Experience with the Operation of the LEP Vacuum System and its Performance for LEP200

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Abstract

The performance of the present LEP (Large Electron Positron storage ring) vacuum system is reported and compared with the future requirements for LEP200. Upgrading of some parts of the LEP vacuum system is necessary mainly because of the higher beam energy and the larger synchrotron radiation power. The static pressure without beam in LEP is in the range of 10^{-11} Torr, while the dynamic pressure rise at the present max. energy of 45 GeV has decreased from the initial value of 10^{-7} to below 10^{-10} Torr/mA and no indication of a levelling-off is found. The reduction of the synchrotron radiation induced gas desorption has been found to be inversely proportional to the accumulated beam dose. The gas desorption rate increases less than linearly with the beam energy in the range from 20 to 46 GeV.

1. INTRODUCTION

Since the start-up of LEP in July 1989 the vacuum system has provided consistently vacuum conditions giving beam-gas lifetimes of many tens of hours together with low beam-gas background levels for the high energy physics experiments. Detailed descriptions of the vacuum system have been published previously [1]. The novel pumping system consisting of a linear NEG pump (Non Evaporable Getter) in the form of a 3 cm wide ribbon mounted in the pumping channel which runs parallel to the main beam duct over most of the 27 km circumference of LEP has provided an operating pressure with beam in the low 10^{-10} Torr range. The reconditioning frequency of the NEG has been very low in operation, typically it is performed once per year or whenever a section of the vacuum system has to be exposed to atmosphere.

2. DYNAMIC PRESSURE

The design of the LEP vacuum system with its extruded aluminium chamber and the NEG pumping system was based to a large extent on experimental results for synchrotron radiation induced gas desorption obtained on a dedicated photon beam line on the DCI machine in Orsay, France [2]. The predicted and the observed dynamic pressure evolution in LEP have been in very good agreement. Figure 1 shows a plot of the calculated dynamic pressure rise per mA beam in an arc of LEP as a function of the beam dose (the time integral of the total beam current in LEP). The continuous curve gives the calculated nitrogen equivalent total pressure, i.e. the sum of the partial pressures of hydrogen, methane as well as carbon monoxide and dioxide. The points represent measurements from a pilot sector (S213) in LEP. The discontinuities of the calculated curve represent the initial assumptions for the reconditioning of the NEG ribbon. In reality, these were performed at a beam dose of about 120, 950, 1500, 4500 and 5500 mAh as indicated by the arrows on the graph.

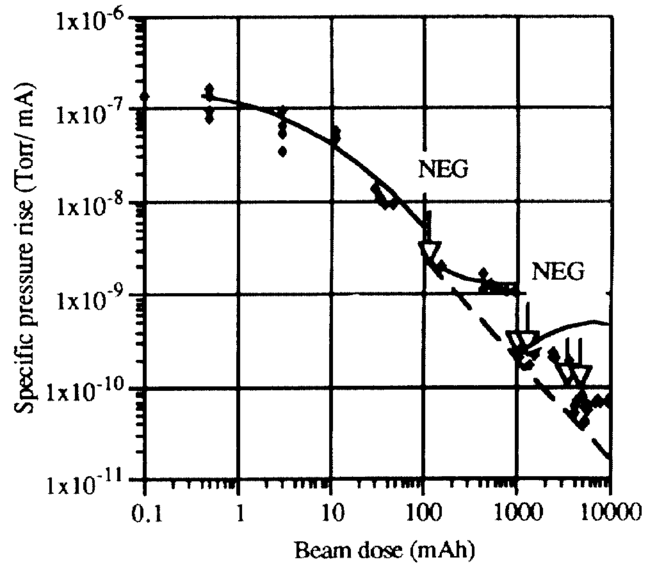

Figure 1. Specific pressure rise predicted for LEP on the basis of synchrotron radiation desorption data from the DCI test beam line compared with measurements in LEP. NEG reconditioning are marked by arrows. The dashed line extrapolates the specific pressure rise for maximum NEG pumping speed.

The dynamic pressure in nitrogen equivalent Torr/mA has been calculated using the expression

$$\frac{\Delta P}{I} = \frac{1}{3.2\ 10^{19}} \frac{1}{I} \frac{dN_\gamma}{ds} \sum \frac{\eta_i\ g_i}{S_i} \ .$$

The photon flux per second and per metre of chamber is obtained from the expression

$$\frac{dN_\gamma}{ds} = 1.28\ 10^{17}\ \frac{E\ I}{\rho}\ ,$$

with the beam energy E in GeV, the beam current I in mA and the magnetic bending radius ρ in m. Here η_i is the molecular desorption yield in molecules per photon as measured in the test beam line at DCI under conditions closely similar to LEP. The relative gauge sensitivities g_i, referred to nitrogen and the gas-specific maximum linear pumping speeds S_i (l /s m) are given in table 1.

TABLE 1

Relative gauge sensitivities with respect to nitrogen and linear pumping speeds in LEP

	H_2	CH_4	CO	CO_2
g_i	0.43	1.6	0.8	1.2
S_i	550	1	500	500

The evolution of the dynamic pressure in LEP during the 1990 and 1991 running period is shown in Figure 2. Here the beam dose axis has been converted to the integrated number of photons per metre of chamber. Due to the combined effect of the cleaning of the vacuum chamber by synchrotron radiation and the temporary loss of pumping speed of the NEG due to its saturation [3], the specific pressure does not evolve along a continuous, smooth curve. Instead, whenever the NEG is reconditioned and its pumping speed restored to its maximum value (see table 1), the dynamic pressure decreases to a minimum value. These points can be fitted by a reciprocal dependence on the beam dose. So far, no indication of a levelling off of the cleaning process could be found.

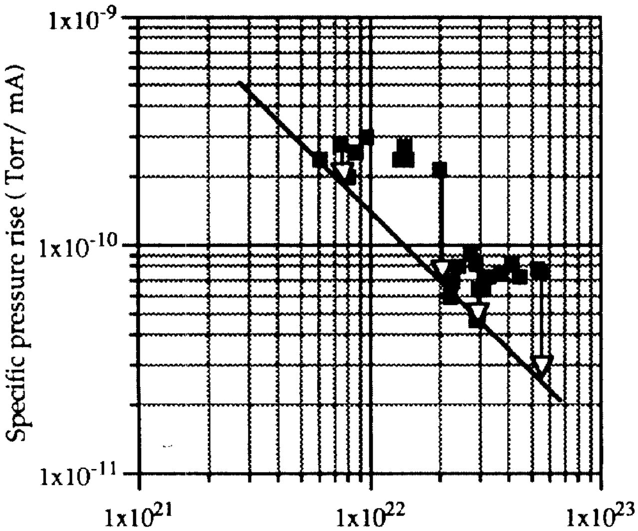

Figure 2, Specific pressure rise in LEP at 46 GeV beam energy during 1990 and 1991 as a function of the integrated photon dose. Arrows indicate NEG reconditioning.

Since $\frac{\Delta P}{I}$ is directly proportional to η, a total molecular desorption yield of less than 10^{-4} molecules per photon has been estimated for LEP at the end of the 1991 running period. The total amount of gas desorbed during this period is estimated as 0.18 Torr l/m

The residual gas composition in LEP has changed significantly since the start of the machine due to the different cleaning rates of the desorbed gas species as shown in Figure 3. Since the pumping speed for methane is provided by small, lumped sputter ion pumps only, its relative contribution in the residual gas spectrum is amplified by about a factor of 500. Nevertheless, due to its faster clean-up rate, CH_4 is now insignificant for the dynamic pressure.

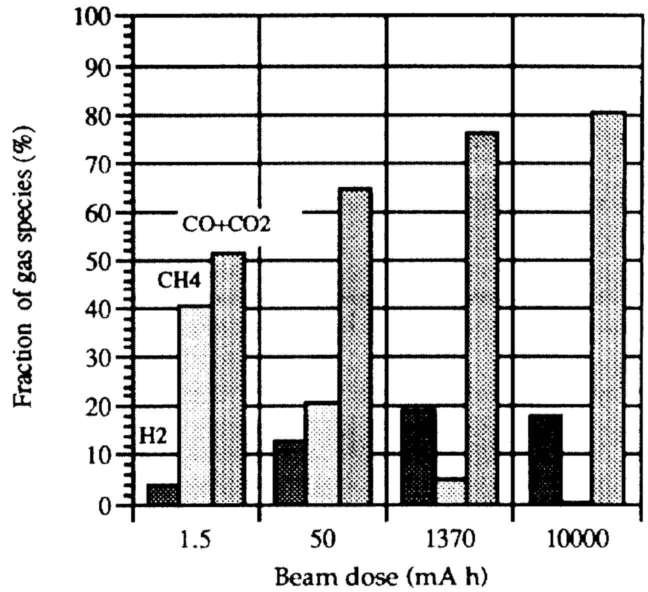

Figure 3. Relative abundance of the desorbed molecular species in the residual gas spectrum of LEP.

3. PERFORMANCE FOR LEP200

It is planned that the beam energy in LEP will be raised by the addition of 192 superconducting accelerating cavities to above 90 GeV by 1994. With higher beam energy and higher beam currents the photon flux and the synchrotron radiation power on the vacuum chamber is expected to increase significantly. The table 2 gives a summary of machine parameters which influence the vacuum performance.

TABLE 2

LEP Parameters

	LEP100		LEP200
Energy (GeV)	20	46	90
Total current (mA)	3 to 12	3+3	6+6
S.R. power ($W m^{-1} mA^{-1}$)	0.235	6.56	96.2
Critical photon energy (keV)	5.72	69.6	522.
Photon flux ($m^{-1} s^{-1} mA^{-1}$)	$8.3\ 10^{14}$	$1.9\ 10^{15}$	$3.7\ 10^{15}$
Beam dose equiv. (photons m^{-1}/A h)	$3\ 10^{21}$	$6.8\ 10^{21}$	$1.3\ 10^{22}$

The major components of the vacuum system have been designed to meet the requirements for operation up to 100 GeV beam energy. Some modifications and upgrading are nevertheless necessary, in particular to increase the cooling capacity and to redesign the vacuum system in the long straight sections due to layout modifications or due to the addition of new machine components.

The measurements of the variation of the dynamic pressure rise with beam energy in LEP have shown that the pressure increase is less than proportional with beam energy. In terms of the molecular desorption yield this implies that the yield per photon decreases with increasing beam energy in LEP. The results for the energy range from 20 to 46 GeV are shown in figure 4.

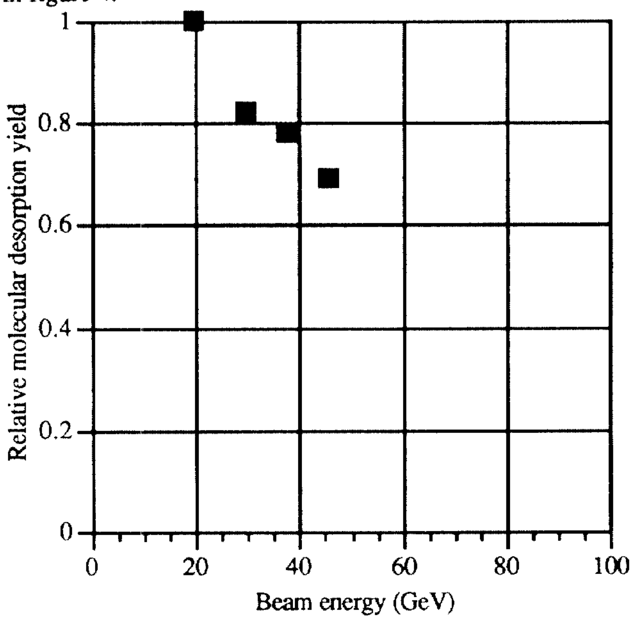

Figure 4. Relative molecular desorption yield in LEP as a function of the beam energy.

A pressure of 3 10^{-8} Torr corresponds to 1 hour beam-gas lifetime. In spite of the stronger photon induced outgassing at higher beam energies, it can be expected from the presently achieved level of beam cleaning - about 2 - 7 10^{-11} Torr/mA at 46 GeV - that a lifetime of about 20 hours for the nominal beam current will be obtained.

4. EXPOSURE TO ATMOSPHERE

In order to maintain the low specific pressure rise after opening the vacuum system to atmosphere for modifications or repairs, it is necessary to rebake the exposed vacuum section in situ to 150°C. Figure 5 shows a comparison of the dynamic pressure between an unbaked and a rebaked section with respect to a section in LEP which has never been exposed to atmosphere since the start of the machine. It can be seen that the samll complication of the bakeout - it is done by simply circulating 150°C hot water in the cooling channels of the vacuum chambers - brings a very significant gain (nearly two orders of magnitude) in the dynamic pressure and/or in the clean-up time: e.g. in LEP it may take up to 2 months to accumulate a 1 Ah beam dose. A rebaked sector maintains almost its full cleaning history, while the unbaked sector looses most of the preceding cleaning and follows closely a new vacuum system.

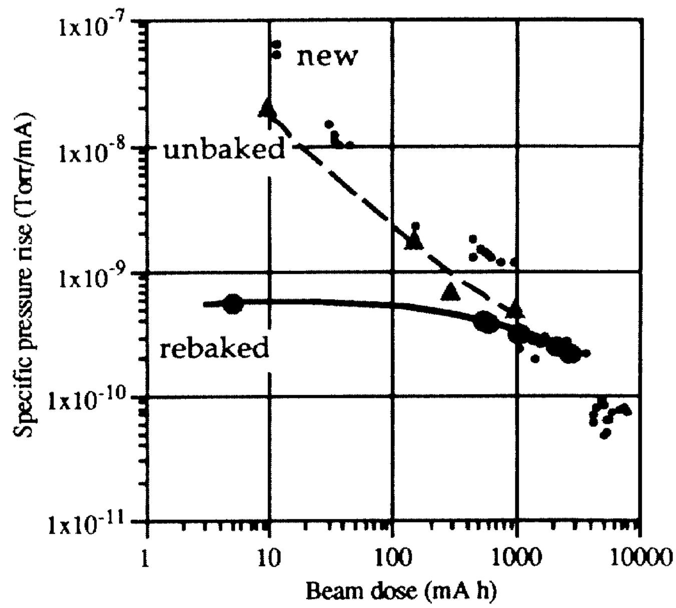

Figure 5. Comparison between a new sector and sectors re-exposed to atmosphere, with and without rebaking.

5. CONCLUSIONS

The predictions of the dynamic pressure in LEP based on the desorption data from the test beam line on DCI, Orsay have been in good agreement with observations in LEP.

The beam cleaning in LEP has been found to be approximately inversely proportional to the accumulated beam dose with no sign of levelling out.

The molecular desorption yield per photon decreases with increasing beam energy, suggesting that the high energy photons are less effective for desorbing gas.

When a vacuum section has to be opened to atmosphere, re-baking at 150°C can maintain the previously achieved low photon desorption yield.

The operational experience with the NEG as main pumping system has been excellent. Following the initial phase of beam cleaning, reconditioning once per year is now sufficient.

With the achieved beam cleaning - about 2 - 7 10^{-11} Torr/mA at 46 GeV - one may extrapolate to a beam lifetime of about 20 hours for LEP200 .

6. REFERENCES

[1] LEP Vacuum Group, *LEP vacuum system: present status*, 11th Int. Vac. Cong. & 8th Int. Conf. on Solid Surfaces, Cologne, p 1882, (1989)

[2] O. Gröbner, A. G. Mathewson, P. Strubin, E. Alge and R. Souchet, Neutral gas desorption and photoelectric emission from aluminium alloy vacuum chambers exposed to synchrotron radiation, *J Vac Sci Technol*, **A7**(2), 223-229 (1988)

[3] C. Benvenuti, F. Francia, CERN-AT-VA/89-61, (1989)