VACUUM PERFORMANCE OF THE DIAMOND LIGHT SOURCE IN-VACUUM INSERTION DEVICES

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Abstract

9 in-vacuum insertion devices (in-vac IDs) have been installed and commissioned in the Diamond storage ring. All 9 units meet the target operating pressure of 5.10^{-9} mbar or lower with a stored beam current of 300mA. At 100mA stored beam current, a similar pressure is achieved with a beam conditioning dose of approximately 10A.h following a new installation. The pressure also recovers rapidly following a vacuum intervention. Installation and vacuum intervention procedures developed at Diamond which do not require *in-situ* bakeout to achieve ultra-high vacuum (UHV) conditions are described. The omission of an *in-situ* bake has no significant effect on the operational vacuum performance and considerably shortens the installation time.

INTRODUCTION

Diamond is the UK’s 3rd generation 3GeV synchrotron light source, now in its second year of user beam operation. The Diamond vacuum systems have been described previously [1]. The 562m circumference UHV storage ring has received nearly 700A.h of beam conditioning. All vacuum systems are performing within target specification with an average storage ring pressure of $1.4.10^{-9}$ mbar and a beam lifetime in excess of 20h at the design current of 300mA. 5 in-vac IDs were installed and operational for first user beam in January 2007 [2]. 4 further in-vac IDs have been installed and commissioned subsequently.

Due to the heavy reliance on in-vac IDs, their vacuum performance is critical to the operation of the Diamond beamlines. To keep Gas Bremsstrahlung levels compatible with the beamline radiation shielding, as well as to avoid stored beam lifetime reduction, the target average pressure along each of the in-vac ID straights is 5.10^{-9} mbar or lower during operation. Furthermore, this pressure needs to be achieved within a short time following installation of a new in-vac ID or after a vacuum intervention.

New beamlines, many with an associated in-vac ID, are planned to be added to Diamond over the next few years at a rate of around 4 per year. Due to the tight operating and installation schedule, it is important to make the most efficient use of the limited machine down time available for the installation and commissioning of new in-vac IDs. This led us to investigate and to successfully develop procedures reported here which do not routinely require *in-situ* bakeout following installation or vacuum intervention while maintaining optimum vacuum performance.

VACUUM DESIGN

Each of the 9 installed in-vac IDs is 2m in length and is installed in the centre of one of Diamond’s 5.3m straights between a pair of all-metal RF gate valves. The remaining space in each straight is allocated to a pair of water-cooled tapers to absorb synchrotron radiation, a pair of ion pumping stations and a pair of interconnecting vessels. The interconnecting vessels in 3 of the straights (SR02I, SR03I and SR04I) are 1m long and manufactured from aluminium extrusions with a non-evaporable getter (NEG) coating to allow later addition of a second, canted out-of-vacuum undulator. In the other 6 straights, the interconnecting vessels are stainless-steel. 3 design variants of the in-vac ID straight are installed in total due to the requirement for different electron beam canting angles.

The in-vac IDs themselves have a main central section which houses two arrays of Ni-plated permanent magnets each mounted on a moveable girder. To either side of this section are water-cooled flexible copper tapers.

Figure 1 shows the vacuum pumping and instrumentation on an in-vac ID straight. Each in-vac ID is fitted with 1000litre/s of noble-diode sputter ion pumps plus a 500litre/s NEG cartridge pump. These figures are effective pumping speeds for nitrogen which are lower than the nominal figures shown in Figure 1. Two titanium sublimation pumps are also fitted to boost the hydrogen pumping speed but it has not been necessary to use these so far.

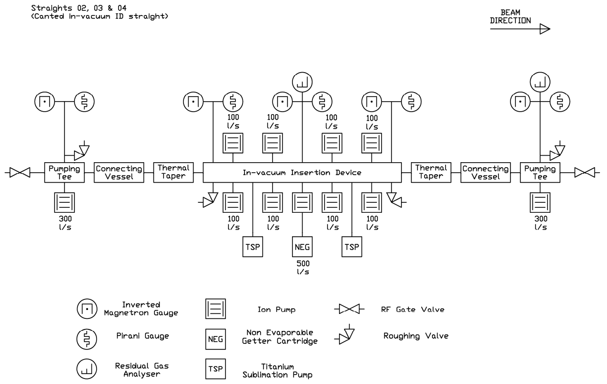

Figure 1 Schematic of vacuum pumping and instrumentation of in-vac ID straight

The total internal surface area of each in-vac ID is estimated at $100m^2$ including the internal vessel surfaces, magnets, magnet holders, girders, support plates, cooling pipes, tapers and RF mask.

During the design process, simulations of the vacuum performance for the entire straight were carried out for

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each configuration, using a program developed at Diamond, to verify the vacuum design and to confirm the required pump sizes and locations. These calculations were used to optimise the designs aimed at achieving a static pressure below 5.10^{-10} mbar and a dynamic pressure at 300mA below 5.10^{-9} mbar. Details of these calculations and comparison with measurements will be the subject of a future publication.

PREPARATION AND INSTALLATION

All internal components and vessels for each in-vac ID were cleaned using conventional UHV cleaning procedures. The main vacuum vessel and the end tapers were pre-baked to 250°C before installation of any of the other internal components. Assembly and test of the magnet arrays and subsequent assembly into the final device were carried out using standard UHV handling techniques in a segregated assembly area.

The completed device was then baked out *ex-situ* at a vessel temperature of 120°C, the maximum temperature allowed without risk of damaging the magnets. The first unit was baked for a total of 400h. Subsequent units were baked for times ranging from 124h to 216h with an average of 165h. Experience has shown that if the bakeout is stopped when a pressure of 2.10^{-6} mbar has been achieved at 120°C, then the system will achieve specification pressure on cool down to room temperature. Continuing the bakeout beyond this point does not produce any useful improvement in vacuum performance. The temperature of the magnets only reaches 95°C during this process so it may be possible to speed up the *ex-situ* bakeout in future by modifications to equipment and procedures so the actual magnet array temperature reaches 120°C.

Following bakeout the entire unit is transported to the storage ring under vacuum.

The process of installation into the storage ring has been refined with each subsequent installation. The in-vac ID is craned into position in the straight and vented to 99.99998% purity bottled nitrogen gas immediately before making the vacuum connections to the other pre-baked components and vessels. These connections are made in a laminar flow tent using a constant flow of the same high purity nitrogen gas to reduce entry of moisture. The whole straight is then pumped down via two manually-valved pumping ports using removable scroll pumps and turbomolecular pumps.

After installation and initial pump down, the vacuum equipment on each in-vac ID is degassed in a defined sequence, the NEG cartridge pump is activated, the turbomolecular pumps are isolated and the ion pumps are turned on.

Where the interconnecting vessels are NEG coated, these also have to be activated, which requires an *in-situ* bakeout sequence of the whole straight as follows:

- Heat the entire straight including the in-vac ID to 120°C at a rate of 10°C/h and hold at this temperature for at least 24h.
- Increase the temperature of the NEG-coated vessels to 180°C at a rate of 10°C/h and hold at this temperature for 4h.
- Decrease the temperature of the NEG-coated vessels to 120°C then cool the entire straight back to room temperature at the rate of 10°C/h.

Only the 3 straights with NEG-coated vessels were baked out *in situ*. Similar procedures were used for vacuum interventions.

OPERATION WITH BEAM

The average pressures from the 3 inverted magnetron gauges fitted to each in-vac ID are plotted in Figure 2 with no stored beam (static pressure) and in Figure 3 with stored beam of 100 mA (dynamic pressure).

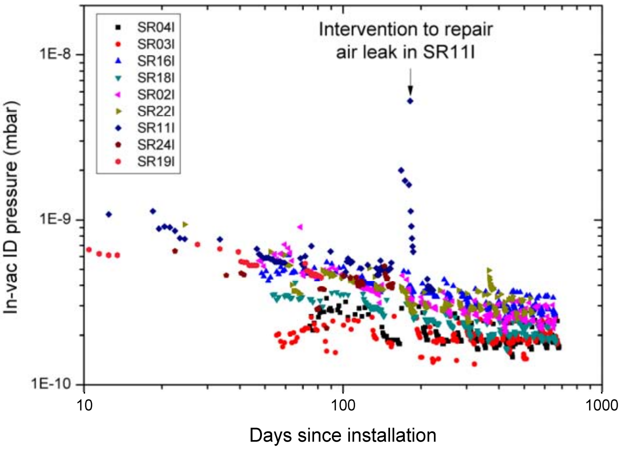

Figure 2 Behaviour of the static pressure (no beam) in each in-vac ID with elapsed time since installation

The zero of the horizontal time/dose scale for each data set corresponds to the installation date of the ID. The horizontal scale chosen for Figure 2 is elapsed time whereas the horizontal scale chosen for Figure 3 is beam dose. In reality it is not possible to separate the effects of elapsed time and beam dose and this is further complicated by the general increase in average stored current in the storage ring as its commissioning and optimisation has progressed.

The plots in each figure are presented in order of installation. For the earlier in-vac IDs, a complete data set is not available as the data archiving system was not fully operational at that time.

It can be seen in Figure 2 that the static pressure in each in-vac ID decreases with time following installation. It is not known to what extent this general static pressure decrease with time is simply an effect of elapsed time on the thermal outgassing rate and to what extent it is an effect of beam cleaning. The rapid recovery of the pressure over a few days following a vacuum intervention in SR11I, which involved venting to atmospheric pressure to repair a nearby air leak, is also evident.

When the electron beam is introduced to the storage ring there is an almost instantaneous rise in the pressure due to stimulated gas desorption from surfaces, followed by a further, slower increase over a few hours as the temperatures of the vacuum vessels and components equilibrate to higher values due to beam heating.

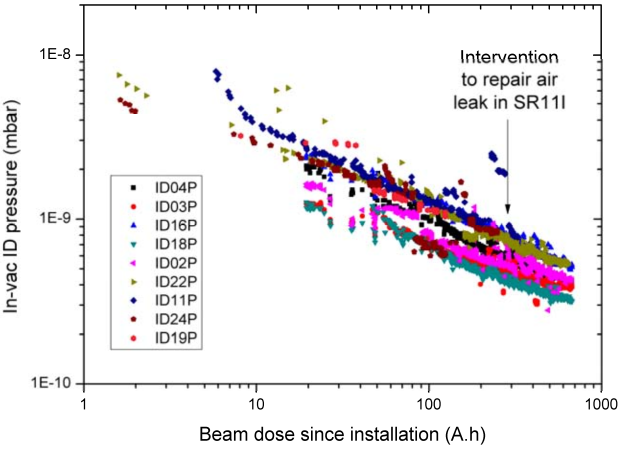

Figure 3 Behaviour of the dynamic pressure at 100 mA in each in-vac ID with beam dose since installation

Figure 3 shows that the dynamic pressure (p) decreases with beam dose (D) generally following a power law $p \propto D^{-0.5}$. This general form is similar to the behaviour of the average pressure in the entire storage ring where a power of -0.7 was observed rather than -0.5 [1].

Further inspection of Figure 3 shows that a beam dose of around 10A.h or less is sufficient for a newly-installed in-vac ID to achieve a dynamic pressure of 5.10^{-9} mbar. This corresponds to an elapsed time of 100h at 100mA. Extrapolation to higher current indicates that a similar period of beam conditioning at 300mA should also be sufficient prior to beamline operation at 300mA.

The rapid recovery of the dynamic pressure over a few A.h following the vacuum intervention in SR11I to repair the nearby air leak can also be seen. The higher pressures for the points immediately before the intervention in Figures 2 and 3 are due to the air leak itself.

Table 1 – Recent values (May/June 2008) of the static and dynamic in-vac ID pressures at maximum ID gap of 30 mm. (*) indicates in-situ bakeout.

ID number	Days since install	Dose since install (A.h)	P 0mA (mbar)	P 260mA (mbar)
SR04I (*)	679	695	$1.7.10^{-10}$	$9.8.10^{-10}$
SR03I (*)	668	695	$1.8.10^{-10}$	$8.9.10^{-10}$
SR16I	654	695	$2.7.10^{-10}$	$1.2.10^{-9}$
SR18I	658	695	$1.9.10^{-10}$	$7.2.10^{-10}$
SR02I (*)	652	695	$2.5.10^{-10}$	$7.0.10^{-10}$
SR22I	535	661	$2.7.10^{-10}$	$1.3.10^{-9}$
SR11I	218	349	$3.8.10^{-10}$	$2.0.10^{-9}$
SR24I	151	271	$4.0.10^{-10}$	$2.3.10^{-9}$
SR19I	78	147	$4.6.10^{-10}$	$2.0.10^{-9}$

Recent values of the static and dynamic pressures for all 9 in-vac IDs are shown also in Table 1. Within a factor of 2, the pressures in all 5 in-vac IDs from the Phase 1 installation (straights SR02I, SR03I, SR04I, SR16I and SR18I) are identical. There are variations from unit to unit but these do not appear to be related to the length of *ex-situ* bakeout, the mechanical configuration of the straight or whether the straight was baked out *in situ*.

The pressures are noticeably higher in the in-vac IDs which were installed more recently. This is consistent with the general decrease in pressure with elapsed time / beam dose seen in Figures 2 and 3 above.

Each in-vac ID is also fitted with a residual gas analyser (RGA) which shows that the residual gas is typically 90% or more H_2, the balance being mainly CO with smaller amounts of CH_4, CO_2 and other trace gases. This is similar to observations of gas composition elsewhere in the storage ring.

CONCLUSIONS

All installed in-vac IDs meet the design requirements for a dynamic pressure of 5.10^{-9} mbar or lower at 300 mA following a short period of beam conditioning following installation. The behaviour is generally as predicted by the vacuum design calculations.

Provided rigorous cleaning and *ex-situ* bakeout procedures are carried out, followed by effective exclusion of moisture and other contaminants during installation, there appears to be no significant advantage of *in-situ* bakeout of the in-vac IDs. The only case where routine *in-situ* bakeout is needed is where interconnected NEG-coated vessels have to be activated.

Following a vacuum intervention, both the static and dynamic pressures recover quickly to the pre-intervention values. After a few days and a few A.h of beam conditioning there is little or no memory of the intervention.

Pre-bakeout of the in-vac ID at 120°C for an average of 165h (1 week) is sufficient to achieve acceptable vacuum performance after installation. There is no significant advantage in continuing the *ex-situ* pre-bakeout beyond this point.

The results presented here validate the processing and installation procedures developed at Diamond which do not require *in-situ* bakeout. Although it will not be used routinely, the facility to bake the in-vac IDs *in situ* will be retained in case it is needed to recover quickly from a vacuum incident, e.g. a water leak. A similar philosophy is applied at Diamond to other storage ring sub-systems, such as front ends.

REFERENCES

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