LEP VACUUM CHAMBERS FOR EXPERIMENTAL REGIONS : EXPERIENCE WITH THE FIRST GENERATION, PROSPECTS FOR THE SECOND GENERATION.

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Abstract

Highly transparent vacuum chambers adapted to the requirements of the detectors have been installed in the four LEP experimental regions. The design of the chambers and their support systems is described together with the installation procedures for these long and fragile parts. The background in the detectors has been minimised by both a sophisticated mechanical design and special vacuum conditioning. The vacuum results achieved during LEP operation and the implications on the background are discussed. The mechanical design of a new generation of vacuum chambers due to be installed in early 1991 is also presented with its technical options, the use of new materials, and the reduced beam pipe dimensions.

General

On the evening of 13 August, 1989, only one month after the first particle injection, physics runs started at LEP (Large Electron-Positron Ring) [1]. The first data were taken by the four large experimental set-ups: L3, ALEPH, OPAL and DELPHI, and almost immediately, Z^0 signatures were detected in the control rooms.

But before they reach the surrounding detectors, the particles generated by collisions of primary beams must escape through the vacuum chamber. This vacuum chamber is the physical interface between the collider and the detectors and should therefore be designed according to their requirements: in particular, an optimised transparency to particles, associated with the ability to maintain an ultra-high vacuum, and to have good electrical conductivity and minimum high-frequency losses as well as perfect shielding of the detectors from the beam-induced noise. Moreover the present vacuum chambers exhibit a large internal diameter (156 mm) in order that no particle-generated synchrotron radiation hits their wall.

Since the start-up of LEP, knowledge of the machine behaviour has improved. By using the collimators, it should be possible to reduce the internal diameter of the vacuum chamber and consequently its wall thickness, and to leave space for new vertex detectors. In February 1990, the decision was taken to install such smaller vacuum chambers, with a reduced internal diameter (106 mm), by the end of this year.

The First Generation of Vacuum Chambers

The basic design of the present vacuum chambers is similar for all four experiments: a cylindrical tube with an internal diameter of 156 mm and about 6 m long, connected by thin bellows to the vacuum equipment at both ends: pumping station and vacuum valve [2].

In order to meet the vacuum and the electrical shielding requirements, the whole central tube has a thin internal metallic skin which is smooth and continuous.

Tubes

Besides the smooth aluminium used for transition parts, three types of tubes have been chosen for this first generation: aluminium ring-stiffened, carbon fiber composite, and beryllium tubes.

Aluminium ring-stiffened tubes are at present the basic solution. They have been machined down to 0.5 mm wall thickness from magnesium-alloyed aluminium seamless tubes by inside honing and outside turning. The shape (Figure 1) has been optimised for general (tube failure) and local (inter-ring failure) bucklings.

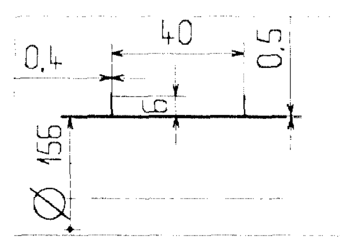

Figure 1

This versatile manufacturing procedure together with a good correlation between computation and tests allows 'customized' solutions: e.g. heavier rings to support a micro-vertex detector; reduced height but thicker rings in order to give clearance for installation, a smooth but thicker cylindrical 'window' with no rings to avoid local disturbances. This cost effective manufacturing solution is satisfactory for most of the 4π detection angle: $0.7\%X_0$ at 90° and less than $15\%X_0$ at 40 mrad.

The concept of carbon fiber composite tubes developed for LEP has already been extensively presented [3]. It consists of a High Modulus carbon fiber impregnated in high-temperature epoxy resin and wound on a continuous cylindrical aluminium skin, 0.1 mm thick. The central part of one experiment is composed entirely of such tubes. Moreover, in this case the vacuum chamber is also part of a pressure vessel, leading to a 4 bar external pressure loading. To create a 'window' for the central detector, the wall thickness has also been reduced to 1.3 mm over a length of 280 mm between stiffening rings (Figure 2).

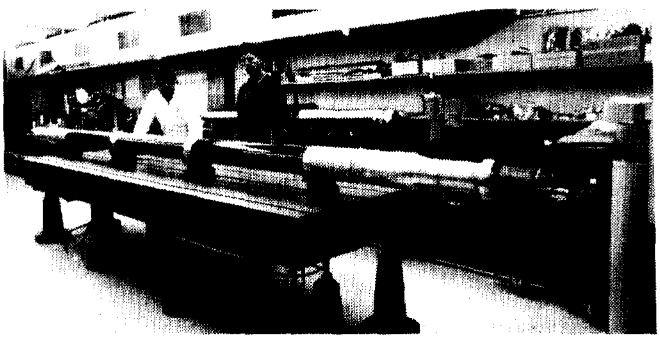

Figure 2

Installation

This installation procedure inside the detectors was different in each case.

- If sufficient clearance had been provided between the vacuum chamber and the central detector, a cradle was used as a support for the installation and was removed in cantilever position.
- Vertical installation was preferred for small clearances (2 mm on the radius); in such cases, a total height of 15 m below the crane was needed to carry out this operation.
- Finally, in one case, a flange had to be welded after it was inserted inside one detector. Consequently, special bake out equipment had to be developed to allow, in a 5 mm gap, a temperature gradient from 150 °C (on the chamber) to only 20 °C (on the detector wall).

If the wall thickness is minimised, too heavy supports may be a large source of scattered particles. Therefore the supports have also been optimised; they are made of a fiberglass epoxy composite, and the stainless steel support wires have a diameter of only 1.0 mm. Specially-made miniaturized load cells based on a strain-gauge technique allow the wire tension to be measured precisely (rupture load is only 40 daN!). Vacuum chamber alignment precision is of the order of 1 mm.

Vacuum conditions

The design principles and the limitations imposed by the surrounding detectors on the vacuum system in the LEP experiments has been already described in detail [2]. The experience gained during the preparation and the installation of these parts of the vacuum system has shown that the required vacuum below 10^{-9} Torr may be obtained without in-situ bakeout and with the limited amount of pumping speed which can be accommodated within the free space in front of the low-beta quadrupole as illustrated in Figure 5. After the prebaking in the laboratory of the fully assembled vacuum chamber including the pumping unit and the gate valve to temperatures between 150 °C and 300 °C for 24 hours, the finished vacuum system has been backfilled to atmospheric pressure with dry nitrogen and thus kept under clean ultrahigh vacuum conditions throughout the final installation sequence in the LEP tunnel. Pumpdown curves for the central vacuum pipes of 3 experiments are shown in Figure 3. For comparison also shown is the considerably slower pumpdown curve of a system (ALEPH) where this rigorous procedure of avoiding exposure to air has not been strictly applied because of the need to replace the filament holders of the titanium sublimation pumps and the cold cathode ionisation gauge on the already installed system.

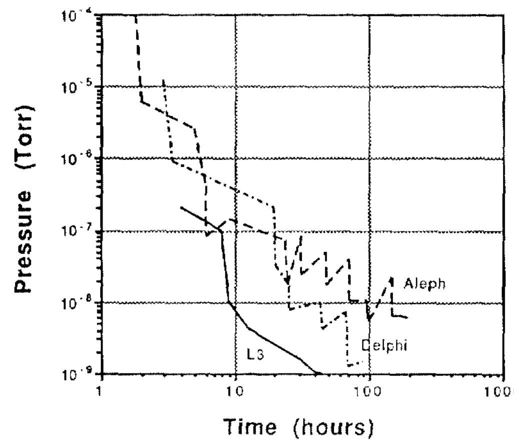

Figure 3

The 'sawtooth' pattern is due to the repeated flashing of the titanium sublimation pumps. The system for ALEPH has been exposed to air, the system of DELPHI is affected by a leak on a vacuum chamber in an adjacent section.

The vacuum pressure upstream of the experiments and extending into the bending arc of LEP contributes significantly to the off-momentum particle background. To achieve good vacuum, sections with stainless steel vacuum chambers have been baked to 300 °C and parts with standard aluminium vacuum chambers to 150 °C resulting in an average pressure below 10^{-10} Torr. However, in operation it has been found that the vacuum in the straight sections far from the bending magnets is still exposed to synchrotron radiation from the quadrupole magnets and hence increases due to photon induced gas desorption. The spacial distribution and the intensity of the photons hitting the vacuum chamber depends strongly on the position of the beam in the quadrupoles and has been found to be subject to changes from run to run and even to changes within periods of stable conditions for physics. More detailed studies are necessary to correlate beam orbits and gas desorption, i.e. the pressure, with background conditions in the experiments.

The Second Generation of Vacuum Chambers

A better knowledge of the LEP behaviour, and projects for new so-called micro-vertex detectors have led to the decision to reduce the internal diameter of the tubes to 106 mm.

The very short time available for realising this project has led to the use already known solutions that are reliable enough to be embedded in the complex experimental detectors.

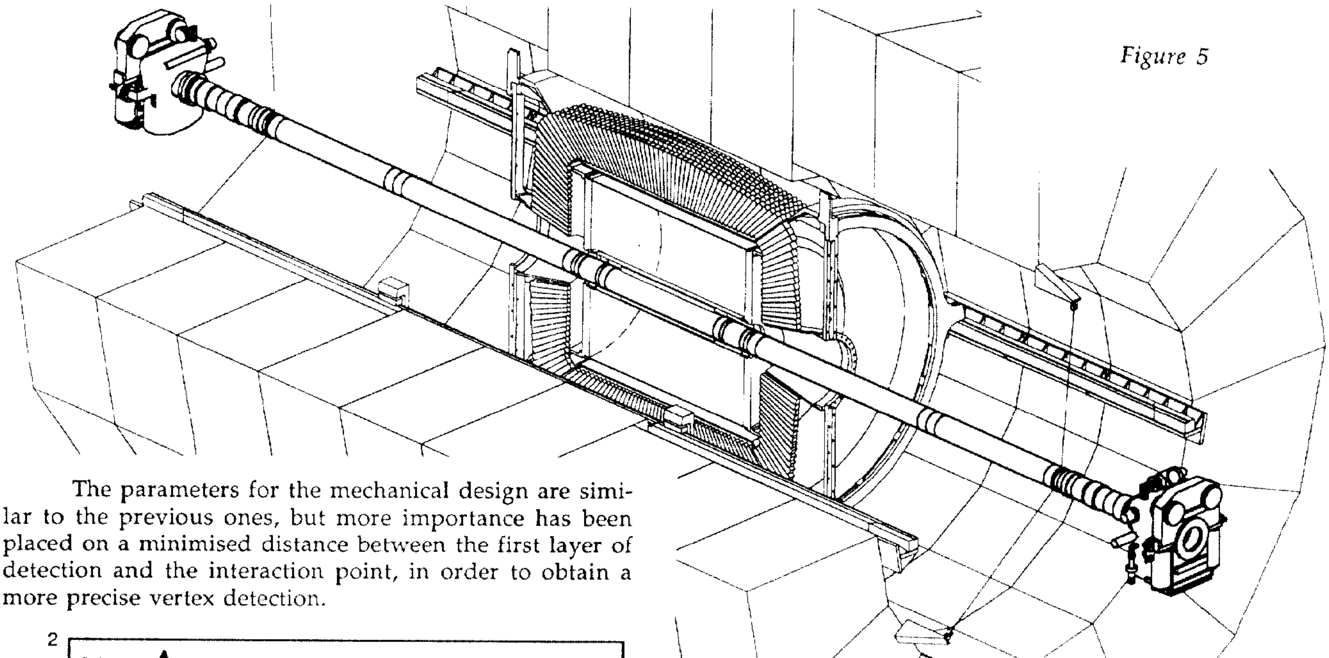

Figure 5

The parameters for the mechanical design are similar to the previous ones, but more importance has been placed on a minimised distance between the first layer of detection and the interaction point, in order to obtain a more precise vertex detection.

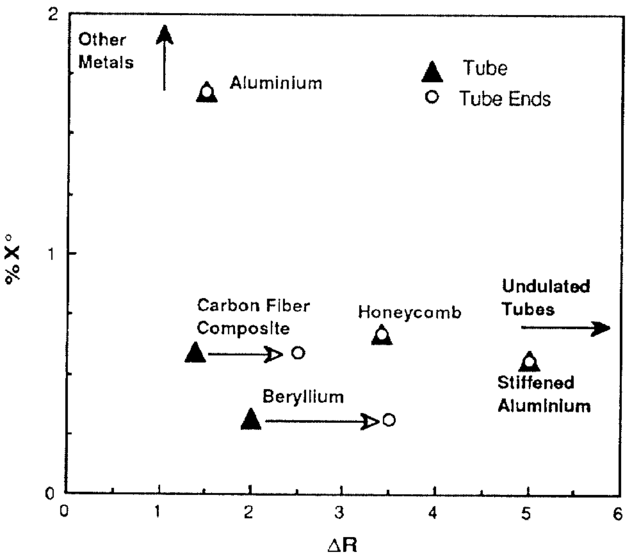

Figure 4

The options proposed to the physicists are summarized in Figure 4. This graph is intended to be used as a guideline. In the case of an internal diameter of 106 mm, the points represent the various possibilities according to the two main parameters:

- the space taken by the vacuum pipe, ΔR, which consequently gives the position of the first detection layer;
- the percentage of radiation length $\%X_0$.

The micro-vertex detectors are very precise, and, in order to obtain an high rigidity, they are made to slide around the vacuum chamber in one single cylindrical piece. In this case, the limiting radial parameter is not the tube itself (triangle) but its ends (circle) which are used to connect the tubes together.

The two best solutions are clearly the beryllium and the carbon fiber composite ones. Beryllium is more transparent than the carbon fiber composite. But on the other hand, the manufacturing process of the former (forming and brazing on a longitudinal splice joint) is less accurate than the winding of fibers on a precise mandril and therefore leads to loss of space.

Consequently, all four experiment teams chose the same type of design: a central beryllium tube whose length (400 to 760 mm) depends upon the micro-vertex detector characteristics, welded to carbon fiber composite tubes. Beryllium tubes are very expensive since the total cost of the beryllium parts is about the double that of the composite ones. The first generation vacuum equipment is re-used after modifications to fit the new dimensions. Figure 5 shows the layout of L3 experiment with its new vacuum chamber.

Since the delicate micro-vertex detectors should be easily removed for access, they are installed after the beam pipes. Therefore, enough space is available to allow an horizontal installation, using as before a cradle to support the pipe.

Acknowledgements

Vacuum chambers for experimental regions are highly technological and fragile products. Reliable finished products have been obtained thanks to many people, in particular J. Haffner, R. Huguenin, R. Lauri, P. Lepeule, C. Margaroli and C. Menot.

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