THE COMMISSIONING OF THE DIAMOND STORAGE RING

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Abstract

The Diamond storage ring has opened for user operation at the end January 2007. The storage ring has been successfully commissioned at 3 GeV in three months by December 2006. An intensive accelerator physics program has allowed the design emittance at 2.7 nm to be reached and the commissioning of the first eight insertion devices. We describe here the results of the measurements performed to characterize accelerator optics, to bring the insertion device in operation and a first analysis of orbit stability and collective instabilities, as well as plans for top-up operation.

INTRODUCTION

The commissioning of the Diamond storage ring at full energy began in Sept. 2006, with the first turns recorded on 5th Sept. and first stored beam at 3GeV on 7th Sept. Over the following three months the operation of the storage ring in the nominal low-emittance lattice was established and the target current for initial operation of 100 mA was reached on Nov. 11th . The milestones of the initial part of the storage ring commissioning can be found in [1].

Eight phase-I insertion devices were commissioned in parallel to the storage ring, starting from 29th Sept. First light was sent to a beamline optics hutch on Oct 12th and beamline commissioning could start on Oct 23rd. First users operated on 29th Jan. and by the end of May 2007 a total of more than 50 days user's operation has been delivered in four users' runs.

An intense machine development program is currently ongoing during the machine development shifts. The activities are focussed on the characterisation and control of the linear and non-linear optics of the machine, on high current operation in both multi-bunch and in single bunch modes and characterisation of the corresponding collective effects. Significant effort has been devoted to the analysis of the orbit stability with thorough comparisons of the measured ground motion with the vibrations of the magnetic elements and the beam orbit data. The fast orbit feedback (FOFB) has been successfully tested and is ready to be used during normal users operation, while the transverse multibunch feedback (TMBF) is under commissioning. A vigorous program for the implementation of Top-Up injection has also been pursued with the aim of delivering Top-up operation to users at the beginning of 2008.

LATTICE COMMISSIONING

The Diamond storage ring is a 3 GeV, 24-cell double bend achromatic lattice with a low emittance of 2.7 nm.rad, obtained by introducing finite dispersion in the straight sections. The lattice has 6 long straight section of 8.3 m and 18 straight sections of 5.3 m. Two of the long straight sections are occupied for injection and RF system respectively. The main parameters of the lattice can be found in Ref [2].

With the first 3 GeV beam stored on Sept. 7th it was possible to obtain clean measurements of closed orbit, integer tunes and orbit response matrices of the 168 e-BPMs and 168 dipole correctors and to obtain first useful indications on the optics of the machine. The orbit corrections were performed using the singular valued decomposition (SVD) of the measured orbit response matrix selecting a threshold on the eigenvalues used in the inversion, typically of $2{\cdot}10^{-3}$ the highest singular value. Although the residual orbit was reduced to 0.7 mm rms in both planes, decisive progress was made only after performing Beam Based Alignment (BBA) to determine the BPM electrical offsets with respect to the closest magnetic quadrupoles centres [3]. With the residual orbit reduced to less than 100 μm rms in both planes and a stored current increased to 25 mA, it was possible to perform cleaner orbit response matrices and the first optics measurements and corrections with LOCO [4]. An initial β-beating of 40% in both planes was gradually reduced to about 10% after four LOCO iterations. Proceeding with this iterative loop based on orbit correction, BBA and optics correction with LOCO, it was possible to achieve a residual orbit of less than 1 μm rms by Oct 22nd using all eigenvalues of the orbit response matrix. The β-beating was reduced to less than 2% by Nov 8th (Fig. 1). Correspondingly also the measured dispersion function is in good agreement with the model.

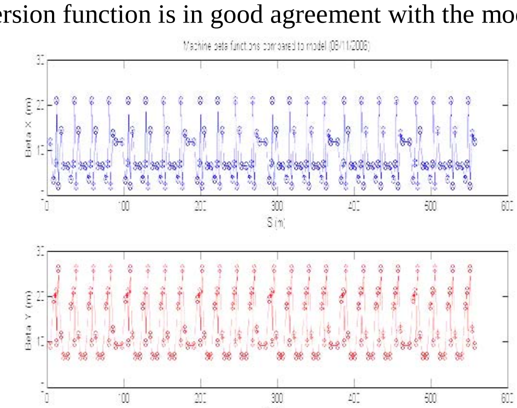

Figure 1: Optics functions at the BPMs after LOCO correction. The dots represent the model values, the crosses are the measured values.

Emittance and energy spread are measured with two pinhole X-ray cameras located at the two dipoles in the arc, in positions with different optics functions. The

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measured emittance values are in the range 2.6-2.9 nm·rad and the energy spread within 0.10-0.11% confirming the good control of the linear optics achieved. Linear coupling was also corrected using LOCO to determine the skew quadrupoles correction. The resulting emittance ratio can be set in the range 0.1-10%. Further detail on these optics measurements can be found in a companion paper [2].

The storage ring is now currently operating at 125 mA during User Mode with a lifetime exceeding 20 h at 100 mA. An accelerating voltage of 2 MV is provided by one SC RF cavity. A second SC RF cavity was installed in April 2007. Operation with two cavities has been successfully proven reaching the design operating voltage of 3.3 MV and will be implemented during users run in the near future.

INSERTION DEVICES

Eight insertion devices (IDs) have been installed in the storage ring and are under commissioning: these are six in-vacuum undulators operating at a nominal gap of 7 mm, one Apple-II type (HU64) and one SC wiggler (SCW) with peak field 3.5 T. Three of the in-vacuum undulators are in a chicane arrangement with 0.25 mrad canting angle. A careful investigation of the perturbation on the closed orbit and on the linear optics has been carried out for all devices. Closing the IDs to their minimum gap generates a residual closed orbit of 20-25 μm rms for the in-vacuum undulators and slightly larger for the Apple-II (50 μm rms). However trim coil feed-forward tables have been set up to correct the orbit disturbance to about 1-2 μm rms at all gap values. The orbit distortion induced by the SCW is somewhat larger, 160 μm rms in the vertical plane, and is corrected with the main correctors. However during the whole ramp process the orbit is well within the 1 mm beam position interlock threshold. Several schemes for the compensation of the IDs effect on the linear optics are under investigation. Further details can be found in a companion paper [5].

HIGH CURRENT OPERATION

A record of 170 mA stored current has been achieved during machine development shifts limited by the availability of only one SC RF cavity. Multibunch instabilities appear in both in the vertical and the horizontal as shown by the appearance of betatron sidebands around the harmonics of the revolution frequency on a spectrum analyser (SA). The current threshold depends on the fill patterns and, at zero chromaticity, it is as low as 10 mA in full fill. A first analysis of the pattern of the betatron lines on the SA points to a mixture of Resistive Wall and Ion-related instabilities. The instabilities can be cured by increasing the chromaticity: using a positive chromaticity of 2 in both planes a 2/3 fill is completely stable up 110 mA. At higher current some instabilities appear again mainly of ion related type as shown in Fig. 2 for 150 mA in 2/3 fill. While a slightly positive chromaticity is actually improving the lifetime it is clear that we cannot rely on high positive chromaticity only to operate the machine in multibunch mode and a TMBF system is presently under commissioning [7].

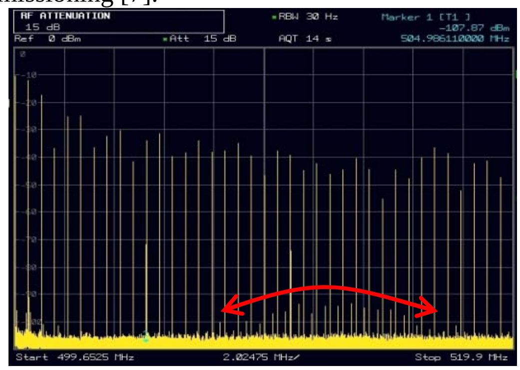

Fig. 2: Spectrum Analyser traces for 150 mA, 2/3 fill, chromaticity +2 in both planes, showing the prevalence of ion related induced instabilities over the Resistive Wall.

During single bunch operations we reached a record of 10 mA per bunch, mainly limited by detrimental effect of the large signal induced in the BPM system. Nevertheless a first analysis of bunch lengthening and energy spread widening in single bunch was carried out using a streak camera for bunch length measurements and the two x-ray pinholes for the energy spread measurements. The results reported in Fig. 3 show that with a voltage of 1.8 MV the initial bunch length of 17 ps is almost tripled at 7 mA. The energy spread curve show clearly the characteristic onset of the microwave instability at a single bunch current of about 1 mA. Numerical simulations with a 2D longitudinal tracking code with a the longitudinal impedance modelled by a RLC broadband resonator show that bunch lengthening and energy spread widening are reasonably well reproduced by assuming a longitudinal broad band impedance $Z_{||}/n$ = 0.4 Ohms.

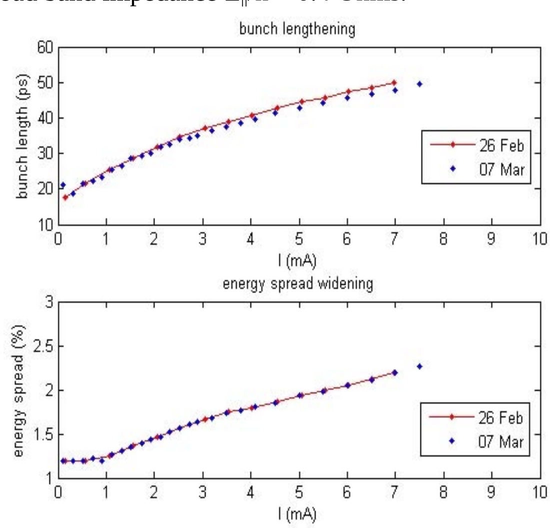

Fig. 3: Bunch lengthening and energy spread curves.

ORBIT STABILITY

Orbit stability has been analysed comparing beam orbit data with the measured displacement power spectral densities (PSD) of the ground motion, and of the vibrations of quadrupole magnets on the three types of girders in the arc cell. The beam motion is measured using the same orbit data sample rate of 10 kHz that is used in the FOFB. Fig. 4 shows that the main sources of motion occur around 15-25 Hz where a total of about 2.5 μm rms horizontal motion and 0.7 μm rms vertical motion are accumulated. The analysis of the integrated horizontal displacement clearly shows that 16-20 Hz are excited through resonances in girders 2 and 3 while the 24.7 Hz is excited through a resonance in the girder 3. Presently a slow orbit feedback running with MATLAB typically at 0.2 Hz is normally used during operation. However a FOFB is currently under final stages of commissioning and will soon replace it.

FAST ORBIT FEEDBACK

First successful tests of the FOFB system were recently performed [6]. The system is based on the 168 Libera eBPMs and 168 dipolar correctors for both planes used also for the slow orbit feedback. Orbit data are acquired at 10 kHz from all BPM synchronously and transferred to a set of 24 CPUs (one for each cell) where the values for the seven corrector magnets of the corresponding cell are computed and written to the power supplies. Presently, the 3dB bandwidth of the system is limited to about 100 Hz due to an internal low pass filter in the power supply. Since the 3dB bandwidth of the corrector magnets plus the stainless steel vacuum chamber is estimated to be larger than 500 Hz, it is expected that faster orbit correction can be achieved after modification to the power supplies. Nevertheless, the success of the FOFB in suppressing the beam motion around the frequencies 15-25 Hz is very clear: Fig. 5 shows the comparison of the integrated position amplitude with FOFB running at full rate and without feedback. The integrated noise is reduced from 4 μm to 1 μm in horizontal and from 1 μm to 0.4 μm vertically up to 100 Hz. The system is planned to be used routinely during users' runs in the very near future.

TOP-UP

Diamond plans to provide top-up operation in early 2008. Multishot single bunch injection at fixed time intervals is deemed adequate to provide a current stability better than 1% at 300 mA. With this aim, a number of problems have been recently addressed: tests of the injection timing systems to target specific bunches in the fill pattern have been successfully carried out [8] and a prototype top-up application has been developed.

The injection efficiency has been optimized to better than 95% with IDs closed, both in single bunch and multibunch mode. The residual oscillations of the stored beam during injection are reduced to 400 μm but will require further optimisation. The timing system will distribute gating signal to the beamlines to allow any remaining perturbation to be masked-out, if required. At the same time, extensive numerical simulations are in progress to analyse the possibility of a top-up accident, in which faulty conditions on one or more magnets conspire to steer an injected beam through the shutter of an open beamline. These simulations will be used to define a system of interlocks capable of preventing such an accident occurring. The first indications are very promising and a stored beam current interlock seems capable of preventing the most probable causes of accidents scenario. Injection tests with shutters open and radiation checks are planned in the forthcoming weeks.

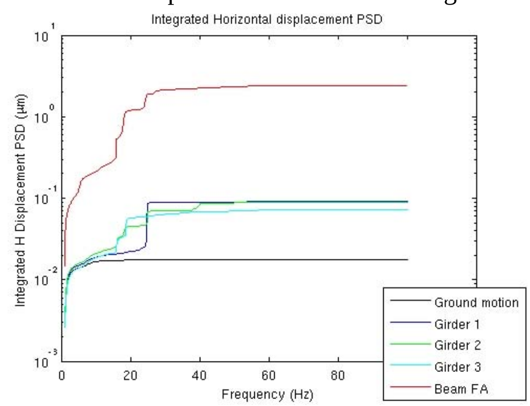

Fig. 4: Horizontal PSD comparison of ground motion with vibration of the three girders and beam motion.

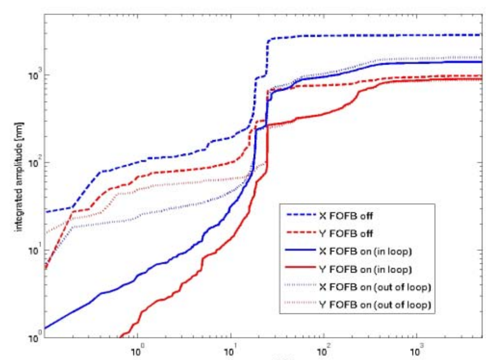

Fig. 5: Results of FOFB tests during commissioning.

ACKNOWLEDGMENTS

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