INSTABILITY STUDIES USING EVALUATED WAKE FIELDS AND COMPARISON WITH OBSERVATIONS AT SOLEIL

R. Nagaoka, Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract

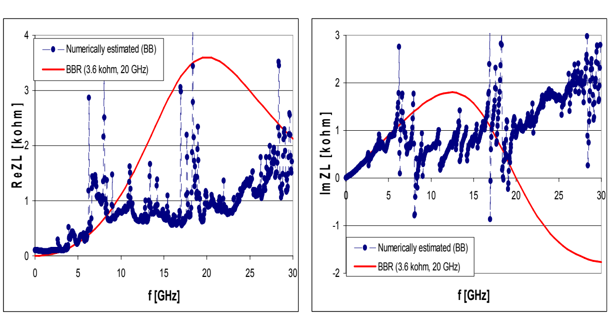
The coupling impedance numerically and analytically evaluated for the vacuum chambers in the SOLEIL ring is used to simulate beam instability. Vertical instabilities are predicted to appear well below the operating current in both single and multibunch. Development of a parallel-processed multibunch tracking code, as well as first instability observations is also reported.

INTRODUCTION

The SOLEIL storage ring, which is being commissioned, plans to be operated at high multi and single bunch currents. A key issue in the construction phase has therefore been to acquire precise knowledge of the geometric and resistive-wall (RW) impedance up to several tens of GHz, in order to minimise and have good control of collective beam instabilities [1]. The vacuum chambers are characterised by their relatively low vertical openings, which are in addition NEG coated to a large part. The simulation of instabilities with the obtained impedance data thus constitutes an important step in preparing measures to overcome the instability, as well as to assess the validity of the impedance data.

USE OF OBTAINED IMPEDANCE DATA

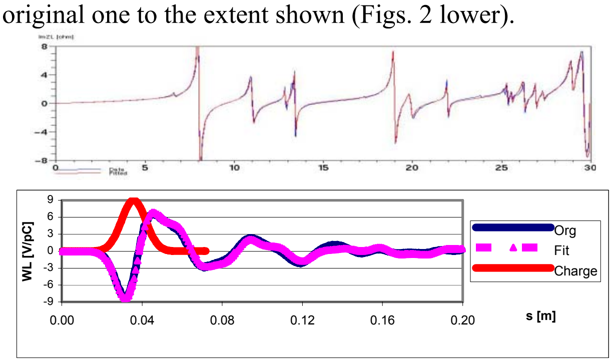
Although instability studies for the SOLEIL storage ring date back to as far as the R&D times, some simplified models had to be assumed for the broadband impedance, leaving some ambiguity in the results obtained due to the introduced uncertainty. Having obtained the impedance budget through component-wise numerical calculation with GdfidL and analytical methods [1,2], we are in the position to re-carry out the instability study with more realistic impedance models. Comparison of the numerically obtained total impedance with the assumed models indicates, commonly in the longitudinal and transverse planes, that the resonant structure assumed around 20 GHz in the models is not present, while the magnitude of inductive components is in good agreement (Figs. 1).



Figures 1: Numerically calculated longitudinal broadband impedance in comparison with the model employed.

The absence of the resistive component is expected to change the instability aspect in both single and multibunch. We may note that a broadband resonance at around 20 GHz was assumed in the vertical plane at the ESRF upon observing the defocusing of m=-1 head-tail mode in single bunch, which was later identified as an incoherent tune shift. Unlike the previous models the calculated impedance exhibits a series of narrow band peaks that originate from components such as BPMs, bellows and flanges.

To make use of numerically obtained impedance in the instability simulation, they must be further processed, since, as known, what calculated with impedance codes such as GdfidL are wake potentials. Instead of aiming to deduce the Green's function by reducing the bunch length, we have chosen to fit the obtained impedance in terms of broadband resonators, purely inductive and resistive components, whose Fourier transforms in the time domain are analytically known. Despite being cumbersome, the procedure was carried out for every component longitudinally, considering the fact that the number of components (such as flanges) may vary with time, as well as to have a better insight into the content of the impedance budget. In the transverse planes, however, the decomposition was made on the total impedance due to the lack of time. An example of such fit is shown below for a BPM, which required 15 resonators and a purely inductive term (Figs. 2 upper). The wake potential re-constructed from the fit consistently reproduces the original one to the extent shown (Figs. 2 lower).



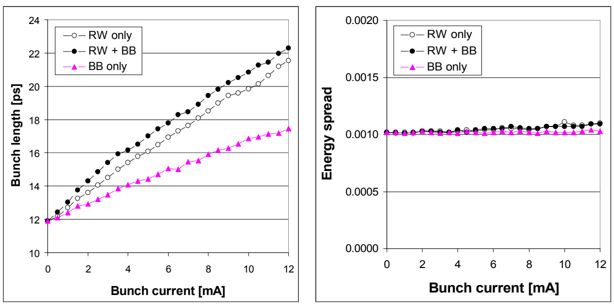
Figures 2: BPM impedance decomposition (upper) and reconstruction of a wake potential (lower).

The use of purely inductive components was avoided in the transverse planes, as they would represent space charge fields which should not be seen by relativistic particles. Satisfactory results could in fact be achieved using only broadband resonators. The decomposed broadband impedance data, as well as the resistive-wall impedance data taking into account the chamber cross section form factors, local conductivity and metallic layers, are uploaded systematically by the instability simulation codes. For time domain codes, wake functions are firstly constructed.

INSTABILITY SIMULATIONS

Single Bunch Instabilities

A single bunch tracking code was used to follow the collective effects. As the high bunch current mode of operation envisaged for SOLEIL consists of eight bunches of 10 mA each, studies focused in this current range.



Figures 3: Bunch lengthening (left) and energy spread widening (right).

It may be noted that in treating the RW field in the longitudinal plane, its $|t|^{-3/2}$ dependence on the time variable t as obtained by Fourier transforming the standard impedance formula was found generate wrong wake potentials due to its diverging behaviour at short range. This mathematical problem was overcome by following the work of Henry and Napoly [3], who investigated the correct short range behaviour of the RW Green's function. The bunch length and the energy spread versus bunch current obtained from the tracking show that; - The bunch length is less than the double of its zero current value at 10 mA. – No energy spread widening is observed up to 10 mA. The large tapers in the cavity section however bring the microwave threshold down to approximately 20 mA. – The RW impedance is contributing more to the bunch lengthening than the broadband impedance. To complete the longitudinal evaluation, the effect of NEG coating must be included, which is expected to enhance further the RW contribution [2].

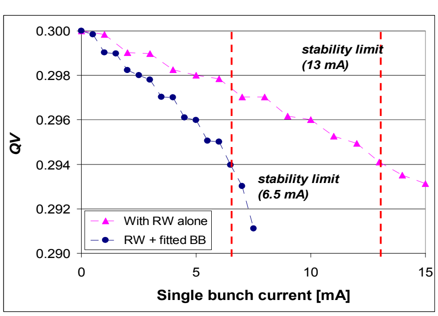
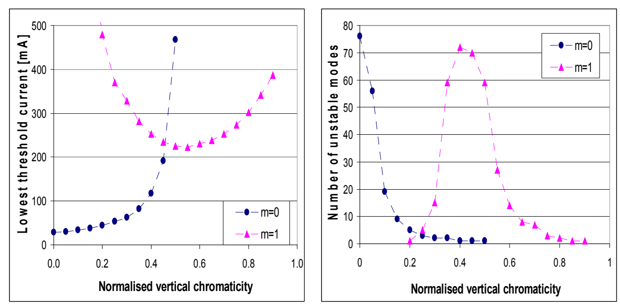


Figure 4: Vertical single bunch instability.

In the vertical plane at zero chromaticity, the current ramp is blocked around 6 mA due to the mode coupling (TMCI) between m=0 and -1. Distinguishing the relative contributions, the RW is found to contribute comparably to the broadband impedance to the mode zero detuning. Again, inclusion of the effect of NEG coating is expected to enhance the contribution of the former. Increasing the chromaticity to positive values, the threshold remained unchanged, with instability taken over by the head-tail instability of m=-1, -2, … Inclusion of bunch lengthening however enabled to go above 10 mA with the normalised chromaticity of 0.3. The situation is much more relaxed in the horizontal plane finding the TMCI threshold at around 30 mA.

Multibunch Instabilities

The main point of interest here is to see the behaviour of the instability at non zero chromaticity where the broadband impedance plays an important role, namely, to compare with the previous result using a model impedance [2]. Instability thresholds were calculated in the frequency domain, by solving the Sacherer's equation and equating the growth rate to that of the radiation damping in the uniform filling.



Figures 5: Vertical multi bunch instability. Threshold (left) and the number of unstable modes (right) versus chromaticity.

Reflecting the smaller resistive impedance of the numerically obtained impedance at higher frequencies as compared to the model employed, as stated earlier, the stabilisation of the mode zero with a larger positive chromaticity is found to be much weaker than previously, resulting in requiring as much as the chromaticity of 0.5 to stabilise the instability due to m=0 (Figs. 5 left). On the other hand, the instability driven by m=-1 mode, which takes over at higher chromaticities, is found to be less harmful. The result indicates that the shifting of chromaticity will not raise the threshold current up to the nominal current of 500 mA, but optical nonlinearity that generates the betatron tune spread could make it possible. There are as many as eighty coupled-bunch modes excited at zero chromaticity and at 0.4, and in between there is a minimum at around 0.2 where the transition of the driving mode occurs between m=0 and -1. In the horizontal plane, although the instability is more relaxed as in the single bunch case, the threshold at zero chromaticity is as low as 65 mA. Reflecting the reduced broadband impedance, no m=-1 mode instability appears at a positive chromaticity, but it requires the chromaticity of 0.3 to stabilise m=0 driven couple-bunch modes.

MULTIBUNCH TRACKING

The previous vertical instability results obtained in the multibunch is worrying. Although a transverse feedback system is being developed to cope with this situation, it is important to investigate in detail the underlying beam dynamics, especially for different bunch fillings as a function of chromaticity. The threshold current has been observed to depend notably on these quantities in several similar machines [5]. Another important element to consider is the betatron tune spread due to the optics nonlinearity that may brings stabilisation. These features being difficult to deal with in the frequency domain approach, a multibunch tracking code had previously been considered and developed, with preliminary results [5]. As the critical issue here being the required computational time, the algorithm has recently been improved to make the computation parallel among tracked bunches using a cluster of processors.

The scheme developed thus consists of a master and slave structure using *pvm* [4], 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 the long range resistive-wall forces, by respecting the distance between bunches over multi turns. In view of both the distribution of the RW impedance and the short time scale of the betatron motion, the transformation is divided in several steps around the ring with the use of transfer matrices.

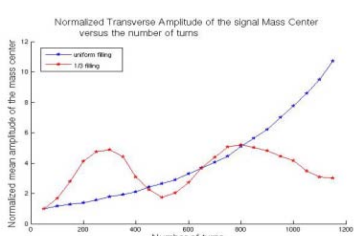


Figure 6: Vertical multibunch tracking with 2000 particles in each bunch with a small positive chromaticity.

The code is nearly ready to be applied to the SOLEIL case. The cpu time required to track the uniformly filled 416 bunches containing 5000 particles per bunch over 2000 turns is merely a couple of hours with less than 10 processors. A comparison of the vertical growth rate averaged over bunches between the uniform and 1/3 filled beam at chromaticity of 0.05 is shown in Fig. 6.

FIRST INSTABILITY OBSERVATIONS

The first current ramping was made with fills in multiples of ¼ of the ring. Even at currents well below the predicted vertical RW threshold of 30 mA, spontaneous beam signals appeared vertically and horizontally at frequencies which were not related to the betatron oscillation, whose amplitudes could be reduced by increasing the chromaticity (Figs. 7 left). The amplitude of the spontaneous signals as well as the injection saturation seems to worsen for fills with a large beam gap. The observed features, along with the fact the vacuum is being conditioned, lead us to suppose that the instability is due to ions, possibly of the type fast beam-ion.

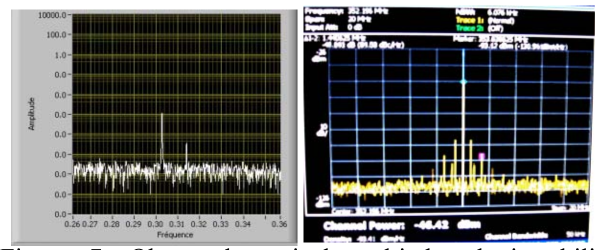


Figure 7: Observed vertical multi bunch instability. Unidentified peak in a partial fill (left) and betatron lines around the RF frequency in the uniform fill (right).

At around 30 mA in the uniform filling, two spontaneous vertical betatron lines were observed in the descending order around the RF frequency, which is likely due to the RW instability. These signals however started to emerge around 20 mA, namely 10 mA below the expectation (Figs. 7 right).

CONCLUSION

Reflecting the absence of broadband resonance at high frequencies in the obtained impedance data, the simulation predicted the microwave threshold to be above the operating current, as well as necessity of a large chromaticity to damp the dipole head-tail mode driven instability in the multibunch filling. The relative importance of the RW impedance was also confirmed. A vertical instability apparently due to RW was observed at a current not far from the prediction. A systematic study is underway with the multibunch tracking code developed.

ACKNOWLEDGEMENT

The author thanks the help of A. Loulergue and the commissioning team for the beam measurement, and A. Rodriguez for multibunch tracking simulations. He is also grateful to M.P. Level for many useful discussions.

REFERENCES

[1] R. Nagaoka, "Numerical Evaluation of Geometric Impedance for SOLEIL", EPAC'04, Lucern, June 2004, p. 2041.
[2] R. Nagaoka, "Study of Resistive-Wall Effects on SOLEIL", EPAC'04, Lucern, June 2004, p. 2038.
[3] O. Henry and O. Napoly, "The Resistive-Pipe Wake Potentials for Short Bunches", Part. Accel **35**, p.235 (1991).
[4] PVM,http://www.csm.ornl.gov/pvm/pvm_home.html
[5] R. Nagaoka, "Study of Resistive-Wall Instabilities with a Multi-Bunch Tracking", EPAC'02, Paris, June 2002, p. 1538.