COMPARISON OF LHC COLLIMATION SETUPS WITH MANUAL AND SEMI-AUTOMATIC COLLIMATOR ALIGNMENT

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Abstract

The LHC collimation system beam-based alignment procedure has recently been upgraded to a semi-automatic process in order to increase its efficiency. In this paper, we describe the parameters used to measure the accuracy, stability and performance of the beam-based alignment of the LHC collimation system. This is followed by a comparison of the results at 450 GeV and 3.5 TeV with (1) a manual alignment and (2) with the results for semi-automatic alignment.

INTRODUCTION

Efficient collimation in the Large Hadron Collider (LHC) is necessary to prevent quenches in the superconducting magnets, absorb abnormal beam loss and protect the machine against radiation effects [1]. Beam-based alignment of the LHC collimators is performed regularly to determine the beam centres and beam sizes at the collimators [2, 3]. This involves aligning the collimator jaws to the beam by moving them one by one in step sizes of 5 μm to 40 μm, while the corresponding BLM signal is observed for loss spikes. A significant loss spike indicates that the jaw has touched the beam.

Collimator setup was performed manually during the 2010 LHC run, whereby the operator would be required to intervene for every jaw movement towards the beam. After operational experience was gained with manual alignment, the setup procedure is being upgraded to a fully automatic process so that it may be performed more frequently and in a shorter time. A detailed description of the newly-commissioned algorithms which have been used for the 2011 LHC run is given in [4]. Apart from speeding up the setup, the automatic algorithms must also ensure that the setup quality is maintained.

The variation in the ratio of the measured beam size to the nominal beam size can indicate the accuracy and stability of manual and semi-automatic collimator alignment. However, this is true only if certain machine parameters remain constant, such as the β-beat. The operational performance can be deduced from the rate of beam intensity loss and the time required during setup. Automatically triggered beam dumps caused by beam losses exceeding a critical threshold are major contributors to the time required for setup, and should be eliminated. The performance of the collimation system is calculated from the cleaning inefficiency [5]. Therefore, any changes in the cleaning inefficiency between both alignment types can be used to compare the setup quality.

This paper is structured as follows. An overview of the collimator setups held in 2010 and 2011 is presented. This is followed by an analysis of the beam size variation at 450 GeV and 3.5 TeV for manual and semi-automatic alignments. The operational efficiency in terms of the beam intensity loss during the setup and the setup times for both alignment procedures are compared. Finally, the cleaning inefficiency of the collimator system is presented.

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COLLIMATOR SETUPS IN 2010 AND 2011

A list of the major collimator setups in 2010 and 2011 is shown in Table 1. Details of the choice of the number and types of collimators for each setup type are given in [4].

Table 1: Setups in 2010 and 2011

Year	Dates	Setup Type	# Collimators
2010	05 - 07 May	Injection	86
	12 - 16 Jun	Flat top	80
	17 Jun	Squeezed	16
	20 Jun	Collisions	16
2011	25 - 01 Mar	Injection	86
	06 - 08 Mar	Flat top	80
	11 Mar	Squeezed	16
	11 Mar	Collisions	16

COMPARISON RESULTS

Measured Beam Sizes

The measured beam size at each collimator is given by [3]:

$$\sigma_i = \frac{x_i^{L,m} - x_i^{R,m}}{(N_0^{k-1} + N_0^{k+1})/2} \quad (1)$$

where $x_i^{L,m}$ and $x_i^{R,m}$ are the left and right jaw setup positions, and N_0^{k-1} and N_0^{k+1} are the half gap openings of the reference primary collimator in σ before and after the centering of collimator i. The beam size ratio is the ratio of the measured beam size in σ to the nominal beam size in σ. The nominal beam size at each collimator σ_i^n is determined from the nominal geometrical emittance, ϵ, the nominal beta functions $\beta_{x,i}$ and $\beta_{y,i}$ at the collimator i and the rotation angle of the collimator jaws ψ_i [3]. Ideally, the beam size ratio is unity.

The histograms in Figures 1 to 4 contrast the beam size ratios obtained during collimator setups for the 2010 and 2011 runs at 450 GeV and 3.5 TeV. In all cases the beam size ratios for 2011 are comparable with those for 2010, meaning that the setup accuracy is maintained with semi-automatic alignment. At both energies, large beam size ratios are observed for the TCLA.A7R7.B1, TCTH.4L2.B1 and TCSG.A5L3.B2. An inspection in the LHC tunnel revealed that they were mis-aligned. After their positions were corrected, beam-based alignment was performed again and the beam size ratios decreased by 38%, 35% and 39% respectively at 3.5 TeV. The beam size ratio can thus be used as an indication of the correct positioning of the collimators in the tunnel.

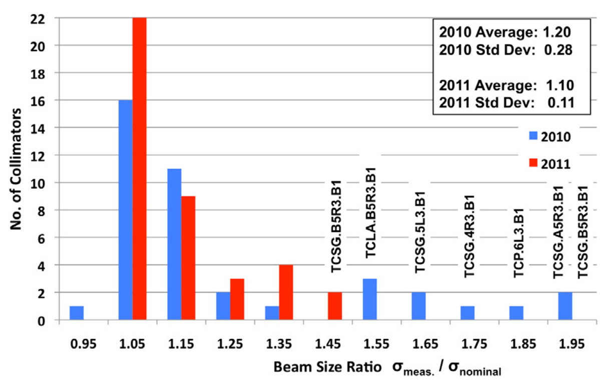

Figure 1: Change in Beam Size Ratio at 450 GeV between 2010 and 2011 B1.

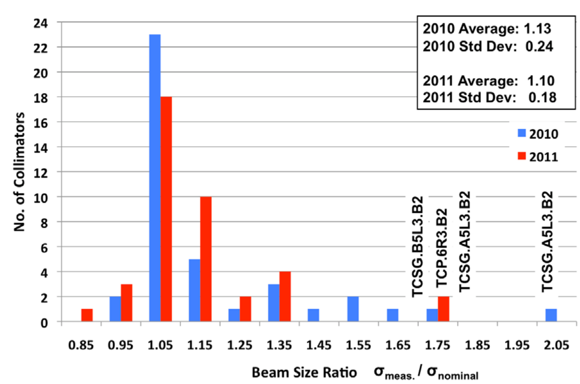

Figure 2: Change in Beam Size Ratio at 450 GeV between 2010 and 2011 B2.

Beam Intensity Loss during Setup

Throughout collimator setup, a certain amount of beam intensity must be maintained to obtain reproducible beam loss spikes when aligning the jaws. In the 2010 run, large

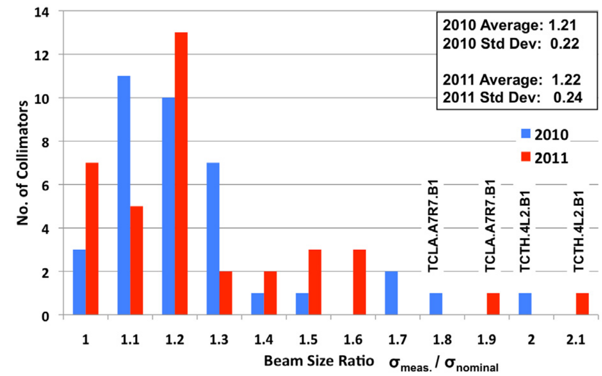

Figure 3: Change in Beam Size Ratio at 3.5 TeV between 2010 and 2011 B1.

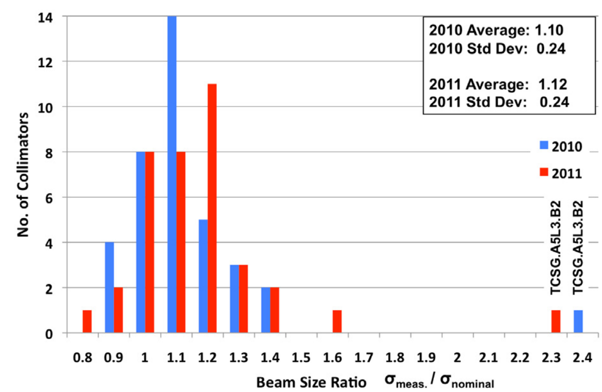

Figure 4: Change in Beam Size Ratio at 3.5 TeV between 2010 and 2011 B2.

step sizes (40 μm) and human error occasionally led to substantial sudden decreases in the beam intensity, if not beam dumps, as illustrated in Fig. 5. Semi-automatic setup allows for smaller step sizes and safer setup, leading to a smoother 'shaving' of the beam shown in Fig. 6.

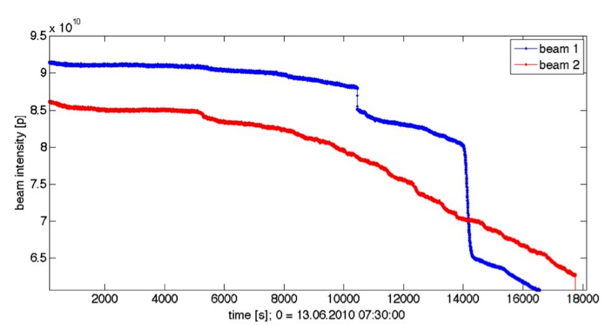

Figure 5: Variation of Beam Intensity during Manual Setup.

Setup Times

The time taken to set up collimators is the most important indicator of the efficiency of a setup algorithm. The

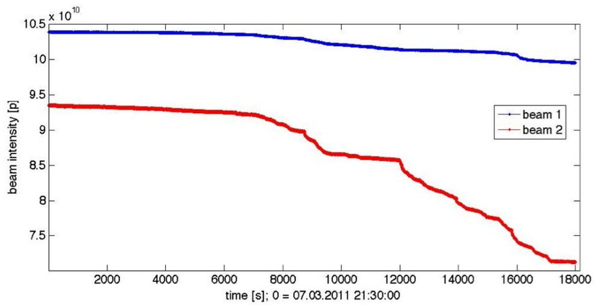

Figure 6: Variation of Beam Intensity during Semi-Automatic Setup.

average time per collimator is defined as the time required for setup divided by the number of collimators setup, while the total shift time is the time used for setup added to the time required to get the LHC back to the operating point in case of a beam dump. The average LHC turnaround times are presented in [6].

The results shown in tables 2 and 3 indicate an increase in the setup time by a factor of 2 for the 450 GeV setup, but this was due to the time required to test the new software. The two beam dumps recorded for the 2011 450 GeV setup were caused by human error when using the manual alignment technique during a phased changeover from manual to semi-automatic software. After debugging was carried out, an improvement by a factor of 1.5 in setup time at 3.5 TeV flat top was registered.

For the setups with squeezed beams, before and after going into collisions, the software was upgraded to allow both jaws to move in parallel to the beam. A speed-up by a factor of 4 and 6.4 for both modes respectively was achieved. No beam dumps were recorded at 3.5 TeV, establishing the safety of the feedback algorithm used in semi-automatic alignment.

Table 2: Setup Times 2010

Setup Type	Avg Time per collim. (mins)	Total Shift Time (hrs)	# Beam Dumps
Injection	5.34	8.35	1
Flat top	9.35	27.27	4
Squeezed	10.8	8.26	1
Collisions	10.8	8.48	1

Table 3: Setup Times 2011

Setup Type	Avg Time per collim. (mins)	Total Shift Time (hrs)	# Beam Dumps
Injection	12	18.52	2
Flat top	13	17.77	0
Squeezed	5.5	2.00	0
Collisions	3.6	1.33	0

Cleaning Inefficiency

The ratio of the highest loss in the collimators to the highest leakage in the cold regions of the LHC is a measure of the cleaning inefficiency of the collimation system [5]. Measurements are performed by creating slow betatron losses around the LHC to produce beam loss maps. Figure 7 illustrates the variation inthe cleaning inefficiency in 2010 (with manual setup) and 2011 (with semi-automatic setup). The cleaning inefficiency measured in 2011 was found to be comparable to the measurements taken in 2010.

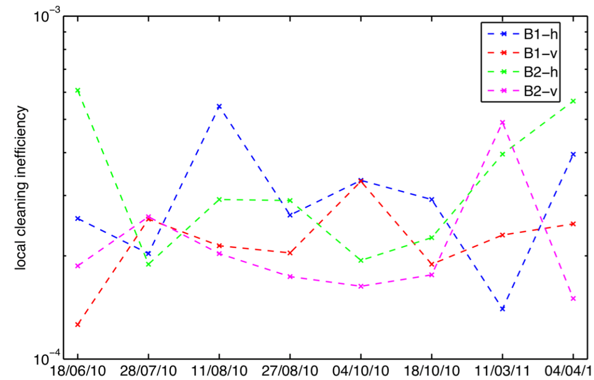

Figure 7: Leakage from the cleaning insertions into the dispersion suppressor magnet Q8 in 2010 and 2011 [courtesy of D. Wollmann].

CONCLUSION

The parameters used to measure the LHC collimator setup accuracy, stability and performance have been defined and discussed. The results show that the semi-automatic collimator alignment method maintains the same collimator setup quality obtained with the slower manual method. An improvement in setup time at the flat top, squeezed and collisions modes was registered. No setup-induced beam dumps were recorded with the new software.

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