HOW TO SAVE MONEY DESIGNING A VACUUM SYSTEM FOR A THIRD GENERATION SYNCHROTRON LIGHT SOURCE

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Abstract

Vacuum systems of the third generation synchrotron light sources should guarantee: i) long beam lifetime due to gas density, ii) short conditioning time and iii) simplicity in modification for new installations. Due to high stored beam currents the wall conditioning is rapid and low specific outgassing rates (~10^{-13} mbar.l/s.cm^2) are reached. A simple and cheap bake-out system seems to be sufficient, even a non bake-out start up can be considered. The low specific outgassing rate implies smooth pressure profiles in between pumps, therefore the number of pumps can be reduced. It is suitable to make fore vacuum up to 10^{-7}÷10^{-8} mbar pressure range by auxiliary turbopumps. Then the UHV conditions can be maintained by sputter-ion pumps (SIPs) of a modest nominal pumping speed. Insertion device (ID) vacuum chambers of 5÷6 m in length can be pumped by pumps installed on both ends only. About 20 of 120 l/s SIPs can be supplied by one power supply in the pressure range 10^{-10} ÷ 10^{-6} mbar. The position of gauges for total and partial pressure measurements has to be chosen carefully. These instruments are strongly affected by external magnetic fields, radiation and RF. Badly placed vacuum heads are useless during machine operation because of difficulties in shielding against the above mentioned interferences. Taking into account this experience a lot of money can be saved.

1 INTRODUCTION

Third generation synchrotron light sources are dedicated for the use of radiation from insertion devices (ID) or from bending magnets (BM). High stored beam currents require a sophisticated ultra high vacuum system (UHV). The UHV conditions drastically reduce the elastic Coulomb gas scattering and bremsstrahlung. The base pressure without beam should reach the 10^{-11} mbar range. However, when the machine is in operation the inside walls of the vacuum chamber are subjected to energetic ion, photon or electron bombardment which desorbs the tightly bound surface gas which may result in large pressure increases detrimental to the running of the machine.

In this paper two and a half years of ELETTRA vacuum system experience is described.

2 TO BAKE OUT OR NOT TO BAKE OUT

In the past, it was generally believed that carefully performed cleaning and pre-baking procedures of all vacuum components, followed by in-situ bake-out of the vacuum chamber can lead to a lower photon induced desorption and subsequently to a longer beam lifetime, one of the most important machine parameters. In our case, the cleaning procedure described in ref. 1 was followed. Before the first run of storage ring commissioning the in situ bake out was partially performed only in one of the six vacuum sectors, to be in accordance with the time schedule of assembly. The base pressure without around the machine was varying from $5x10^{-9}$ mbar up to $1.5x10^{-8}$ mbar. In the residual gas spectra scanned at different beam currents the masses 2 (H_2^+), 16 (CH_4^+), 18 (H_2O^+), 28 (CO^+), 44 (CO_2^+) and their fragment ions were dominant as it is typical for unbaked vacuum systems. The mass 30 (NO^+) - fragment ion of HNO_3 - was also observed at the beginning of the commissioning. Nitric acid could be constantly produced by the reaction of photons with moisture of the air. The NO^+ production is enhanced by the high voltage at the ion pump feedthroughs which could cause corrosion of the braising. In these vacuum conditions we first succeeded to circulate the first 2 000 runs (October 6, 1993), followed shortly afterwards by the accumulation of beam currents up to 410 mA@1 GeV. The highest pressure with beam never dramatically exceeded $1x10^{-7}$ mbar. After about 2 Ah of conditioning the water content rapidly decreased and NO^+ ions were no more observed.

At the end of November 1993 (~ 12 Ah of dose) the base pressure without beam reached the high 10^{-10} mbar range. The remaining sectors of the ring were baked successively during various shutdown periods. On two occasions it happened that the bake out procedure started at quite acceptable pressure (at least in 10^{-8} mbar range) but after a bake out cycle the pressure increased up to 10^{-4} mbar range due to some leaks that opened during the cooling of the vacuum chamber.

After five months of ELETTRA operation all storage ring sectors had been baked and the equilibrium pressure had stabilised in the low 10^{-10} mbar range, the dynamic pressure measured at 100 mA@1 GeV was $1.1x10^{-9}$ mbar.

During commissioning a number of events occurred that are relevant to the vacuum conditions. From the vacuum point of view, the most important intervention was the replacing of faulty gaskets of all RF cavities [2]. During this intervention more than 70% of the SR vacuum chamber had to be opened and vented. After repairing, the normal machine operation started without performing any bake out of vacuum sectors. Other less important modifications have been made, such as the installation of beam stopper, and replacement of a photon absorber. In all these cases at least one vacuum sector had to be opened, but no bake out was performed after intervention, and the operation pressure in the 10^{-9} mbar range was reached soon.

In Table 1 both positive as well as negative aspects of the-in situ bake out are summarised.

"+" ASPECTS	"-" ASPECTS
1. Total pressure decrease (from 10^{-8} to 10^{-10} mbar)	1. Thermal stress (SIPs supports lubricated)
2. Water content decrease (from 10^{-8} to 10^{12} a.u.)	2. More conditioning time is needed
3. Clean vacuum, i.e. only H_2, CH_4, CO, CO_2 is present	3. Time consuming (3 ÷ 5 days per sector)
4. Sputter-ion pumps outgassing	4. Non negligible costs
5. Partial NEG moduls activation	5. Necessity of cooling (heaters removed)
6. Machine is ready to operate at the nominal power	2. Possibility of creating quite big leaks after cooling (10^{-4} mbar)

Table 1 - Aspects of in-situ bake out

Another aspect of the pre-treatment vacuum components that should be revaluated is the necessity of pre-baking components in a high vacuum oven. Mathewson [3] has experimentally verified that high temperature vacuum outgassing of stainless steel makes no difference to the photon desorption yield coefficient η. A similar effect has been observed also during ELETTRA commissioning. Insertion device (ID) vacuum chambers installed in the storage ring were not pre-treated in the oven, only in-situ bake out at 150 ˚C was done. The pressure increase with beam and conditioning time was the same as for the rest of the ring of which all components were outgassed at high temperature. Dynamic pressure (measured at 200 mA@2 GeV) in the 10^{-12} mbar range was reached after ~35 Ah of conditioning.

3 PUMPING AND MEASURING SYSTEM

Following the earlier design calculations [4] the pumping system of ELETTRA has been designed taking into account the relevant machine parameters listed in Table 2.

Beam energy [GeV]	2
Beam current [mA]	400
Critical energy [keV]	3.2
Required pressure with beam [mbar]	$2x10^{-9}$

Table 2 - Machine parameters

Assuming a conservative value of η = 10^{-6} mol/photon a total pumping speed for the whole chamber of 10^4 l/s was required. This request has been fulfilled by installation of the following pumps in each vacuum sector: i) four 400 l/s SIPs combined with 2 NEG St 707 modules WP 1250, ii) eighteen 120 l/s SIPs modified by 1 NEG module, iii) two lumped NEG pumps for short straight sections, iv) four double NEG modules WP 950 for the light ports. Until now, the NEG modules have not been activated at the temperature of 450 ˚C. During the bake out of the SIPs they might have been only partially activated at about 200 ˚C. With these pumping conditions an operating pressure in the 10^{-10} mbar, or 10^{-9} mbar (in the rhomboidal chamber or in the light ports, respectively) is routinely maintained at 200 mA@2 GeV.

An interesting experiment, from the pumping efficiency point of view, was carried out during ion trapping studies. For those experiments it was necessary to deteriorate the operating pressure in the SR, while changes in lifetime were monitored. We started to switch off firstly 4 of 400 l/s SIPs, then 6 SIPs 120 l/s were switched off in each vacuum sector. At the end of this experiment more than 60% of pumps were switched off. Pressure and lifetime changes are shown in fig. 1.

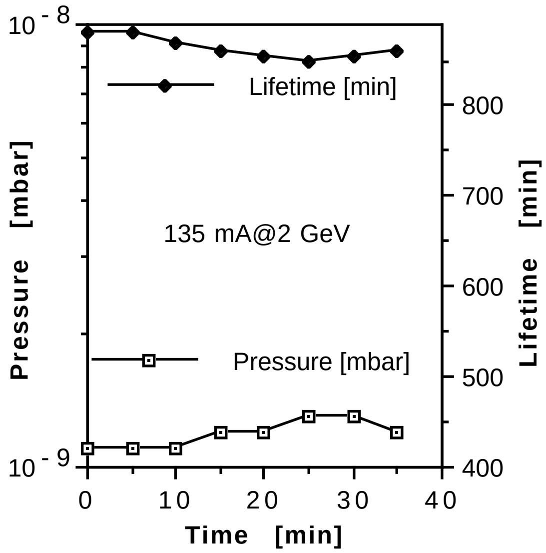

Fig. 1 - Pressure and lifetime changes after 60% of SIPs switched off

From this pressure versus lifetime behaviour, it can be deduced that the number of pumps which determines the total pumping speed of the system is not so important. In fact, this measurement was done after about 80 Ah of conditioning. At that time the specific outgassing rate of about $1.5x10^{-13}$ mbar.l/s/cm^2 and the desorption yield coefficient in the high 10^{-7} mol/phot range were reached.

In our opinion, the pumping system design based on the equilibrium state between the gas load and the nominal pumping speed does not correspond to reality. In fact, the high desorption causing the highest gas load occurred only at the beginning of commissioning, when stored currents are usually low during procedure of optimizing the machine settings. Going on towards higher currents the gas load is less and less pronounced, but also the pumping speed decreases with the decreasing total pressure. It means that the designed current and energy are reached in that time when the desorption yield and subsequently the total gas load is very low. Then the modest pumping speed is sufficient to maintain UHV conditions without lifetime decrease.

This fact is also important for the ID pumping system. Originally, the ID vacuum chamber has been pumped by four 120 l/s pumps, two central and two installed at either end. Switching off both central pumps during machine operation, a negligible pressure increase was observed in this region, and lifetime practically did not change. At present a new 4.8 m length ID vacuum chamber is under construction which will be pumped only at both ends.

A new approach to pumping system design based on two and a half years of experience with the ELETTRA vacuum system will be presented at the European Vacuum Symposium [5]. In this approach the dominant vacuum parameter is not the pumping speed but the ultimate pressure reachable by installed pumps.

A carefully chosen pumping system is very useful also from the pressure measurements point of view. Calibrated SIPs can be used as quite accurate vacuum gauges [6]. The current I absorbed for each pump is measured and an automatic current to pressure P conversion made - $I = K P^n$. This system is now calibrated, i.e. coefficients K and n are found, for SIPs of 45, 60, 120, 230, 400 and 900 l/s of nominal pumping speeds. In the UHV and HV regions, currents absorbed by each pump are very small, in $10^{6} \div 10^{4}$ A range. For this reason one power supply is sufficient to supply more pumps, while the sum of all adsorbed currents is lower than the nominal current. In one experiment 20 pumps were supplied by one μ-8000 power supply without any problems.

Using SIPs pressure readings a very reliable vacuum interlock system has been developed, which moreover overcomes known start-up problems of Penning gauges. Cold cathode inverted magnetron gauges were chosen for a negligible outgassing, simple maintenance, low contamination in oil-free system, interface with computer and acceptable cost. But during machine operation these gauges are strongly disturbed by external magnetic fields, radiation as well as by radio frequency [7]. The best shielding against magnetic field seems to be the double iron (Armco) sheet, because the μ-metal foil becomes saturated over 300 Gauss of magnetic field intensity and then even deteriorates both total and partial pressure measurements.

A proper shielding of vacuum gauges against radiation has still not been found. An installation of gauges through an elbow or "T" only attenuates the effect of radiation, but the difference between the real and measured pressures is more than two decades. Precise electronic measurements performed on non supplied gauges, with and without beam in the vacuum chamber, did not confirm the presence of photoelectrons [8]. Recently, a new shielding structure is under testing.

4 CONCLUSIONS

Based on thwo and a half years of the ELETTRA vacuum system experience we can conclude:

1. The machine start up can be performed without in situ bake out procedure of the SR vacuum chamber. Similar experience has been presented by Daressbury Vacuum Group. It seems, that the best cleaning agent is the well focused beam.

2. UHV conditions can be maintained by lower number of SIPs, if conditioning is correctly performed.

3. Using the SIPs pressure readings the number of installed gauges can be significantly reduced.

4. The gauge shielding against external magnetic field, R.F. and radiation is not a simple task. It is more convenient to find a proper place free of disturbances (if there is enough space!).

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