BEAM DYNAMICS EFFECT OF INSERTION DEVICES AT DIAMOND STORAGE RING

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Abstract

Diamond operates with 10 in-vacuum insertion devices at 5 mm gap, two Apple-II, two superconducting and two normal conducting wigglers. We report here the correction of the linear optics of wigglers and measurements of nonlinear effects such as dynamic aperture and frequency maps and their impacts on injection efficiency, lifetime and loss distribution in operation of the storage ring.

INTRODUCTION

The Diamond storage ring operates 10 in-vacuum IDs, one out-of-vacuum (OV), two APPLE-IIs (installed in same straight), two superconducting wigglers (SCWs) and one normal conducting wigglers (NCW). The superconducting wigglers I15 (B_0(max)=3.5T), I12(B_0(max)=4.2T) and normal conducting wiggler I20 (B_0(max)=2.0T) are installed in standard straights which has small vertical β_y of ~1.6m in order to have minimal effects on linear optic perturbations. The theoretical studies of first phase of IDs on linear and nonlinear dynamics and initial investigations of beam dynamics and commissioning experiences are presented in ref.[1,2,3]. Other IDs operate at peak magnetic field $B_0 \leq 1$T and are installed in low β_y straights only. All In-vac IDs are operating at minimum gap of 5mm as planned. The measured linear tune-shifts are small and hence beta-beating is also small as expected. The main perturbations to linear optic are produced by the SCWs which can produce a $\Delta Q_y \approx 0.012$ and y-beta-beat of ~12% each while I20 can produce $\Delta Q_y \approx 0.005$ and y-beta-beat ≈ 5%.

MEASUREMENTS OF LINEAR OPTICS PERTURBATION

The beta-beat produced by SCWs are measured using LOCO[4] as described in ref.[1]. The linear tune-shifts and beta-beats produced by SCW I15and I12 are listed in table below and are nearly same as predicted.

Table 1: Vertical tune-shift and beta-beat

SCW	B_0(T)	ΔQ_y	$\Delta\beta_y/\beta_y$(%)
I15	3.5T	.011	11%
I12	4.2T	.011	12%
I15+I12	3.5T+4.2T	.023	24%

When both SCWs are operated at full field without correcting the vertical tune Q_y, the injection efficiency is significantly reduced. However, the injection efficiency can be easily restored if Q_y is corrected globally.

CORRECTION OF LINEAR OPTICS

Firstly we investigated optics correction using two methods - LOCO algorithm and alpha-matching/global tunes correction. Here we report the results of investigations not previously reported in [1] due to technical problems encountered with operating the I15 SCW at peak field at that time.

LOCO algorithm:

This algorithm was applied to generate quadrupole settings to operate ring with both wigglers at peak fields. The beta-beat before correction was 20% in x and 40% in y. The beta-beat in x and more than predicted in y were due to uncorrected machine optic with wigglers off. It took two iterations before optic was corrected as shown in figure1a. The maximum relative variations of ~10% to the strengths of strengths of quadrupoles are required in first iteration. The residual beta-beats were less than 5% in both planes. The ring was operated using this file before feed-forward tables were introduced for the SCW.

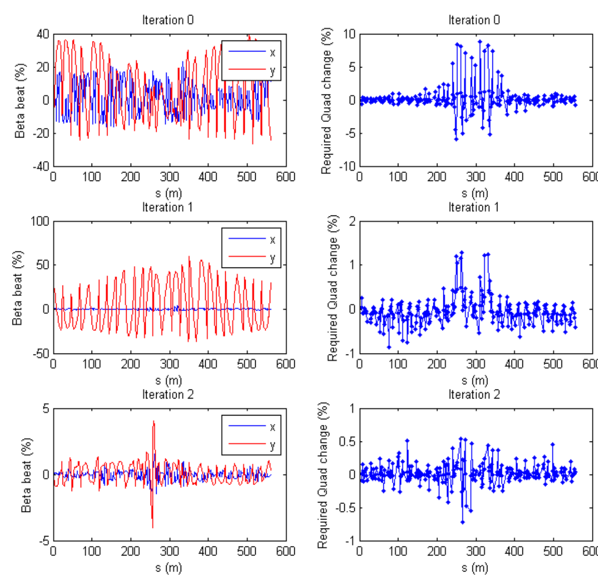

Figure 1a: The beta-beats and required relative variations of 240 quadrupoles for optic correction.

Alpha-matching:

The alpha-matching was applied for both wigglers using local Q1B and Q2B families of quadrupoles and tunes were then corrected globally using Q2D and Q3D families in the long insertion straights. The measured residual beta-beats (<6% except at locations of wigglers) are shown in figure1b.

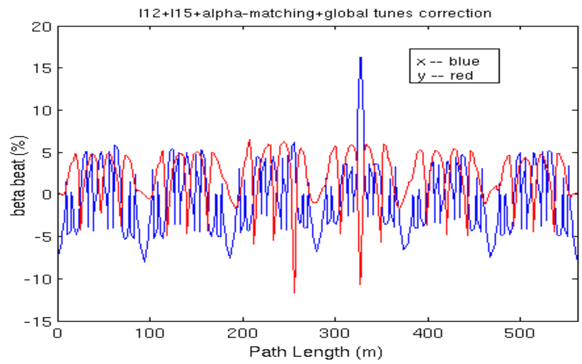

Figure 1b: Residual beta-beat for both wigglers I12 and I15 operating at peak fields.

Though residual beta-beat is smaller in the case of LOCO algorithm, due to the reduced number of magnets involved and smaller changes required it was decided to run wigglers with feed-forward tables generated by alpha-matching and global tunes correction for ramping up/down of magnetic field of individual wigglers.

The feed-forward tables are implemented as EPICS genSubs running on the individual magnet power supply IOCs. The tables are generated as the corrections required to each magnet at a discrete set of wiggler fields, usually in steps of 0.5T with linear interpolation in-between. There are currently two tables implemented for the I12 and the I15. A third table for the I20 (NCW) has been tested and will be implemented shortly.

Further investigations were made into the benefit of optics correction on the nonlinear dynamics of the ring. These are required because of symmetry loss for the sextupoles in the ring due to the wigglers. The dynamic aperture (DA) and frequency maps (FM) were measured using pinger magnets at low stored current of 10 mA to avoid orbit interlocks in order to reach the border of the DA. The border of DA was determined as the pinger current at which stored current in ring drops by 0.1% for next step in pinger current. The measured DA was for two cases: a: wigglers with feed-forward, b: wigglers without feed-forward but tunes corrected by usual method. No reduction in DA was noted but FMA shows thinning and shortening of tail in case b due to excitation of 7th order resonance (see figure 2). Therefore it is other benefit of optic correction which restores the symmetry of ring in addition to the linear tunes.

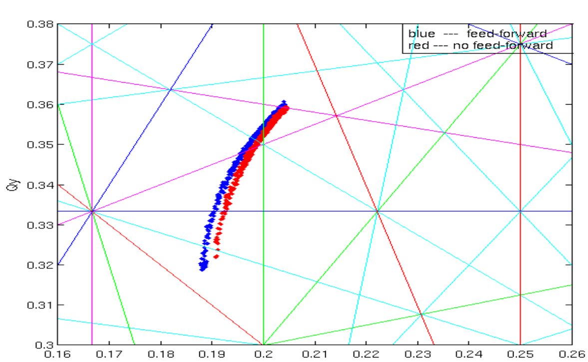

Figure 2: FM: blue) feed-forward tables (I12+I15), red) only tunes corrected without feed-forward tables.

MEASUREMENTS OF DA AND FM FOR IN-VACUUM IDS

To further study the nonlinear dynamics of in-vac IDs in Diamond ring the on-momentum DA and FM were measured for different IDs. The measured DA with collimators open and closed for different in-vac IDs closed to a minimum gap of 5mm are shown in figure 3a and figure 3b respectively. It is noted that the x-DA for I04 and y-DA for I02 shrink in comparison to other in-vac IDs when collimators are open. I04 has also been noted as the source for degradation of injection efficiency by ~12% as reported in following section. The storage ring operates in top-up mode with collimators closed when in-vac IDs are closed and hence required high injection efficiency. The DA with collimators closed (figure3b) further confirms the reduction of x-DA for I04 close to 5mm gap. To investigate further the reason the FM were measured for I04 closed to 5mm and with all IDs open as shown in figure 4.

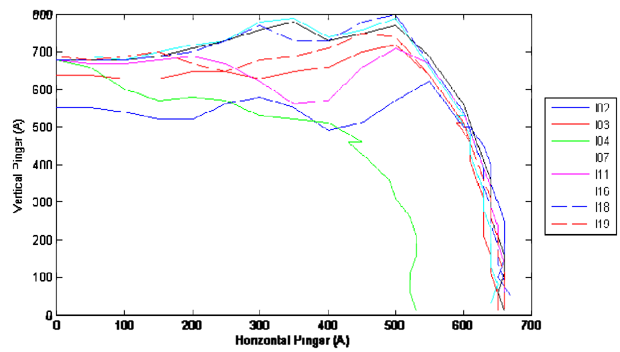

Figure 3a: On-momentum DA in terms of pinger current (A) for in-vac IDs close to 5mm gap with collimators open

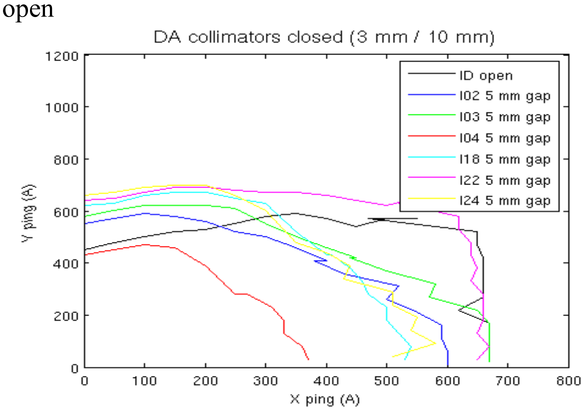

Figure 3b: On-momentum DA in terms of pinger current (A) with individual in-vac IDs closed to 5mm gap with collimators closed.

It can be noted that FM with I04 closed to 5mm gap shrinks from tail (red) and ends at the skew octupole resonance line $3Q_x+Q_y$ (magenta) which indicate excitation of this resonance. This resonance can not be excited by systematic field of an ID, therefore octupolar field errors may be arising from field errors of I04. The measured horizontal field integral was analysed which didn't indicate source for so strong octupolar resonance that can excite this resonance. Further investigations have launched to measure the field integral in machine which are still under way.

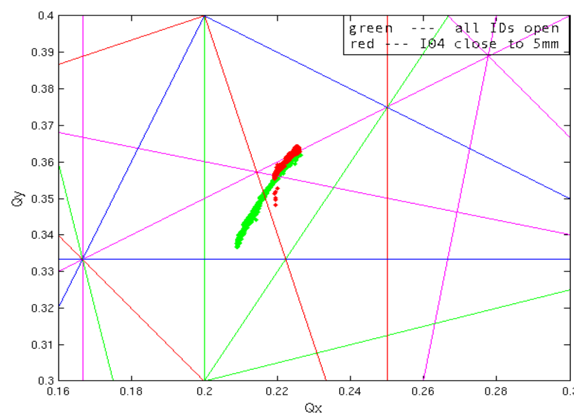

Figure 4: FM: red) I04 closed to 5mm gap, green) all IDs open

To further ascertain the cause Q_x was moved to bring working point (Q_x=27.22, Q_y=12.36) away and nearer to this resonance line and DA was measured. The results are shown in figure 5. The DA recovers for Q_x=0.235 (moves away) while it further shrinks for Q_x=0.215 (move in) which validates the excitation of skew octupolar resonance. Now working point has been shifted further below after this resonance line to (27.205, 12.36) which gives injection efficiency between 80-90% with all IDs closed including SCWs with feed-forward tables in normal operation.

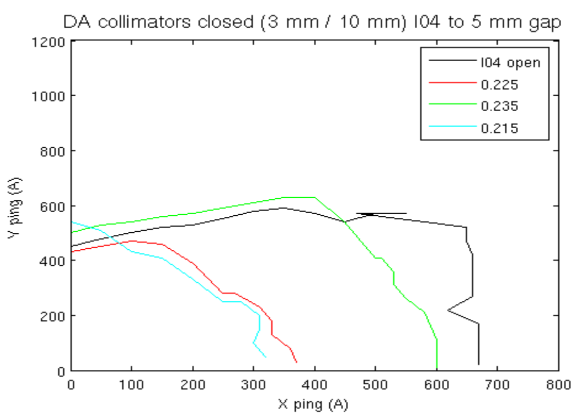

Figure 5: The on-momentum DA with different Q_x (Q_x=.235,.225(normal),.215).

EFFECTS OF IDS ON INJECTION EFFICIENCY AND LIFETIME

The effects of closing each in-vacuum ID individually down to 5mm were investigated. The effects were initially seen to be large, and presented a problem during routine operation of the ring when in-vac IDs to be closed to 5mm gaps. The main cause has been discussed in previous section. Since moving to a new working point that avoids this resonance, no ID has a significant impact on injection efficiency, with maximum reductions on the order of 2% for individual devices as shown in figure 6. The two APPLE-IIs and wigglers running with feed-forward have negligible effects on injection efficiency. The IDs at Diamond have small effect on beam lifetime.

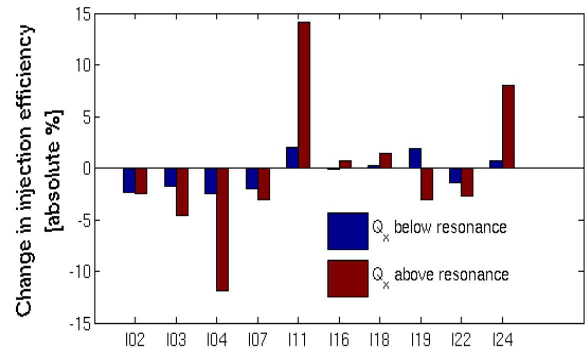

Figure 6: Change in injection efficiency for individual in-vac ID closed to 5mm gap Q_x below/above $3Q_x+Q_y$ resonance line.

EFFECTS OF IDS ON STORED BEAM LOSSES

The variation of stored beam losses with ID gaps was also investigated. The loss monitors on the downstream girder before the first dipole in each cell were used and provide data on the variation of losses. The average particle loss over 10 seconds was measured (figure 7).

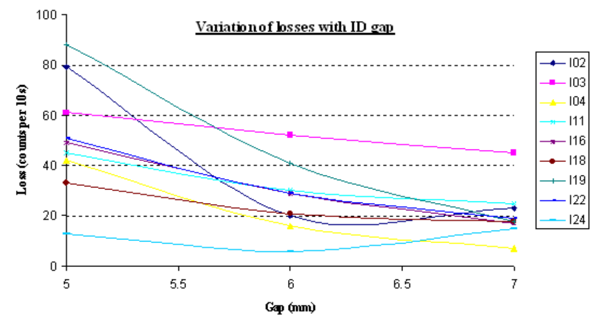

Figure 7: The loss particles per 10s with gap for in-vac IDs as can be seen, there is significant variation in the trends for different IDs, even between similar devices such as I02, I03 and I04. The reason for this variation is not well understood.

CONCLUSIONS

The wigglers generated linear optic distortions have been corrected well using feed-forward tables and loco algorithm. The former method is found to be more suitable for operation which is implemented for DIAMOND with good injection efficiency and lifetime. The new working point has been found to offset the effect of I04 on injection efficiency due to skew octupolar resonance. The source of corresponding field error is under investigation.

ACKNOWLEDGEMENTS

It is a pleasure to offer thanks to G. Rehm and C. Christou of Diamond.

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