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DESIGN ASPECTS OF LEP EXPERIMENTAL VACUUM CHAMBERS

O. Gröbner and C. Hauviller
CERN, Geneva, Switzerland

SUMMARY

The design options which have been adopted for the 7m long interaction region vacuum chambers for the LEP experiments are discussed. The mechanical design of the thin and transparent beam pipe relies on the extensive use of sophisticated computer programs combined with model work. The materials chosen are either metallic or high-performance composite materials. They provide a good price to performance ratio and can be optimized for the particular requirements of each LEP experiment. The vacuum aspects of the chambers are described in the context of the boundary conditions imposed by the experiments and by the detector design.

GENERAL DESCRIPTION

Physics experiments will be installed around four interaction regions of the Large Electron-Positron Ring (LEP). The design of the experimental vacuum chambers is strongly determined by the requirements of the surrounding detectors. High transparency, large detection angle and low background are of prime importance. The sensitive experimental apparatus must be shielded from beam induced electro-magnetic signals and kept at constant temperature. The machine requires good vacuum and a beam pipe with low RF losses and good electrical conductivity.

A good compromise between these sometimes conflicting requirements has led to the design shown in figure 1.

The vacuum equipment (figure 2) consists of a gate valve and a pump group designed to fit inside the detectors. Since they are supported by the cryostat of the low-beta quadrupole while the central beam pipe has to be supported by the detector, relative movements of up to ± 5 mm are taken up by a set of low-impedance bellows.

The central part is a cylindrical tube of 156mm diameter. On both sides the vacuum chambers inside the superconducting low-beta quadrupoles have an aperture reduced to 120 mm. Thus, synchrotron radiation photons produced in the upstream sections, primarily in low-beta quadrupoles, cannot reach the central beam pipe. This eliminates direct photon background for the experiment and synchrotron radiation induced gas desorption for the vacuum system.

The beam pipe has a continuous, smooth and electrically conducting inner surface to shield the detector from beam induced electro-magnetic fields and to keep RF losses low. For the same reason, the housing of the pump is fitted with an internal electric shield and the vacuum bellows are made with minimum size convolutions. The transition from the 156 mm central section to the 120 mm aperture in the pump unit is achieved by a tapered section. According to calculations, the power dissipation from parasitic mode losses in the interaction region vacuum chamber will be less than 40 W [1].

VACUUM ASPECTS

Pumping

The cross section of the central beam pipe provides a sufficiently large vacuum conductance to enable the system to be pumped from both ends. A specially designed sputter ion pump together with a Titanium sublimation pump are combined in a compact housing (see fig. 2) which includes also the other ancillary vacuum components like vacuum gauges and a manual valve to the fore vacuum line.

Imposed by the tight space requirements of the experiments, this vacuum equipment has been designed to take up a minimum amount of transverse (max. diameter 560 mm) as well as longitudinal space in the beam direction (320 mm).

The sputter ion pump has been developed for operation in the high magnetic field of the detector solenoid (up to 1 Tesla), but it can equally be operated with its own permanent magnet as a conventional pump whenever the experiment is switched off. The pumping speed achieved is 60 ls^{-1}.

Conditioning

As a consequence of the very limited access and of the design of the central detector, which is mounted either directly on the beam pipe or with only a minimum clearance, in-situ baking of the interaction region vacuum system is impractical.

As an alternative method it is forseen to bake only once the completely assembled system in the laboratory where clean room conditions may be guaranteed and where it can be extensively tested. For all subse-

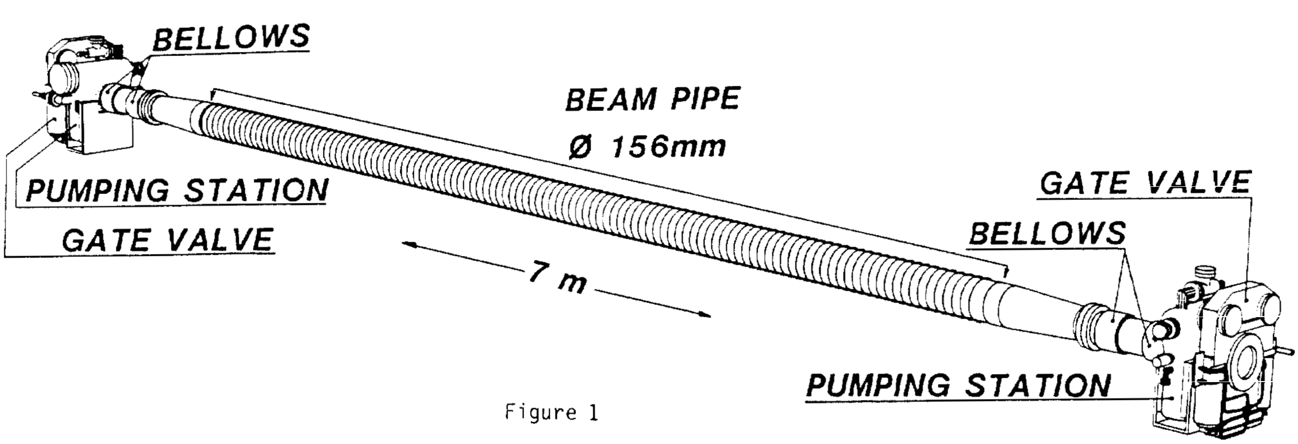

Figure 1

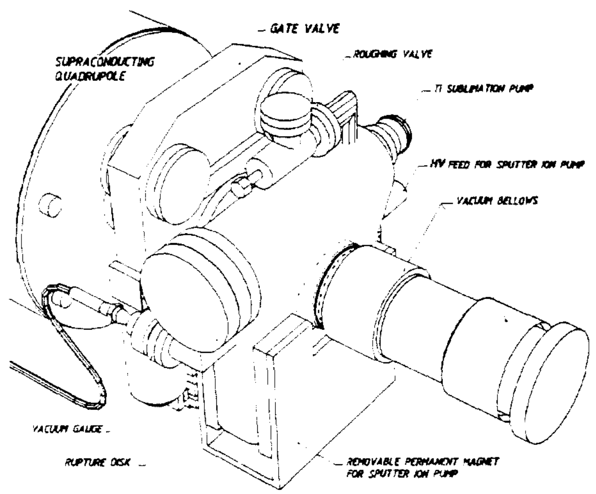

Figure 2

quent operations the vacuum system is maintained under controlled, clean conditions by back-filling with dry nitrogen gas. Figure 3 shows the vacuum performance of an aluminium prototype system which has been pumped down, first unbaked, but subsequently baked as well as back-filled with dry nitrogen. The pressure in the center without in-situ bake is below 10^{-9} Torr. The temperature for the vacuum bake-out has been limited to 150^0C compatible with aluminium and composite materials, but nevertheless adequate for reducing the thermal outgassing rate by a significant amount.

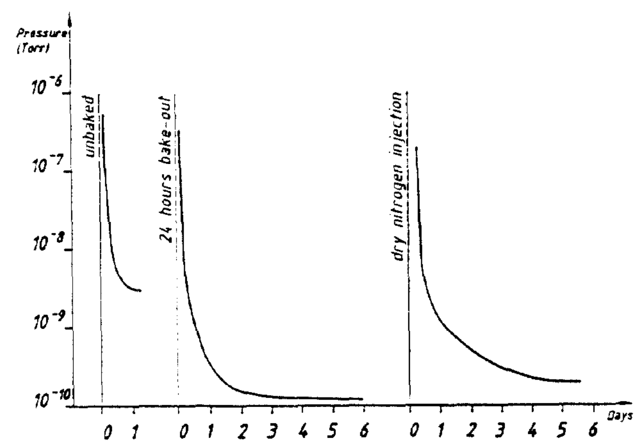

Figure 3

Gate valves

The interaction region vacuum system will be installed at an early stage in the detector, long before the system can be connected to the rest of the LEP vacuum system. To facilitate the installation and the assembly, and to reduce the risk of contaminating the vacuum system during the operation when the central beam pipe is connected to the adjacent sections, full aperture gate valves will be mounted on both ends of the interaction region vacuum system in the laboratory. Once the experiment has been installed in the machine, the valves serve the purpose of isolating the delicate interaction region vacuum from the adjacent sections which have to be exposed to atmospheric pressure and even partially demounted to give access to the central detector.

BEAM PIPE DESIGN

Shapes

Various axisymmetric shapes have been studied but only cylinders retained. Despite the advantage of providing good transparency for forward detectors, cones have been eliminated because of the large quantity of extra material needed to support the 'windows' and of the high RF losses resulting from the changes of section.

Mechanical loading

The chambers are subjected to external - generally 1 bar atmospheric - pressure. However, for one LEP experiment, the beam pipe fulfills the double purpose of the vacuum envelope and as the inner wall of a large detector employing pressures of up to 4 bars. The chambers must also withstand several 24 hour bake-outs at 150^0C during vacuum conditioning.

The failure mode of thin-shell structures under such loading is usually buckling for which a minimum safety factor of 3 must be systematically applied. Design has been based upon external pressure buckling, but coupling may occur with bending due to a discrete supporting structure (thin wires at up to 3 meters distance) and local loads from detectors.

Towards an optimal design

The best materials should combine high transparency and high stiffness. A rationalised approach based on a set of non-dimensional parameters combining radiation length and Young's Modulus allows a selection to be made for simple shapes like cylinders [2].

The second step towards an optimal design has been to find a wall geometry maintaining a smooth inside. Basically, the critical buckling pressure increases with the inertia of the wall. But the choice of a complicated geometry nested inside a detector leads to a large diameter. Therefore a compromise has to be found between transparency and space. Figure 4 presents various possibilities for LEP beam pipe dimensions taking into account technological aspects. It shows a diagram of (minimum value of thickness (t) / radiation length (L_R)) and radial space (ΔR) occupied by the wall.

The optimum point lies on the lower left corner, no loss of space and no material : the experimenter's dream ! Uniform metallic walls are located on the left side of the graph : except for beryllium, all metals represent over 2 % of a radiation length. Composites, e.g. boron-aluminium and carbon-epoxy (CFC), have a performance close to beryllium. On the lower right-hand side, more elaborated wall shapes can be found like the stainless steel (SS) and titanium ondulated chambers manufactured for the ISR [3] and the aluminium ring-stiffened tube developed for LEP. Finally, two technologies may successfully compete with beryllium : carbon fibre composite (CFC) with ring-stiffening and honeycomb sandwich structure.

Design tools

The design of the experimental vacuum chambers relies on the extensive use of computers. Besides computer-aided design (CAD) for all the drawings and installation studies, structural analysis computer programs have helped considerably the optimisation process. Specifically BOSOR 4 allows buckling pressures to be computed with a better precision than manual methods. Good correlation has been found between experimental and calculated buckling values [4].

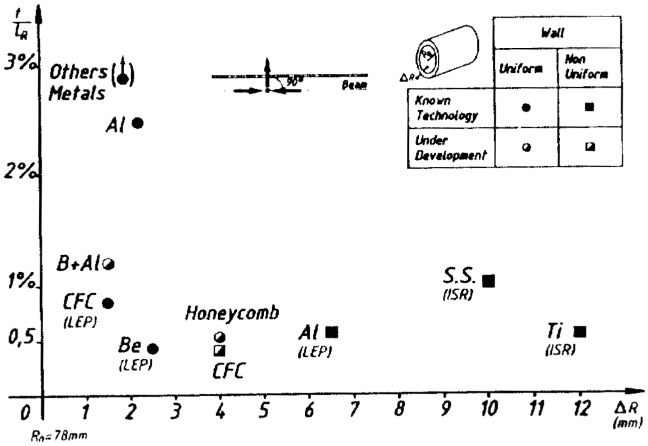

Figure 4

Beam tubes

The first generation of LEP beam pipes consist of assemblies of ring-stiffened aluminium, carbon fiber composite and beryllium tubes according to the experimenter's needs.

Aluminium ring-stiffened tubes

This is the basic solution for LEP. Elements are machined from aluminium alloy (5052X) seamless tubes by inside honing and outside turning (figure 5) down to 0.5 mm wall thickness. Ring spacing and dimensions have been optimised for general (tube failure) and local (inter-ring failure) buckling.

This cost effective solution is satisfactory in all respects : t/L_R is less than 15 % at 40 mrad.

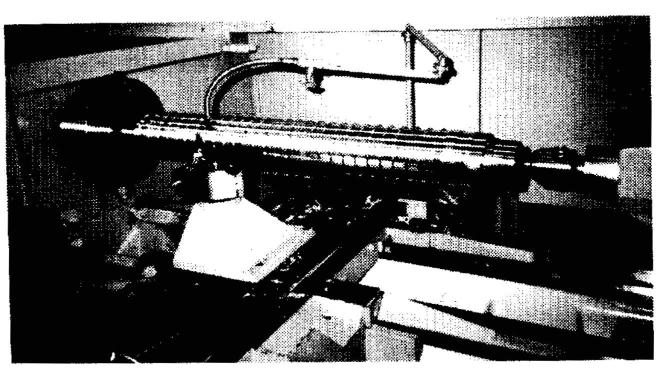

Figure 5

Carbon fiber composite tubes

This technology has been used in other accelerators before [5], but the lack of a perfectly continuous and sufficiently thick metallic inner lining has created shielding problems for the detectors.

The present tubes, specified by CERN and manufactured by industry, have an internal aluminium wall machined down to 0.1 mm. They are TIG welded to give a continuous beam pipe with metallic surface - good for vacuum and shielding. The structural resistance is provided by filament-wound High Modulus carbon fibres impregnated with high temperature epoxy resin. Long term tests have shown the viability of this technology.

Ring-stiffened CFC tubes are now under development (figure 6). Despite the complexity of the stability computations for composite structures, very good correlation has been obtained in over-pressure tests.

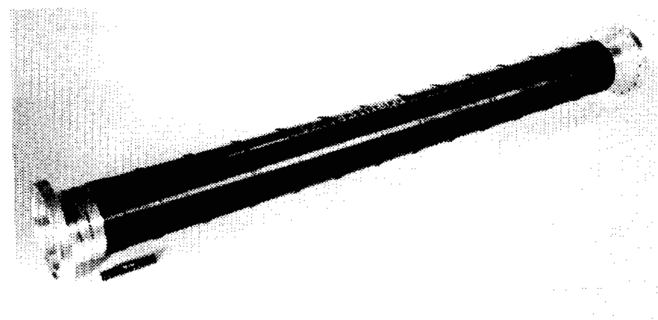

Figure 6

Beryllium tubes

Beryllium tubes, manufactured by the industry, give still the best performances but their very high cost and the safety hazards drastically limit their use.

Sandwich tubes

A tube of this type has been installed previously in an accelerator [6], but such structures still need more development. In order to compete with beryllium, the radial space must be minimized and vacuum bake-out be possible.

Prototypes with thin aluminium alloy skins (0.1 to 0.2 mm) glued to a Nomex® honeycomb core (4 mm thick) have given very encouraging results. Results from long term tests are expected soon.

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