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SINGLE-BUNCH THRESHOLDS FOR THE DIAMOND-II STORAGE RING

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Abstract

The proposed Diamond Light Source upgrade will see the storage ring replaced with a multibend achromat lattice, increasing the capacity of the facility whilst reducing the emittance and providing higher brightness for the users. As part of the design work, tracking studies have been performed to determine the single-bunch thresholds including both the resistive-wall and geometric contributions to the impedance. As the machine design also foresees a third order harmonic cavity, the paper also provides an initial assessment of the effects of bunch lengthening on the single-bunch thresholds.

THE DIAMOND-II UPGRADE

An upgrade is planned of the Diamond Light Source to replace the present storage ring with a multibend achromat lattice, providing both higher brightness as well as space for more beamlines. The latest progress on the storage ring lattice is presented in detail in [1] whereas this paper discusses the impedance effect on the single-bunch thresholds.

The storage ring is planned to be operated with two different fill patterns, a standard mode providing lowest equilibrium emittance and longest lifetime for high brightness users and a hybrid mode with an isolated single bunch in a gap for timing users. A third order harmonic cavity will also be installed to increase Touschek lifetime, damp instabilities and reduce intrabeam scattering. The standard mode will require short gaps in the fill pattern for ion-clearing, whereas the gap length for the hybrid mode is set by the user requirements and therefore much longer. For both modes the gaps will lead to transient beam loading, affecting the performance of the harmonic cavity. The minimum gap lengths for the fill patterns and choice of harmonic cavity technology are currently being studied. The exact bunch charge requirements are therefore not yet decided, but will be in the range 0.6 nC (uniform fill) to 3 nC (aim for hybrid bunch).

IMPEDANCE MODEL AND SIMULATION TOOLS

The impedance for the Diamond-II storage ring is described in more detail in [2]. For the purpose of tracking simulations the impedance contributions have been separated into two parts, resistive-wall and geometric, and how these are included in the simulations are described below.

The storage ring design includes NEG coating of almost 75% of the ring for vacuum pumping. The resistive-wall impedance has therefore been calculated using the code `ImpedanceWake2D` [3], which can handle both single and multilayered vacuum pipe walls with different geometries. Since the exact properties of the NEG coating is still unknown, two different options have been included in the simulations, a 1.0 μm layer with conductivity 1e6 S/m or 1e5 S/m, respectively. The thickness is based on an estimation of achievable coating thicknesses whereas the conductivity range is based on the experimental findings presented in [4].

The geometric impedance is simulated using CST [5] assuming perfect electric conducting material. So far, all the components have been simulated using a bunch length of 3 mm due to computer resources, but the aim is to reduce this to 1 mm.

The obtained impedances are then included in tracking simulations using a lumped impedance model, including in the transverse planes a normalisation with local beta function with respect to the beta function at the lumped impedance. Due to a minimum bunch length around 3 mm, a maximum frequency range of 100 GHz has been used. The results presented in this paper have been obtained with `Elegant` [6, 7], but have been benchmarked against `AT` [8] with good agreement.

Since the fill patterns and harmonic cavity are still under study, an initial estimation of the effect on the single-bunch thresholds due to bunch lengthening from a harmonic cavity has been done using a cavity without beam loading set to achieve the flat potential conditions [9, 10]. Self-consistent simulations taking into account the effect of transient beam loading in both main and harmonic cavity are planned for future studies.

So far, only the bare lattice has been simulated and the effects of the insertion devices will require further work. This does not only include increased impedance due to closed in-vacuum undulator gaps, chambers, tapers etc., but the insertion devices also have significant effect on the beam properties, especially a large reduction (factor 2-3) on the radiation damping times compared to the bare lattice.

LONGITUDINAL EFFECTS

Figure 1 shows the time shift of the bunch centroid, bunch length and energy spread caused by the longitudinal impedance. The effect of the NEG coating is mostly additional bunch lengthening and within the current range of interest no significant differences can be seen between the two cases of NEG conductivity. The geometric impedance also contributes to the bunch lengthening due to being highly inductive and is the main contributor compared to the resistive-wall impedance. In all cases, no significant effect on the energy spread can be seen within the current range of interest.

Figure 2 shows the bunch lengthening compared to the zero current bunch length as function of current with and without a third order harmonic cavity set to the flat potential conditions. The simulations show that a bunch lengthening above 4 times can be achieved with the harmonic cavity, but this is only possible for a uniform fill pattern. Due to the

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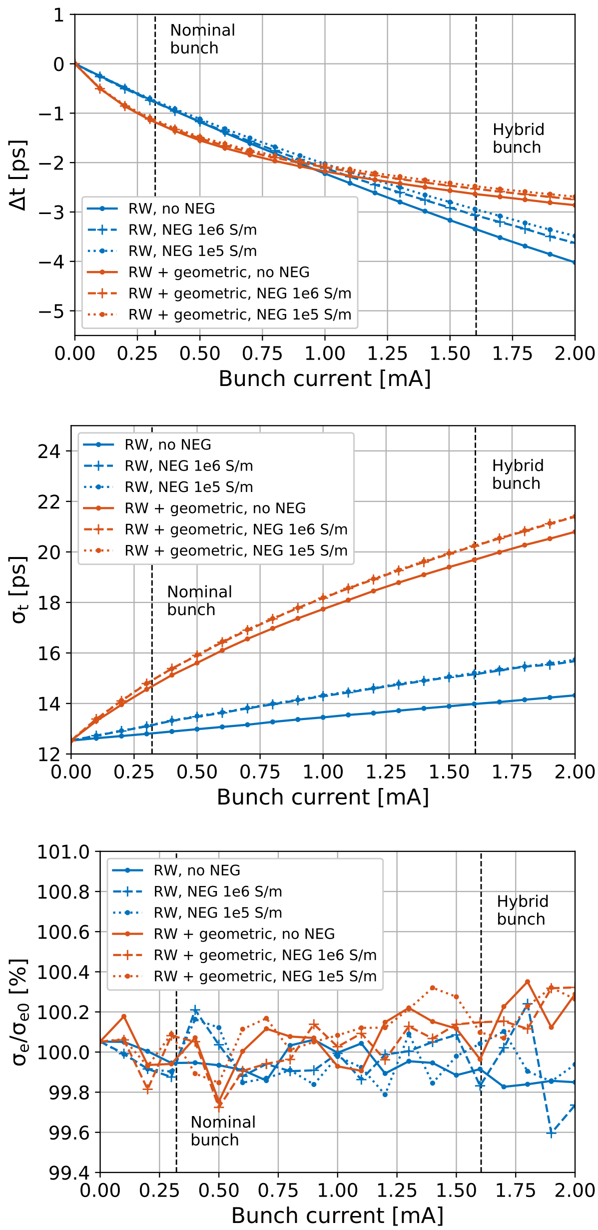

Figure 1: Longitudinal centroid shift (top), bunch length (middle) and energy spread (bottom) as function of bunch current. The bunch current requirements for a bunch in uniform fill (nominal) and the hybrid bunch are marked.

need for gaps in the fill pattern and the resulting transient beam loading, this is likely an overestimation of the effect. However, these simulations still provide a useful reference for evaluating the performance during future simulations including transient beam loading.

Figure 3 shows the bunch profiles for a 0.6 nC (nominal) and 3 nC (hybrid) bunch, respectively for the case with NEG coating with conductivity 1e5 S/m. It can be seen that the bunch centroids are shifted slightly to compensate for the energy loss to the impedance, but the profiles remain mostly symmetric. For the case with harmonic cavity, this might no longer be true when including transient beam loading and the effect of asymmetric bunch profiles also has to be considered in future simulations.

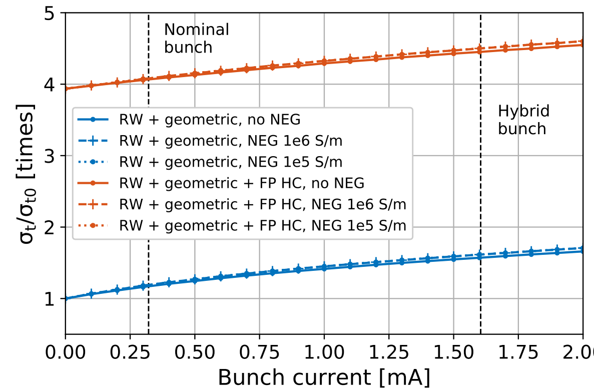

Figure 2: Bunch lengthening compared to the zero current bunch length as function of current including longitudinal resistive-wall, geometric impedance and a third order harmonic cavity set to flat potential conditions. The current requirements for a bunch in uniform fill (nominal) and the hybrid bunch are marked.

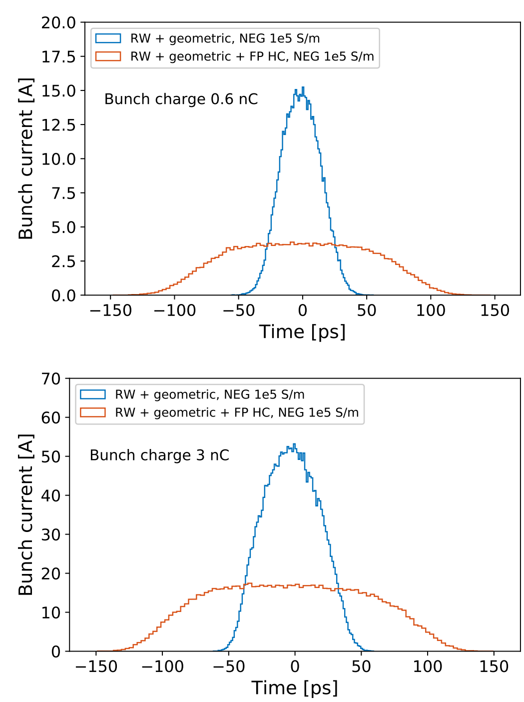

Figure 3: Longitudinal bunch profiles for 0.6 nC bunch (top) and 3 nC bunch (bottom) including resistive-wall (NEG 1e5 S/m), geometric impedance and a third order harmonic cavity set to flat potential condition. In both cases the zero time point corresponds to the zero current synchronous phase.

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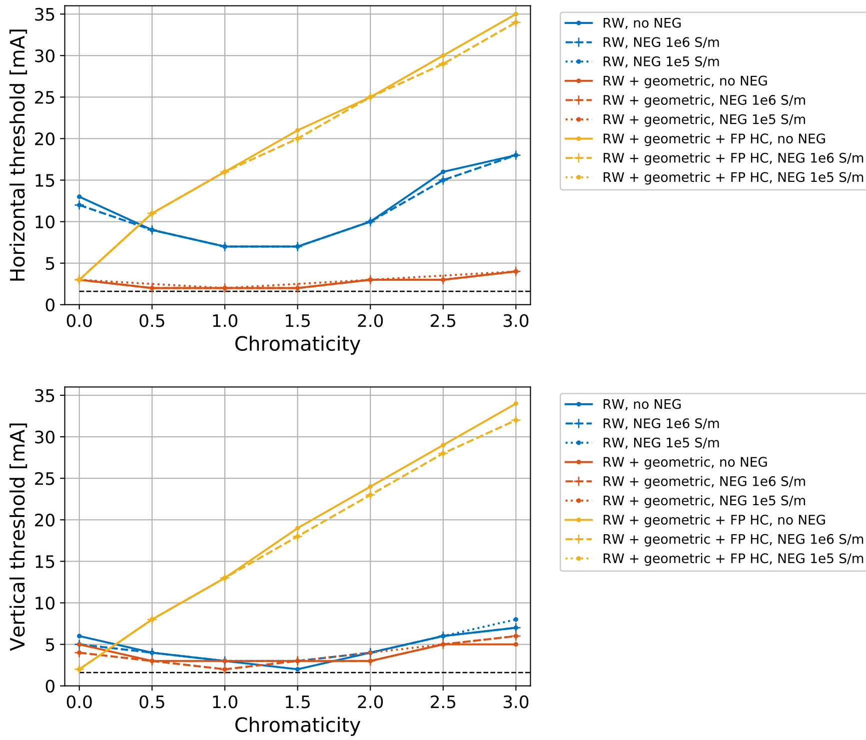

Figure 4: Horizontal (top) and vertical (bottom) threshold currents as function of chromaticity. In these simulations only the transverse impedances have been included. The current requirement for the hybrid bunch is marked (black dashed).

TRANSVERSE THRESHOLDS

Figure 4 shows the transverse single-bunch thresholds as function of chromaticity. For the shown thresholds, only the transverse impedance in the respective plane has been included so the bunch lengthening from the longitudinal impedance is not taken into account. The horizontal threshold is dominated by the geometric impedance, which is due to the horizontal impedance of the dipole vessel [2]. In the vertical plane, the effect of the geometric impedance is less significant. It can however be noted that the effect of the NEG coating is less significant compared to the longitudinal plane in both transverse planes. When including the harmonic cavity, the vertical TMCI threshold (at zero chromaticity) is reduced whereas the horizontal remains unaffected. For positive chromaticity the thresholds are significantly increased in both planes. Similar behaviour can be seen when including the longitudinal impedance, but further studies are required of the convergence of the microwave threshold to determine its effect on the bunch lengthening and the consequences for the transverse thresholds.

FUTURE WORK

The engineering design of the vacuum chambers for the Diamond-II storage ring is still in progress so renewed simulations of the single-bunch thresholds will be performed as the impedance model develops, but only small changes are expected at this point. The most significant part yet to be studied is the effect of transient beam loading on the single-bunch thresholds. This is especially of importance for the hybrid bunch due to both the higher charge requirement and the large gap in the fill pattern, which will lead to significant transient beam loading. Self-consistent simulations of this including beam loading in both the main and harmonic cavities are planned for both passive and active harmonic cavity options.

To better understand the behaviour of the transverse thresholds as function of chromaticity, it might be of interest to benchmark the tracking simulations against against a Vlasov solver. Depending on the progress of the lattice studies it might also be of interest to study a larger chromaticity range.

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