SEMI-AUTOMATIC BEAM-BASED ALIGNMENT ALGORITHM FOR THE LHC COLLIMATION SYSTEM

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Abstract

Full beam-based alignment of the LHC collimation system was a lengthy procedure as the collimators were setup manually. A yearly alignment campaign has been sufficient for now, although in future this may lead to a decrease in the cleaning efficiency if machine parameters such as the beam orbit drift over time. Automating the collimator setup procedure can allow for more frequent alignments, therefore reducing this risk. This paper describes the design and testing of a semi-automatic algorithm as a first step towards a fully automatic setup. Its implementation in the collimator control software and future plans are described.

INTRODUCTION

Collimators are required to intercept unavoidable beam losses in the Large Hadron Collider (LHC), which may cause quenches in the super-conducting magnets and radiation effects [1]. Beam-based alignment or setup of the LHC collimators is necessary to determine the beam centres and beam sizes at the collimators. This ensures that the correct collimator hierarchy is maintained during normal operation. Regular collimator setups are required as the beam orbit may change over a few months [2], and the time needed for a full alignment limits the frequency of the setups. In turn, the long time intervals between setups place constraints on the minimum β* achievable and consequently the integrated luminosity reach of the LHC [3].

In the 2010 collimator setups, the alignment was performed manually using the single collimator control application [4, 5]. A 'manual' setup means that an operator would have to intervene for every collimator jaw movement and check every BLM data value to determine whether the jaw is aligned to the beam. A disadvantage of this method is the setup time required (up to 27 hours [6]), which is non-negligible for LHC operation. Human error may result in incorrect jaw movement, leading to high losses and beam dumps, therefore contributing to the setup time. This process can therefore be automated in order to reduce manual intervention and optimize the setup time.

The first section of this paper describes the collimator setup sequence established in the 2010 run. This is followed by the semi-automatic feedback loop algorithm that has been developed, tested and commissioned in the LHC. Once this algorithm was operational, it was used as a backbone for parallel alignment, which is presented in the third section. In the fourth section, setup parameters developed through experience with the software are discussed.

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COLLIMATOR SETUP SEQUENCE

Each collimator is setup in a four-step process [7]. Figure 1 depicts the alignment sequence, where initially both jaws of the reference collimator are aligned. The reference collimator is taken as the primary collimator in the same plane (horizontal, vertical or skew) as the collimator *i*.

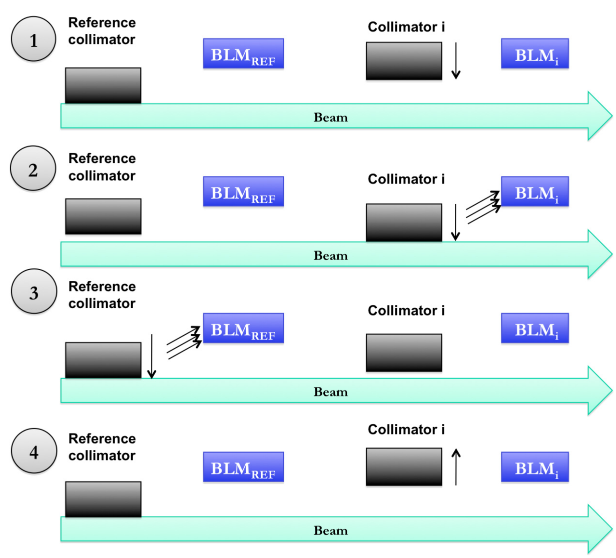

Figure 1: Setup Sequence.

A collimator jaw is defined to be setup if a jaw movement towards the beam produces a satisfactory loss spike in an assigned Beam Loss Monitor (BLM) located downstream. A loss pattern cannot be attributed to a particular jaw movement unless only that particular jaw was moving in at the time. Therefore, the left and right aligned jaw positions are determined separately. After both jaws of the reference collimator are aligned, the same procedure is performed for the collimator *i*, and finally the reference collimator is aligned again. The beam centre and the beam size can then be established from the jaw positions of collimator *i* and the reference collimator [7].

The number and types of collimators setup depends on the machine configuration. At 450 GeV all 86 ring collimators are setup for both beams with 1 nominal bunch per beam. When the energy is ramped to 3.5 TeV flat top, a setup is performed for all collimators except for the injection protection collimators, which are left at parking after injection. After squeezing both beams to the operational $\beta*$ in the experimental insertion points, the 16 tertiary collimators are aligned, since a large change occurs in the beam sizes and beam centres for these collimators. No setup is required for the other collimators since the orbit does not change at these collimators. This procedure is repeated during collisions.

COLLIMATOR JAW ALIGNMENT ALGORITHM

The collimator jaw alignment algorithm allows the user to specify four input parameters to move in one or both collimator jaws to the beam. The four inputs consist of the left and right jaw step sizes in μm, a BLM loss threshold and the repetition time of the movement. Figure 2 illustrates the control panel from which the operator can specify the input parameters to the algorithm.

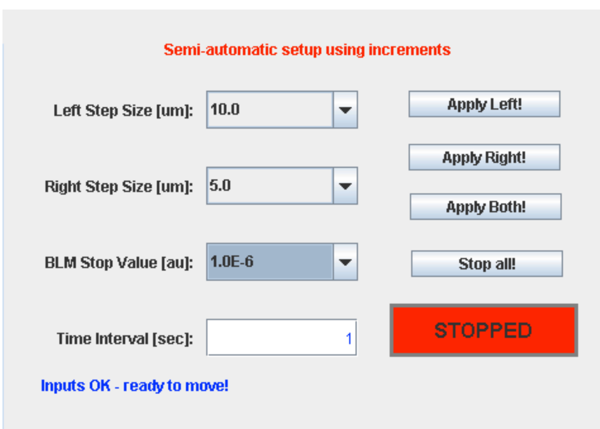

Figure 2: Semi-Automatic Input GUI.

A set of pre-defined possible values exists for each input, based on experience with the collimation system in the 2010 LHC run. With every jaw step, the algorithm obtains feedback from the BLM associated with the collimator being moved, and stops the thread controlling the jaw movement if the BLM loss threshold is exceeded. The BLM data is acquired at a rate of 1 Hz. The algorithm therefore automates two key parts of the setup process:

- Collimator jaw movement towards the beam with a user-defined step size and time interval
- Collimator jaw stopping when the beam losses exceed a user-defined threshold

A flowchart of the semi-automatic alignment algorithm is shown in Fig. 3. The left and right collimator jaw positions are logged automatically, so that the beam centre and beam size can be displayed. The collimator jaw alignment algorithm was implemented into the top-level collimator control software [4], and was tested and commissioned during the collimator setup at 450 GeV held at the end of February 2011.

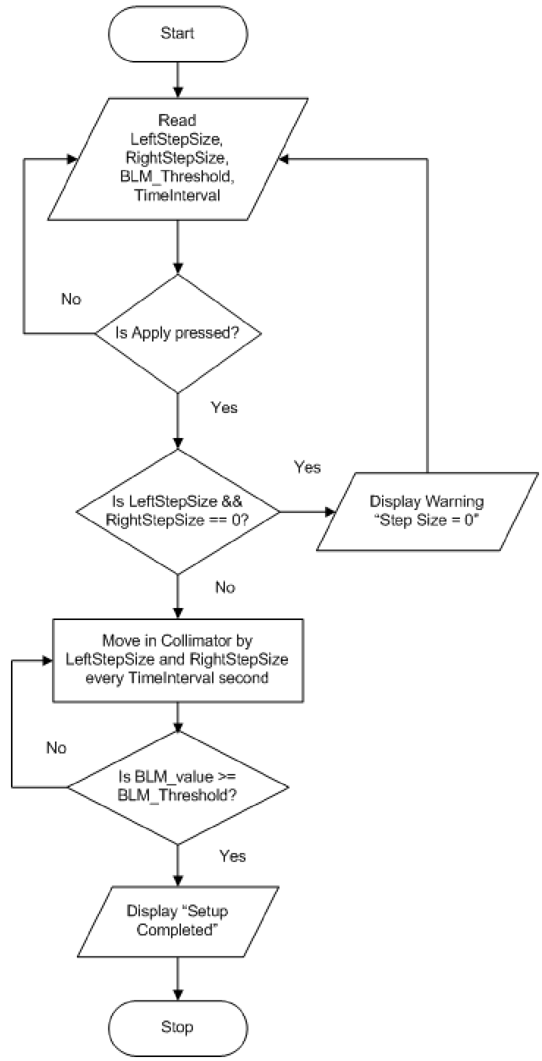

Figure 3: Semi- Automatic Algorithm Flowchart.

PARALLEL COLLIMATOR SETUP

Parallel collimator setup was developed in order to optimize the setup time, in which the user can select any number of collimators to be aligned in parallel to the beam. This means that the collimator jaw alignment algorithm discussed in the previous section is executed for each selected collimator. Currently, parallel collimator setup is used to provide a coarse but quick way of positioning a set of collimator jaws at a few micrometers from the beam, after which each collimator is finely aligned in sequence.

Parallel collimator setup was tested and commissioned during the collimator setup at 3.5 TeV flat top held in March 2011, as well as the 3.5 TeV setups after squeeze and during collisions on the 11th March 2011. During the testing of this technique, a cross-talk effect was observed, in which the loss patterns generated by a particular collimator were also being detected on other collimators around the LHC. This prevented the parallel setup method from functioning efficiently, and another algorithm was designed to identify which collimator jaw is at the beam.

The parallel setup optimizer algorithm uses a timer task to check whether any collimators have stopped moving. As soon as a single collimator stops moving due to an exceeded BLM threshold, another timer task is started to determine whether any other collimators also stop within a pre-defined time period (from experience set to 2 seconds). If this is the case, then all the other collimators moving in parallel are stopped so that the algorithm can concentrate only on the first collimators. These collimators are then moved in one by one depending on options set in the window in Fig. 4.

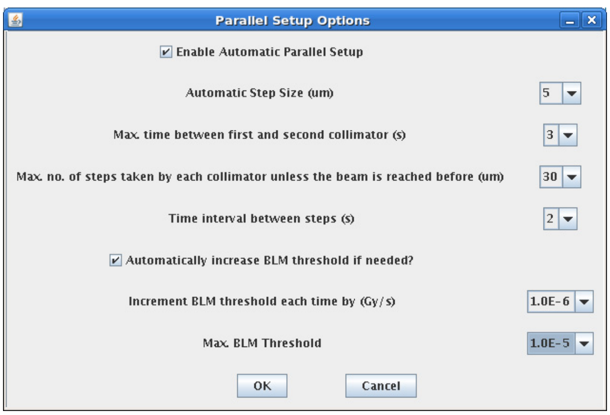

Figure 4: Parallel Collimator Setup Settings.

In case the BLM threshold set during the previous movement is now too low (i.e. the collimator cannot be moved in again by a single step), an option allows the user to instruct the program to automatically increase the BLM threshold in steps up to a maximum amount. If the threshold is exceeded after the second step or thereafter, the collimator jaw is declared to be aligned to the beam, and the algorithm terminates. A flowchart of the parallel collimator setup algorithm is shown in [8]. Testing was carried out during an LHC Machine Development (MD) time slot on the 2nd July 2011 and during a beam recovery period.

SETUP PARAMETERS

During the setups at 450 GeV and 3.5 TeV with semi-automatic alignment, it was necessary to change the algorithm inputs depending on the beam energy. For example, at injection energy step sizes of at least 20μm were required to be able to observe a significant loss spike, while at 3.5 TeV step sizes of 5μm to 10μm were sufficient.

A detailed comparison of the collimator setup performance with manual and semi-automatic alignment is given in [6]. With the latter method, a reduction in the setup time by a factors of around 1.5 and 5 in setup time at the "flat top" and "squeezed" modes was registered. Additionally, an elimination of setup-induced beam dumps shows that the usage of a BLM threshold as a stopping value for the semi-automatic algorithm is safe.

The BLM threshold is usually set to 1×10^{-6} Gy/s before any of the jaws of a particular collimator have touched the beam, and is then raised manually according to the "background" loss signal observed after each loss spike, up to a maximum value of 1×10^{-4} Gy/s. The period of the movement is initially set to 1 second, and is then increased to 2 or 3 seconds after the first loss spike. This caters for "loss spike overshoot", which occurs when losses continue to increase after the jaw movement has stopped. It is preferable to generate a significant loss spike, part of which is overshoot, with a single jaw movement than to cut further into the beam with multiple jaw movements.

CONCLUSION

The development and implementation of the semi-automatic algorithm is part of a phased transition from manual to fully automated collimator setup. Its achievements in decreasing the setup time and reducing the need for manual intervention has opened the door to fully automatic collimator setup. The use of a user-defined BLM threshold as a stopping value for the jaw alignment algorithm has proven to be safe and efficient in terms of collimator-triggered beam dumps and setup time.

FUTURE WORK

Pattern recognition of loss spikes to determine which loss patterns indicate that a jaw is aligned to the beam is currently ongoing. Future work will concentrate on the development of a collimator setup simulator, which would allow new algorithms to be tested offline.

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