FIRST YEAR'S EXPERIENCE OF DIAMOND INSERTION DEVICES

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Abstract

Diamond was commissioned at 3 GeV with seven insertion devices (IDs) already installed. The Phase I IDs include five in-vacuum (IV) pure permanent magnet (ppm) undulators, an APPLE-II variable polarization device, and a superconducting wiggler [1]. Since initial commissioning of the ring, four more in-vacuum undulators have been installed, and another three devices will be installed in the coming year. In this paper, we describe commissioning, characterizing, and operating with these IDs.

INTRODUCTION

Since January 2007, Diamond has operated for over 4500 hours for user operation. The current user mode has two injection periods per day, with a maximum current of 175 mA, and a typical lifetime of 21 hours with 1.9 MV RF voltage when all IDs and the superconducting wiggler (SCW) are at full field [2]. Diamond currently operates with one SCW and will have a second installed within the next year. Out-of-vacuum (OV) devices comprise two APPLE-IIs installed in the same straight, and another standard ppm out-of-vacuum ID which will be installed in a canted straight downstream of an in-vacuum device later this year. There are currently 9 in-vacuum devices installed in the ring, and a 10th will be installed this year. The minimum gap for the in-vacuum devices during normal operation is currently 7 mm, where there is no measured effect on the lifetime, however this will be reduced in the near future. During machine development operation, the minimum gap of the IV undulators is 5 mm, and much of this paper will describe the change in machine parameters between these two modes of operation. Table 1 summarises the ID parameters.

UNDULATOR STRAIGHT COMMISSIONING PROCEDURE

The first 16 insertion devices at Diamond will all be installed in 5.3 m (short) straights. Commissioning of the straights includes any ID correction table construction as well as chicane commissioning for straights which include them. Figure 1 shows the standard short straight layout.

The preferred method for commissioning ID trim coils and chicanes is to measure the response matrix of each individual element and then to iteratively change the fields to produce the smallest orbit distortion possible.

Table 1: IDs installed in Diamond (*as of Dec. 2008). I04.1 and I06, 16 mm gap; IV devices 7 mm (5 mm) gap

Beam-line	**ID Type**	**Period [mm]**	**No. of Periods**	**Field [T]**
I02	IV	23	85	0.70 (0.92)
I03	IV	21	94	0.64 (0.86)
I04	IV	23	85	0.70 (0.92)
I04.1*	OV	30.8	21	0.45
I06	APPLE-II	64	2 x 33	0.94
I11	IV	22	89	0.67 (0.89)
I15	SCW	60	22.5	3.5
I16	IV	27	73	0.8 (1.0)
I18	IV	27	73	0.8 (1.0)
I19	IV	21	94	0.64 (0.86)
I22	IV	25	79	0.75 (0.97)
I24	IV	21	94	0.64 (0.86)

Trim Table Construction

Trim coils for horizontal and vertical orbit correction are installed at both ends of every ID. The change in orbit compared with zero field is recorded for each gap and the response matrix of each trim coil measured (since some trim coils move with the gap). Appropriate trim coil fields to minimize the orbit distortion are found iteratively and the value is recorded in a table which is fed forward to the power supplies as a function of gap. The tables are typically constructed with 1 mm steps (10 mm for the OV device) in gap with interpolation between points to the 1 µm level. For the APPLE-II devices, the trim tables are 2-dimensional to allow different field settings for all gaps and phases. Generally, the orbit distortions due to IV devices are <4 µm (max) for all gaps when the feed forward tables are in use, and <20 µm (max) due to the APPLE-IIs at all gaps and phases. This residual distortion is removed by the fast orbit feedback (FOFB) system.

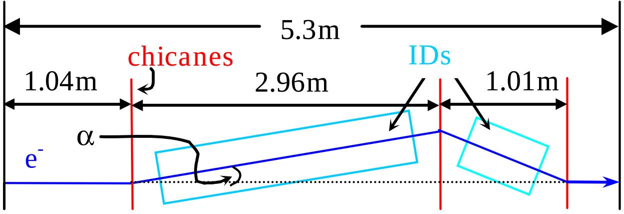

Figure 1: Schematic of short straight with chicane.

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Chicane Commissioning

Three of the 9 in-vacuum IDs installed in standard straights are not canted, three are in chicanes where the photon beam is pointed through an angle (α, in figure 1) of 0.25 mrad out of the ring, and four are at an angle of 1.5 mrad out of the ring. The purpose of the canting was to reduce gas Bremsstrahlung background radiation as well as to allow the option of installing second (shorter) IDs in the straight at a later time. The first of these short (0.6 m) devices, I04.1, will be installed this year.

The original proposal for the chicane commissioning was to measure the response matrix of each of the magnets individually to produce a calibration for producing a closed bump through the straight. It proved difficult to overcome the hysteresis observed in the magnets for large field changes, so the procedure was slightly modified. The magnets were set to a nominal field based on manufacturer's data, after which small changes of the fields in the second two magnets in the bump are applied to measure the individual response matrices and iteratively close the bump. The primary drawback of this method is the lack of an absolute calibration of the first magnet in particular which provides the beam to the main beamline, and there was a small deviation from the manufacturer's data required for the 0.25 mrad chicanes to get beam into the beamlines which had to be found empirically.

Photon Beam Position Monitoring

In general, photon beam position monitors (XBPMs) are not included in any feed-forward or feed-back systems for commissioning the trim tables or chicanes

XBPMs are centred on the photon beams from their respective IDs [3] and then movements away from this nominal zero position can be observed. In the case of the in-vacuum IDs, with FOFB running, the photon beam generally moves less than 100 μm over the full range of measureable gap motion (7 to 15mm). Similarly for the APPLE-II devices between 16 and 80mm in circular mode this movement is also approximately 100 μm (significantly smaller than the beam size at that position).

Since commissioning the first 1.5 mrad chicane, it has been observed that the horizontal angle and position of the photon beam changes with the RF frequency (1 μrad and 10 μm, respectively for a 200 Hz RF frequency shift). This implies that a long term study will have to be undertaken to see if the slow changes of the RF frequency (~300 Hz over months) during user mode when RF feedback is used cause measureable shift of the photon beam position.

ID INFLUENCE ON BEAM PARAMETERS

During normal operation there is no observed effect of the IDs on lifetime. Currently, we do not inject into closed IDs during normal operation, but the injection efficiency for 7 mm gaps has been checked and there is no measureable effect from having all IV devices closed to 7 mm. Similarly for OV devices, no effect on lifetime or injection efficiency has been observed.

IV IDs at Smaller Gaps

Studies of the effects of IV gaps smaller than 7 mm are ongoing. Initially, it was observed that there were significantly larger effects from the single ID in I02 than from similar devices in equivalent straights. In fact for some time, there was a drop in lifetime when this ID was taken even to 7 mm gap during user operation. The lifetime drop at 7 mm gap was rectified by more careful centring of the device vertically than had been achieved previously which resulted in a campaign of re-checking the centring of all IV IDs, which is still in progress. Generally, it has been found that the external alignment of the devices is not reliably better than ~300 μm (centre of gap to e-beam). Table 2 shows the most recently measured centred positions (if available) and the effects of various IV IDs at 5 mm gap on lifetime and injection efficiency.

Table 2: Effect of IV IDs on lifetime and injection efficiency at 5 mm gap

Beamline	Offset from centre [μm]	Lifetime Change	Inj. Eff. Change
I02	≤ 40	-30%	-20%
I03	~ 250	-22%	0%
I04	≤ 40	-16%	-2%
I16	not measured	-14%	0%
I18	≤ 40	-14%	0%
I22	~ 260	-24%	-3%
I24	not measured	-10%	0%

It has generally been observed that the lifetime decreases by ~10 % per mm below 7 mm gap, which is consistent over many IDs, currents, and RF voltages. Despite the improved alignment, there continues to be a larger effect from I02 on both lifetime and injection efficiency which is still under investigation.

Shifts in the tunes of up to 0.002 have been observed for IV ID gaps below 5 mm.

Wiggler and OV IDs

As reported in [2], the SCW at full field has an impact on lifetime (~10 %) due to reduction of the RF acceptance. There have been observed effects from the wiggler on the vertical tune which, as previously reported, increases by about 0.001 between zero and maximum field, as well as the measured coupling [4] which typically increases by about 0.05 % (on 1% nominal). The measured coupling increase is most probably due to the known vertical orbit distortions induced by error fields in the wiggler. It is planned to install trim coils in the future to try to address this problem. Recently, the injection efficiency into the SCW at full field was measured, without any optics corrections, and found to have reduced by about 3% compared with zero field[2].

The APPLE-II devices have not been observed to produce any shift of beam parameters or decrease in lifetime or injection efficiency.

RESULTS FROM BEAMLINES

Eight of the Diamond beamlines have now been in operation for more than a year. Generally, for the lower period devices (up to 23 mm), harmonics up to the 9th are used to fulfil their primary energy requirements, whereas longer period IV devices are routinely using the 13th harmonic. Data from beamline I22 which has a 25 mm period IV device are shown in figure 2 which shows intensity in arbitrary units versus gap and energy. The breaks in intensity are between different injections/data acquisition periods.

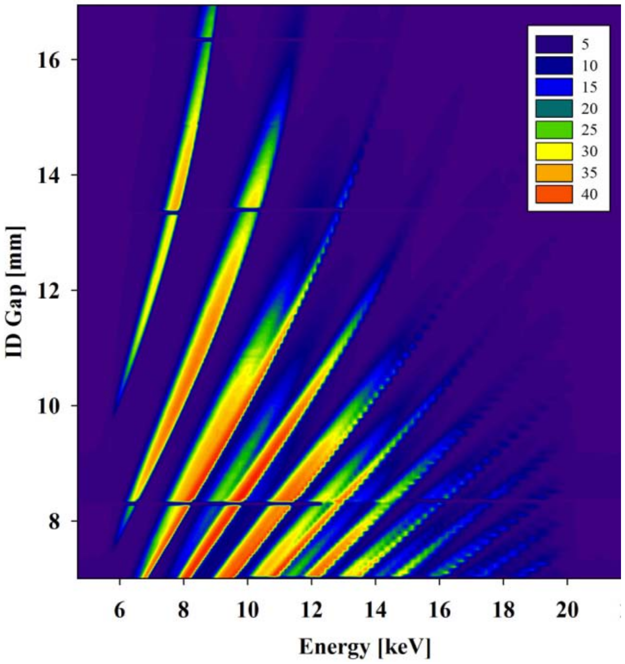

Figure 2: U25 in-vacuum undulator intensity (a.u.) versus ID gap and energy. At 7 mm gap, the 5th (~7 keV) through 14th (~19 keV) harmonics are visible.

A useful consequence of having undulator spectra as well as gap scans from the same beamline is the ability to derive an estimate of the storage ring energy and energy spread. We used SRW [5] for calculation and comparison of spectra and used SPECTRA8.0 [6] to create simulated gap scans (a comparison of spectra from both programs was also carried out to verify consistency). Presuming that Twiss parameters are the nominal, the electron beam energy and energy spread can be found through matching harmonic spacing and widths. The results of this investigation, which to this point has only used data from a single beamline, was that the energy spread appears to be the nominal 0.1% (+/-0.001%), and the ring energy is 3.052 GeV (+/- 2 MeV), significantly larger than the nominal. Examples of the experimental and simulated spectra are shown in figure 3, where flux was measured and calculated through a 90 x 60 µrad aperture on I16.

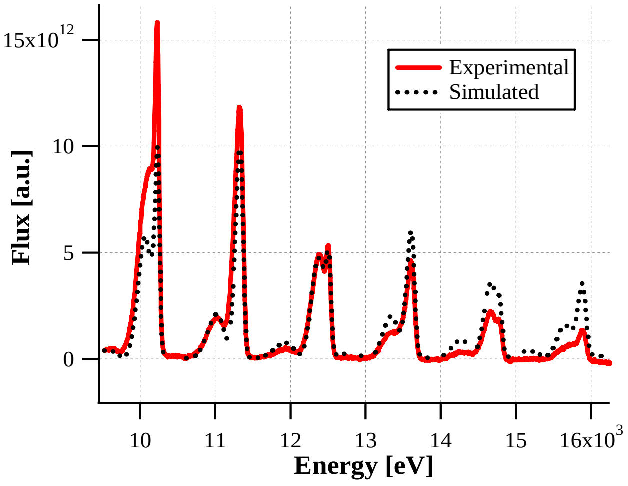

Figure 3: Spectrum of U27 undulator measured by the beamline for 7.525 mm gap showing the 9th through 14th harmonics. Simulation was scaled to match the intensity of the 11th harmonic.

CHALLENGES & CONCLUSIONS

Generally, the ID commissioning has been straightforward; with early problems caused by absolute encoders requiring reboots after beam dumps resolving naturally through the reduction of beam dumps. Similarly, a problem with a flange design in the SCW causing helium consumption to be an order of magnitude higher than expected has been resolved through replacement. Alignment (particularly vertical) has since proven to be the biggest challenge for characterization of the IDs, though with a much more reliable lifetime measurement and more flexible height control, the final centring of IV devices seems within reach. Operation of IDs has been relatively smooth from the beamline perspective, with the next challenge on the horizon being synchronous scanning of the IDs and monochromators which is due to be tested in the coming months.

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