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Zusammenfassung / Summary This document discusses the effect of transitioning from lattice B to B+ on the threshold for the longitudinal microwave impedance. The important change in terms of the threshold is in the momentum compaction, which is now positive. The machine impedance now leads to a bunch lengthening, which compensates for the lower absolute value of the momentum compaction and for the reduced single bunch energy spread. Looking at the analytical region of stable effective impedances, there is reason to assume, that lattice B+ will even gain some margin in the threshold due to the inductive behavior of our machine impedance. The principal effect has been proven using up to date lattice data, but quantitative results still need to be obtained. But we can say already now, that lattice B+ will perform at least equal, probably better than B.	

Introduction

As has been stressed at the last machine advisory committee meeting, the project should make a decision soon between lattices B and B+ and this memo gives our best assessment of the state of things. It is based on the optics, as it is currently defined and uses a relatively complete machine impedance model. As of now, a full set of simulations taking into account e.g. also transient beam loading effects still needs to be done. We are confident, that combining analytical estimates with first single bunch tracking results should provide enough information for that decision. A full quantitative result also will rely also on the theoretical and practical validation at the SLS.

Table 1 gives a comparison of lattice B+ and B without and with superbends
(values from Andreas Streun)

lattice	B+	b016_000	B	b000_000
superbends	w/o	with	w/o	with
Circumference [m]	288	288.0002	288	288.0002
Tune x	39.20884	39.20882	39.38001	39.37996
Tune y	15.27332	15.27331	15.4	15.40002
Chroma x	-99.4681	-99.4249	-100.458	-100.41
Chroma y	-30.0888	-30.0923	-33.1528	-33.1556
MCF alpha	9.18E-05	9.07E-05	-1.21E-04	-1.22E-04
Rad.loss [MeV]	0.42631	0.442594	0.58829	0.605963
Emittance [nm]	0.120135	0.12853	0.108026	0.111184
Energy spread	9.73E-04	1.03E-03	1.04E-03	1.09E-03
Damping time x [ms]	6.09488	5.966773	4.411894	4.338663
y [ms]	10.81652	10.41855	7.83829	7.609688
E [ms]	8.827571	8.308881	6.407113	6.106924

Table 1 above shows the most relevant parameters for the lattice options B and B+. Evaluating the effect on the longitudinal single bunch threshold, the most significant difference is in the momentum compaction factor, which goes from negative to positive with a 25 % reduction in the absolute magnitude. This means, the rms bunch length will be shorter at zero current for B+, but due to the positive alpha, the length will increase with the bunch charge (More on that in the next section). The other significant parameter, the rms energy spread, is very slightly lower.

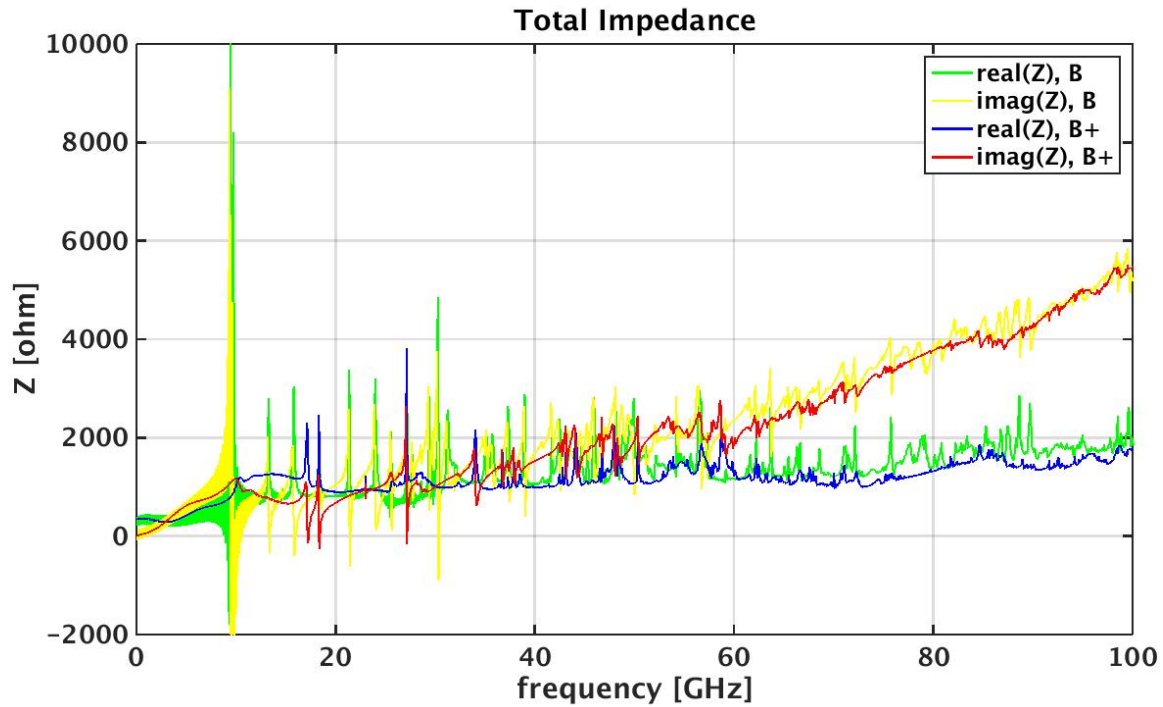


Abbildung 1: Total machine impedance (1 turn) for lattice options B and B+

Figure 1 shows impedances for both lattices. The chamber aperture for B uses a 17 mm cross section, whereas B+ is slightly larger at 18. The wall is coated with 500 nm NEG in both cases. Transitions for insertion devices and cavities are assumed to be the same in both cases (Our best guess at the current state). The peak magnetic field for B+ is lower, as also the total absolute bending angle leading to some reduction in the CSR contribution. A large improvement in the lower frequency range comes is due to a new design of BPM buttons, which removes the significant resonance peaks near 9 GHz as well smaller ones further up. Comparing both curves shows a small improvement in the overall impedance for B+, which should help with the threshold.

Comparison using analytical relations

The classical analytical KSB formula for the instability threshold is from Keil and Schnell[1] for coasting beams, which was expanded by Boussard[2] to include also bunched beams:

$$\left| \frac{Z}{n} \right| \leq F \frac{m_0 c^2 \beta^2 \gamma |\eta|}{e} \frac{(\Delta p/p)^2}{I_0}$$

Plugging in the nominal values parameters and assuming an equal to slightly shorter bunch length (that is slight incread bunch current I_0) leads to a reduced threshold for B+ of approximately 30%. In this relation, the absolute value of the momentum compaction is used. Its sign affects the threshold only indirectly via its effect on the bunch length,

Tabelle 2: Effect of positive versus negative alpha: The same machine impedance and magnet optics was used in both cases. Shown are values for (near) zero current values and 1 mA (0.95 nC), both without harmonic cavity.

	$I_b = 10 \text{ uA}$	$I_b = 1 \text{ mA}$
$L_{\text{rms}} [\text{mm}] (\alpha > 0)$	2.68	3.55
$L_{\text{rms}} [\text{mm}] (\alpha < 0)$	2.67	2.62
$dE/E [10^{-4}] (\alpha > 0)$	9.73	9.73
$dE/E [10^{-4}] (\alpha < 0)$	9.73	9.73

Table 2 compares the effect using the magnet optics of B+ for near zero and nominal bunch current. The energy spread stays constant in both cases, so we look at the stable region. But where the bunch size ever so slightly decreases for negative alpha, flipping the sign gives a 30% increase. For the overall threshold, this means, the bunch lengthening would compensate for a reduced momentum compaction.

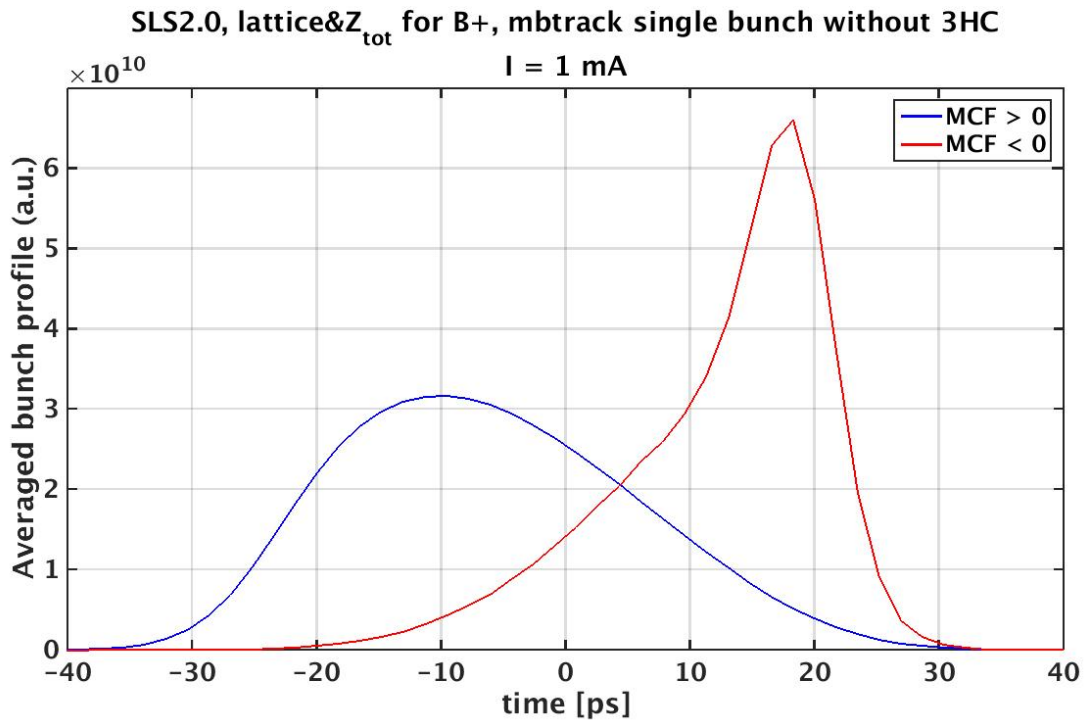


Abbildung 2: Intra bunch charge distributions at 1 mA for positive/negative momentum compaction

Figure 2 shows the charge distributions in both cases, which have been obtained by tracking simulations with mbtrack. The spiky distribution for negative alpha indicates that we are already relatively near to instability in this case.

Things become even more interesting, if we take a look at the analysis behind KSB. As can be seen in figure 3, the real region of stability in the complex impedance plane is not circular but looks like a pan handle (The disk described by KSB is simply the maximum circle, which can be inscribed into that area).

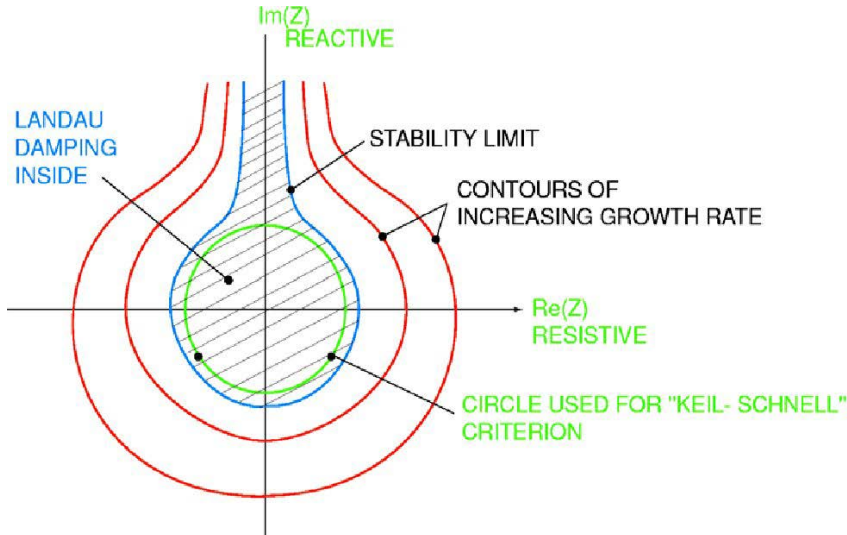


Abbildung 3: Stability region in the complex (normalized, effective) impedance plane for positive momentum compaction. The blue line gives the threshold impedance, the green circle the criterion given by the Keil Schnell Criterion (plot from K. Schindl, CAS 2004).

The orientation of this pan handle is a function of the sign of the momentum compaction. The orientation for positive alpha is shown in Fig. 3. The real region of stability is actually unbounded for pure inductive ($\text{Im}(Z) > 0$, $\text{Re}(Z) = 0$) impedances. Tracking the B+ lattice and using a pure inductive wake function, we were able to reproduce this effect.

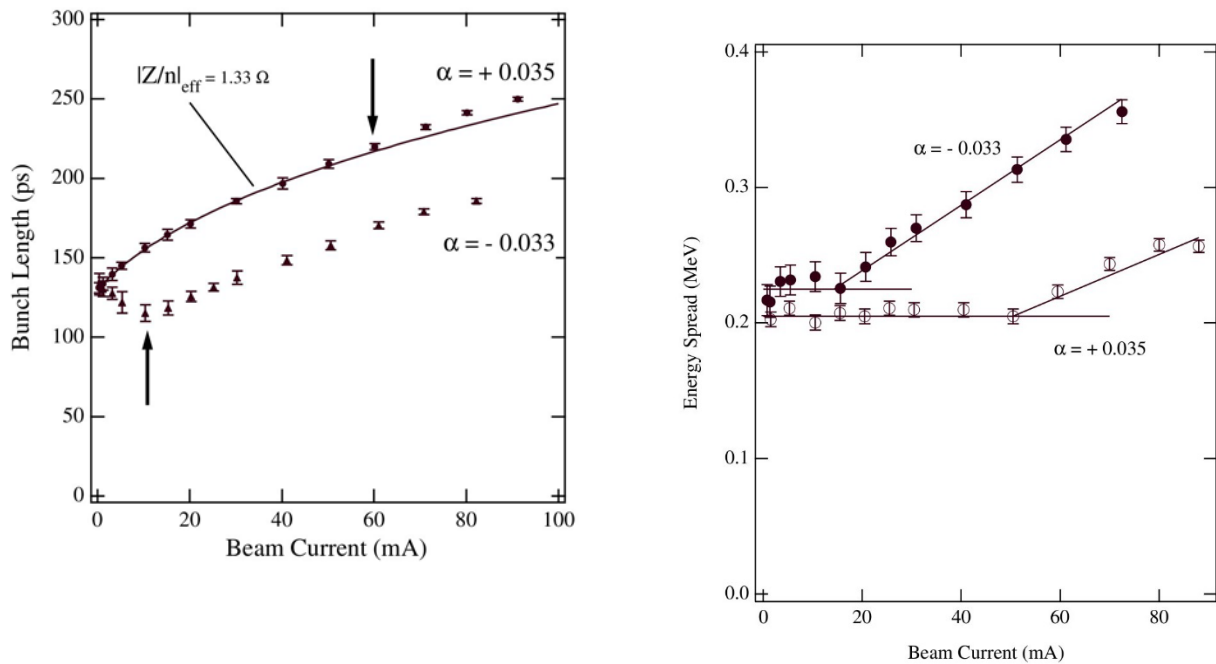


Abbildung 4: Bunch length and energy spread for positive/negative momentum compensations in UVSOR [3]

How will the orientation of the pan handle change, if we flip the sign of α ? The region of stability gets mirrored on the real axis, the handle of the area now looks downward and it's purely reactive impedances with a negative imaginary part, which are unconditionally stable. A purely inductive impedance (positive imaginary part) should see a threshold very near to the KSB criterion.

The main source of negative reactive impedance is space charge inside the bunch, which, for electron accelerators in the GeV range, is negligible. In our case, we have a typical impedance with some losses ($\text{Re}(Z) > 0$) and a positive inductive part ($\text{Im}(Z) > 0$). For negative momentum compaction (pan handle looking downwards), this means qualitatively, that, with increasing bunch charge, we will hit the threshold relatively fast and that it will be quite near to the KSB value. In the case of positive α , the threshold will be strongly influenced by the amount of losses, represented by the real part of the impedance (which should be minimized by very smooth tapers and transitions). So, for a well designed machine, the sign of the momentum compaction may have a very strong influence on the threshold. In the literature, it's difficult to find studies comparing both cases. But two examples are shown in Fig. 4 and 5, one looking at the effect in the UVSOR ring, the other coming from a study by Heifets and Novokhatsky. In both cases, the bunch length follows the classical pattern described before: Positive α leads to a monotonous growth of bunch length versus charge, whereas the negative case leads to an initial shortening. Thresholds are very significantly influenced by the sign of α , we see differences in the order 3-5.

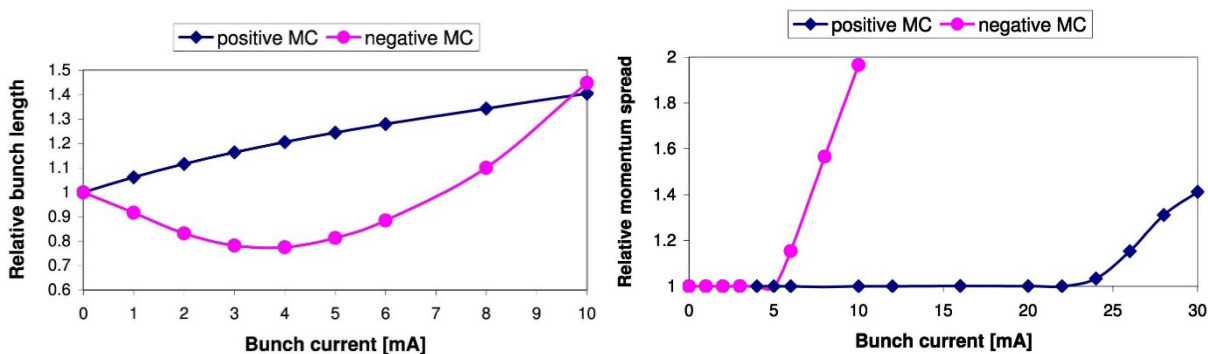


Abbildung 5: Bunch length and energy spread for positive/negative momentum compactions [4]

Where does this leave us for SLS 2.0? Tracking simulations using simplified assumption – no harmonic cavity, no transient effects – show a marked increased threshold for lattice B+ as compared to lattice B (As well as for lattice B+ with $\alpha > 0$ versus B+ combined negative α). Also the variation of bunch length versus current show a behaviour similar to refs [3] and [4]. For the project, we need to answer two questions:

- The urgent one is number one, the feasibility of B+: From what we see, we are quite sure, that this lattice will perform at least equal, probably even significantly better than lattice B.
- Question number 2 - less urgent - concerns a quantitative prediction for the threshold: Here we definitely need more time. One important input in that direction is the ongoing simulation work for SLS 1, which will be validated at the machine and should give us a better idea on the physics behind

Other effects:

For TMCI, no clean simulations have been done at the moment. We expect no dramatic changes. Concerning coupled bunch instabilities, the damping times are longer and in the case of the longitudinal plane, the synchrotron frequency is lower. This leads to lower thresholds, but we need to rely on bunch by bunch feedbacks anyway.

References

- [1] E. Keil and W. Schnell, Concerning longitudinal stability in the ISR, CERN-ISR-TH-TR-69-48, 1969
- [2] D. Boussard, Observation of Microwave Longitudinal Instabilities in the CPS, LABII/RF/Int./75-2, 1975
- [3] M. Hosaka et al., Longitudinal Beam Dynamics on Electron Storage Ring with negative Momentum Compaction Factor, proc. 1st APAC, pp. 426, 1998.
- [4] S. Heifets and A. Novokhatski, Coherent beam stability in the low momentum compaction lattice, PRST-AB 9, 044402, 2006