EXPERIMENTAL STUDIES OF BEAM COLLIMATION SYSTEM IN THE FERMILAB BOOSTER*

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Abstract

A two-stage collimation (2SC) system was installed in Fermilab Booster around 2004 and consists of 2 primary collimators (PrC), one for each of the horizontal and vertical planes and 3 secondary collimators (SC) each capable of acting in both planes. Presently, only SC are used as the single-stage collimation (1SC). Part of the Fermilab Proton Improvement Plan (PIP) includes a task to test 2SC for Booster operations. In this paper we describe preparatory steps to fix SC motion issues and installation of a 380μm thick aluminum foil PrC and post-processing software for beam orbit and beam loss measurements. The initial experimental results for 2SC in the vertical plane are also presented. The tuning of 2SC system was performed using fast loss monitors allowing much higher time-resolution than existing BLMs. Analysis of losses and beam transmission efficiency allow for the comparison of 1SC and 2SC schemes.

INTRODUCTION

The Fermilab Booster [1] is a 15Hz rapid cycling synchrotron which accelerates protons from 400 MeV to 8 GeV with the beam transmission efficiency of about 90%. Booster is made up primarily of combined function magnets and RF cavities, and it is divided into 24 equal-length periods. Approximately 10% of protons are lost during accelerating cycle; the majority of the protons are lost at the beginning of the cycle near injection energy.

The Proton Improvement Plan (PIP) [2], established in 2012, is aimed to increase the beam throughput while maintaining the present residual activation levels. One of 22 PIP tasks is a possible upgrade of the Booster colli-mation system installed in 2004 at its periods 5, 6 and 7.

The booster collimation system was designed as a two-stage collimation (2SC) system. However, this design was incompatible with frequent radial orbit variations inherent in the RF cogging scheme used in Booster until 2015. Therefore, the collimation system was used in a single stage (1SC) mode, while still ensuring a significant reduc-tion in Booster activation.

Implementation of new magnetic cogging in 2015 [3] - keeps the beam on a central orbit and creates conditions to use 2SC system. The principle aim of the 2SC system is the reduction of uncontrolled beam losses generated during multiturn injection, RF capture, creation of the extraction notch and enabling the control feedback. In this paper, the collimation effectiveness of the 2SC mode for the vertical plane is measured and compared with that of

the existing 1SC mode. The sum of all 64 BLMs in the Booster is used as a figure of merit in this evaluation.

BOOSTER COLLIMATION SCHEME

Each Booster period contains two horizontally focusing magnets (F) and two horizontally defocusing magnets (D) along with a 6.0-meter "long straight " section, a 1.2-meter "short straight" section, and a 0.5-meter short drift spaces between F and D magnets. The 2SC system was installed in the unused straight sections of periods 5, 6, and 7.

Figure 1 shows layout of the 2SC system, which consists of horizontal (H-prim) and vertical (V-prim) primary collimators located in the short drift spaces nearby of Short-5 and three identical 1.2 m-long secondary collimators (or absorbers) 6A, 6B, and 7A located in Long-6 and Long-7. Near the primary and secondary collimators beam position monitors (BPM), beam loss monitors (BLM) and fast loss monitors (FLM) [4,5] are used to evaluate the beam position, radiation rate and when the collimators intercept the beam tails.
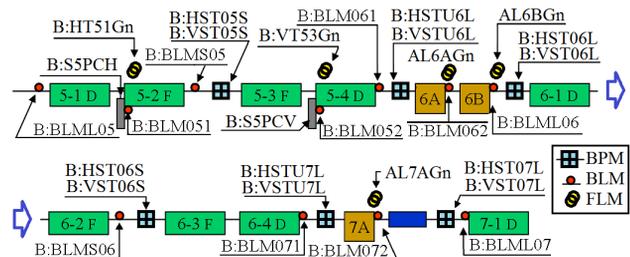

Figure 1: Layout of 2SC system in periods 5,6 and 7.

The primary collimators are movable thin scattering foils. The absorbers are movable steel cubes with square beam apertures. According to the 2004 original 2SC design [6,7] protons within 3σ are considered the beam core and the normalized 95%-emittance equal to 12π mm•mrad. For collimation in the vertical plane, collimators V-prim, 6B and 7A are used. V-prim is placed at the lower edge of the beam core. The jaws of the 6B and 7A collimators are positioned with a 2mm offset from the beam core, while the jaw of collimator 6B is located below the beam and the jaw of collimator 7A is located above the beam.

In 2015, improvements were made to realize the original design of the 2SC. These improvements include: design and installation of 0.380μm thick aluminum primary collimators [8,9] and improvements in the accuracy and reliability of the absorber motion.

4: Hadron Accelerators

T19 - Collimation

The purpose of the 2SC system is to localize proton losses at the secondary collimators, reducing irradiation of the rest of the machine to the acceptable levels. The collimation system should interact only with halo protons which are considered to be lost later in the accelerating cycle while preserving the beam transmission efficiency.

COLLIMATION TESTS

In the studies presented here, we consider only vertical collimation. The horizontal positions of collimators were unchanged during the study. Figure 2 shows the vertical collimator positions relative to the beam for 1SC. Note that all three absorbers are used in the 1SC mode.
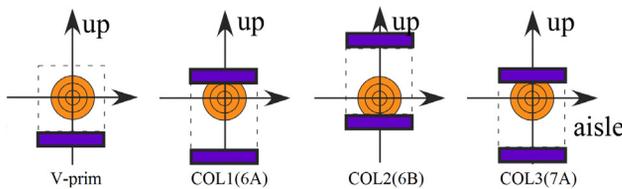

Figure 2: Transverse positions of collimator jaws at 1SC

Each collimator touches the beam from one side. Preparatory to the test, the vertical beam position throughout the entire accelerating cycle was arranged in such way that all collimators touch the beam at the beginning of the cycle (approximately 300 turns). During these studies, the vertical beam position at the collimators was observed to vary no more than 0.5mm from cycle to cycle. Losses were recorded around the booster both before and after the 2SC tests for comparison.

Below is an outline of the collimation optimization procedure. An increase in FLM rate (gated for 100μs around injection) indicates when collimator is touching the beam core.

1) Move 6A, 7A out of beam vertically.
2) Move V-PRIM in to touch beam edge
3) Move 6B in to intercept (touch) scattered beam
4) Move 7A in to intercept (touch) scattered beam (opposite side).
5) Small adjustments to ensure optimization (monitoring booster efficiency).

Figure 3 shows the configuration of the 2SC system at optimization. Absorbers only touch the beam core, while V-prim intercepts the beam.
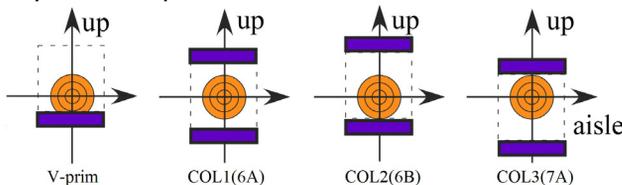

Figure 3: Transverse positions of collimator jaws at 2SC.

Figure 4 shows the collimator positions and booster beam transmission efficiency as a function of time in the study. The letters indicate points when the losses from the BLMs were recorded around the booster. Points A, B and L indicate routine 1SC with all 3 absorbers used. Points C and D indicate 1SC with a single absorber (6B). Points J-K represents the optimized 2SC.
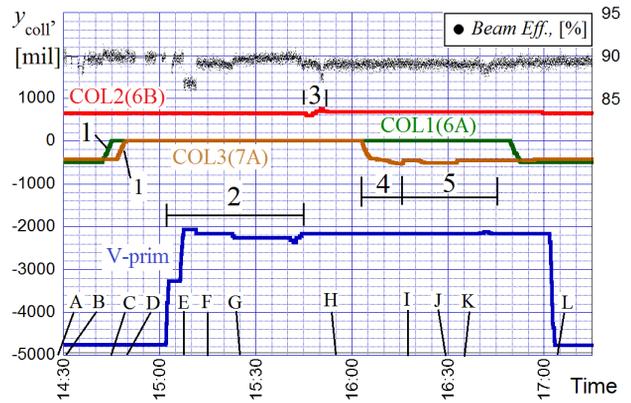
Figure 4: Vertical collimator positions (left scale) and the Booster beam transfer efficiency (right scale) vs time.

Figure 5 shows the BLM readings for the sum of all 64 BLMs in the booster normalized to give fractions of the radiation trip points.
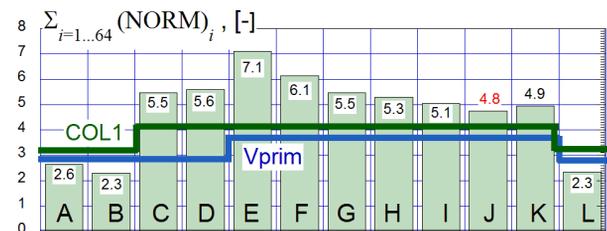

Figure 5: Normalized BLMs values summed over 64 BLMs around the ring at the different time points.

The relative lengths of the vertical bars in Figure 5 allow us to compare the effectiveness of 2SC and 1SC modes. For example, the BLMs sum for the 1SC with single absorber (point D) is 5.6, while for the optimized 2SC (point J) is 4.8. It can be concluded that the optimized 2SC reduces the BLMs sum by 14% in comparison to the 1SC with single absorber. Details of such improvement are illustrated in Figure 6, which shows normalized BLMs values around the ring.
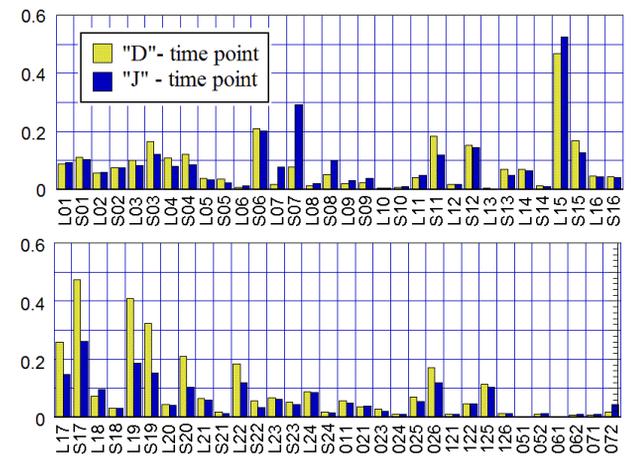

Figure 6: Normalized BLMs values around the ring for time points "D" and "J".

One can see the radiation is reduced at BLMs in Booster sections S03, L04, S04, S11, S15, L17, S17, L19, S2, L22. However, the radiation is increased in sections S07 and L15. Note, that L15 contains an RF cavity which represents an aperture restriction.

On the other hand, the BLMs sum for routine 1SC with three absorbers (point B) is equal to 2.3, which is about twice lower than one for the optimized 2SC (points J or K). Figures 7 and 8 show the screen snapshots of data available in the Fermilab Main Control Room for the time points B and K.
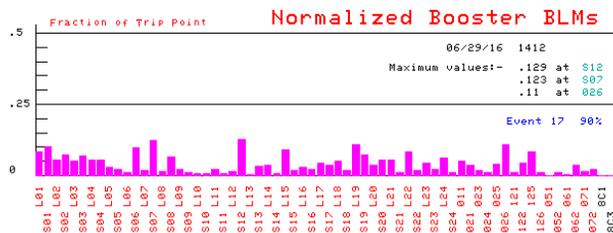

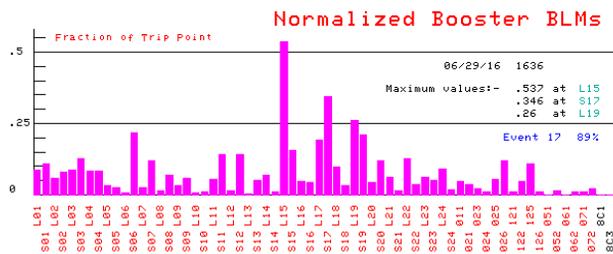Figure 7: The fraction of trip points for time point B.

Figure 8: The fraction of trip points for time point K.

The above plots clearly demonstrate that the optimized 2SC has increased radiation levels for most BLMs around the Booster and is less effective than the routine 1SC using all 3 absorbers. Additional details of these studies may be found in ref. [10].

CONCUSIONS

The results of the tests for the Booster collimation system presented here suggest that in the vertical plane:

1) the beam orbit patterns within accelerating cycle were stable within 0.5mm during all test time (~2.5hr);

2) the vertical 2SC is operational and showed an improvement by 14% compared to 1SC using a single absorber;

3) compared with vertical routine 1SC, 2SC is less effective by a factor of ~2.

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