected. Invalid monitors which give erroneous readings need to be removed from the calculation. The interpolation accuracy derives from the linearity of the BPM system. This is equivalent to 1% of the half radius, corresponding to ~130μm for arc BPMs. The BPM-interpolated orbit is one of the features provided by the LHC Aperture Meter [3], an application which provides the operators with real-time information on the current machine bottlenecks.

The interpolated orbit at each collimator was extracted for the same timestamp at which the collimator was aligned. Both datasets are acquired and logged at a rate of 1 Hz. Comparison results between the measured beam center and the BPM interpolation were presented in [4]. The average delta between the data sets is of ~550 μm.

Experimental Results

The tool was tested during a LHC Machine Development (MD) study performed at 450 GeV in April 2012. In the study, 23 horizontal collimators in IR3 and IR7 in both beams were moved from the initial parking positions to tighter settings around the interpolated orbit.

The TCP cut was made at 4.2 σ, and the safety margin was set to 2 σ to give an overall half gap of 6.2 σ. The initial and final jaw positions in mm and beam σ are shown in Fig. 4(a) and Fig. 4(b). If these collimators were to reach the tighter settings in a simultaneous movement using the BLM feedback loop which ensures that the BLM signal is below a pre-defined threshold before each step, the elapsed time would be much larger. Typically, if a step of 5 μm is made every 1 s, the time taken for all these collimators to reach the tighter settings would be 27 minutes.



(a) Initial and final jaw half gaps in mm

(b) Initial and final jaw half gaps in beam sigmas

Fig 4. Comparison of the initial parking positions and the tighter half gaps after the tool was executed, in units of mm (left) and σ (right). Note the large change for collimators initially positioned with a half gap of more than 10 σ.

References

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