THE PERFORMANCE OF THE ULTRA-HIGH VACUUM SYSTEM OF LEP AND THE EXPERIENCE GAINED DURING THE FIRST YEAR OF OPERATION.

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Abstract: The 27 km long ultra-high vacuum system of LEP has been successfully operated during the first year of running. In most of the 130 vacuum sectors, with lengths up to 474 m, an average pressure of about 5 10-10 Torr has been achieved in the presence of circulating beams. The performance and the experience with the operation of the pumping system of LEP, which uses a combination of non-evaporable getter strip (NEG) and lumped ion pumps is described. The reduction of the synchrotron radiation induced pressure rise with the accumulated beam dose has followed closely the behaviour expected from measurements on test vacuum chambers. After several months of operation the beam lifetime due to gas scattering has increased from several minutes, for the very first circulating beam, to many tens of hours for colliding beam runs.

Main Characteristics of the LEP Vacuum System

A detailed description of the vacuum system for LEP may be found in previous notes [1,2], the main characteristics are the following: Of a total circumference close to 26.6 km, about 22 km represent a regular, repetitive structure in the bending arcs of the machine and consist of a succession of 3 bending magnet vacuum chambers of 11.7 m length each and of shorter, 3.6 m long chambers in the straight sections. The vacuum chambers are connected with stainless steel bellows of 0.168 m length [3].

The standard type vacuum chambers are made from an extruded aluminium profile. The extrusion provides an elliptic beam channel and a parallel pumping duct for the linear NEG ribbon. The NEG pumps through a single row of pumping slots of 20 by 8 mm. A single row of 40 slots per m provides a conductance for nitrogen of about 600 l/s/m. The synchrotron radiation power and the heat dissipated by the NEG [4] during activation and reconditioning are removed by 3 cooling water ducts. A lead radiation shield has been applied to the outside of the chamber to absorb the intense synchrotron radiation power when LEP operates at high energy.

In the 8 straight sections, each about 500 m long, accelerating cavities, vacuum tanks for electrostatic separators and special equipment for beam collimation are installed. Wherever possible, the regular structure of the arcs has been maintained in the straight sections permitting the use of standard type of vacuum chambers with integrated pumps.

Near the LEP experiments, in the low-beta quadrupoles and in the region of the RF accelerating cavities, the vacuum chambers are made of stainless steel with a circular aperture of 156 mm and 100 mm diameter respectively. These chambers have no provision for installing the linear NEG pump and, because of the lower level of synchrotron radiation power, no water cooling is necessary. Specially shaped cruciform vacuum chambers have been installed in the low-beta quadrupoles to provide the largest possible aperture required for the background in the experiments. The stainless steel sections are pumped by a combination of lumped ion pumps and of titanium sublimation pumps mounted at an average distance of about 10 m. The average pressure in the straight sections after bakeout at 300°C is in the low 10^{-10} Torr range.

The vacuum conditioning and the vacuum performance of the accelerating cavities is outlined in a separate contribution [5]. A detailed description of the vacuum system for the 4 large LEP experiments can be found in a contribution to this conference [6].

To reduce the cost, a minimum number of ion pumps has been installed in LEP, under the assumption that - apart from the initial phase of LEP operation - the contribution of inert gases, argon and methane, would represent a small fraction of the gas load only. Test measurements in a photon beam line at the DCI storage ring have indeed shown, that methane cleans up more rapidly than the other gases contributing to the dynamic pressure [7] and that the vacuum system, once cleaned, maintains its low outgassing rate after venting to N_2.

The monitoring of a vacuum system the size of LEP requires a large number of gauges and many km of installed cables. To reduce this cost, pressure readings to 6 10^{-10} Torr are derived directly from the approximately 1800 ion pumps. The achievement of the required low level of leakage current has been the result of a very careful and systematic high voltage treatment on all pumps after the vacuum bakeout [8]. For measurements at lower pressure down to 10^{-12} Torr a small number of uhv ionisation gauges and of quadrupole residual gas analysers are installed in sections which serve as a reference for the machine.

Commissioning of the vacuum system

During installation the vacuum sectors have been baked in-situ to 150°C for 24 hours by pressurized water circulation in the cooling channels [2]. During the end of a bakeout and with all vacuum chambers still at 150°C, the NEG pumps are activated. A 'static' average pressure well below 2 10^{-11} Torr has been achieved in all NEG pumped sectors. The static pressure in sectors with conventional lumped ion pumps and titanium sublimation pumps has been below 10^{-10} Torr.

Dynamic pressure rise with circulating beams:

With the first stored beam circulating in LEP a specific pressure rise of about 1.7$10^{-7}$ Torr/mA has been measured. A significant first observation has been that the pressure increased uniformly in all bending sections of the machine, indicating that the cleaning of all 3000 vacuum chambers of the series production had been closely controlled resulting in a uniform surface cleanliness. A pressure survey in LEP with circulating beam is shown in Figure 1. The data are derived from individual pump currents and give the average pressure for each of the 130 vacuum sectors.

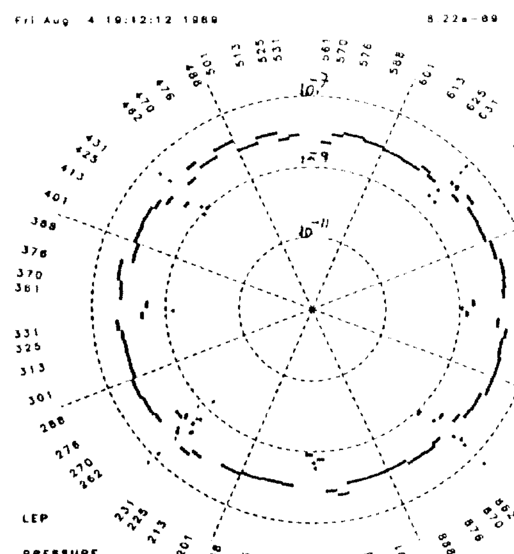

Fig. 1 showing the average pressure in the 130 vacuum sectors as derived from the ion pump currents. The plot has been taken with 0.4 mA total current shortly after obtaining the first circulating beams.

The sectors representing the long straight sections, far from the bending arcs, show a lower pressure rise due to the reduced synchrotron radiation level. Exceptions from the uniform pressure rise may be found in special locations with higher synchrotron radiation load, e.g. downstream of the wiggler magnets and in the injection regions.

Figure 2 shows a detailed plot of the dynamic pressure in a single vacuum sector. The lower part of the graph represents the initial static pressure before beam is stored. The upper part shows the pressure increase at two current levels, 0.042 and 0.172 mA respectively.

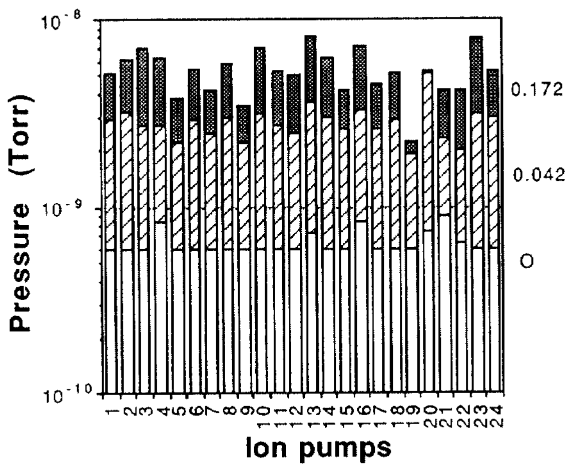

Fig. 2 Pressure distribution in pilot vacuum sector S213 at two current levels during the first runs with circulating beams. The initial static pressure is below the threshold of the measuring system of $6 10^{-10}$ Torr .

During the initial beam cleaning phase the residual gas composition has been dominated by CH4 with relative fractions of typically 5% H2, 40% CH4, 40% CO and 15% CO2. For a baked ultrahigh vacuum this composition is rather uncommon but it can be attributed to the very selective pumping speed from the combined NEG and ion pump system.

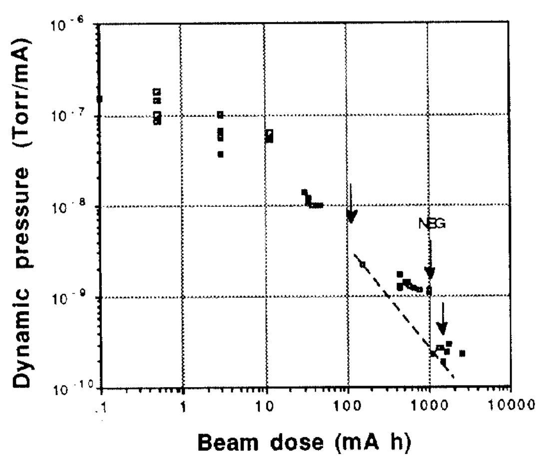

Fig. 3. Dynamic pressure and beam cleaning in a LEP vacuum sector. The arrows point to NEG reconditionings. The dotted line joins points with maximum pumping speed.

In Figure 3 is shown the gradual reduction of the photon induced desorption during exposure to beam with a relatively steep slope of about -1. However, it must be remembered that the beam cleaning curve reflects the global effects of the cleaning of the vacuum chamber surface and of the gradual saturation of the NEG pumps. In order to guide the eye, the dotted line joins those points on the graph which correspond to the maximum pumping speed obtained immediately after reconditioning the NEG.

The dependence of the specific pressure rise on the total circulating beam current for two beam energies is shown in Figure 4. The data have been taken after a beam dose of about 2.5 Ahours. Between 20 and 45 GeV beam energy the pressure has been found to increase by a factor of 1.4 while scaling the desorption with the photon number would give a factor of 2.25. The observed lower energy dependence is in line with previous estimates and with laboratory measurements [9] which indicate that the desorption decreases with photon energy.

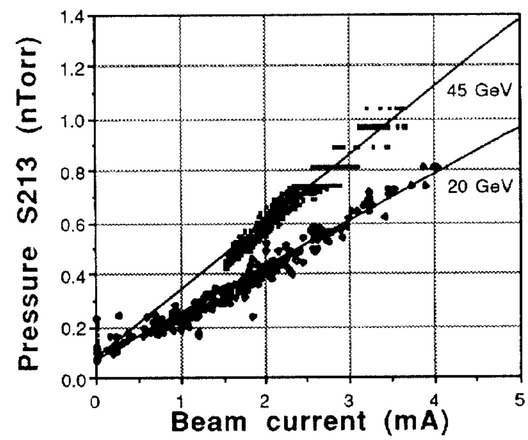

Fig. 4 Dynamic pressure rise as a function of the circulating beam current for 20 GeV and 45 GeV beam energy measured after an accumulated beam dose of 2.5 Ahours.

Beam -gas lifetime

During the first beam runs the measured beam lifetime has been in the rage of 0.2 to 0.3 hours for 1 mA beam current, in line with expectations from laboratory measurements. The gradual improvement of the beam lifetime is shown in Figure 5. Here the dotted curves represent the expected performance scaled from test chamber measurements. The upper curve applies to a hypothetical constant, maximum NEG pumping speed, while the lower curve is for 30 l/s/m, corresponding to a NEG pump after adsorbing approximately 0.2 Torr l/m of CO and CO_2.

The measured lifetime has followed closely the expected trend from the beam cleaning and shows a significant increase after each NEG conditioning. Nevertheless, two comments can be made: firstly, that the important contribution of the hydrocarbons, which are not affected by the varying NEG pumping speed, decreases with the ongoing beam cleaning and show the most noticeable effect at small beam dose, secondly, that at high beam dose the measured beam lifetimes tend to be lower than expected from the pressure, which suggests that other effects besides the vacuum contribute to the beam lifetime.

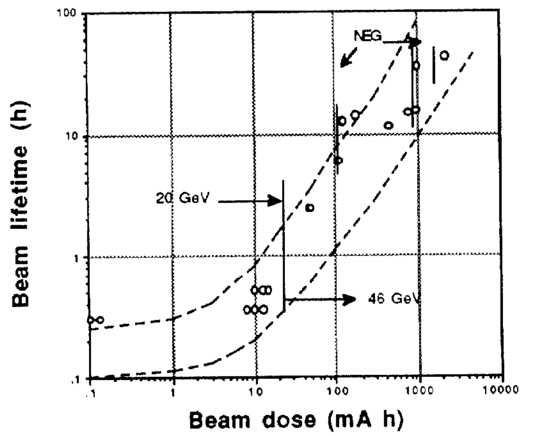

Fig. 5 Beam lifetime normalised to 1 mA as a function of the integrated beam dose. The dotted lines apply to upper and lower limits for the linear pumping speed of the NEG and are scaled from photon desorption data from test vacuum chambers. The upper curve is obtained for constant maximum NEG pumping speed, the lower curve is for a partially saturated NEG pump.

NEG pumps

The operational experience has confirmed the laboratory performance of the NEG pumps. Due to the high effective pumping speed available, the pressure rise with beam has been low and the beam-gas lifetime has been long and has never limited the machine performance. Since the start-up of LEP in July 1989, the NEG pumps have been reconditioned 3 times. The first time after a beam dose of about 120 mAh, at the beginning of September, the second time after 950 mAh towards the middle of November and the third time after 1.4 Ahours before restarting operation in March 1990. During the first two pumping cycles the effective linear pumping speed for CO and CO_2 has decreased from the maximum value of about 500 l/s/m to approximately 70 l/s/m. The reconditioning of the NEG has been performed remotely from the LEP control room. This operation requires closing of the sector valves and switching off the ion pumps to avoid deterioration of the leakage current performance due to the increased hydrogen pressure when the NEG temperature rises above 450°C. The whole system has been treated in less than 8 hours and this time may be further reduced if necessary. For practical reasons, the reconditioning is now performed towards the end of a long machine stop at intervals of several months.

The total quantity of gas pumped by the NEG until May 1990 is estimated to less than 0.4 Torr l/m for CO and CO_2 and to about 1 Torr l/m for H_2 (equivalent to about 3 monolayers). However, these quantities are small as compared to the total capacity which exceeds 30 Torr l/m for CO+CO_2 and 300 Torr l/m for H_2 [4].

Experience with vacuum components

The first months of operation have confirmed the excellent experience with the LEP-type joints with aluminium to stainless steel flanges and aluminium gaskets during the installation and commissioning phase [2]. The available statistics concerning the 6 leaks which were detected during LEP operation is indeed very encouraging [10]. The items which have developed leaks are: three ion pump feedthroughs, one beam position monitor feedthrough, a beryllium window on a beam monitor and a weld on a stainless steel chamber. Mechanical damage by 'traffic accidents' during access periods have caused a further two broken pump feedthroughs. Leaks by corrosion , on two of the ion pump feedthroughs, have occurred exclusively in places where water leaking into the tunnel has caused excessively high humidity. To reduce the risk of electric leakage currents on the ion pump connectors - but also to avoid corrosion -, small heating elements have been installed. Among the other components, the mechanical reliability of the gate valves are of concern since several valves have leaked and have developed mechanical defects.

A serious problem which is intimately linked with the vacuum chambers and their radiation shield has been identified as the remanent magnetisation of the approximately 9µm thick nickel diffusion barrier which forms part of the lead coating. The effect of the residual field on the performance of LEP and ways to eliminate this magnetisation are under study [11].

Vacuum chamber impedance

During the design phase all aspects concerning higher mode losses due to vacuum chamber impedance have been studied with great attention. As a consequence, the vacuum bellows in line with the elliptic beam ducts have been fitted with internal, smooth RF-bridges and the step of a cross section change reduced below 1 mm. The gaps between flanges have been bridged by special RF-finger contacts. The relatively small number of circular vacuum bellows mounted between the RF-accelerating cavities and between circular vacuum chambers have no internal RF-bridge but they have been specially designed with small corrugations only.

Unavoidable cross section change between elliptic and circular vacuum chambers employ tapered transition elements. Direct pump ports to the beam channel for have been replaced by connections either to the NEG pump channel, or through small perforations in the wall of the beam pipe. So far no problems have been observed which would be related to higher mode losses in vacuum chamber elements.

Acknowledgements

The performance of the LEP vacuum system presented here is the result of the common effort of all members of the LEP vacuum group and reflects the global result of a large number of individual and specific contributions in the field of ultrahigh vacuum techniques.

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