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EXPLORING THE POTENTIAL OF THE SWISS LIGHT SOURCE

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Abstract

The Swiss Light Source (SLS) has been operational since 2001. Although its performance meets the specifications, it still has a potential to achieve better storage ring beam parameters. We explore possible improvements on the beam lifetime and the beam emittance.

INTRODUCTION

The Swiss Light Source (SLS) has been operational since 2001. The SLS has met its design goals, and yet it has a potential to achieve better storage ring beam parameters. We explore two possible improvements of the storage ring electron beam parameters.

The first possible improvement is for the beam lifetime. The beam lifetime of the SLS is mainly determined by Touschek lifetime and therefore depends on the bunch population. From the lifetime point of view, a uniform filling is the best. On the other hand, an ion cleaning gap is essential to suppress ion instability. For this reason, 390 bunches are nominally stored whereas the harmonic number of rf is 480, leaving 90 buckets empty. After many years of operation, however, the vacuum condition has improved since the SLS was first turned on. Hence it is possible to shorten the gap in the filling pattern such that the beam lifetime can be prolonged. This study may be also useful to consider possible filling patterns in SLS 2.0, which is the upgrade plan of SLS [1].

The second improvement concerns beam emittance or energy spread. The nominal energy closed orbit coincides with the axes of quadrupole magnets while an off-momentum closed orbit is off-centered through quadrupoles. Therefore the damping partition is shifted for the off-momentum closed orbit, and the beam emittance can be decreased at the expense of a larger energy spread and vice versa. This was successfully achieved in the SPring-8 storage ring [2] and the ESRF booster [3]. We study whether it is applicable to the SLS storage ring.

SLS PARAMETERS

The parameters, which are important and/or relevant to this study, are summarised in Table 1.

BEAM LIFETIME

We have spent several machine development shifts to examine how short the gap of the filling pattern can be allowed. The beam lifetime, the bunch length and the vertical beam size were measured for the number of bunches of 390, 410 and 430, which correspond to the gaps of 90, 70 and 50, respectively. During the measurement, top-up injection was

Table 1: SLS Parameters

Parameter	Value
Circumference	288 m
Beam energy	2.4 GeV
Rf frequency	~500 MHz
Harmonic number	480
Harmonic cavity [4]	Passive, ~1.5 GHz
Compaction factor	0.0006
No. of bunches	390 nominal
Beam lifetime	about 8 h
Beam current	400 mA
Beam emittance	5.5 nm
Energy spread	0.09%

applied as in the user operation mode to keep the beam current within a range of 400–402 mA and the filling pattern was controlled with a filling pattern feedback [5]. The beam lifetime was evaluated using the reading of current transfer between injections. Figure 1 shows the measured beam lifetime.

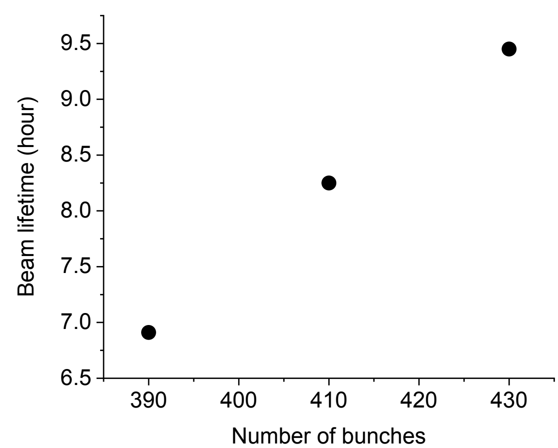

Figure 1: Measured beam lifetime for various number of bunches.

As seen in Fig. 1, the lifetime improved as the number of bunches increased. The measurement was performed with insertion devices being turned off. Since the lifetime was optimized with the insertion devices turned on, the initial lifetime of about 7 hours was a little shorter than the value routinely achieved during the user operation (8–9 hours). The vertical beam size was about 13.8 µm rms and essentially constant over the number of bunches up to 430, indicating a good suppression of ion instability. The vertical beam size was measured using the beam size monitor described in [6].

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Afterwards, when we applied a lifetime optimization with correction sextupoles with the insertion devices turned on, we achieved a lifetime of about 11.3 hours for the filling with 430 bunches and a vertical beam size of 10.9 µm rms.

The observed increase of lifetime was more than what was expected from the corresponding bunch population decrease. The latter is about 10% while the former is more than 30%. This is because of an additional benefit arising from the increased number of bunches, i.e., a reduction of beam loading effect in the third harmonic cavity, which is passively driven by the beam. With the nominal filling pattern, the averaged bunch lengthening factor is only about 1.9 [7].

The bunch length measurement with a streak camera (Fig. 2, top) showed that the bunch lengths were slightly prolonged at the beginning and at the end of the bunch train. The longitudinal shift of bunch centroid along the bunch train was also found from the streak camera image as presented in Fig. 2 (bottom). The centroid shift decreased as the number of bunches increased. These measurements indicate a relaxation of beam loading.

A further increase of the number of bunches resulted in a full beam loss. The cause of beam loss has not yet been clarified, and it may not necessarily be the ion instability.

BEAM EMITTANCE AND ENERGY SPREAD

The variation of beam emittance and energy spread was investigated first with simulation. The emittance module implemented in MAD-X was used to compute the beam emittance and energy spread as a function of momentum deviation. The result for the SLS lattice is shown in Fig. 3. At the momentum deviation of −2% for example, the emittance can be 64% of the nominal value at the expense of about 15% energy spread increase.

The above variation is mostly due to the damping partition shift, for the energy loss per turn varies marginally. The damping partition as a function of momentum deviation is shown in Fig. 4.

We had one short machine development shift to examine the off-momentum working point. The storage ring rf frequency was shifted while the magnetic field was kept constant. So far, we examined a frequency shift only up to a range of about ±1.8 kHz, corresponding to about ±0.6% momentum deviation. The off-momentum orbits were recorded as shown in Fig. 5.

In order to examine a larger frequency shift, we have to disable an interlock, which imposes a limit to orbit deviation. We also observed that the third harmonic cavity voltage was increasing when the fundamental rf frequency was increased, i.e., the beam was "tuning in" the harmonic cavity resonance frequency. Therefore, the third harmonic cavity may have to be retuned for a larger rf frequency shift, and perhaps other systems may be required to be adjusted. Furthermore, it may be necessary to rematch the storage ring optics for a large momentum deviation.

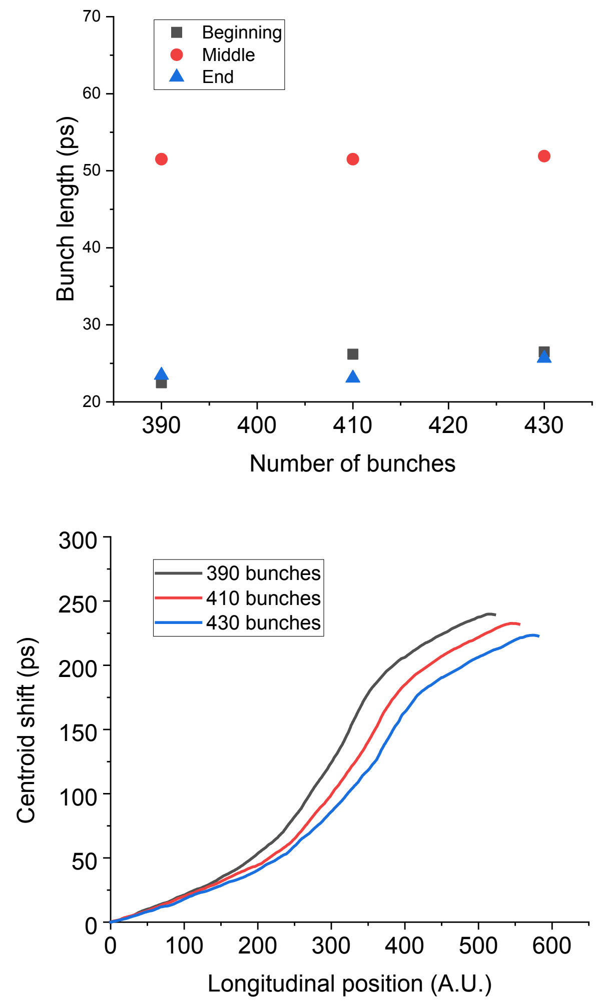

Figure 2: Measured bunch length (top) and bunch centroid shift (bottom). Bunch length was measured for the bunches at the beginning, middle and end of the bunch train. The centroid shift is with respect to the bunch at the beginning of the train.

SUMMARY AND OUTLOOK

We have explored the potential of the SLS with respect to two aspects, namely beam lifetime and beam emittance. The gap in the filling pattern necessary for suppressing ion instability was conservatively large, and we found that, with beam, the gap can be shortened from the nominal 90 empty buckets to 50. The beam lifetime was increased more than 30% with the shorter gap because of not only the lower bunch population but also the less beam loading to the passive third harmonic cavity.

The beam emittance can be reduced at the expense of energy spread increase and vice versa. We have examined, so far, a frequency shift of about ±1.8 kHz, corresponding to about ±0.6% momentum deviation. Further machine developments to this end may require some modification to the sub-systems and the optics such that a larger frequency shift can be accepted. Shifting the strength of all the storage ring

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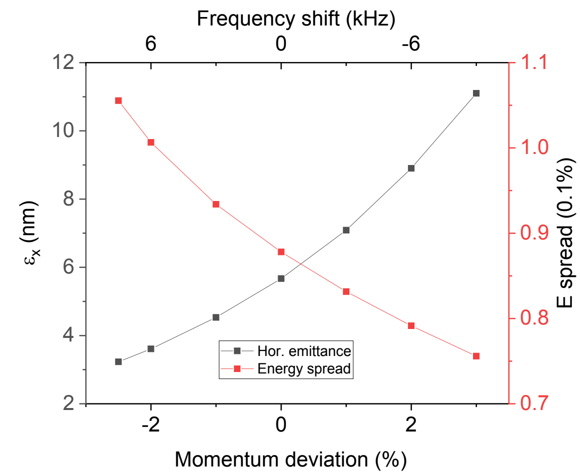

Figure 3: Computed beam emittance and energy spread as a function of momentum deviation. The frequency shift Δf is related to the momentum deviation as $\frac{\Delta f}{f} = -\alpha\delta$, where α is the momentum compaction factor and δ is the momentum deviation.

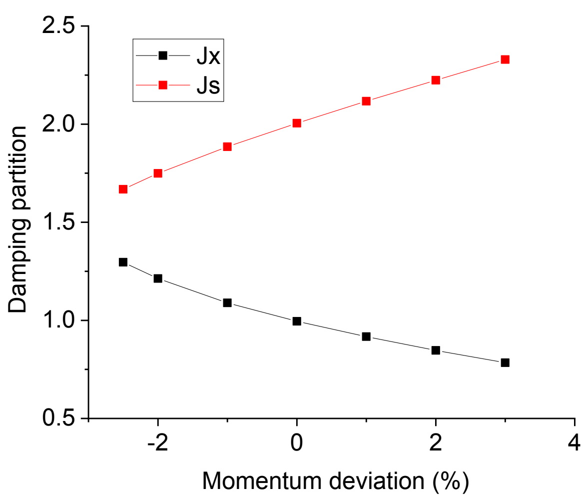

Figure 4: Computed damping partition as a function of momentum deviation. J_x is the horizontal damping partition and J_s is the longitudinal one.

magnets instead of the rf frequency may be an alternative approach to be tested.

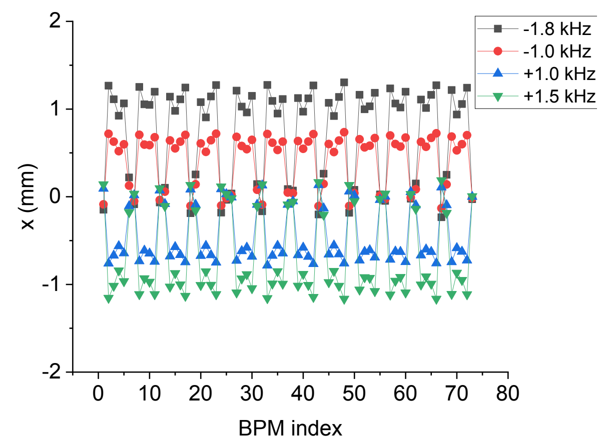

Figure 5: Measured off-momentum orbits.

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