THE VACUUM UPGRADE OF THE CERN PS AND PS BOOSTER

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1. THE VACUUM SITUATION PRIOR TO 1990

The PS was designed and build in the mid 50ties and entered service in 1959. Vacuum was realised with some 100 pumping groups each one composed of a rotary pump and an oil diffusion pump. Most of the seals were made of elastomer materials. The pressures reached at that time were in the 10^{-4} Pa region. Besides the high pressure the bad influence on the beam of the heavy hydrocarbon molecules was detected and in the late 60ties the change to Ion Getter Pumps was made. This left of course much of the vacuum containment wall contaminated. It was only after the mid 80ties that all 100 magnets received new vacuum chambers made out of vacuum fired 316L+N stainless steel. Almost all seals used were by then made in metal; lead, aluminium or copper. Most of the big equipment tanks like for septa, or kickers were equipped with rectangular covers with vacuum seals made up out of a diamond shaped aluminium extrusion bend and welded in the appropriate form. The total installed pumping capacity with some 8o x 200 l/s and some 40 x 400 l/s gave the average pressure in the late 80ties in the 1 x 10^{-6} Pascal region under static conditions. By then also intensities of the particle beam had increased such that the created desorption due to proton losses and to synchrotron radiation from leptons gave rise to pressure flashes and increases by a factor of three.

The PS Booster was designed and build in the early 70ties with its 4 stacked rings each one with a length of a quarter of the PS circumference. The vacuum system was made of corrugated Inconel tubes in the magnets, the rest being mostly made of stainless steel 316L+N or 304L. The large amount of diagnostic, injection and ejection equipment for the 4 rings gave rise to high gas loads in the system. With its some 38 getter ion pumps, each one of 400 l/s the static pressure obtained was around 2 x 10^{-6} Pascal. Up to early in 1994 there was hardly any influence found from the circulating particle beams on that static pressure.

2. REQUIREMENTS OF THE HEAVY ION PROJECT

Around '87, '88 the requirements to vacuum in view of the acceleration of partially stripped lead ions were formulated for the PS and for the PSB. Based on earlier measurements [1] the aim was to improve the pressure in the PS by a factor of 5, and in the PSB by a factor of 10 with a gas composition of at least 50% of hydrogen in both machines. The difference between the 2 machines stems from the difference in the particle energies as well as from other factors like acceleration time. As formulated then, pressure was understood to be the sum of the partial pressures of the non-hydrogen components of the rest gas.

3. THE PROPOSED UPGRADE

In order to reach the required vacuum improvement, besides a general cleaning action, adding sublimation pumps and cryo pumps to the existing ion pumps was considered. There exists a CERN design of a Ti sublimation cartridge depositing Ti on the inside of a ø 200 mm pump body along a length of some 150 mm. Connected with a proper conductance that gives a pumping speed around 600 l/s for air mixture at the beam tube. That would so roughly quadruple the pumping speed there. For the PS that would not be entirely sufficient, for the PSB a factor of more than 2 would still be missing.

The choice of cryo pumping to improve pressure in high outgassing areas was not retained, but improving the vacuum quality of the beam tubes and specially of the necessary equipment in tanks was considered to be a more economic approach, certainly point of view of later exploitation cost.

4. THE FIRST EVALUATIONS

In February '88 the first measurements were made in the PSB [2]. Four Ti-sublimation pumps, each one with an estimated pumping speed of 1200 l/s, were installed in a sector covering some 10 % of the circumference of the machine and containing the ejection septa. With those supplementary pumps activated an average pressure of 3 x 10^{-7} Pa was measured in the sector. The pressure measured in the tank where the ejection septa are installed, a high pressure area, was 1.3 x 10^{-6} Pa. In the same place the gas composition was measured, expressed here for some gases as pressure in % of the total pressure, see table 2, first column.

In 1991 a test stand composed of a standard 6 m long PS magnet vacuum chamber with a 200 l/s ion pump and a prototype 1200 l/s Ti-sublimation pump was assembled in order to measure also for that machine the effect of added pumping speed. Pressures in the 10^{-8} Pa range were attained, also in the middle of the vacuum chamber length.

5. THE DEFINED UPGRADE

Based on these preliminary results it was concluded that it would indeed not be needed to rebuild the complete vacuum system such that for instance it could be baked. In a first stage a proper cleaning limiting outgassing of existing beam tubes plus adding to each getter ion pump a Ti sublimation pump were estimated to give a low enough pressure to obtain a high enough transmission rate for the Lead Ion facility to be commissioned. Some optimisation of the distribution of pumping speed would give some improvement as well. column 2 in Table 2 gives an estimate of pressure that was expected to be reached with these means in the PSB, with its rest gas composition. The table below gives an early estimate as it was made then of the needed equipment for such an upgrade in both machines. This equipment plus cost of installation foreseen in stage 1 for the PS and the PSB added up to over 10^6 CHF. Not included is the expenditure for the Heavy Ion Linac itself.

Ti sublimation pumps complete	150
Ion getter pumps complete	20
Pressure measurement eq.	70
Rest gas analysing equipment	6
Roughing groups	6

- Table 1 -

A second stage [3] would comprise rebuilding equipment and their large rectangular vacuum tanks both in the PS and in the PSB to limit outgassing in order to obtain the highest possible ion transmissions within the general options taken. In the PS the most recent vacuum tanks containing equipment for Lepton injection were already designed to be round with dished end covers and copper wire seals allowing a soft bake in situ. This could reduce local outgassing rates by a factor of more than 10.

Before the execution of the upgrade programme started a complete homogeneous system of pressure measurement with Pirani-Penning gauges was installed in both machines to be able to follow and evaluate in steps the vacuum improvements. In December 93, before the first installations in the frame of the upgrade programme, a new mass scan was made in the PSB in a different and more representative place for the whole ring as a reference value, see table 2, column 3.

6. THE EXECUTION

Mechanical design and manufacturing

The design and manufacturing job started in 1990. Besides many small changes three main items were needed for the first stage. The existing vertical manifolds in the PSB interconnecting the 4 beam tubes were to be modified to accept besides the getter ion pump a sublimation pump body connection and a third connection for a second getter ion pump was foreseen. This would increase the safety factor in the case of one getter ion pump braking down. For the PS a manifold was designed that would interconnect the pumping manifold to the standard PS magnet vacuum chamber with a pump body for the sublimator and with the existing getter ion pump. Manufacturing of those items was farmed out via the CERN/MT division's production procurement services and via direct contacts with collaborating institutions. Extensive inspection and vacuum testing was done on all parts received before the installation was allowed.

Installation

It was estimated that the execution of this first stage would require altogether some 2 man years on top of the normal maintenance work force only for the foreseen dismantling, cleaning and installation work in this upgrade programme in the 2 machines. Installation started in the 1993 shut down and continued in '94 and '95. The foreseen interventions required sometimes simply installation of newly manufactured equipment but in other cases also each time in the 2 month period dismantling, modification, cleaning, testing and reinstallation of the equipment, for instance the adaptation of the existing manifolds in the PSB. This required a strict planning of the work to be done, also in view of radiation doses to the personnel.

Stage two

In the mean time some doubts had risen on the validity of some of the parameters used to come to the decisions. More precise measurements on loss of ions with well known pressure and rest gas compositions had confirmed that the initial presumptions were somewhat optimistic. Subsequent corrections showed that one could maintain the same philosophy as initially adopted, but one should really try to obtain the maximum improvement as foreseen. It required to include at least part of stage 2 foreseen for later years in the base programme. In the PS the redesign and replacement of the big square flanged equipment tanks was speeded up. New equipment tanks are now round and will allow a soft bake out in situ. In the PSB pumping speed was increased by adding 9 new vertical manifolds interconnecting the 4 vacuum tubes to the 30 existing ones, which were already foreseen to be modified. This also required the welcome sacrifice of 3 columns of 4 sector valves each. This gave a PSB machine with only 2 sectors, the injection-ejection area and the rest of the machine.

Now the upgrade programme is enlarged including now also new round copper sealed vacuum tanks in the PSB, a complicated and difficult design with the 4 stacked rings, besides the redesign and improvement of the vacuum quality of the equipment inside. Execution of this has started and will be implemented during the '96 and '97 machine shut downs.

7. CONTROLS

Ti-sublimation pumps power supply

A new design for the Ti-sublimator power supply was developed in order to obtain the maximum number of sublimations from a 2 mm ø Ti wire before break down. This requires to control precisely its temperature and therewith the sublimation rate since that varies strongly with the temperature and so with the heating current send through it. It was already known that the electron emission from the wire, when put at a negative polarisation voltage against the surrounding volume, could be measured and used as a reference value [4]. The control unit reads that emission current I_e and adjusts then the heating current I_h through the wire so that it stays constant at a set value. At some 1410˚C the wire emits an I_e of 10 mA in the given geometrical configuration. That will then correspond to a sublimation rate of some 40 mg/h of Ti. This current will be switched on with a smooth rise in order to prevent thermal shock and early break down of the wire. It will then stay at this high temperature for some 90 sec, depositing a few monolayers of fresh Ti on the inside of the pump body. This required also a special design of the sublimator cartridge with the 2 Ti wires insulated from ground and a central anode at ground potential. With the increasing number of sublimations the characteristics of the wire change, but the regulation system keeps the emission current and so also the sublimation rate constant. This will increase the possible number of sublimations from a single filament to up to above a thousand, and with the second filaments as spare, a lifetime of more than one year is guaranteed for the sublimator cartridge.

General control system

During the last 2 shut downs in a consolidation programme all HV power supplies for getter ion pumps were changed to eliminate PCB. The general control system in the 2 machines was also changed. Instead of the CAMAC system before now high power local VME crates (DSC's) that contain much of the programmes are controlled via Ethernet and can be accessed from work stations spread over the site. Sophisticated application programmes can be started there that will allow to switch on as needed groups of sublimators at preset intervals for a fixed number of times. In this way one aims for the best effect on the vacuum for a minimum of Ti consumption and so guarantee a maximum lifetime.

8. RESULTS

Pressure and gas composition measurements were made mainly in the PS Booster before any installation in the frame of the upgrade programme started, and also before, during and after the first Lead Ion injections into the PSB and PS. Due to pulsating magnetic and radio frequency fields it is difficult to measure pressure, and more so rest gas composition during operation of the machines. For this reason most measurements are made under static conditions, that means without those fields and so without beam. On the other hand it is important to know the dynamic behaviour of the vacuum, since during the super cycle, mostly in the PS, different types of particle beams circulate of which some have, due to their character or intensity, big influence on desorption and so on the pressure and therewith on the transmission of heavy ions in following cycle. Due to these circumstances it is extremely difficult to come forward with precise predictions on heavy ion transmission rates through these machines. With continuous and high repetition rate acquisitions and signal treatment one can nevertheless obtain for instance approximate rest gas composition read outs from analysers and together with pressure readings calculate these rates, as presented in the table 2 below. The partial pressure percentages are based on quadrupole spectrometer measurements corrected for different instrument sensitivities. The bottom line shows an estimate of the transmission based on more recent measurements [5]. It is calculated with the help of a programme that derives from the pressure and the rest gas composition the density and the squared sum of all Z's which then together with the duration of the acceleration is used to obtain the apparently optimistic estimate of the transmission rate.

9. CONCLUSION

Up till end 1994 in the PSB work was concentrated on cleaning and the pumping capacity was considerably increased. In the PS mainly some equipment tanks were changed. This together with general care was sufficient to obtain a transmission rate good enough for commissioning, see column 4 in table 2. During this year 1995 the pumps in the PS will also be activated. This will allow to obtain assure good conditions for the Heavy Ion run in the second half of this year. Due to the character of the transmission phenomena and within the limits of the options taken a vacuum pressure improvement will always improve transmission. The execution of the rest of the upgrade programme will hopefully bring total transmission through the two machines well above 70%. This will depend also from decisions taken on the mode of operation of the machines, specially the types of particles and their intensity in the different cycles as well as their order in the train of the super cycle.

Date	Febr.'88	Febr.'88	Dec.'92	Dec.'94	Apr.'95
Pascal	1.3×10^{-6}	3.0×10^{-7}	1.8×10^{-6}	3.0×10^{-7}	3.1×10^{-7}
H_2	73	80	74	82	89
CH_4	1.5	2	2	0.3	1
H_2O	12.5	10	17.7	3	5
CO	-	-	4.5	2	-
N_2	13	8	-	12	5
Ar	-	-	-	0.3	-
CO_2	-	-	1.1	0.2	-
Transm.	0.31	0.68	0.13	0.65	0.73

- Table 2 -

[1] Acceleration of Lead Ions in the CERN PS Booster and the CERN PS, at this conference. Horst Schoenauer et al.
[2] Vacuum tests in the PSB with sublimation pumps. PS/ML-TN-88-10. M.Brouet, M. Bourgeois et A. Poncet
[3] Upgrade of the PS vacuum system for Lead Ions. PS/ML-NI-87. A. Burlet et A. Poncet.
[4] A study of a new method to control precisely the evaporation rate of Titanium sublimation pumps. CERN-ISR-VA/79-34. Pierre Strubin.
[5] Private communications. O. Groebner, M. Schneider.