STUDIES OF COLLECTIVE EFFECTS IN SOLEIL AND DIAMOND USING THE MULTIPARTICLE TRACKING CODES SBTRACK AND MBTRACK

R. Nagaoka, Synchrotron SOLEIL, Gif-sur-Yvette, France
[1,2]R. Bartolini, [1]J. Rowland, [1]Diamond Light Source Ltd, Oxfordshire, UK
and [2]John Adams Institute, University of Oxford, UK

Abstract

Single bunch and multibunch instabilities measured in SOLEIL and Diamond storage rings are analysed using the multiparticle tracking codes *sbtrack* and *mbtrack*. It is found that coupling of the longitudinal collective effect plays an important role in raising the vertical single bunch threshold in Diamond. For multibunch, the filling pattern and the headtail mode dependence of vertical instabilities is pursued with *mbtrack*. Although qualitative agreement is met in part, more precise characterisation of the broadband impedance appears necessary, among other potentially important effects, to achieve quantitative description of the instability versus chromaticity.

INTRODUCTION

Good understanding of instabilities is of great importance in light source rings such as SOLEIL and Diamond that provide high current beams. The inherently large machine impedance, which often evolves with continuous changes of insertion devices, enhances collective effects that need to be well controlled to assure the machine performance. The problem is usually not straightforward, however, as one must quantify short and long range wakes that excite single and multi bunch instabilities, the coupling between instabilities and different planes, as well as Landau effects in arbitrary filling modes. In view of this complexity, multiparticle tracking in the time domain was considered most suited for the analysis of instability and two code *sbtrack* and *mbtrack* have been developed to this end [1]. While *sbtrack* performs 6-dimensional single bunch tracking, *mbtrack* does its direct extension to multibunch. Recently, it was agreed between SOLEIL and Diamond, upon their common interest, to collaborate on this subject, by using and developing the two codes. Below we shall report on the results obtained so far.

TRACKING CODES

sbtrack

sbtrack is a single bunch tracking code with wake fields in fully 6-dimensional phase space, written in c. Its core module handling the wake potential convolution follows the algorithm developed by G. Besnier. Special efforts were made to treat different kinds of wake functions, particularly those computed numerically with impedance codes via decomposition into a series of fundamental wake functions [1]. Modules are also prepared to automate computations of bunch lengthening with current or transverse instability threshold variation with chromaticity. Recently, a Matlab version has also been created [2].

mbtrack

mbtrack is a multibunch tracking code written in c. It was developed to be able to investigate multibunch instabilities under arbitrary beam filling, by preserving internal bunch motions. It is a straightforward extension of *sbtrack* to multibunch, where each bunch consists generally of a large number of macroparticles, and the presence of long range wake fields couples the motion of different bunches.

In order to reduce the enormous cpu time required, parallel processing of a large number bunches was introduced employing a cluster of processors. The scheme developed consists of a master and slave structure using *pvm* [3], in which each slave, in the first step, transforms particles within a bunch with intra bunch forces in the conventional one turn approximation. Centre of mass motions, such as dipole moment, are then deduced and sent to the master, which collects the information over all bunches and stores over multiple turns. In the second step, each slave adds kicks to particles in a bunch due to long range inter-bunch (resistive-wall) forces, by respecting the distance between bunches over multi turns. In view of both the resistive-wall impedance being well distributed around a ring and the high frequency of the betatron oscillation, the transformation can be divided in several steps around the ring with the use of transfer matrices. To give an idea of the required cpu time, tracking uniformly filled 416 bunches in the SOLEIL ring, each containing 5000 particles, over 1000 turns takes roughly one hour with 24 processors, at SOLEIL. A preliminary module simulating the fast beam-ion interaction was added in *mbtrack* in 2007 in order to study the instability of this kind existing at high beam current at SOLEIL.

SIMULATION RESULTS IN COMPARISON WITH MEASUREMENT

Single Bunch Instabilities

As stated already, we shall focus here on the impact of coupling between different planes, specifically between longitudinal and transverse, as well as that of the nonlinear betatron tune spread, on the transverse threshold. Regarding the bunch lengthening and the energy spread widening in Diamond, it was found earlier that a broadband resonator (BBR) with R_s=20 kΩ, f_{res}=48 GHz and Q=1 describes well the measured energy spread widening, but underestimates the former [4]. Here, a purely inductive impedance $Z(\omega)=iL\omega$ with L = 149 nH was added to better reproduce the two longitudinal quantities (Figs.1).

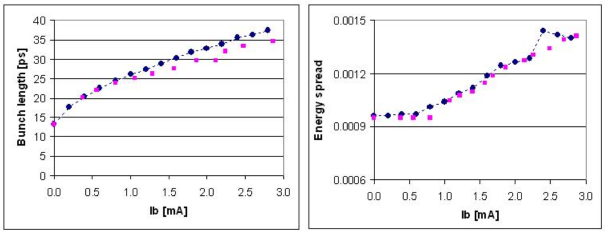

Figure 1: Bunch lengthening (left) and energy spread widening (right) calculated with *sbtrack* (circles), in comparison with measurement (squares) in Diamond. See text for the impedance used.

Through the measurement and fit of the vertical TMCI (Transverse Mode Coupling Instability) at zero chromaticity in Diamond, a BBR impedance with R_T=1 MΩ/m, f_{res}=6 GHz and Q=1 was previously obtained [4].

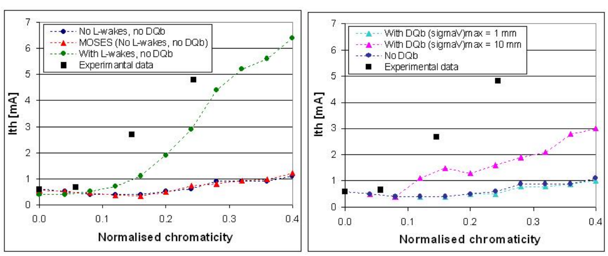

Figure 2: Measured (black squares) and calculated vertical thresholds versus chromaticity in Diamond. See text for the conditions of calculations.

We shall look at the vertical instability threshold versus chromaticity using the fitted BBR in *sbtrack*, with and without the two effects mentioned above. Firstly, without them, the threshold is found to remain low below 1 mA up to the chromaticity of 0.4, clearly underestimating the measured threshold (Figs. 2 left). The threshold curve obtained with *sbtrack* is nevertheless in good agreement with MOSES calculated under the same condition. Now including the longitudinal wakes in the tracking, a significant increase appears on the threshold, giving much better agreement with the measurement (black squares in Figs. 2 left). To see if the betatron tune spread gives another important stabilisation, the second-order amplitude-dependent tune shift due to sextupoles was included while turning off the longitudinal wakes (Figs. 2 right). The vertical beam blow up is found to relax significantly, effectively raising the threshold curve. In the figure, two curves indicating the current at which the vertical beam size reaches 1 and 10 mm are plotted. It is found, however, that the current at which the onset of beam blow up occurs is basically unaltered with respect to no tune spread case. For SOLEIL, a similar result that the longitudinal instability raises significantly the vertical threshold with the chromaticity shifted to positive values was found, even though the beam stays under the potential well regime (i.e. only bunch lengthening). Since the BBR impedance originally assumed in the simulations (R_T=0.17 MΩ/m, f_{res}=22 GHz and Q=1) turned out to largely underestimate the measured TMCI threshold, a fit was made, giving R_T=0.50 MΩ/m, f_{res}=15 GHz and Q=1. These two sets of BBR models shall be used for SOLEIL in the subsequent multibunch simulations with *mbtrack*.

Multibunch Instabilities

One of our primary interests here is to see if some of the features already found for SOLEIL with *mbtrack* could be observed for Diamond as well, and to make a quantitative comparison between the two machines. In most of the calculations performed below, 5000 macro-particles per bunch were tracked over 1000 turns.

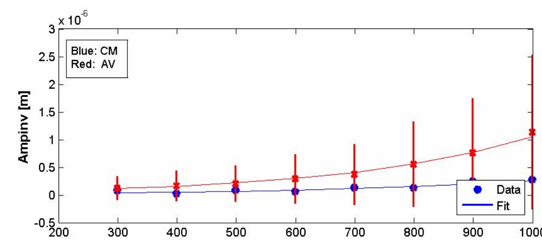

Figure 3: Invariants of the betatron motion averaged over macro-particles and bunches, versus number of turns. Computation assumes 2/3 filling at 300 mA in Diamond with normalised chromaticity of 0.3. See text for the meaning of the two curves.

The instability growth rate was evaluated using the "invariant" of betatron motion of a beam calculated in two ways: Either as that of the centre of mass of a bunch (blue in Fig.3), or those of individual particles averaged over a bunch (red in Fig. 3), which were further averaged over all bunches. Note that in partial fillings such as 2/3 filling, the growth rate may be significantly larger towards the tail of a bunch train than the head, but here this difference is ignored. While the two invariants are roughly equal when instability is dominated by a dipolar mode, the former may vanish when a higher-order headtail mode takes over. An example of such situation is shown in Fig. 3. The growth rates were followed by taking the larger one of the two.

Prior to calculating the threshold curves, the impact of multiturn wakes on the growth time (rate) was evaluated, as the predominant resistive-wall wake decays slowly in time. In both machines, the growth rate shows oscillatory behaviour with decaying amplitude (Figs. 4). For SOLEIL, the convergence occurs around 11 turns, while it is around 6 turns for Diamond. The obtained result appears reasonable in view of the nearly 1.6 times larger machine circumference for Diamond. In both cases, the converged growth rates turn out to be roughly 25% *smaller* than those that ignore the multiturn effect. It must be noted however that the present model takes no account of the diffusion of wake fields through the finite thickness chamber walls, which is yet to be justified.

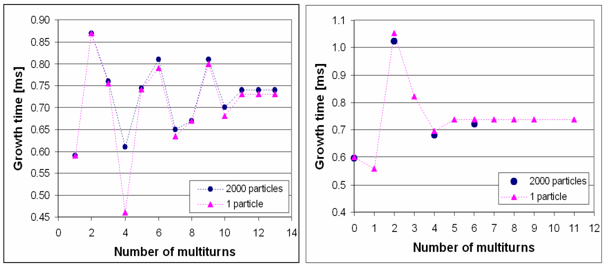

Figure 4: Calculated growth time as a function of turns up to which, decaying wakes are retained. Left: SOLEIL. Right: Diamond. With the chromaticity set to zero, the results are verified to be nearly identical between 2000 particles per bunch and 1 particle per bunch cases.

Vertical multibunch thresholds were calculated for the two machines, by including the resistive-wall and the BBR wake fields described above (Figs. 5). Unlike with *sbtrack* where the beam current was explicitly ramped up until the threshold is reached, here the growth rate evaluated at a given current was used to deduce the threshold via equilibrium with the radiation damping. No longitudinal wakes and tune spreads were yet included in the present results.

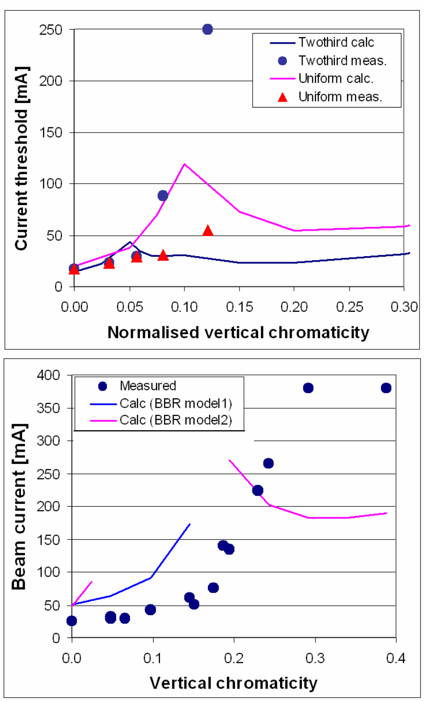

Figure 5: Calculated vertical multibunch threshold versus chromaticity in comparison with measurement. Upper: Diamond. Lower: SOLEIL. The filling pattern is ¾ filling for SOLEIL. See text for the conditions of calculations.

The calculated threshold curves indicate, first of all, that *mbtrack* manages to reproduce the transition of different headtail modes driving the coupled-bunch instability, as can be seen from the "edges" on the threshold curves, which should only be possible by correctly simulating the internal collective motions of a bunch. Secondly, the filling pattern dependence of instability is apparent in the Diamond result, not only on the threshold values, but also on where on the chromaticity axis the transition occurs.

It must be pointed out, however, that the present results are not satisfactory in comparison with the measured data. This is seen for example in the lower threshold found for the 2/3 filling than the uniform filling in Diamond (Figs. 5 upper), which is contrary to the measured results, or in all of the BBR models predicting the headtail transition to occur too soon (Figs. 5). The firstly considered cause for the latter is the fact that these BBR models were introduced upon fit of TMCI in single bunch, without taking into account the resistive-wall contribution. Thus, refined impedance models would have to be pursued, which are compatible with both single bunch and multibunch data. The impact of longitudinal wakes and betatron tune spread is to be investigated in parallel.

SUMMARY

It was shown that the multiparticle tracking code *sbtrack* and *mbtrack* can be well applied to study single and multibunch collective instabilities in Diamond and SOLEIL in a consistent and systematic manner. Parallel processing of different bunches in *mbtrack* allowed performing multibunch tracking in arbitrary beam fillings in reasonably short cpu times.

The importance of coupling between longitudinal and transverse instabilities was demonstrated in the analysis of the vertical single bunch instability in Diamond with *sbtrack*. In multibunch, the necessity of improving the broadband impedance model was made clear to fill the gap between simulation and measurement. The present collaboration is planned to be continued to achieve a comprehensive and quantitatively satisfactory picture of the beam instability in SOLEIL and Diamond.

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