OVERVIEW OF UHV ACTIVITIES ON CERN ACCELERATORS

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ABSTRACT

Ever since its birth, 45 years ago, CERN has been active in Ultra High Vacuum Science and Technology, faced with the ever-increasing demands of its storage rings and particle accelerators. In many instances, newly discovered beam-gas particle limiting phenomena have led to new developments and solutions in pumping hardware, surface preparations, thin films, etc. Today, the CERN new challenge is to construct the Large Hadron Collider. This machine, like its predecessors, demands new solutions in UHV techniques.

1. INTRODUCTION

CERN operates a large panoply of particle accelerators ranging from LINACS (p, p⁻, e⁻, e⁺, ions), synchrotrons (BOOSTER, PS, SPS, used for p, p⁻, e⁻, e⁺, ions) and storage rings (ISR –now dismantled- for protons, LEAR, AA, ACOL, AD for antiprotons, EPA and LEP for e⁻, e⁺) and the future Large Hadron Collider LHC, a 7 TeV superconducting proton storage ring under construction to be installed in the 27 km LEP tunnel.
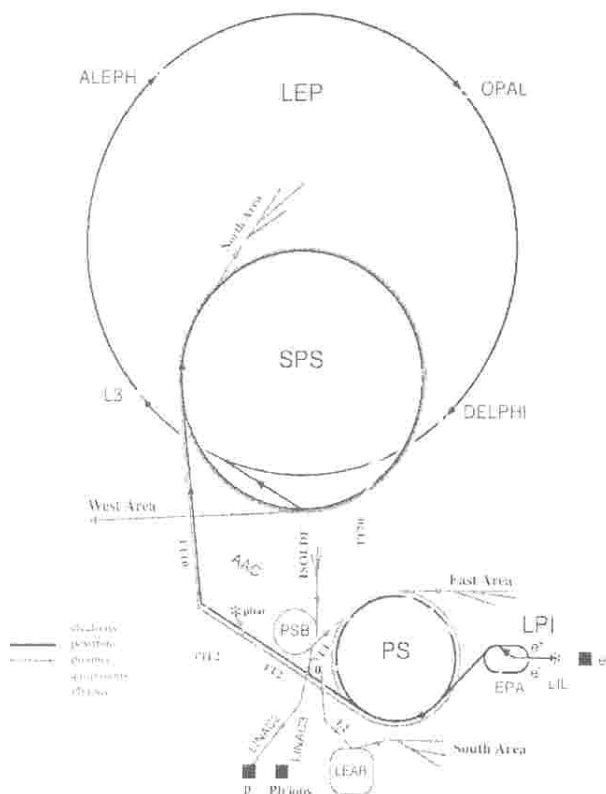
Since their initial construction spanning over the 48 years of existence of the Laboratory, CERN vacuum systems have been continuously upgraded and/or designed to match new challenges dictated by the ever-increasing demands and performance of existing and new machines. [1]

A brief review of existing machine activity is presented, with more emphasis on novelties induced by the future LHC.

2. UHV DEVELOPMENTS ON LEP AND LHC INJECTORS

Built some 30 years ago, the CERN PS Booster and Proton Synchrotrons vacuum systems have been upgraded many times, spanning a baseline static average pressure ranging from 10^{-4} to 10^{-9} mbar, five orders of magnitude! (lifetime, beam related ion problems, ion instabilities of various kinds...). These machines, like their late pioneering storage ring companion ISR, paved the way to many innovations in pumping and measuring hardware, and surface preparations, in close co-operation with Industry. The latest challenge of these synchrotrons is to accelerate heavy ions (Pb) for use in the future LHC. In order to achieve reasonable transmission rates of ions produced in a specially built LINAC and presenting large interaction cross sections with the residual gas, the average residual pressure of these machines has to be reduced by more than an order of magnitude, to 10^{-9} mbar. In these unbaked stainless steel machines, this is achieved by the addition of a large number of lumped titanium sublimation pumps, fired automatically at regular intervals, like was done in the 7 km CERN SPS, when it had to be transformed into a p and p⁻ storage ring. [2]
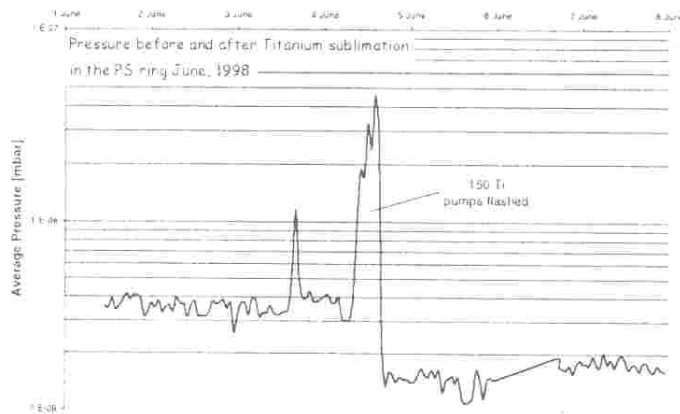

Figure 1: Schematic layout of CERN accelerators

Figure 2: PS & Booster Vacuum pressure improvements

3. THE ANTIPROTON DECELERATOR - AD

The chain of Antiproton Storage Rings (AA, ACOL, LEAR) is currently being modified or dismantled. LEAR, with its 10^{-12} mbar average pressure UHV system is being continuously improved, for studies of low energy partially strips heavy ion storage. AA is being dismantled, while ACOL, an unbaked UHV system (10^{-9} mbar) is being turned into a low energy Antiproton Decelerator (AD), its UHV system being upgraded to yield low average pressures (at and below 10^{-10} mbar). [3]

4. THE LEP ENERGY UPGRADE

With the installation of more than 300 Superconducting Accelerating cavities since 1993, the LEP energy is progressively increased from 45 GeV to more than 95 GeV at the time of writing. The LEP vacuum system pioneered the use of Non Evaporable Getter Strips (NEG) mounted inside the all aluminium vacuum chamber. Table 1 recalls the main relevant parameters governing the dynamic gas load into the systems.

Table 1: LEP & LHC UHV system relevant parameters

		LEP2	LHC
Beam particle		e^+, e^-	p
Circumference	km	26.7	26.7
Beam energy	GeV	100	7000
Beam current	mA	6	530
Critical photon energy	eV	$7 \cdot 10^5$	45
Synchrotron radiation power	kW	$1.7 \cdot 10^4$	7.4
Linear power density	W/m	882	0.44
Desorbing photons	$(s.m)^{-1}$	$2.4 \cdot 10^{16}$	$7 \cdot 10^{16}$

During its 18 years of continuous beam operation, LEP has accumulated a beam dose of more than 200 Ah. The machine continuous clean up, as expressed by the specific pressure rise has covered more than 4 orders of magnitude, down to 10^{-11} mbar/mA and below at 45 GeV. Doubling of the beam energy at 95 GeV has resulted in a factor 10 increase, proportional to the radiated power [4].
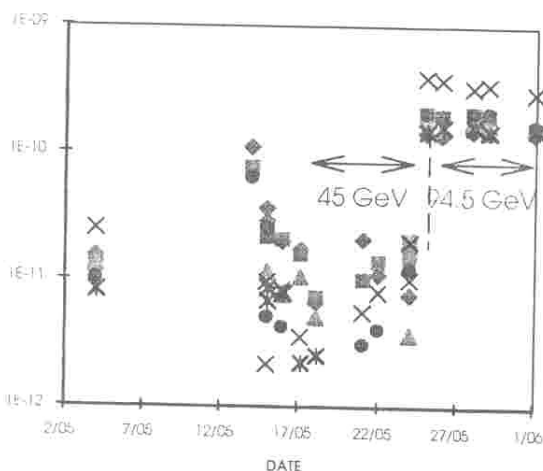

Figure 3: LEP dynamic pressure rise with accumulated beam dose and beam energy

The LEP performance has thus demonstrated the rightness of the choices concerning the vacuum system; namely lead cladded, flanged, aluminium chambers, baked in-situ, and of the pumping principle using NEG strips. The reliability of the system over the years has been remarkably high. [4]

5. THE LHC VACUUM SYSTEM

The Large Hadron Collider (LHC) under construction involves two proton storage rings with beam energies of 7 TeV. The two vacuum chambers are the inner walls of the superconducting magnet helium vessels, operating at 1.9 K. This provides very large pumping speed and capacity, therefore avoiding in principle the use of additional pumping hardware.

However, due to the very high beam energies, the intense (0.8 Amperes, ultimate) proton beams radiate a sizeable amount of synchrotron radiation, at a characteristic energy of 45 eV. The cryogenic system at 1.9 K cannot take the corresponding energy and a beam screen cooled at a higher, less costly, temperature of 20 K is interposed between the beam and the cold bore.

This beam screen is perforated with pumping holes, letting the synchrotron radiation desorbed gas escape to the 1.9 K pumping wall. The screen has a high conductivity copper layer to reduce RF losses due to image currents and to increase broad band resistive wall instability thresholds. [5]
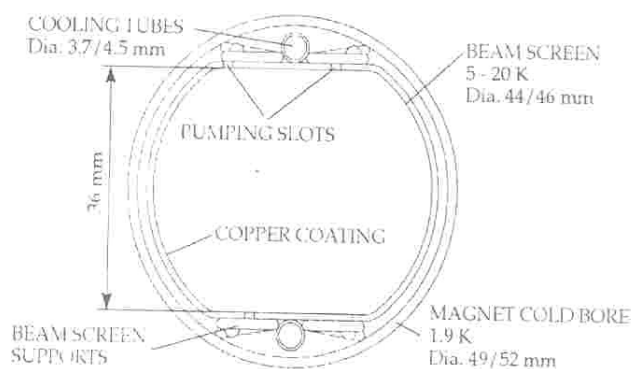

Figure 4: The LHC beam screen

LHC contains most known beam gas interactions susceptible to complicate the design of the vacuum system, as in high intensity electron or positron machines, with in addition the difficulty resulting from the very limited power absorption capacity of a 1.9 K cryogenic system.

The gas related limiting effects for the LHC beams are of several nature. Lifetime, limited by nuclear scattering, is not the only criteria to keep the gas density low. Energy deposited in the superconducting magnets by protons lost on the gas may cause them to undergo resistive transitions (quench). Photoelectrons produce an important dynamic pressure rise, LHC having a higher photon flux than LEP2. The beam parameters (bunch spacing, intensity) bring the machine close to ion induced pressure bumps stability limits. And finally multipacting of the photoelectrons in resonance with the beam bunch structure has to be controlled by all means to avoid thermal power deposition into the cryogenic system.
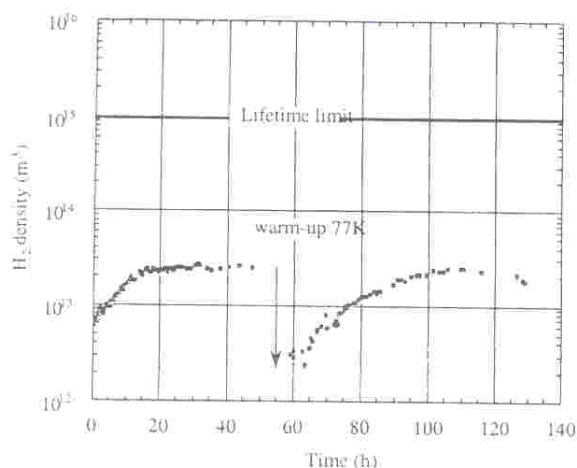
Figure 5: Evolution of the gas density inside the LHC beam screen during photon exposure

Figure 7: Effective desorption yield of H_2, CO, CO_2 and CH_4 for an equiatomic TiZr coating

Electron multipacting is a problem for B factories running large beam intensities, which necessitates the development and use of surface low electron emission coatings (TiN in Slac HER).

CERN is currently in the process of developing new coatings based on gettering materials, activable at normal bakeout temperatures, such as Ti Zr. These magnetron-sputtered coatings look very promising for reducing primary and secondary electron emission, to reduce surface outgassing and achieve extreme vacua, and to pump gas. [6] [7] [8].
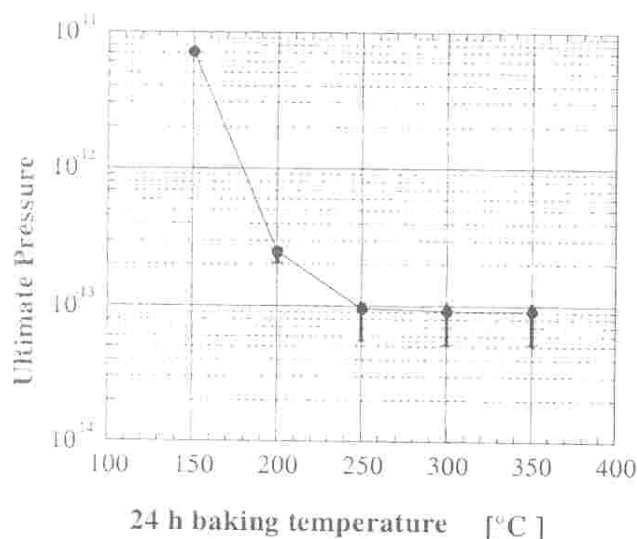

Figure 6: Ultimate pressure achieved on a 2 m long TiZr coated test chamber after 24 hours baking

These coatings permit to reduce the desorption yields under particle and photon exposure. They could find applications in synchrotron radiation machines like light sources and LHC.
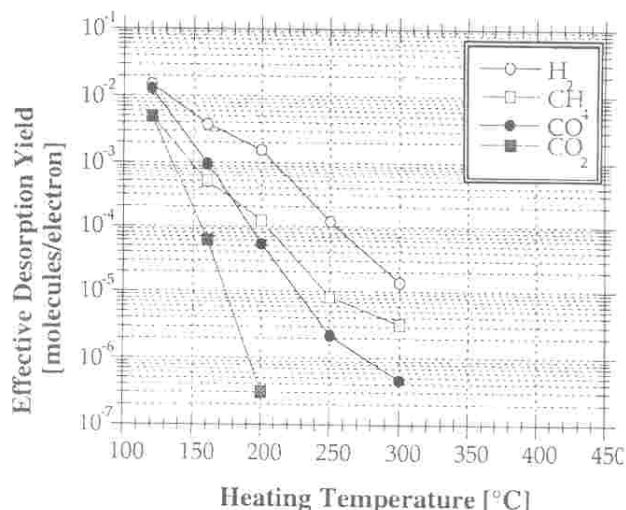
REFERENCE:

[1] A. Poncet, UHV for Accelerators, CERN MT/95-03, Int. Conf. On Vacuum Science & Technology and SRS systems, INCOVAST 95, Indore, India, 1995.

[2] J.P. Bertuzzi et al, The Vacuum Upgrade of the CERN PS and BOOSTER, CERN Vacuum Technical Note 95-11, September 1995.

[3] M. Brouet and O. Gröbner, Upgrading the AC Vacuum System for the Antiproton Decelerator (AD), CERN Vacuum Technical Note 97-06, April 1997.

[4] N. Hilleret, Experience with the LEP Vacuum System during Operation Energies exceeding 90 GeV, presented at EPAC98, Stockohm, Sweden, June 1998.

[5] O. Gröbner, The LHC Vacuum System, LHC Project Report 191, PAC, Vancouver, Canada, 12-16 May 1997.

[6] C. Benvenuti et al, Non Evaporable Getter Films for UHV Applications, J. Vac. Sci. Technol. A 16 (1), 148, 1998.

[7] C. Benvenuti et al, A novel route to extreme Vacua : the thin film getter coatings, to be published in Vacuum, May 1998.

[8] B. Henrist et al, The Secondary Electron Yield of the Non Evaporable Getter alloys TiZr and TiZrV, CERN Vacuum Internal Note 98-08, April 1998.