Study of Initial Dynamic Pressure Rise Behaviour in Indus-2

Tripti Bansod, Samod K Shukla, K VANPS Kumar and S.Kotaiah
UHV Section, Raja Ramanna Centre for Advanced Technology, Indore – 452013.

E-mail ID : tripti@cat.ernet.in

Abstract: UHV system for synchrotron radiation source Indus-2 was developed and commissioned. The specified ultimate vacuum in $10^{-10}$ mbar range was achieved. This vacuum deteriorates with the injection of electron beam into the storage ring mainly due to photon induced desorption (PID). Initially, the PID yield may be as high as $10^3$ molecules / photon and the resultant dynamic pressure rise may be very high. However, the PID yield decreases with beam cleaning, provided by beam dose accumulation. For Indus-2, initially 550 MeV electron beam was injected and by now more than 5.8 A.Hr beam dose has been accumulated. The maximum beam current stored was 72.81 mA at 550 MeV. Once the beam energy was ramped up to 2.4 GeV also, but regular ramping was restricted to 2 GeV. The maximum current was 51 mA at 2 GeV. Since the Indus-2 has eight unit cells, any one unit cell is a representative of entire storage ring. This paper shows the dynamic pressure rise behaviour of one of them. The pressure rise per mA of beam current has been measured and compared at different stages of beam dose accumulation. Variation in the values of PID yield with beam dose has also been studied. The specific dynamic pressure rise calculations were done for both the GDC cleaned as well as non-GDC cleaned dipole chambers. For non-GDC cleaned chambers these values were larger by more than one order of magnitude. This paper discusses the details of dynamic pressure rise behaviour of Indus-2 in its initial stages of commissioning.

1. Introduction

Indus-2 vacuum chambers were made from the Aluminum alloys. With proper chemical cleaning, careful handling and baking, the thermal outgassing rates of $5 \times 10^{12}$ mbar.l/s/cm$^2$ were obtained for Aluminum chambers. By reducing the thermal outgassing rates, the ultimate vacuum can be achieved. When the chambers are subjected to synchrotron radiation, the photon induced gas desorption exceeds the thermal outgassing by orders of magnitude and it is this effect which mainly determines the vacuum performance of the machine and beam lifetime, especially during initial commissioning phase.

With continued exposure to synchrotron radiation, the surface gets cleaned up and the gas desorption decreases. The rate at which this desorption decreases with machine running time, is more important since this determines the operation time needed to get specified beam-gas lifetime. Therefore, the vacuum chambers should be thoroughly cleaned to accumulate sufficient current in a reasonable time. In order to get smaller PID yield initially, the chambers were cleaned exsitu by GDC up to ion dose of $2 \times 10^{19}$ ions/cm$^2$. This ion dose was experimentally selected and with this dose the ESD yield reduced to $10^{-3}$ molecule /electron [1].

2. Details of Indus-2 Vacuum system

The synchrotron radiation source Indus-2 is designed for 2.5 GeV, 300mA electron beam current. The circumference of storage ring is 172.4 meters. There are 16 bending magnet chambers and 46 straight section chambers, in addition to large number of diagnostic components etc. Each bending magnet
chamber has bending angle of 22.5° at 5.55 m radius. At present 98 numbers sputter ion pumps (SIP) and 96 numbers of titanium sublimation pumps (TSP) are used as main pumps. 45 numbers of Bayard-Alpert Gauges and 11 numbers of Residual gas analyzers are installed in the ring for total and partial pressure measurements, respectively. The whole ring is divided into 8 unit cells. Each unit cell has two dipole chambers, three long and three short straight section chambers, as shown in Figure 1.

![Figure 1: An unit cell for Indus-2](image)

Each dipole chamber was pumped by 3 numbers of 270 l/s SIP and 600 l/s TSP combination. In straight section chambers 6 numbers of TSP, 3 numbers of 270 l/s SIPs and 3 numbers of 140 l/s SIPs were installed in parallel combination. The pump installation scheme at dipole and straight section chamber is shown in Figure 2. 5 numbers of BA gauges were installed on each unit cell for vacuum monitoring. The effective pumping speeds for series combination on dipoles was 600 l/s and it was approximately 115 l/s for parallel combination installed on straight sections.

![Figure 2: Installation scheme for pumps on vacuum chambers of Indus-2](image)

3. Synchrotron radiation induced desorption

The electrons undergo centripetal acceleration in the magnetic field of bending magnets and emit radiation. For relativistic electrons, this radiation is directed into a narrow cone in forward direction. These energetic photons fall on the wall of the vacuum chambers and desorb the gas molecules and lead to a large dynamic pressure increase, this is called photon induced desorption, which is an important factor in limiting the beam lifetime in the machine. PID is a two-step process where at first photons produce photoelectrons and these photoelectrons excite strongly bound gas molecules on the surface and releases them into the system. The PID yield is the number of molecules desorbed per photon incident on the metal surface.

Initial photon induced gas desorption is important since it affects the initial beam life time and therefore, the beam accumulation rate in the storage ring in the initial stages of its commissioning. PID yield is dependent on the material, the surface treatment, the accumulated photon dose and the critical energy, angle of incidence of synchrotron radiation. The rate of desorption decrease with machine
running time, is more important since this determines the time for which the machine must be operated before significant improvement in beam lifetime can be obtained. The PID yield $\eta$ is given by [2]

$$\eta = \frac{3.3 \times 10^{19} \Delta P. S. 2 \pi R}{\Gamma} \text{ (molecules / photon)}$$

Where,
- Photon flux, $\Gamma = 8.1 \times 10^{17}. E. I$ (photons/s)
- $\Delta P$ is the absolute pressure increase due to the photons (mbar)
- $S$ is the specific pumping speed (l/s/m)
- $I$ is the beam current (mA)
- $E$ is the beam energy (GeV)
- $2\pi R$ is the circumference of storage ring (m)

At 550 MeV beam energy, $\eta$ values were calculated for different beam currents and beam doses for a 28m long segment of Indus-2. Total pumping speed installed on this segment was 4800 l/s. For $\eta$ calculation pressure readings of 5 gauges were integrated with distance in mbar x m unit.

4. Energy dependence of the molecular desorption yield

PID yield is dependent on the critical energy of the synchrotron radiation. The critical energy for synchrotron radiation is given by

$$\varepsilon_e (eV) = \frac{2.2 \times 10^3. E^3 (GeV)}{R (m)}$$

During the initial commissioning stages, the machine was running in beam accumulation mode at injection energy. Although the machine is designed for 2.5 GeV, now the beam energy is regularly ramped to 2 GeV only. The critical energy at the injection energy of 550 MeV is 66 eV, but it is 3.19 keV at 2 GeV electron beam in Indus-2. However, most of the time beam was circulating at 550 MeV only. The $\eta$ value calculations were done for 66 eV and 3.19 keV critical energy photons. During the machine operation, beam cleaning or beam scrubbing of the vacuum system effectively reduces the molecular desorption yield by orders of magnitude. Since it would not be possible to provide sufficient pumping speed needed to take care of initial PID gas load and to guarantee the required beam lifetime at the start-up. All the synchrotron radiation sources take advantage of the beam cleaning effects and the required vacuum performance can be achieved only after substantial conditioning time. The cleaning time or more specifically, the integrated beam dose required to reduce the molecular desorption yield from its initial large value, can be estimated with good accuracy by using the exponential dependence on the beam dose $D$ (A hr)[3].

$$\eta = \eta_o D^a$$

The exponent ‘a’ is found to vary between 0.6 to almost 1 depending on the specific machine.

$\eta_o$ is the initial gas desorption yield for cleaned vacuum chamber.

Therefore if the $\eta_o$ is low for a properly conditioned vacuum chamber, the requirement of the beam dose to achieve the specified vacuum with electron beam will be less and beam-cleaning time is drastically reduced.

5. Observations

The beam injection trials were started with 450 MeV electron beam from the booster synchrotron. But there was not much beam accumulation in Indus-2. The injection energy was increased to 550 MeV and probably by little orbit correction and energizing the sextupoles, the accumulation of beam started. Thereafter, the observations on UHV system were made at this injection energy and also on the ramped energy of 2 GeV.

5.1. First injection into the Indus-2

First beam at 450 MeV was accumulated into the storage ring on 20-Jan 2006. As expected there was a large rise in pressure. The initial dynamic pressure rise for Indus-2 at 550 MeV and 2 GeV beam energy is shown in Figure 3. The lower part of the graph represents the initial background pressure
before beam injection. At initial injection of 1.97 mA beam at 550 MeV, the maximum pressure rise was almost $1 \times 10^{-7}$ mbar. But after 560 mA.Hr beam dose the beam energy was ramped up to 2 GeV and at 17.23 mA beam current the maximum pressure rise was $8 \times 10^{-6}$ mbar. At dipole chamber #9 and the dipole chamber #13, which are installed in vacuum segment Vs-5 and Vs-7 respectively, the pressure rise was high compared to other dipole chambers. This may be attributed to the fact that DP#9 was not GDC cleaned and one SIP was off in DP#13 at that time.

5.2. Specific Dynamic pressure rise in Indus-2
For comparing the performance of UHV system, it is more pertinent to study pressure rises with unit beam current i.e the specific dynamic pressure rise. Accordingly, specific dynamic pressure rises were calculated and plotted for the whole ring. Figure 4 shows the change in specific dynamic pressure rise ($\Delta P/I$) for Indus-2 with time at different stages [4] at 550 MeV. The upper most graph shows that the specific dynamic pressure rise at initial injection of beam is $5 \times 10^{-8}$ mbar/mA for 550 MeV electron beam in Indus-2 and with beam dose it reduced to $1 \times 10^{-10}$ mbar/mA. It increased only to $1 \times 10^{-9}$ mbar/mA, after the accidental air exposure of ring on 4th October, 2006, indicating a significant memory effect of beam cleaning. The dynamic pressure rise has further reduced to $10^{-11}$ mbar/mA range in August 2007.

5.3. Study of Beam Cleaning effect
With the continued operation of Indus-2, mainly at 550 MeV, chambers got cleaned up and dynamic pressure rise decreased. In order to study beam cleaning effect, more clearly, a 28 m long section of
ring was chosen and specific dynamic pressure was plotted w.r.t accumulated beam dose[5] as shown in Figure 5. BAG#2, 4 on VS-2 and BAG#2 on VS-3 are installed on the dipole chambers. BAG#5 (installed on the long straight section chamber of VS-2) showed lower pressure rise / mA, due to the fact that the straight section chambers are subjected to lower photon fluxes compared to the dipole chambers. It was also observed that the specific dynamic pressure reduced by two orders after giving a beam dose of 2.47 A.Hr. At this point, Indus-2 was accidentally vented to atmosphere due to failure of bellow in VS-3 and on resuming the operations, the specific dynamic rise was one order less compared to the first injection in Feb 2006. After another 2.0 A.Hr dose the pressure rise per mA was 8x10\(^{-11}\) mbar/mA. After venting, the increase in the specific pressure rise in BAG#4 of VS-2 was more compared to other sections, because the air in rush was more from this end during the accident.

The PID yield as a function of the accumulated beam dose [6] for unit cell is shown in Figure 6. For 66 eV critical photon energy, (corresponding to 550 MeV beam energy) the initial desorption yield for GDC cleaned vacuum chamber started at 1.3x10\(^{-2}\) molecules per photon and it reduced to 3x10\(^{-4}\) molecules/photon after a beam dose of 5 A.Hr. When the energy was ramped to 2 GeV, the desorption yield increased by 3 times for the corresponding photon critical energy of 3.19 keV [3,7].
5.4. The behaviour of Chambers with and without GDC cleaning
To study improvements in performance due to GDC, two dipole chambers installed in Indus-2 were deliberately kept without GDC cleaning and the specific dynamic pressure rise for 2 GeV electron beam was plotted with the accumulated dose. Figure 7 shows the beam cleaning depicted as decrease in specific pressure rise for dipole chambers with and without GDC cleaning. The pressure rise per mA was almost one order higher in the non-GDC cleaned dipole chamber compared to that in the GDC cleaned chamber.

![Figure 7: Effect of GDC in dipole chambers at 2 GeV](image)

6. Conclusion
The dynamic behaviour of the vacuum system of Indus-2 was studied at different stages and different beam energies. Before the first injection, the background pressure was $1 \times 10^{-10}$ mbar. But it increased to $1 \times 10^{-7}$ mbar for 1.97 mA beam at 550 MeV. The pressure increased to $8 \times 10^{-6}$ mbar at 2 GeV energy ramping. After an accumulated beam dose of 5 A.Hr, PID yield reduced by two orders of magnitude. At higher photon critical energy the desorption yield was 3 times higher. It was also observed that in the GDC cleaned chamber the dynamic pressure rise was almost an order less. After air exposure desorption yield was not as high as it was before beam cleaning, implying that there was significant memory effect of beam cleaning. After 5.8 A.Hr beam dose, specific pressure rise with 2 GeV beam energy was one order higher compared to that at 550 MeV beam energy. Therefore, to reduce the beam cleaning time for Indus-2, it is needed to operate it at 2 GeV.

7. Acknowledgements
Authors would like to acknowledge the technical help provided by Mr Vijay Shinde and Mr C. B. Kulkarni. The guidance and encouragement from Director, RRCAT is sincerely acknowledged.

References
Tripti Bansod, Proceeding of IVSNS- 2005 (83-86).
A.G.Methewson, AIP conf. proceeding no-236, AVS series-12,(313-323).
Oswald Grobner Proceeding CAS vacuum thch 28 May-3June, (127-138).
O. Grobner and P Strubin, AIP conf. proceeding no-236, AVS series12,(18-29).
M. Oishi, AIP conf. proceeding no-236, AVS series12,(142-151).
A.G. Mathiewson, Synchrotron radiation news, vol-3 no.1.1990.
H. F. Dylla, AIP conf. proceeding no-236, AVS series-12.(388-403).