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Beam feasibility study of a collimator with in-jaw beam position monitors

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ABSTRACT

At present, the beam-based alignment of the LHC collimators is performed by touching the beam halo with both jaws of each collimator. This method requires dedicated fills at low intensities that are done infrequently and makes this procedure time consuming. This limits the operational flexibility, in particular in the case of changes of optics and orbit configuration in the experimental regions. The performance of the LHC collimation system relies on the machine reproducibility and regular loss maps to validate the settings of the collimator jaws. To overcome these limitations and to allow a continuous monitoring of the beam position at the collimators, a design with jaw-integrated Beam Position Monitors (BPMs) was proposed and successfully tested with a prototype (mock-up) collimator in the CERN SPS. Extensive beam experiments allowed to determine the achievable accuracy of the jaw alignment for single and multi-turn operation. In this paper, the results of these experiments are discussed. The non-linear response of the BPMs is compared to the predictions from electromagnetic simulations. Finally, the measured alignment accuracy is compared to the one achieved with the present collimators in the LHC.

1. Introduction

To intercept unavoidable losses of particles from the beam halo that would otherwise risk to hit the superconducting magnets, the Large Hadron Collider (LHC) has a powerful collimation system with 44 movable collimators per beam [1–3]. Most collimators consist of two jaws, which can be moved independently, with the beam passing through the center of the jaws. Each jaw is called 'left' or 'right' depending on its position with respect to the beam when viewed from the upstream side of the collimator. For optimal performance, the jaws have to be centered around the local orbit. This has so far been done using a beam-based alignment procedure for each collimator [4], where each jaw is moved separately towards the beam until it starts intercepting the halo particles. This is verified by monitoring the signal of a nearby downstream beam loss monitor (BLM), which registers the secondary shower particles created by impacts on the collimator. For machine protection reasons, the alignment procedure requires dedicated fills at low intensities that are done infrequently because the procedure is time consuming [5]. The introduction of a semi-automatic set-up procedure and constant improvements in the algorithms allowed to significantly reduce the set-up time in 2011 and 2012 compared to the first manual set-up in 2010 [6,7]. When all collimators have been centered around the beam, the cleaning performance is verified by provoked losses to create a so-called 'beam loss map'. In subsequent high-intensity fills, the collimators are driven back to the previously found positions, relying on the machine reproducibility. This implies strict requirements on the long-term orbit stability, as the time-consuming setups cannot be performed too frequently. The excellent performance of the LHC collimation system during run 1 has recently been discussed in [8].

To overcome these limitations, a new collimator design with in-jaw beam position monitors (BPMs) was proposed. Four BPM pickups are installed at the extremities of each jaw to provide a measurement of the beam orbit at the upstream and downstream sides of the collimator. Beam tests were successfully carried out

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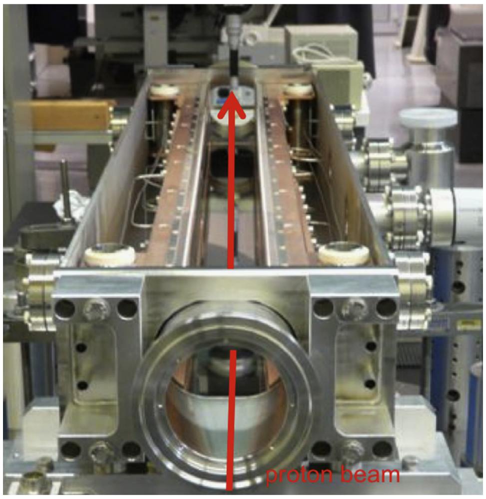

Fig. 1. Photograph of the prototype collimator from one end. The moveable jaws are centered around the beam path (red arrow) and enclosed by a 1.2 m long tank. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

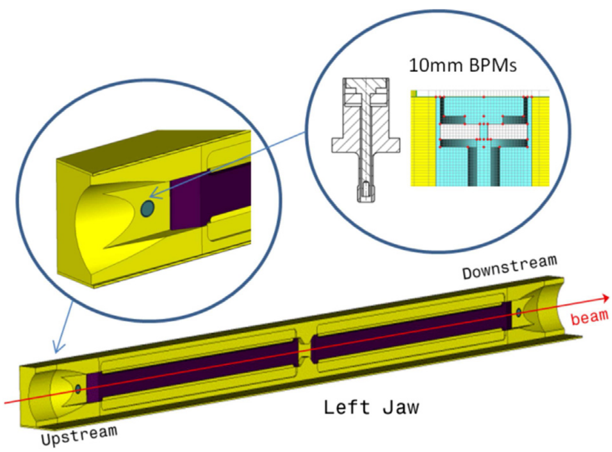

Fig. 2. A model of a single jaw of the prototype collimator with embedded BPM pick-ups at both ends.

with a mock-up collimator in the CERN Super Proton Synchrotron (SPS) [9,10]. Fig. 1 shows a photograph of the prototype collimator. The moveable jaws are centered around the beam path (red arrow) and enclosed by a 1.2 m long tank. A sketch of the mock-up jaw with the BPM pick-up buttons in the beginning (upstream) and end (downstream) of the jaw is depicted in Fig. 2. Fig. 3 shows a zoomed view of one BPM pick-up button in the upstream taper of the jaw during laboratory measurements of the button position with respect to the jaw surface.

A BPM-based alignment, where it is not necessary to touch the beam with the collimator jaws, would allow a fast and non-destructive beam-based collimator set-up, which would reduce the need for special fills with intensity constraints. In addition, it would allow to continuously monitor the beam offsets in the collimators with a much better resolution than is currently possible with the standard LHC BPMs, as the distance between the buttons and the beam would be much smaller and there would be no need to interpolate the orbit from the closest BPMs at the collimator location. The collimators could follow orbit drifts and therefore provide more flexibility for local orbit changes, which are regularly required around the experimental insertions. Measuring the beam offset at both ends of the collimator jaws will make it possible to position them fully parallel to the beam trajectory by introducing a longitudinal tilt angle to the jaws. For

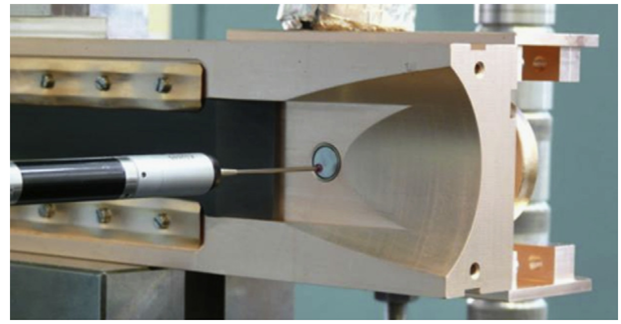

Fig. 3. Zoomed view of one BPM button in the upstream jaw taper during laboratory measurements of the button position with respect to the jaw surface [10].

the time being, the tilt angle of the jaws with respect to the beam can only be evaluated with long and detailed jaw scans and is hence only applied for the injection and dump protection collimators. Furthermore, the margins for orbit drifts between collimator families could possibly be reduced [11], which would eventually allow smaller beam sizes at the experimental interaction points (IPs) and lead to an increased luminosity of collisions.

This paper is structured as follows. Section 2 describes the BLM-based and BPM-based alignment techniques. This is followed by results from multi-turn and turn-by-turn beam measurements in Sections 3 and 4 respectively. Finally, the measurements are compared to simulations using an electromagnetic (EM) model in Section 5.

2. BEAM-based alignment

2.1. BLM-based alignment

The LHC collimators are currently aligned using feedback from the BLMs. Each jaw is moved separately to the beam on either side until the halo is touched, and the beam center is subsequently calculated as the average of the two aligned left and right jaw positions, J_L and J_R:

$$X_{beam} = \frac{J_L + J_R}{2} \tag{1}$$

Fig. 4 shows a typical BLM-based alignment with the mock-up collimator in the SPS. The jaws were moved in steps of 50 μm by means of two stepping motors installed at both extremities. The touching of the beam halo was recorded by a BLM installed about 50 cm downstream of the collimator. One jaw is considered to be aligned, if the signal of the BLM reaches $\sim 1 \times 10^{-6}$ Gy/s. This value may vary depending on the average losses without jaw movement, as a spike needs to be clearly distinguished from the background signal. This also defines the minimum step size. Note that in the LHC step sizes of 5–20 μm are used due to a better beam quality and higher particle energies. This technique unfortunately does not allow the alignment of the individual jaw corners.

2.2. BPM-based alignment

The mock-up collimator consists of two copper jaws and a 10 mm thick graphite layer on each jaw surface. The four stainless steel button electrodes of diameter 10.3 mm are placed at the upstream and downstream jaw extremities at 10.6 mm below the graphite surface. With such a setup, the total distance B between BPM electrodes, referred to as the *BPM aperture*, is $B = G + 2 \times 10.6$ mm, where G is the distance between the jaws in units of mm, referred to as the it jaw gap. According to [12], the coefficient of linear conversion