

PAUL SCHERRER INSTITUT 	Project SLS 2.0
Title SLS booster fast head-tail instability characterization and cure	Document identification SLS2-KJ81-002-1
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1 Introduction

During booster studies in 2019, a strong correlation between the vertical position jitter, beam size increase and the bunch charge was found on the ABRDI-SM-2 and ABRDI-SM-3 screen monitors in the booster to ring transfer line. As the bunch charge was increased, the vertical jitter was increase. Some jitter growth was also observed in horizontal plane, however seemingly significantly stronger in the vertical plane. It was then estimated that the introduced jitter was could be an issue for the injection into the SLS 2.0 storage ring due to the tight injection constraints.

During 2020, an effort was put into improving the beam coming from the booster. One of the action areas was the minimization of the vertical emittances: vertical closed-orbit offsets in sextupoles lead to transverse coupling. Since no orbit control is possible (at the time of this document) and due to all dipole magnets having a sextupole component together with all regular sextupoles, it was estimated that the largest contribution to the transverse coupling in the booster (measured to be $|C| \approx 0.02$) was due to the vertical orbit offset in these magnets. Evidently, a minimization of the vertical orbit in sextupoles could lead to a minimization of the vertical beam size. The vertical beam size was minimized by performing closed orbit bumps everywhere around the ring, recording the vertical beam size on the ABRDI-SM-2 screen monitor. Consequently, it was possible to reduce the vertical beam size from $\approx 370\mu\text{m}$ to $\approx 180\mu\text{m}$ together with an approximately factor 10 decrease in $|C|$. For details, see [1]

2 Observation of instability and beam loss

However, together with the minimization came a stronger beam position and blow up, see Fig. 1 and 2. At the nominal operation bunch charge of $\approx 180\text{pC}$ the beam would be lost during the ramp. After consulting with Lukas Stingelin, it was suggested that the beam instability could be a fast head-tail instability. During initial booster commissioning, a similar instability was observed by Marc Munoz and reported in [2]. Back then, the instability was observed before any of the two regular sextupole families were excited. This was somewhat expected based on calculations by Munoz suggesting that eddy currents induced in the dipole magnets would introduce negative chromaticity [3]. The instability was cured by ramping the sextupoles such that the chromaticities should be $[\xi_x, \xi_y] \approx (+5, +5)$ according to simulations.

To confirm that the chromaticity was as expected, we measured it at the end of the booster ramp by changing the rf frequency $\pm 2\text{kHz}$ around the operational rf frequency while measuring the tunes. The chromaticity is

$$\delta Q = \xi \frac{\Delta P}{P} = -\frac{\xi}{\alpha_c} \frac{\Delta f}{f_{rf}}, \quad (1)$$

where we assume the design momentum compaction of the booster $\alpha_c = 0.005$. Since there is no working automatized tune measurement in the SLS booster, we simply kick the beam using the extraction kicker set to

a current of ≈ 100 A. The betatron oscillations are measured using the turn-by-turn data from one of more of the working BPMs in the booster. The transverse coupling of the beam (or rotation of the extraction kicker) allows for enough vertical betatron oscillation that the vertical tunes can also be measured. See Fig. 3 for measurements of the tune variation as a function of the energy spread. Surprisingly, the chromaticity was found to be $[\xi_x, \xi_y] \approx (+7.9, -2.1)$; the negative vertical chromaticity could indeed be the issue.

The calculations by Munoz was redone (assuming correctness of the equations) and found to be consistent with the ramp patterns of the sextupoles. To create positive vertical chromaticity, the SD sextupole family current was increased from ≈ -2.4 A to ≈ -4.4 A at the end of the ramp, see Fig. 4. After this adjustment, the chromaticities were found to be $[\xi_x, \xi_y] = (+5.5, +4.8)$. A simple comparison between the beam sizes and jitter on the ABRDI-SM-2 screen monitor with the old and new SD ramp is given on Fig. 5. Both beams has a vertical beam size of $\approx 180 \mu\text{m}$ at the lowest beam current. Clearly, the instability has been cured. The measurement of Fig. 5 was limited in bunch charge by the linac. If more charge can be injected in the future, it would be interesting to see if some instability onset will be seen at significantly higher charges. The small increase in horizontal and vertical beam size is thought to be use to saturation effects of the YAG screen used for the measurements.

The reason for the negative chromaticity in the first place is yet unknown, since the ramp patterns used was based on the calculations on Munoz. However, one could imagine that the hard-edge model of the booster dipoles used for modeling the lattice is not accurate, see e.g. [4, 5].

Note that the chromaticity measurements presented here were done without using the vertical beam size minimization; the negative chromaticity is not a consequence of the minimization, but the instability becomes stronger due to the minimization. We believe that this is due to the decoupling of the transverse planes. High coupling might have a stabilizing effect on the instability.

References

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SLS note: SLS2-KJ81-001-1_booster_vert.beamsize
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- [5] I. Martin, "Open questions for the Diamond-II booster", presented at ESLS'20, http://www.esrf.eu/files/live/sites/www/files/events/conferences/2020/28th%20ESLS%20Workshop/MARTIN_DII_Booster.pptx

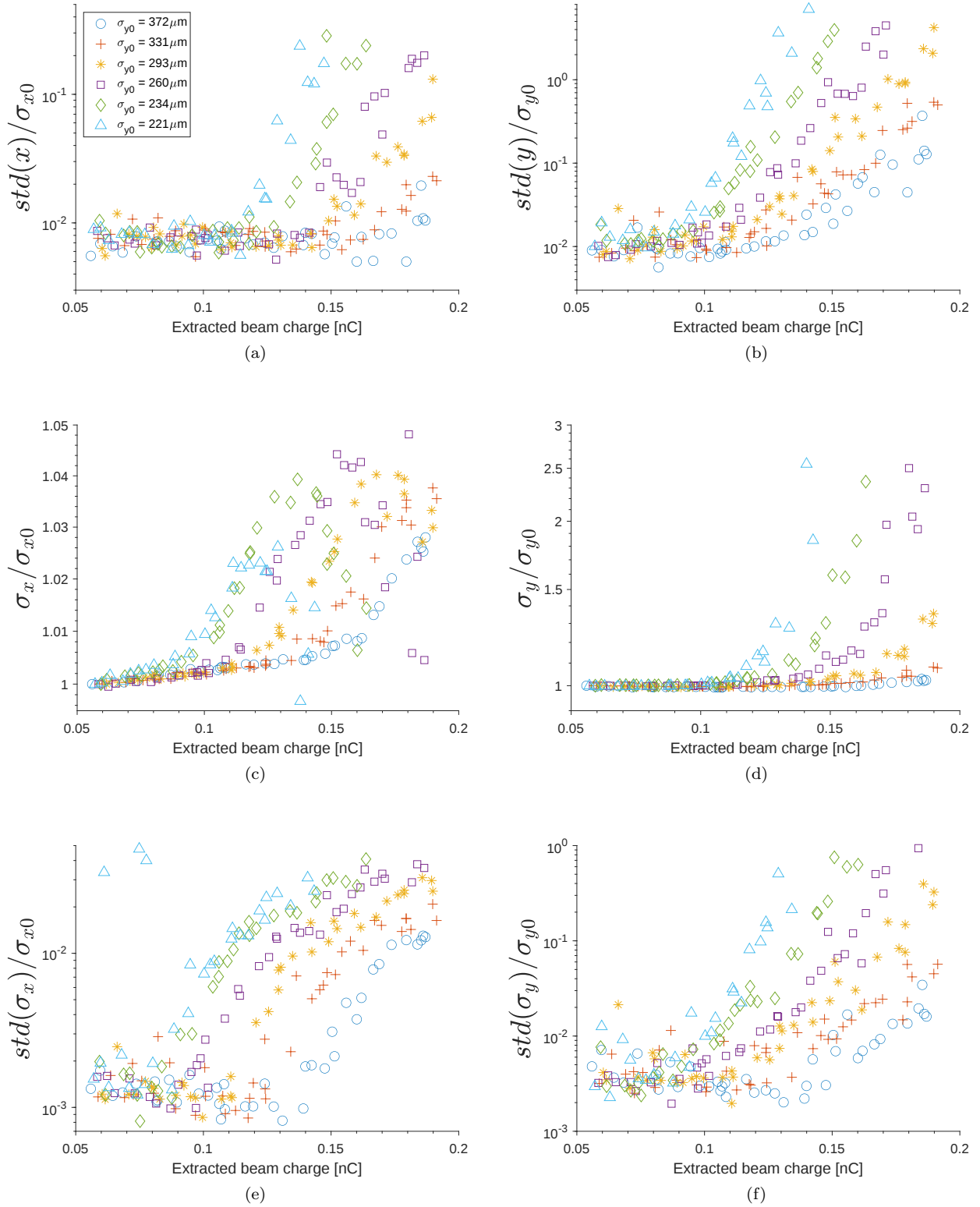


Figure 1: Beam sizes and jitter measured on the ABRDI-SM-2 screen monitor with different vertical beam size minimizations, using the old SD sextupole family ramp.

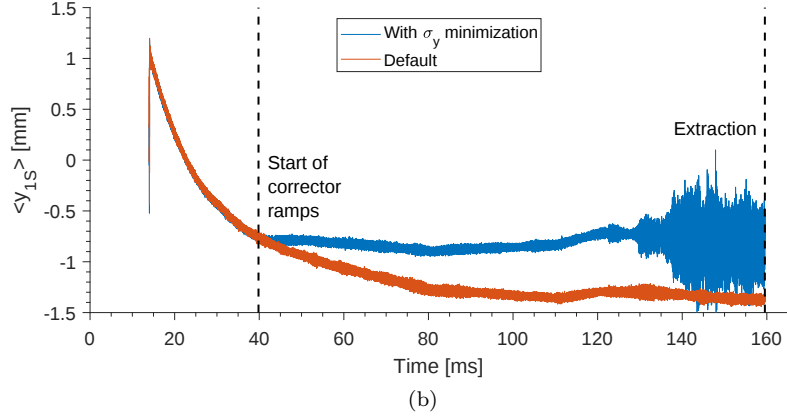
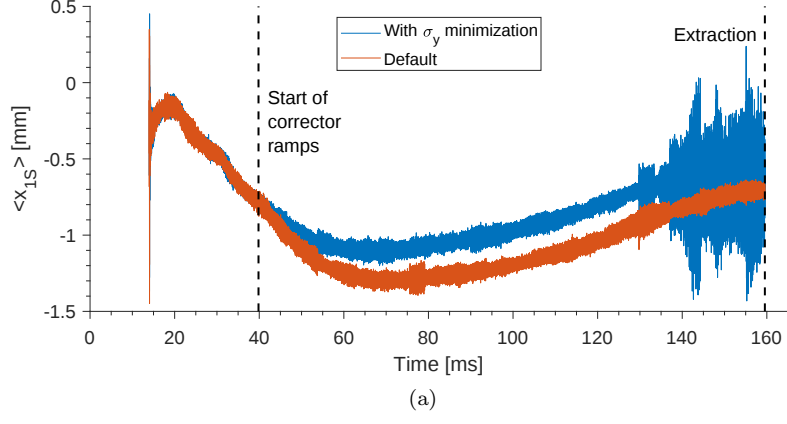


Figure 2: Averaged turn-by-turn data along the whole booster ramp measured on the ABODI-BPM-1S beam position monitor. The instability is observed to generally start around 30 ms before extraction.

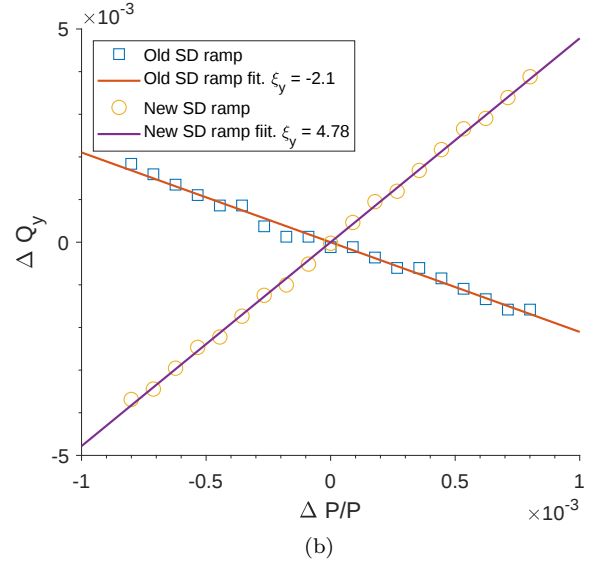
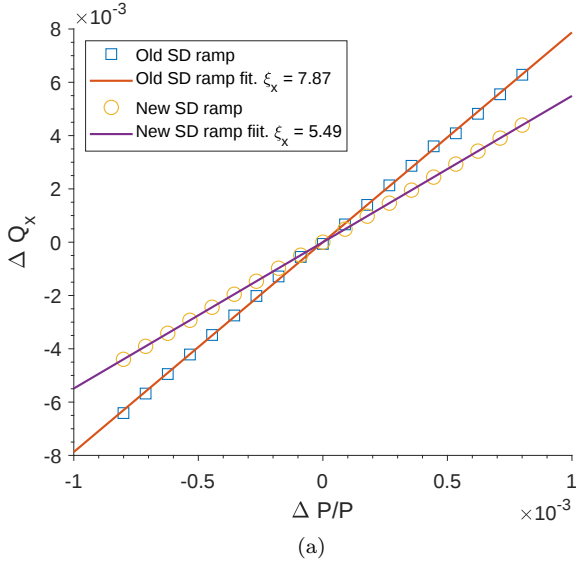


Figure 3: Chromaticity measurements at the end of the booster ramp with the old and new magnetic ramps for the SD sextupole family. The modified ramp leads to a change in chromaticity $[\xi_x, \xi_y] = (+7.9, -2.1) \Rightarrow (+5.5, +4.8)$.

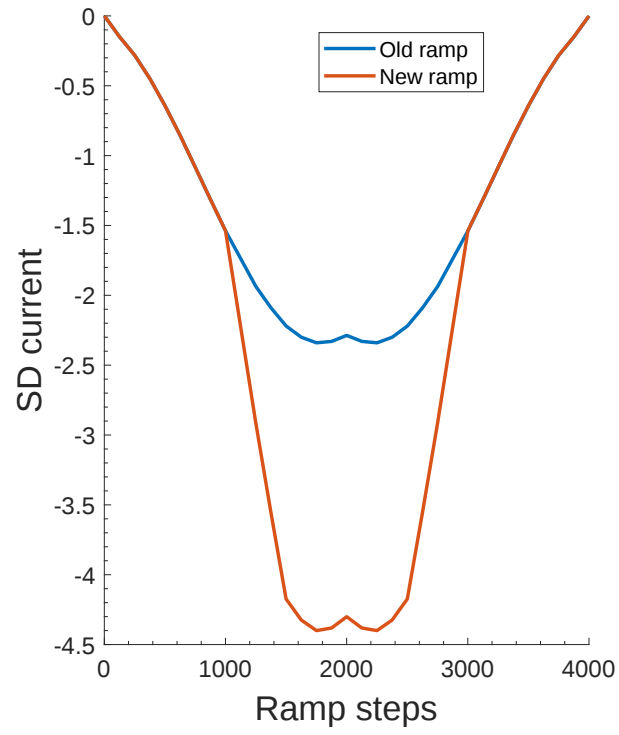


Figure 4: Old and new SD sextupole family ramps leading to a change in chromaticity at the end of the ramp of $[\xi_x, \xi_y] = (+7.9, -2.1) \Rightarrow (+5.5, +4.8)$.

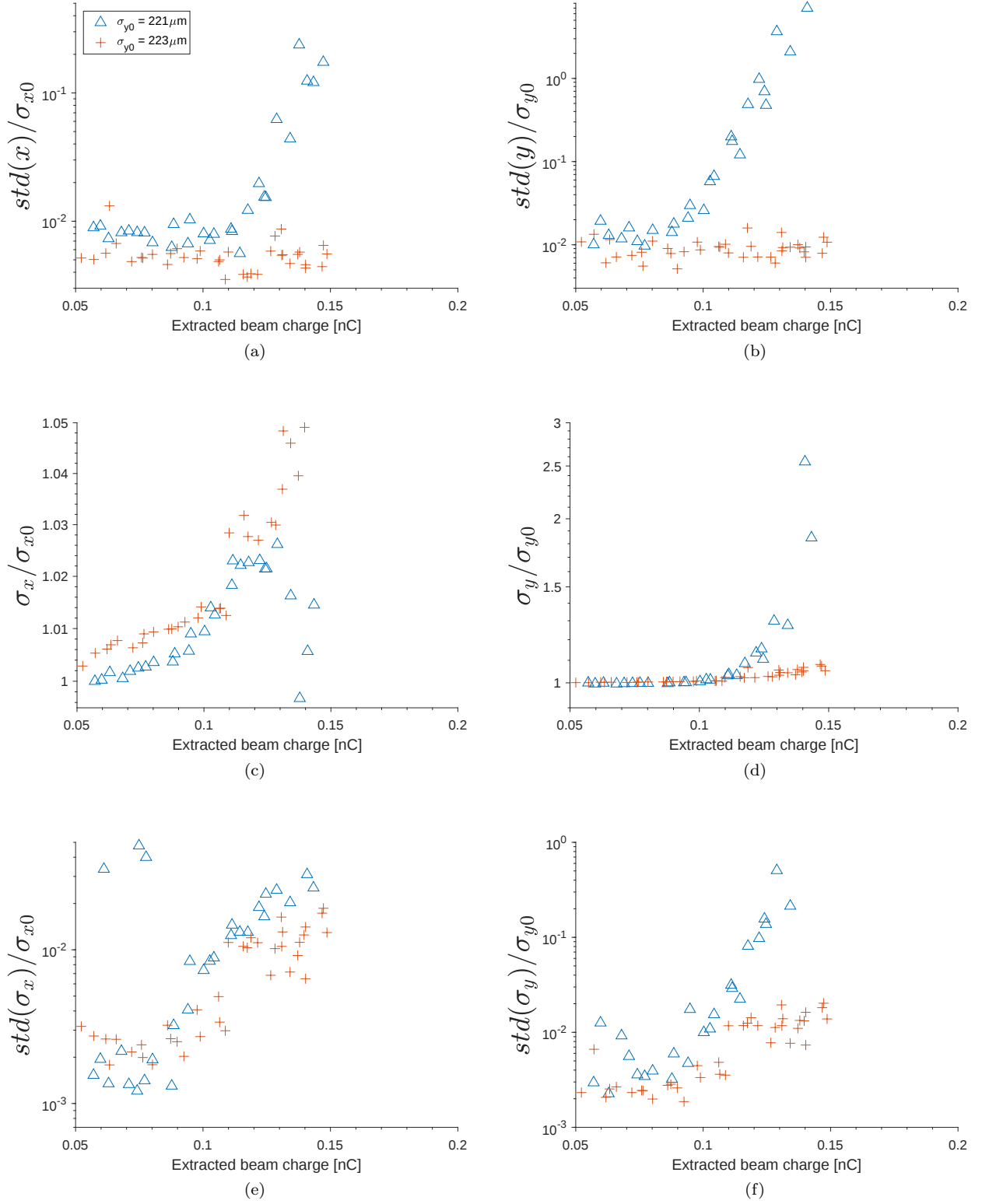


Figure 5: Comparison of the instability onset as a function of beam charge before (blue triangles) and after (red plus-signs) SD-sextupole family ramp change.