Characterization of linear and non-linear optics in the CERN PS Booster

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Introduction

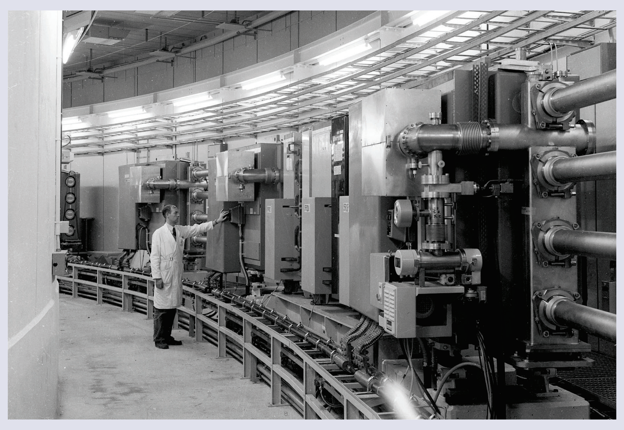
Motivation

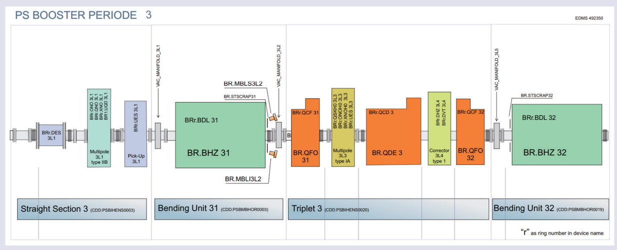
Planned high-luminosity operations at CERN will require the PS Booster to deliver higher intensity beam with a maximum of 5% allowable beam loss and emittance increase [1]. At higher intensity increased space charge forces will cause a larger tune spread, making it more difficult to find a working point that avoids all resonances that could cause beam loss. The goal of my work is to measure both linear and nonlinear optics, determine the distribution of errors around the ring, and compensate for higher-order resonances to improve beam stability.

		$N(10^{11})$	$\epsilon(\mu m)$	$E(GeV)$
Post-LS1	50*ns*	12.4/11.8	1.4/1.5	0.05/1.4
Post-LS1	25*ns*	17-22/16-21	2.1-2.6/2.2-2.8	0.05/1.4
Post-LS2	50*ns*	12.5/11.8	0.8/0.9	0.16/2.0
Post-LS2	25*ns*	24.9/23.6	1.7/1.7	0.16/2.0
HL-LHC	50*ns*	27.2/25.9	1.9/2.0	0.16/2.0
HL-LHC	25*ns*	34.2/32.5	1.5/1.6	0.16/2.0

Table 1. Desired beam parameters in the PSB at injection and extraction. Hi-Lumi LHC operations will require increasing the intensity by a factor of two while maintaining a maximum of 5% beam loss and emittance increase.

The PS Booster





- First synchrotron in the chain of accelerators that provides beam for the LHC
- Accelerates beam from 50 MeV to 1.4 GeV in about 530 milliseconds
- Composed of four vertically stacked rings, each with a sixteen period F-D-F triplet structure
- Working point: Qx≈4.2, Qy≈4.3 (betatron phase advance between periods ≈ $\pi/2$)

Linear optics from orbit response

Overview

Measurement and analysis of closed orbit response using Linear Optics from Closed Orbits (LOCO) technique [2] will allow for identification of linear optics perturbations and determination of the distribution of focusing errors in the machine.

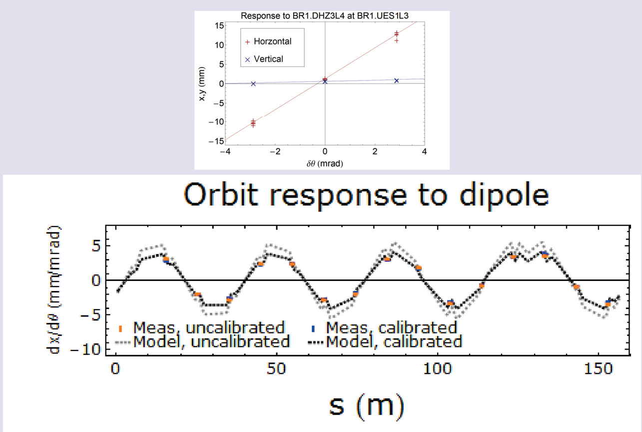


Figure 1. Comparison of measured and MADX model orbit response before and after LOCO model calibration.

- Change in closed orbit at all of i beam position monitors due to perturbation of each of j dipole correctors is measured.
- Dependence of model orbit response on a chosen set of variable parameters (quadrupole strength errors and tilts, corrector dipole and bpm calibration and tilt) is calculated to solve for values that minimize the difference between measurement and model.

$$\chi^2 = \sum_{i,j} \frac{1}{\sigma_{ij}^2} \left(\left(\frac{\partial x_i}{\partial \theta_j} \right)_{meas} - \left(\frac{\partial x_i}{\partial \theta_j} \right)_{model} \right)^2 + \sum_q (w_q \Delta K_q)^2 \qquad (1)$$

Eq. 1: Function minimized to solve for variable model parameters; i is the BPM index, j is the dipole corrector index, σ_{ij} is the standard error of the linear fit, ΔK_q is the change to the q^{th} parameter, and w_q is a weighting factor for the q^{th} parameter [3]. The second term constrains parameter excursions, without which the optimization gives unrealistically large values for quadrupole errors in the PSB.

Preliminary results

- We completed full orbit response and dispersion measurements on all four rings before LS1.
- An initial analysis has been done for all rings; study of methods to improve fit results is ongoing.

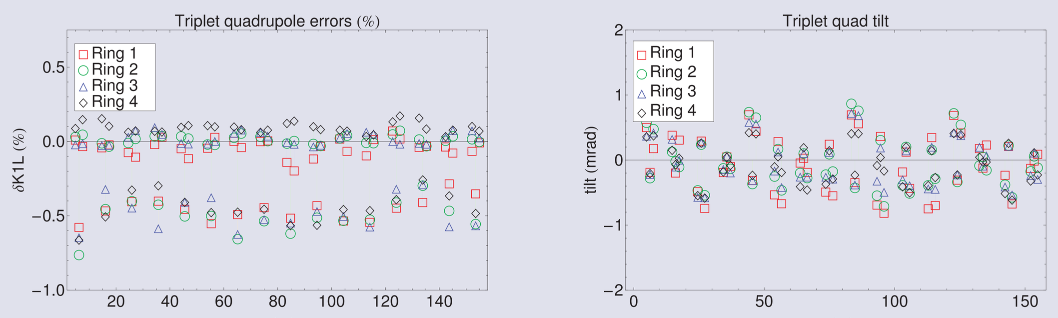


Figure 2. Strength and tilt errors of triplet quadrupoles found from LOCO analysis.

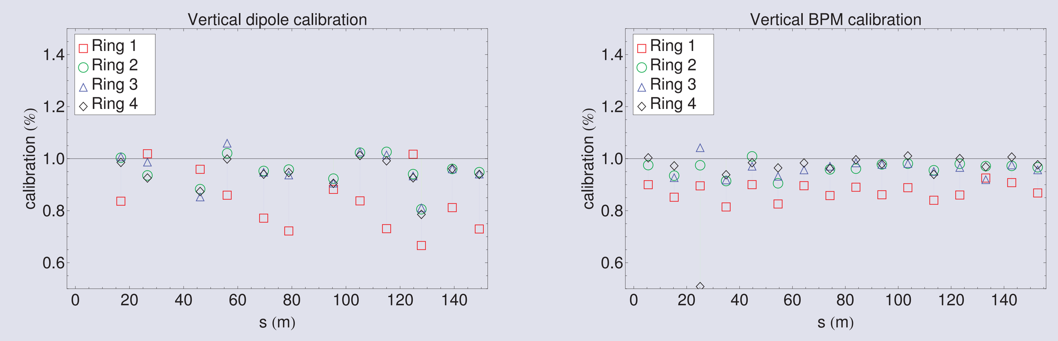


Figure 3. Strength and tilt errors of vertical dipoles found from LOCO analysis.

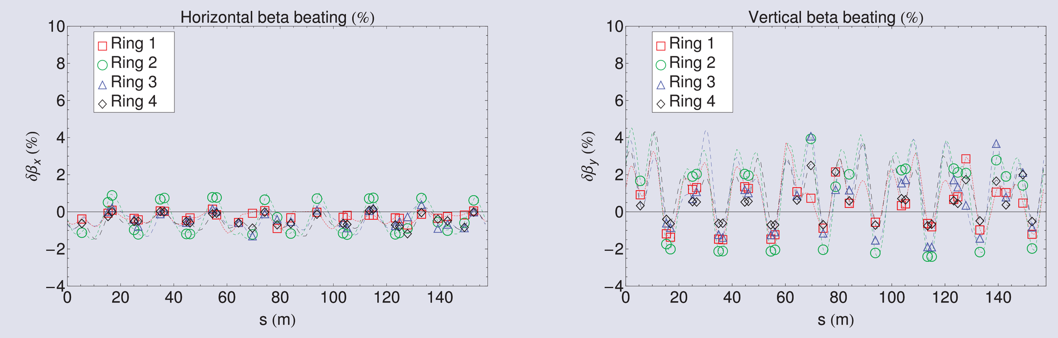


Figure 4. Horizontal and vertical beta beating from calibrated MADX model.

Nonlinear optics from coherent oscillations

Overview

Measurement and analysis of turn-by-turn oscillations will allow for identification and compensation of higher-order resonances.

- The strength of higher-order resonance driving terms can be found from spectral analysis of beam oscillations around the ring.
- These resonances can then be corrected with multipole corrector magnets, reducing beam loss and emittance blowup.

Commissioning status

- Three bpms were capable of acquiring turn-by-turn beam position for pre-LS1 studies; the rest will be commissioned during LS1 [4].
- Trial measurements were made using various means for creating a large transverse oscillation, including causing free oscillations with a tune kicker and driving oscillations with the transverse damper.
- Full measurements will begin after LS1.

Preliminary results

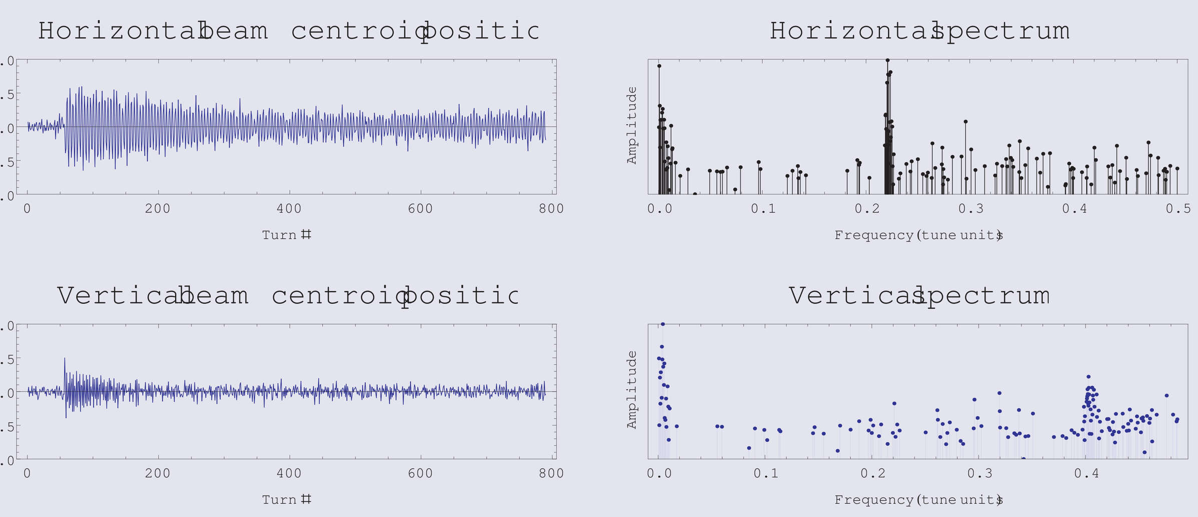


Figure 5. Measurement of transverse turn-by-turn beam position after excitation with a tune kicker, and frequency spectrum of oscillations.

Conclusions

The preliminary analysis of orbit response data in the PS Booster suggests beta beating of only about two percent in the horizontal plane and about six percent in the vertical plane, but the lattice errors found by this fitting method are sensitive to the choice of constraints. While preliminary values for machine errors are reasonably consistent with recent surveying data, studies to fully understand the effects of constraint methods on the solution and to determine the distribution of errors around the ring are ongoing
The initial test of turn-by-turn measurements for determination of higher-order resonance driving terms has been promising. With ideal beam conditions the noise level is below the requested limit of 100 μm, and hardware modifications are underway to allow for precise measurements under normal operating conditions. More effective methods of exciting the beam are still being investigated to improve the signal-to-noise ratio for oscillation measurements. We expect to be ready to perform a full set of resonance driving terms measurements shortly after the end of LS1.

Acknowledgments

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References

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