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NEW SHAVING SCHEME FOR LOW-INTENSITY BEAMS IN THE CERN PS BOOSTER AND FEASIBILITY AT 160 MeV

M. Kowalska, CERN, Geneva, Switzerland, EPFL, Lausanne, Switzerland
E. Benedetto, CERN, Geneva, Switzerland
V. Forte, CERN, Geneva, Switzerland, Université Blaise Pascal, Clermont-Ferrand, France
B. Mikulec, G. Rumolo, CERN, Geneva, Switzerland

Abstract

The PS Booster (PSB) is the first synchrotron in the CERN proton accelerator chain, serving all downstream machines. As part of the LHC Injector Upgrade (LIU) Project, the PSB injection energy will increase from 50 MeV to 160 MeV and a new H^- charge-exchange injection scheme will be implemented. Beam losses are a concern due to the increased injection energy, and mitigation scenarios are under investigation.

On the other hand it is desirable for low-intensity beams to have the possibility to precisely tailor sub-micron beam emittances through controlled scraping (transverse shaving process) towards a suitable aperture restriction. Challenges are the higher activation potential of the beam and the smaller transverse beam sizes around 160 MeV as compared to 63 MeV, at which the shaving is presently done.

This paper describes the proposal of a new shaving scheme, more robust with respect to the steering errors and the choice of the working point, which localizes the scraping losses on the main PS Booster aperture restriction. The robustness of the new method, together with the results of simulations and measurements are discussed for the current (50 MeV) and future (160 MeV) situation.

INTRODUCTION

Shaving is presently the main method to control the beam emittance and beam intensity in the PS Booster. The beam is supposed to be scraped on the aperture restriction of the machine, located in period 8 – called Window Beam Scope (WBS) [1]. It is a carbon, 40 mm thick absorber. Its physical dimensions are: 28.6 mm and 50 mm in the vertical and horizontal plane, respectively.

The global aperture limitations in the lattice are built by the quadrupoles in the horizontal plane (57 mm) and at the scrapers that protect the dipoles in the vertical plane (29.7 mm). A small difference between the dipoles aperture and the WBS aperture makes the vertical place fragile for any uncontrolled orbit perturbation or variation of working point with respect to the nominal one while shaving. Figure 1 is an example of an unsuccessful shaving due to the introduced closed orbit error.

The current shaving method, which consists in inducing closed orbit oscillations by a single kick (Figure 1), causes losses around the machine. In order to localize the losses at the PS Booster aperture restriction – Window Beam Scope (WBS), a new shaving scheme based on a closed bump was proposed and tested.

The closed bump scenario was first studied in simulations and then tested during the 2014 machine run. Dedicated measurements were performed in order to investigate the robustness of the method. Measurements of intensity, beam profiles and orbit excursion were made for both scenarios: at the future, foreseen upgraded injection energy - 160 MeV - and for the existing operational situation, at 63 MeV, when shaving occurs.

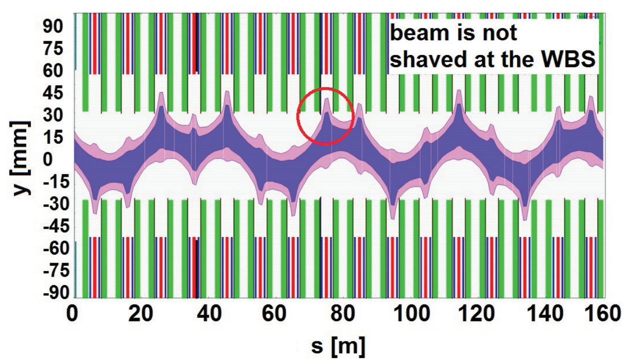

Figure 1: Lattice of the PSB and the illustration of the 3 sigma beam while conventional shaving. The 3-sigma beam is plotted in violet while 5 sigma is in magenta. The beam envelope is calculated for the vertical plane, with $Q_x = 4.37$ and $Q_y = 4.45$. Main lattice elements are shown in different colours: bending magnets in green, focusing quadrupoles in blue and defocusing quadrupoles in red. The scrapers are marked in maroon and WBS with the red circle.

EXISTING SITUATION IN OPERATION

Currently, operational shaving is performed by inducing a closed orbit global oscillation (Figure 1), using a single kick either in the horizontal or in the vertical plane. The vertical plane is preferred, mostly due to the absence of the dispersion and higher stability of the beam envelope in this plane. Closed orbit distortion (COD), induced during the shaving, depends strongly on the applied kick strength [2], which is adjusted independently for each type of the shaved beam. Moreover the shaving with the single kick is very sensitive to the working point and to steering errors.

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PROPOSED SOLUTION

In order to increase the reliability of the shaving, a new method, consisting in creating a closed bump at the aperture restriction, was studied. First evidences come from the preliminary MAD-X studies, where the independence of the working point for the new scheme was shown. The tunes, used in these studies, were extracted from the OP documentation [3] and are Q_x = 4.37 and Q_y = 4.45. Beam parameters were assumed as presented in Table 1.

Table 1: Beam Characteristics

Parameter	Unit	Value
Shaving energy current/future	MeV	63/160
Maximum momentum spread δp/p (1 σ rms)		$1 \cdot 10^{-3}$
Initial intensity	p+	$170 \cdot 10^{10}$
Normalised H/V initial emittance (1 σ rms)	π.mm.mrad	2.5/2.5
Target intensity	P+	$40 \cdot 10^{10}$
Target normalized H/V emittance	π.mm.mrad	1.05/1.15
Shaving tune	n/a	4.37/4.45

Figure 2 shows the MADX simulated closed orbit in both cases: for the current shaving and the proposed closed bump solution. A closed bump is created using the two kickers: DBSV7 and DBSV9. They were used in the past for emittance measurements [4,5] at high (1 GeV) energy, so their performance at low current (around 5% of the nominal current) was under investigation. Measurements showed that the kickers are able to work in the low energy regime.

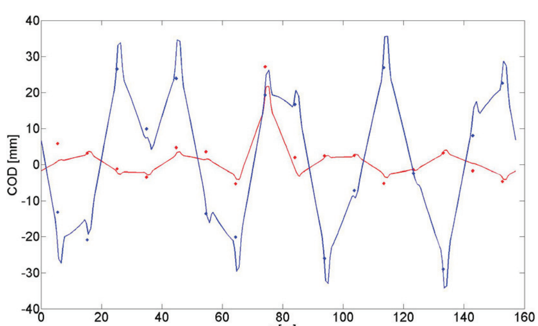

Figure 2: Simulated (continuous line) and measured (points) vertical closed orbit distortion in the machine. The operational shaving is marked in blue colour and the proposed new shaving scheme in red colour.

The maximum remaining orbit distortion (22 mm) is foreseen to occur downstream of the WBS, at the PSB quadrupole triplet (Figure 2). The lattice sequence allows to accommodate such an orbit excursion due to the big quadrupole yoke. Hence, the losses are foreseen to accumulate at the aperture restriction in period 8.

Second, simulations with the PTC-ORBIT code [6] were launched, for 500 000 macro particles, including space charge effects and the dynamic machine model. Since it proved to be robust and feasible, the new scheme was tested in operation.

Simulation Results

The PTC-ORBIT simulations confirmed the advantages of the new shaving scheme over the one that is currently in operation. For both cases, 50 MeV and 160 MeV, losses are localized mostly at the WBS. In case of the current shaving, the hot spot is located in period 10 (Figure 3), due to the local aperture limitation in conjunction with a big orbit excursion. 98% of the losses are concentrated at the bending magnet of period 10, while in case of the closed bump, losses accumulate (95%) at the Window Beam Scope and only a few percent of the beam is lost downstream of the aperture restriction.

The loss pattern for both scenarios is shown in Figure 3. Thanks to new shaving scheme, losses are foreseen to be localized in period 8, which is also proposed to accommodate the future PS Booster collimation system.

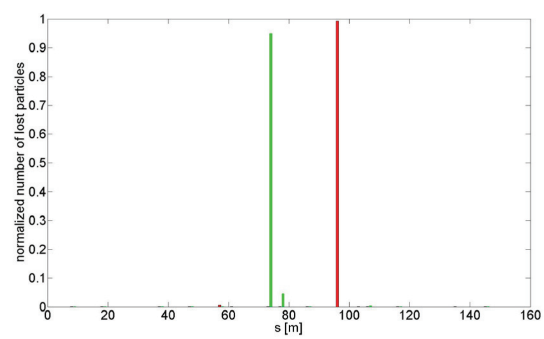

Figure 3: Simulated losses in the machine at 63 MeV for the current situation (red colour) and the proposed new shaving scheme (green colour).

Independence of the working point during shaving was proved in the range of current machine tune values used in operation. The shaving efficiency while varying the tune was studied. Qy was changed from 4.49 to 4.2 and the closed orbit excursion was observed. For all cases, the beam loss was localized at the WBS, also independently of the applied magnet misalignments and field errors. The promising results of the MAD-X and PTC-ORBIT simulations were a good motivation for the 2014 measurements.

Measurements at 63 MeV

Shaving measurements were made during the 2014 PS Booster run. In order to study shaving for operational purposes, a clone of a PSB beam, which undergoes the intensity tailoring – EASTA, was used. The goal of the measurements was first to study the existing shaving in operation and second to reproduce it with the DBSV7 and

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DBSV9 kickers. During the experiment, the intensity, emittances and orbit were measured.

DBSV7 and DBSV9 kickers were ramped in parallel with steps of 0.1 A from 2.8 A up to 3.2 A and the intensity evolution was registered for each step. Since the EASTA beam has a safety threshold of 40 e10 p+, its parameters must be well controlled. In Figure 4 one can observe the intensity drop, due to the shaving occurring at 305 ms for different currents. The method was proved to be easily adjustable and flexible in terms of the final emittance values and intensity level while varying the kicker strength, as shown also in Figure 4.

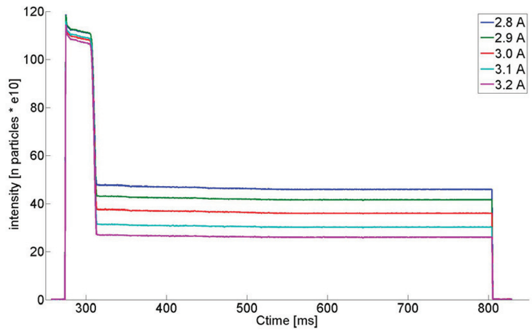

Figure 4: Intensity versus time in the cycle for different shaving currents set on DBSV7 and DBSV9.

Figure 2 shows closed orbit excursions measured with the set of 16 BPMs (Beam Position Monitors), marked as points. The maximum orbit excursion was detected in period 14, as predicted in the simulations, which included the misalignment and field errors. Looking at each BPM the signal along the cycle, it was proved that the distortion introduced in the closed bump method is immediately dumped and remains negligible in the downstream periods (red curve in Figure 5). The oscillation induced by the traditional method (blue curve in Figure 5) continues along the machine as long as the shaving lasts (up to t=350 ms). Figure 5 shows the signal from BPMs placed in consecutive periods 8, 9 and 10.

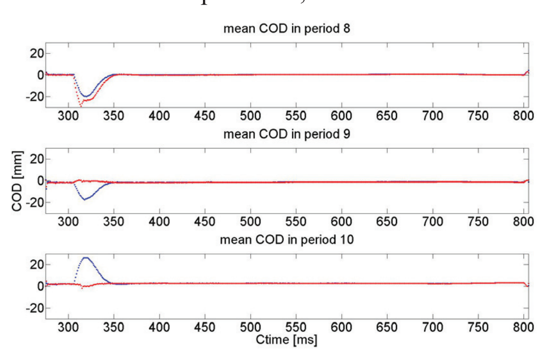

Figure 5: Measured COD in period 8, 9 and 10 for the two shaving methods: conventional one marked in blue and new, studied method, using a closed bump in red.

Measurements at 160 MeV

One of the requests for the shaving at around the future 160 MeV LIU injection energy is the possibility to tailor the beam to the micron emittances. A dedicated beam, accelerated up to a 160 MeV flat top, was used in this experiment. By creating a closed bump, the beam was shaved and its emittance was calculated using the measured data coming for the PSB wire scanner. Again, intensity, emittances and closed orbit excursion were tracked for the different currents in the range of 0.5 up to 6A (with a step of 0.5A) at DBSV7 and DBSV9, ramped simultaneously.

The feasibility of the new shaving method was checked for the upgraded scenario and the robustness of the method was also proved at this energy. In particular tailoring the beam to 1 µm rms emittance was confirmed to be achievable, with shaving in the vertical plane, and the results are plotted in the Figure 6.

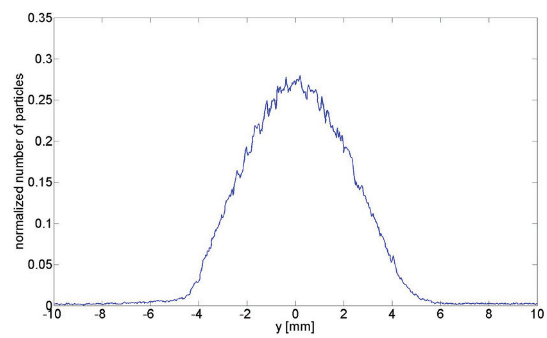

Figure 6: Vertical measured profile after shaving at 160 MeV. The 1σ beam profile was calculated to be 2.25 mm, giving a normalized emittance of 0.8 µm.

CONCLUSIONS

A new "shaving" scheme, to precisely tailor the beam intensity and transverse emittance was proposed for the PS Booster. Changes are planned to be integrated in operation and are foreseen to be maintained for the upgraded scenario.

The method was studied and proved to be robust with respect to the working point as well as to the steering errors. For both the present and the future LIU shaving energies, the appropriate measurements were performed and confirmed the feasibility and tunability of the new scheme.

Further studies are planned in autumn 2015 once the new PSB Beam Loss Monitor system becomes operational, as it will allow to precisely localize and quantify turn-by-turn losses. Studies of the tail repopulation, after shaving the beam, are also foreseen for the 2015 run.

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