VACUUM PERFORMANCE IN THE MOST RECENT THIRD GENERATION SYNCHROTRON LIGHT SOURCES

E. Al-Dmour, CELLS, ALBA, Edifici Cn, C3-central, Campus UAB, 08193 Bellaterra, Spain.

Abstract

Several 3rd generation synchrotron light sources were built and commissioned during the last ten years. The vacuum system of these light sources was designed using different approaches but with the same objectives which guarantee the lowest outgassing rate and the highest pumping speed that by the end will achieve the lowest influence in the circulated beam (longest life time, the lowest impedance and instabilities…etc).

The vacuum performance of recently commissioned rings (DIAMOND, SOLEIL and the Australian Synchrotron) are presented, together with a comparison of the different approaches which have been used in the design of the vacuum system and the lessons for the design of vacuum systems for the new machines.

INTRODUCTION

Nine medium energy third generation synchrotron light sources were designed, constructed and operated since 10 years, the main objectives for the design were to have the highest brightness by reducing the beam emittance, to have the largest space for insertion devices, to increase the beam stabilities and to increase the beam life time and/or having a top-up injection. Among other factors, the vacuum system design and performance of these sources has an impact on these objectives.

The vacuum systems were designed to guarantee a set of objectives: 1) the system must warranty the lowest possible thermal and photon stimulated desorption (PSD) outgassing into the vacuum chambers; this has been achieved by optimisation of the manufacturing processes of the vacuum components, proper surface treatment and cleaning, careful assembly and vacuum conditioning and by non evaporable getter (NEG) coating, 2) the highest effective pumping speed for the system, this has been achieved by designing the chambers with high conductance, working at cryogenic temperature and by using distributed pumping (e.g. NEG strips, NEG coating…etc), 3) to warranty the maximum operational time for the users, this is achieved by fast recovery and conditioning after interventions and failures, reliability, stability and flexibility of the vacuum system, 4) smooth surfaces facing the beam to assure low impact on the impedance of the machine, this has been accomplished by careful design and manufacturing of the tapers, flanges, feedthroughs…etc, 5) ability to safely absorb the unused part of the radiation fan by means of crotch and distributed absorbers. These objectives need to be considered during all the stages of the machine life from design, production, assembly and conditioning.

NEW SYCNHROTORN FACILITIES AND VACUUM CHALLENGES

The main vacuum related machine parameters of the newly designed and operative machines are shown in Table 1, [1] - [8].

The beam energy for these machines is in the range of 3.0 GeV (medium energy) with small emittances and a high ratio of total length for insertion devices to the machine circumference (up to 46% for Soleil). Depending on the design current and the beam energy, the amount of power to be removed from the system varies from 144 kW to 472 kW, and the total PSD outgassing rate varies from 3.1×10^{-4} - 2.1×10^{-5} mbar.l/sec.

Table 1 Main Vacuum Related Machine Parameters for New Synchrotron Radiation Facilities (* preliminary data).

Parameter	Unit	Diamond	Soleil	ASP	ALBA	NSLS-II*	TPS*
Beam Energy, E	GeV	3	2.75	3	3	3	3-3.3
Design current, I	mA	300	500	200	400	500	400
Storage ring Circumference, C	m	561.6	354.097	216	268.8	792	518.4
Horizontal emittance ε	nm.rad	2.7	3.7	7-16	4.5	2.0, (0.6 with damping wigglers)	1.7
Straight sections (number of straights x length in meters)		6x8m, 18x5m	4x12m, 12x7m, 8x3.8m	14x4.5m	4x8m, 12x4.2m, 8x2.6m	15x9.3m, 15x6.6m	6x12m, 18x7m
Total power from bending magnets (BM) at the design current, P_T	kW	301	472	187	407	144	341
Total PSD outgassing from (BM) at the designed current at the accumulated beam dose of 100 A.h	mbar.l/sec	5×10^{-5}	3.1×10^{-4}	4×10^{-5}	7.0×10^{-5}	3×10^{-4}	2.1×10^{-5}
Status		operational			construction		

These parameters put challenges on the design and the manufacturing of the vacuum system; proper design and manufacturing are needed to reduce and remove the outgassing together with handling the high power generated from the circulating beam, while having small space to place the vacuum equipments needed.

THE VACUUM SYSTEM DESIGN OF NEWLY COMMISSIONED MACHINES

Diamond.

The storage ring of Diamond is divided into 24 cells and split into 48 main vacuum sections via RF gate valves; the main chambers of the storage ring are made of 316LN stainless steel with an octagonal profile of 80mm x 38mm (HxV) for the quadrupole vacuum chamber (antechamber for the dipole chambers only), 7 chambers (1x5 m and 6x1 m) for the insertion devices (ID) are made of extruded aluminium with NEG coating, the connections between the chambers are made by conflat flanges (CF) of spigot type in order to reduce the effect on the machine impedance. The crotch absorbers are constructed from oxygen free high conductivity (OFHC) copper.

Diamond vacuum system is characterized by the extensive use of the vacuum equipments; 718 noble diode sputter ion pumps (SIP) with an overall nominal pumping speed of 117,000 l/s are installed in the storage ring, together with titanium sublimation pumps (TSP) and NEG pumps. 374 pairs of cold cathode gauges and Pirani gauges were used to monitor the pressure around the storage ring together with 154 residual gas analysers (RGA) for partial pressure measurement. The use of these instruments paid off as they were very useful tools during the commissioning of the machine and later for the investigation of the problems.

In addition, Diamond chose not to bakeout the vacuum chambers in-situ (except the straight sections), however, strict and proper vacuum conditioning was used which gave good results; the vacuum vessels were assembled, pre-baked and tested in an assembly area, then put together with the magnets on the girders and moved under vacuum to the tunnel where they have been vented with dry nitrogen and connected to the neighbouring chambers inside a laminar flow cabinet, see Figure 1 [9].

Figure 1 one Diamond girder assembly in the way to the tunnel.

Soleil.

The storage ring of Soleil is divided into 16 cells which split into 48 vacuum sections via RF gate valves.

Soleil vacuum system is characterised by the broad use of the NEG coating technique, which supposed to reduce the PSD outgassing and to give some pumping speed to the system once the NEG coating is being activated. Around 56% of Soleil storage ring (the quadrupoles vacuum chambers) are manufactured from extruded Al 70 mm x 25 mm (HxV) and coated with 0.5-1.5 μm NEG material (including a 10.4 m of 14 mm aperture), the dipole vacuum chambers of Soleil storage ring are machined from 316LN stainless steel, antechamber is implemented into the design to allow the beam to pass to the front ends. Soleil chose to connect the chambers via CF flanges (bimetallic flanges were used for the Al chambers) with special RF shield to reduce the effect of the gap between the connected flanges on the machine impedance. As the crotch absorbers are exposed to high power densities (the max. power density is 256 W/mm^2); Glidcop® was chosen for the construction of the crotch absorbers.

To provide pumping down for noble gases triode SIPs are connected to the chambers through Al ports, also TSPs are used, this made around 55,000 l/s nominal pumping speed for the storage ring from conventional pumps.

As activation is needed for the NEG coating, Soleil installed heaters around the chambers to provide an in-situ bakeout, see Figure 2. [10], [11].
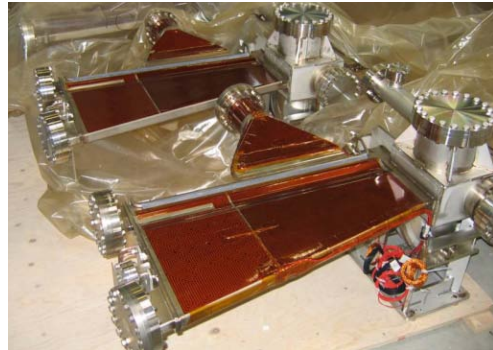

Figure 2 the heaters around the Al chamber of Soleil storage ring.

ASP.

The storage ring of the Australian Synchrotron is divided into 14 sectors comprising of a straight section followed by a double bend achromat; the main chambers of the storage ring are made of 3 mm thickness 316LN stainless steel with a key hole profile of 70mm x 32mm (HxV), all the chambers have antechamber to allow the radiation to pass to the crotch absorbers, which are constructed from OFHC copper. VATseal® flanges are used to connect the chambers, this will not only allow having low effect on the total impedance of the machine, but also these flanges can correct the manufacturing errors (in term of total length) following their welding to the chamber body.

07 Accelerator Technology Main Systems   T14 Vacuum Technology

Diode SIPs together with NEG pumps were used to pump down the vacuum system; the total nominal pumping speed is 31,000 l/s.

For the conditioning of the vacuum system, ASP followed the approach which has been adapted earlier by SLS and CLS: a complete sector is assembled (together with the valves), pumped down, baked and then moved into the tunnel under vacuum, following this; the chambers of the straight sections are connected to the two assembled sectors and baked in-situ (see Figure 3). With this procedure, the results for vacuum conditions are similar to those for an in-situ bakeout for the vacuum system [2].

Figure 3 installation of complete sector inside the tunnel of the Australian Synchrotron

VACUUM PERFORMANCE AND THE COMMISSIONING OF THE NEW SOURCES

Diamond, Soleil and Australian Synchrotron are operating since almost two years, the commissioning results and the main problem faced during this period are presented here.

Diamond.

The installation of the storage ring was complete on April 2006 and the operation started on Sep. 2006.

The measured average static pressure inside the storage ring was $4.2x10^{-10}$ mbar; this value is similar to the calculated results [12]. As for the measured average dynamic pressure: after the first operation with 700 MeV of beam energy and 2 mA beam current, the pressure increased into low 10^{-8} mbar range near the crotch absorbers and at low 10^{-9} mbar in the vacuum chambers [9]. With further beam scraping, the dynamic pressure improved as well as the beam lifetime, recent results (Apr. 2008) show that the measured dynamic pressure was $1.5x10^{-9}$ mbar with 300 mA beam current and 600 A.h accumulated beam dose and the beam lifetime increased into 22 hours.

The dynamic pressure and beam life time vs. accumulated beam dose are shown in Figure 4 [13]. In addition, it has been observed that fast recovery of the

vacuum pressure was obtained after the exchanging of the straight sections with insertion devices.
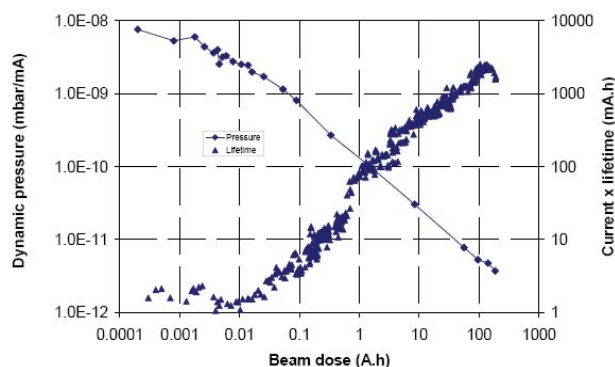

Figure 4 dynamic pressure and beam lifetime both normalised to beam current vs. accumulated beam dose for Diamond storage ring.

Few failures were faced during the commissioning stage of Diamond however they have managed to solve them and continue with the commissioning; the failures were mainly due to manufacturing issues, for example, coating adhesion of one kicker, bellows failure of some shutters in the beam lines, unreliable reading from Pirani gauges due to heating up in the gauge and low striking efficiency for the cold cathode gauges.

Soleil.

The installation of the storage ring was completed and the operation of the machine started on May 2006 [3].

The measured average static pressure following the complete bakeout and activation of the NEG coating of the storage ring vacuum chambers was $4.0x10^{-10}$ mbar.

Following the first injection the pressure increased with a maximum value of $2x10^{-8}$ mbar with 0.8 mA, with beam cleaning, the pressure reduced into $1.9 x10^{-9}$ mbar with accumulated dose of 620 A.h and current of 300 mA, the measured beam life time is around 12 hours. Figure 5 shows the average pressure and the beam lifetime of Soleil storage ring vs. accumulated beam dose [10].

Almost all of Soleil NEG coated chambers are equipped with pumping ports (except the ID chambers), some measurements carried out by Soleil and the ESRF estimated that the PSD yield for those chambers have higher PSD yield by around 20 times than those which are coated and without pumping ports, a possible explanation is that these ports are not NEG coated, and they could contribute in high value to the PSD yield by scattering or other processes [11].

As for Diamond, Soleil faced few vacuum related failures during the commissioning stage; the failures were mainly malfunctioning of some equipment in the early stages of the machine commissioning, e.g. in the RGAs, ion pump controllers…etc, these equipments have been replaced or disconnected from the control system without affecting the commissioning schedule or procedure. In addition, Soleil had few problems with the RF shielded bellows of the storage ring where the RF finger falling

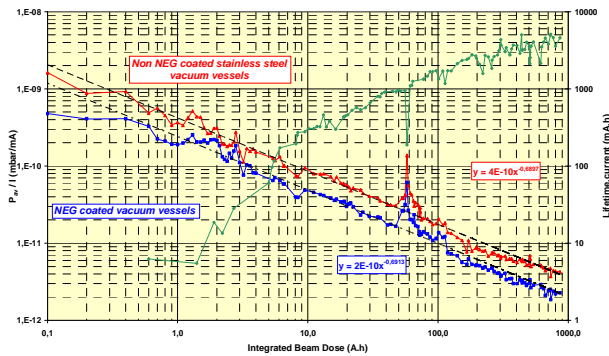down into the electron beam channel acting as an obstacle for the circulating beam.

Figure 5 average pressure and beam lifetime normalised to beam current vs. the accumulated beam dose of Soleil storage ring.

Australian Synchrotron

The installation of the storage ring of the Australian Synchrotron was complete on May 2006 and the first beam was delivered to the users on April 2007.

The measured average static pressure inside the storage ring without beam was in the range of 4×10^{-10} mbar.

Following the first injection into the machine, the pressure increased into low 10^{-9} mbar range (with 1 mA of current at 2 A.h of accumulated dose).

With beam scraping process, the dynamic pressure in the machine recovered and data from May this year shows that the dynamic pressure is 6.4×10^{-10} mbar with 172 mA and 700 A.h of accumulated beam dose. The beam lifetime with this accumulated dose and beam current was around 41 hours; Figure 6 shows the dynamic pressure and beam lifetime both normalised to beam current vs. beam dose for Australian Synchrotron storage ring [14].

The results of the dynamic pressure for the vacuum chambers after interventions show a clear recovery to almost the original pressure before venting; this is expected due to the memory effect of the vacuum chambers.
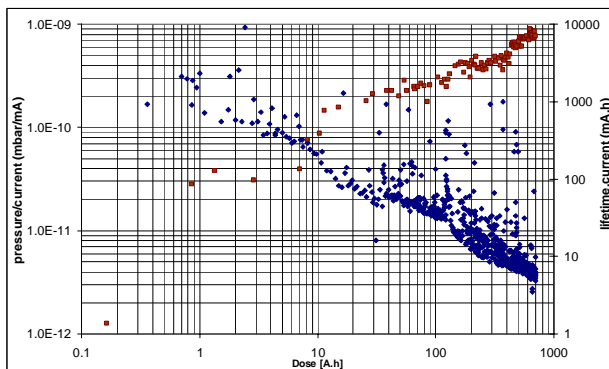

Figure 6 dynamic pressure and beam lifetime both normalised to beam current vs. accumulated beam dose for Australian Synchrotron storage ring.

It is noticeable that the dynamic pressure reduction with the accumulated beam dose of the three machines follows a D^{-a} dependence (where a is around 0.7). Further more it has been reported that the contribution of the vacuum related parameters to the impedance in these sources were limited (this can be realised by the operation of these machines at the designed current or close to it); the main contribution to the impedance in these sources is the resistive wall impedance. The choice of material of the vacuum chamber and the vertical size of the beam channel determine it value. Soleil has the smallest half vertical aperture within these three machines; however its effect was compensated by choosing aluminium (with NEG coating) as the fabrication material for the large percentage of the vacuum chambers.

FUTURE MACHINE'S VACUUM SYSTEM

The machines which have been built after the commissioning of Diamond, Soleil and ASP, used similar technologies to those adapted earlier, with some extend to new technologies; nevertheless, the objectives of the design remained unchanged.

ALBA.

The design of the vacuum system of ALBA is based on SLS/Australian Synchrotron approach. The storage ring is divided into 16 sectors with RF gate valves; the 316LN stainless steel vacuum chambers (beam channel cross section 72 mm x 28 mm (HxV)) have an antechamber everywhere where crotch absorbers are installed, narrow gap chambers for the insertion devices are made of extruded Al of vertical aperture of 10 mm and coated with NEG material. Pumping will be by SIPs and NEG pumps (in places with high outgassing and limited space), the overall pumping speed from SIP of around 57,000 l/s; these pumps are connected with a wide port to have a large conductance to the system. This will maintain an average dynamic pressure of around 1×10^{-9} mbar to achieve a beam lifetime >15 hours at the design current.

Each sector will be conditioned ex-site; after the assembly of one sector (including the sector valves), the bakeout will be performed in a 14 m oven and the chambers will be moved to the tunnel under vacuum, the straight section chambers will be baked in-situ.

NSLS II.

The storage ring of NSLS II is divided into 30 cells, almost all of the chambers will be manufactured from extruded Al (with beam channel cross section 76 mm x 25 mm (HxV)) with bimetallic flanges, as for the crotch absorbers, they will be made from Glidcop® or copper and to be fitted from the antechamber through photon exit gap into beam channel. Two NEG strips will be placed at top and bottom of the antechamber. In addition, SIPs and TSP will be positioned under the absorbers to remove the PSD gas load and reduce the beam channel pressure. New challenge for NSLS II is to remove the high outgassing which is expected due to the

use of damping wigglers in order to achieve very low emittance for the storage ring.

Following the installation and the alignment of the chambers, an in-situ bakeout will be performed using foil type electric heaters attached on chamber wall at magnet free location.

Taiwan Photon Source (TPS)

TPS is Taiwan new synchrotron radiation facility, the design and the prototyping phase is over and the main components are under manufacturing. The storage ring is divided into 24 cells; Al was chosen for the construction of TPS vacuum chambers. The choice of material adds some challenges on the design, machining, welding, joining and cleaning of these chambers; however, NSRRC had a good experience with dealing with Al as it was the material used for TLS vacuum chambers structure. The dipole vacuum chambers are designed with an antechamber to allow the radiation to pass through into the copper crotch absorbers, local pumps (SIP and NEG pumps) are placed close to these absorbers where high outgassing is expected. The cells will be conditioned in a similar manner to SLS, ASP and ALBA [15]

MAX IV.

MAX IV is a new synchrotron facility proposed to be built at MAX-lab, Lund, Sweden. The 530 m circumference, 3.0 GeV storage ring has a horizontal emittance of 0.24 nm.rad with the IDs in operation. The small dimensions of the vacuum system (imposed by the small aperture magnets which has minimum radius of 15 mm) yield a poor vacuum conductance, this problem can be solved by the introduction of NEG coating. NEG-coated copper tube dipole chamber was installed in one of the MAX II storage ring dipoles [16], it is planned to be used all around MAX IV ring. CH_4 (which can not be pumped down by the NEG surface) could be pumped by discrete small ion pumps. The copper vacuum chamber solution will moreover offer an elegant way of avoiding lumped absorbers; the synchrotron radiation power is distributed along the tube, yielding a low power density.

CONCLUSION

The designs of the newly commissioned machines are characterised with the general use of stainless steel as construction material with Al used for simple geometries (like ID straight sections), conventional pumping (SIPs, TSP and lumped NEG pumps) is the main choice with an increased use of new technologies like NEG coatings. More attention is given to the preparation and the conditioning of the system by applying restrict cleaning, assembly procedure and in-situ and ex-situ bakeout.

The results of the vacuum commissioning and performance of the new machines were presented: cleaning by the photon beam was very efficient for all of them, with the reduction of the outgassing rate producing a corresponding reduction of the dynamic pressure and increased the beam lifetime. The latter was due to the reduced beam-gas scattering effect steadily observed as the accumulated dose increased.

The future machines adapted various design approaches, though conventional design procedures are still dominant. However, confidence is being given to new techniques such as NEG coating and the use of copper and Al for the chamber structures, this can be explained by the experience being built over the last decade to these technologies, the good results being achieved in term of longer beam lifetime, low radiation levels and low contribution to the impedance, gave assurances to the vacuum designers to explore these technologies and implement them into the new projects [17].

REFERENCES

[1] G. LeBlanc, "Status of Australian Synchrotron Project", APAC 2007, p. 583.

[2] E.Huttel et. al. EPAC04, "The Vacuum System of the Australian Synchrotron", EPAC 2004, p. 1663.

[3] Z. T. Zhao, PAC07, "Commissioning of New Synchrotron Radiation Facilities", PAC 2007, p. 17.

[4] R. P. Walker, "Overview of the Status of the Diamond Project", EPAC 2006, p. 2718.

[5] L. Nadolski, et. al. "Status of the Soleil Project", APAC 2007, p. 578.

[6] E. Al-Dmour, et. al., "The Vacuum System for the Spanish Synchrotron Light Source (ALBA)", EPAC 2006, p. 3398.

[7] J.B. Murphy et. al., "NSLS II: The Future of the NSLS", PAC 05, p. 3345.

[8] C.C. Kuo, et. al., "Design of Taiwan Future Synchrotron Light Source", EPAC 2006, p. 3445.

[9] M.P. Cox, et. al. "Diamond Light Source Vacuum System Commissioning Status", EPAC 2006, p. 3332.

[10] C. Herbeaeux, these proceedings.

[11] C. Herbeaux, "Soleil vacuum system coating and conditioning", OLAV II workshop.

[12] O. Malyshev, et. al., "Pressure Distribution for Diamond Storage Ring", EPAC 2002, p. 2571.

[13] M.P. Cox, "Commissioning of the Diamond Light Source Storage Ring Vacuum System", IVC-17.

[14] Brad Mountford, private communication

[15] G. Y. Hsiung, "Operation Status of TLS and Latest Vacuum Design for TPS", OLAV II workshop.

[16] A. Hansson, et. al., these proceedings.

[17] R. Kersevan, et. al, " Status Report on the Performance of NEG-Coated Chambers at the ESRF", EPAC 2006, p. 1420.