ANALYSIS OF COLLECTIVE EFFECTS AT THE DIAMOND STORAGE RING

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Abstract

The Diamond storage ring has achieved its nominal operating current of 300 mA in multi-bunch mode and up to 10 mA in single bunch mode. Several collective instabilities have been observed and their dependence on machine parameters such as chromaticity, RF voltage and fill pattern have been investigated. We report here the analysis of the observed current thresholds compared with analytical estimates and tracking simulations. We also present the results of MAFIA simulations performed with the aim of understanding the main contribution to the impedance of the ring and establishing a machine impedance database.

INTRODUCTION

The Diamond storage ring is currently operating for users with a current of 200 mA in a multibunch 2/3 fill. During machine developments the current has reached the nominal value of 300 mA in a 2/3 fill and up to 10 mA in single bunch. Collective effects were clearly observed during these runs and several shifts were devoted to the quantitative assessment of their characteristics. The availability of the bunch-by-bunch data with the initial commissioning of the Transverse Multibunch Feedback (TMBF) [1] has given access to very good quality data describing the dynamics of single bunches isolated or within the multibunch train.

The current thresholds of various instabilities have been measured and compared where possible with numerical codes or semi-analytical estimates to obtain information on the transverse and longitudinal impedance of the ring. A wealth of data has been collected over time to monitor the variation of the machine impedance as new IDs have been gradually installed.

In parallel we are investigating numerically the impedance contribution of various items in the Diamond vacuum chamber which are held responsible of contributing significantly to the overall machine impedance. A campaign of MAFIA simulations is ongoing with the aim of characterising and providing a better understanding of the impedance and its effect on the beam.

SINGLE BUNCH INSTABILITIES

Diamond can operate with a wide variety of fill patterns thanks to the flexibility of its timing system [2]. This has allowed the possibility of studying single bunch collective effects and of characterising the longitudinal and transverse broad band impedance.

Potential Well Distortion (PWD) and the onset of the Microwave Instability (MI) were clearly detected since the early days and investigated for different voltages. In Fig. 1 we report the bunch lengthening curves measured with a streak camera and the energy spread widening curves measured from the two X-ray pinholes located at the two dipoles of a unit cell. The current threshold for the microwave instability occurs at about 1 mA, well above the foreseen single bunch current required for nominal multibunch operation, nevertheless it constitutes a potential problem for hybrid or few bunch filling modes for time resolved experiments.

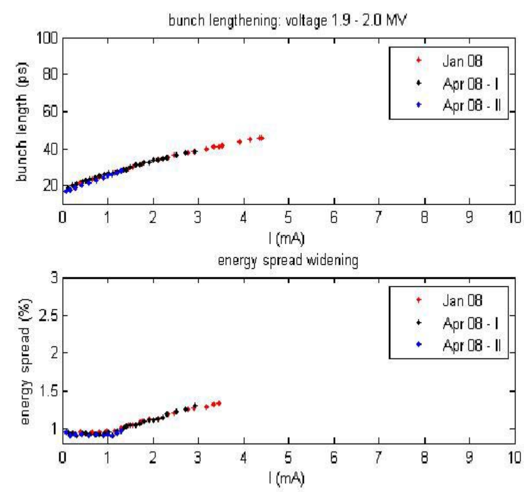

Figure 1: Bunch length and energy spread as a function of single bunch current at an accelerating voltage of 1.9 MV.

Numerical simulations with a simplified 2D longitudinal model including a broad band impedance resonator were performed in order to reproduce the measured curves. It proved difficult to match simultaneously the bunch lengthening curve and the microwave instability threshold: the best agreement was obtained assuming a broad-band resonator with central frequency 48 GHz and shunt resistance of 20 kΩ for the onset of the energy spread widening and about 60 kΩ. for the bunch lengthening curve. The longitudinal impedance $Z_{||}/n$ inferred from these simulations ranges from 0.2 Ω to 0.6 Ω. A more precise comparison will require a more realistic impedance model. A slight increase in the current threshold of the MI from 0.9 mA to 1.1 mA was detected as new IDs have been installed. A conjecture was put forward about the effect of the large tapers of the make-up vessel removed when the ID chambers went in, and it is under investigation [3].

Transverse single bunch collective effects have been investigated and both the Transverse Mode Coupling Instability (TMCI) and head-tail instability have been detected at sufficiently large charge. Storing a single bunch at zero chromaticity produces negative vertical tuneshift with current and a sudden vertical beam blow-up at 0.6 mA after which injection saturates. Fig. 2 reports the betatron spectrum of a single bunch as detected by the TMBF electronics. It proved quite difficult to detect the mode –1 frequency in this case, to unequivocally show a TMCI mechanism. Nevertheless the instability threshold increases with the RF voltage indicating a dependence on the distance of the synchrotron sidebands from the tune frequency which is a signature of the TMCI.

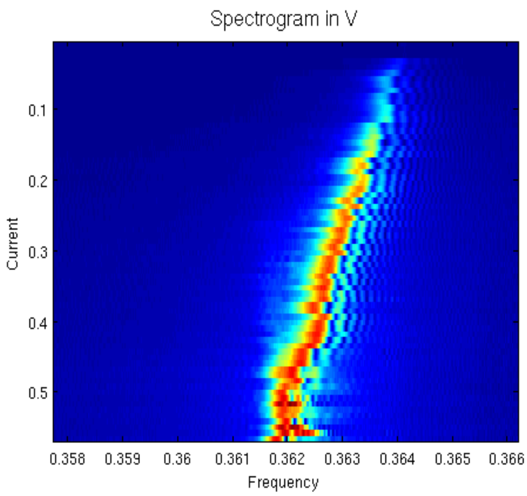

Figure 2: Vertical tuneshift with current and TMCI detected in the vertical plane.

The code MOSES [4] was used to fit the vertical broad band impedance parameter that reproduces the observed current threshold. The best match was found for a broad band resonator impedance with central frequency 6 GHz and shunt resistance of 1 MΩ assuming an average β of 10 m. The tuneshift with current in single bunch amounts to –2.1 kHz/mA in the vertical plane and is negligible in the horizontal showing that the coherent dipole wakefield effect is compensated by the incoherent quadrupole wakefield already in single bunch operation.

Increasing the chromaticity to $(\xi_x, \xi_x) = (2, 2)$ stabilises the TMCI and it was possible to inject current in the single bunch beyond the TMCI threshold. Nevertheless at positive chromaticity the classical head-tail modes become unstable and the injected current is still limited. The tuneshift with current is negligible in the horizontal plane and 1.3 kHz/mA in the vertical plane. Several head-tail modes are excited as the current increases as reported in Fig. 4. Injection is finally saturated at 3.3 mA when the head tail mode –3 becomes strongly excited.

A progressive deterioration of the maximum current that can be stored in single bunch has been observed in the last year and is under investigation. The maximum stored current using a positive chromaticity of (2, 2) has dropped from 10 mA to 3.3 mA. It is very likely due to the progressive modification of the vacuum chamber due to the installation of new insertion devices.

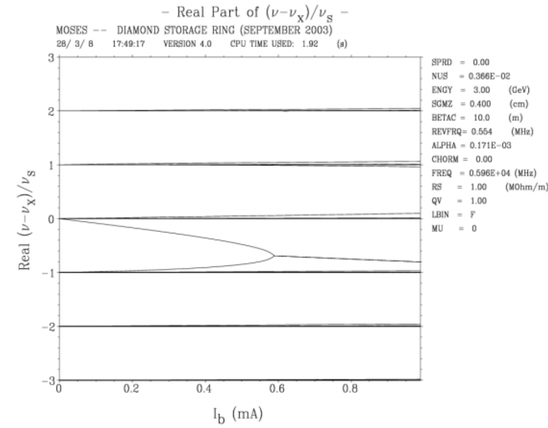

Figure 3: Single bunch TMCI in the vertical plane as simulated by MOSES.

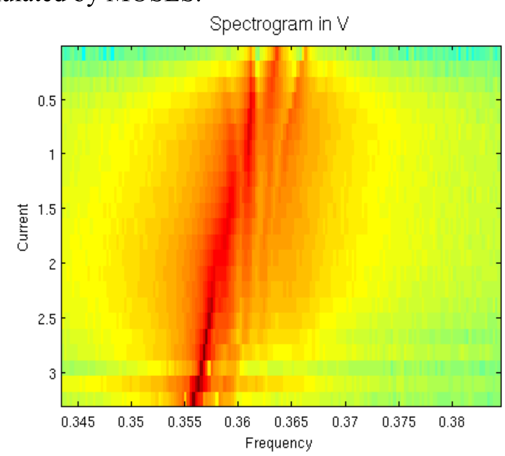

Figure 4: Head-Tail modes as a function of current in the vertical plane (see text for explanation).

MULTIBUNCH INSTABILITIES

Multibunch instabilities have been clearly observed at Diamond from the early days of commissioning. Indeed the operation with the nominal zero chromaticity lattice is prevented at multibunch currents as low as 10 mA in a uniform fill with 936 bunches. A positive chromaticity of two units in both planes has so far been sufficient to stabilise the electron beam up to 300 mA.

Investigation of multibunch instabilities has been performed both with a spectrum analyser and with the bunch-by-bunch TMBF data. These last data can be analysed on a multibunch modes of oscillations basis where the multibunch pattern is Fourier decomposed in the 936 modes and the amplitude of these modes can be followed with time. Fig. 5 shows the results of the analysis of the multibunch modes for a 2/3 fill with a chromaticity of two in both planes. The amplitude of the modes changes as a function of the stored current: in the vertical plane the modes around number 36 appear to be strongly excited at a current of 100 mA. The subsequent saturation of the instability is not fully understood and is under investigation. The analysis of the bunch-by-bunch oscillation within the multibunch train reveals that these instabilities develop with increasing amplitudes along the bunch train, as shown in Fig. 6, suggesting the onset of fast-ion instability mechanisms.

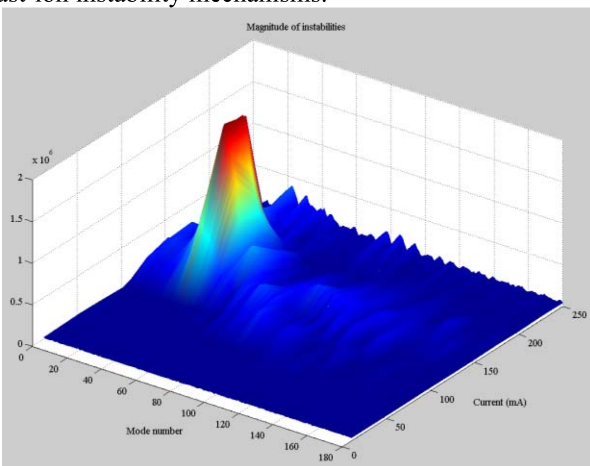

Figure 5: Colour plot of the vertical mode excitation vs current for a 2/3 fill, chromaticity two in both planes.

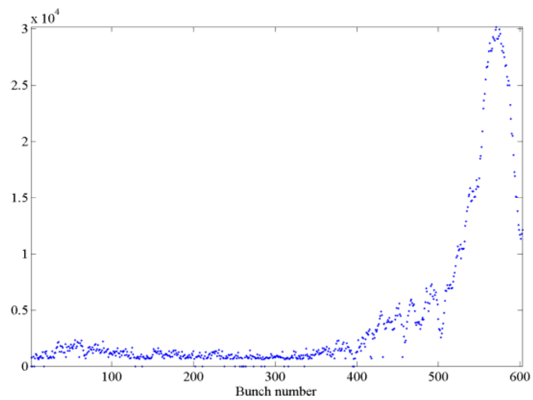

Figure 6: Amplitude of vertical oscillations along the bunch train.

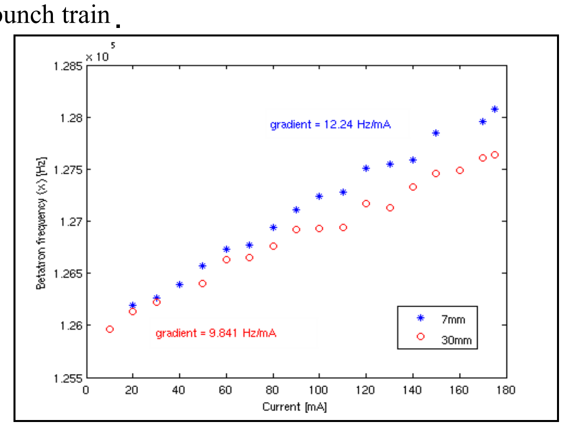

Figure 7: Tuneshift with current with ID open and in-vacuum IDs closed to 7 mm gap. Horizontal plane.

The tuneshift with current was measured in multibunch mode both in the horizontal and vertical planes. The measured slopes are 9.8 Hz/mA horizontal and –12.7 Hz/mA vertical and their different signs is ascribed to the contribution of the long range quadrupolar wakes which becomes more significant in the multibunch mode.

Closing all IDs to 7 mm gap slight variations on the tuneshift with current were observed. Fig. 7 reports the comparison of the slope measured with IDs open and IDs close in the horizontal plane. The measured slope increases to 12.2 Hz/mA in the horizontal plane and –13.4 Hz/mA in the vertical plane.

IMPEDANCE SIMULATIONS

A campaign of MAFIA simulations is ongoing in order to produce an database of the most significant items contributing to the machine impedance [5]. With the first high current run we noticed a heating of the primary BPM blocks. This could only be partially cured by using a longer fill, thus reducing the single bunch current, and it eventually required additional local air cooling. The temperature rise is modest (below 50^{o}C) nevertheless a more carefully investigation of the impedance contribution given by the two types of BPM blocks present in the ring was undertaken. The buttons in the primary BPM blocks are located 10 mm vertically from the beam. This distance is 19 mm in the in the standard BPM blocks. The impedance of the primary BPM is shown in Fig. 8. The loss factor is 0.075 V/pC for the primary BPM and 0.029 V/pC for standard BPMs showing that the primary BPMs have a factor 2.6 higher power loss.

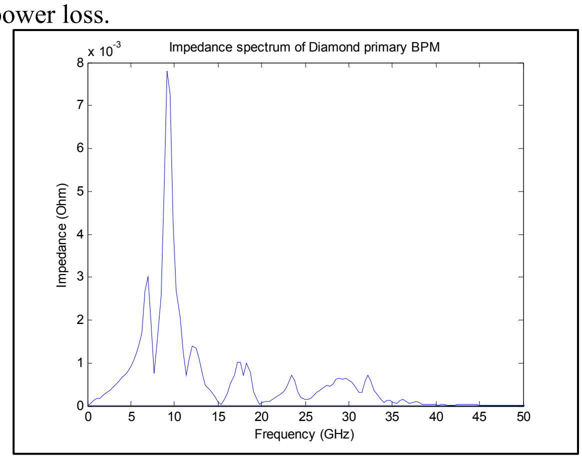

Figure 8: Longitudinal impedance at the primary BPM block.

CONCLUSION AND ACKNOWLEDGEMENTS

The characterisation of collective effects at the Diamond storage ring is underway in parallel with a computational effort aimed at understanding the main items contributing to the machine impedance. The help of M. Dehler (PSI) with MAFIA simulations and many discussions with R. Nagaoka (SOLEIL) are gratefully acknowledged.

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