METALLIZED CERAMIC VACUUM CHAMBERS FOR THE LEP INJECTION KICKER MAGNETS

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Abstract

The two LEP injection kicker systems consist each of 3 fast pulsed ferrite magnets, equipped with a 1.3 m long monolithic ceramic vacuum chamber of 200 mm x 49 mm internal aperture. A novel technology has been developed to connect the chamber to the adjacent metallic vacuum pipe of LEP. The circular ceramic flanges of 260 mm diameter are glass-bonded to both end-faces of the ceramic tube and clamped via metallic seals to the stainless steel flanges of the LEP chamber. The assembly can be baked up to a temperature of 200 °C. The inside of the chamber wall is metallized with a 1.7 µm thick layer of titanium, applied with a magnetron sputtering technique.

This paper describes the design and the construction of the chamber, its sealing technique and the development of the magnetron sputtering system.

Introduction

The fast pulsed magnet systems for the injection of e+ and e- bunches into LEP are composed of 2 groups of 3 full aperture ferrite kicker magnets [1]: In proton accelerators which operate at lower bunch intensities the ferrite magnets are usually housed in vacuum tanks. In LEP the electromagnetic field generated by the short high intensity bunches (σ_b < 20 mm, 4.10^{11} ppb) would induce gyromagnetic resonances in the ferrite, provoking excessive heating. The ferrite yokes of the injection kicker magnets are therefore mounted around ceramic vacuum chambers metallized on their inside. The metallization is thin enough to allow penetration of the comparatively low frequency field of the kicker pulse, but sufficiently thick to retain the high frequency wakefields of the lepton bunches.

Performance Requirements

The chamber must have a length of 1.3 m and an internal aperture of 200 mm horizontal and 49 mm vertical. The wide horizontal aperture is necessary to accommodate on one chamber side the injected beam, located about 73 mm from the central orbit. On the opposite side the chamber must be widened by about 43 mm to avoid direct contact with synchrotron radiation. To keep the wall thickness small, a material of high mechanical strength preferably ceramic must be used. As the total LEP vacuum system will be baked at 150 °C, the chamber must also comply with this requirement, imposing in particular limitations on the choice of the metal to ceramic joint.

The metallization must have a minimum resistivity of 0.5 Ω/□ to avoid a too strong attenuation and deformation of the magnetic field . A very homogenous and well adherent layer is required otherwise the high voltage pulse induced by the pulsed magnetic field would cause destructive sparks along the metallized surface.

Choice of Basic Chamber Design

The most suitable material for the chamber is alumina because of its mechanical strength, its excellent UHV properties, its relative high thermal conductivity and its excellent characteristics as substrate for metallization. We have chosen a 97.5 % Al_2O_3 grade which has a high crossbreaking strength of 366 MN/m².

The length of the chamber together with the large ratio between width and height makes it very difficult to use conventional connection techniques for the transition between ceramic and the adjacent metallic vacuum chamber. In the usual manganese molybdenum process the end faces of the ceramic are metallized at about 1500 °C in a H_2 atmosphere. Thereafter thin metal sheet is brazed to the metallization followed by welding those sheets to the metallic vacuum flanges. The Mn-Mo process could not be used here because the necessary high temperature metallizing-brazing furnaces of the required size could not be found in Europe. Moreover, the large ratio of horizontal to vertical aperture would adversely affect the strength of the connection. We have therefore chosen a technique which has been applied at the synchrotron of the Spallation Neutron Source at Rutherford Appleton Laboratory [2]: where circular ceramic flanges are glass-bonded onto the ends of the ceramic tube at 1100 °C. The strength of the bond is >120 MN/m², largely sufficient for our application. The adjacent metallic beam pipe can then be connected by a clamping technique ensuring a reliable ultra-high vacuum assembly after repeated bakeouts at 200 °C.

Manufacture

The chamber cross-section is composed of 2 straight sections of 151 mm width connected by 2 circular half shells of 24.5 mm radius (Fig. 1). The nominal wall thickness is 8 mm. Finite element calculations located the maximum stress of 45 MN/m² in the horizontal mid-plane. This corresponds to a theoretical safety factor of 9. The chamber is isostatically pressed. This method is preferable compared to slipcasting, because of its higher mechanical strength and the less expensive tooling. The pressing tool consists of a stainless steel mandrel and a large, shaped rubber sack. To allow vertical suspension of the chamber in the kiln during firing, the pressed chamber (the green piece) has over a short part of its length a larger cross-section and thicker walls. This suspension piece is cut after firing. The overall length of the green piece is 2.5 m. Fig. 2 shows the tube after firing suspended in the kiln. The lower end touched the ground before firing, thus illustrating clearly the shrinkage.

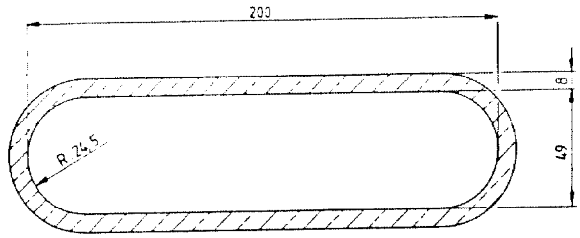

Fig. 1. Chamber cross-section.

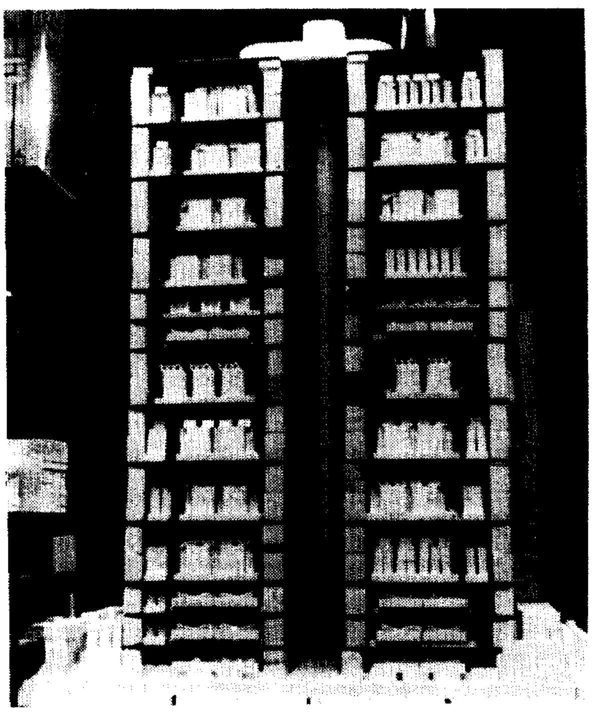

Fig. 2. Tube suspended in the kiln after firing.

The Bakeable Ceramic to Metal Connection

Fig. 3 shows the clamping device providing the vacuum transition between the ceramic flange and the stainless steel bellow of the LEP vacuum chamber. The clamping system consists of 16 segments. A segmented device has been chosen in order to eliminate any bending stresses on the ceramic flange.

The design of a clamped bakeable UHV connection faces 3 main difficulties :

- The alumina flange, even if highly polished cannot be used as sealing surface for metal gaskets at higher temperatures. Extensive vacuum tests of such assemblies gave erratic results. Leakage occurs at the grain boundaries of the ceramic material. Therefore, a thin ringshaped glass layer has been applied to the ceramic flange, providing an excellent sealing surface.

- The large difference in expansion coefficients between alumina and stainless steel results in strong wear and reduction of sealing pressure on the gasket during bakeout, possibly causing leaks. By using a gasket that allows radial as well as axial movement these difficulties can be avoided. Best results have been obtained with a stainless steel wire spiral, overwrapped with a silver sheet, type Helicoflex, manufactured by Cefilac, F-St. Etienne. This gasket has a circular cross-section and can in a rolling movement increase its diameter in radial direction, following the radial expansion movement of the metal flange.

- The axial expansion difference between the thick ceramic flange and the stainless steel clamping screws would reduce the sealing pressure during bakeout considerably. A compensator has been integrated in the design to overcome this difficulty. It consists of a ring made of a material with a high expansion coefficient (aluminium) placed radially outside of the screws. Using the clamping segments as a lever arm and the screws as a pivot the device is designed so as to keep the compression force on the gasket constant during bakeout.

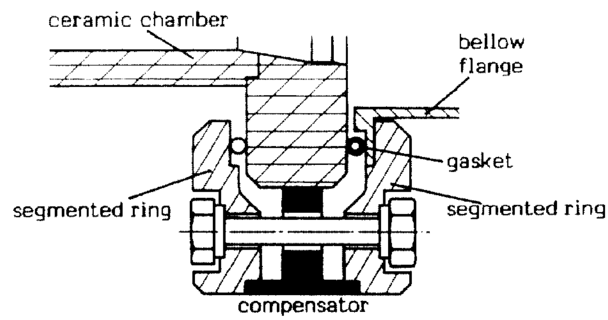

Fig. 3. Clamping device.

Extensive tests have shown that the device can withstand at least 20 heating cycles at 200 °C. Cefilac gaskets of this dimension need a compressing force of at least 2200 N/cm to obtain helium leak tightness. The nominal working point of this assembly is 2900 N/cm. As only part of the force of each screw is transmitted onto the gasket (the other part is taken by the compensator) a total compression force of 380 kN is required. Fig. 4 shows the clamping system.

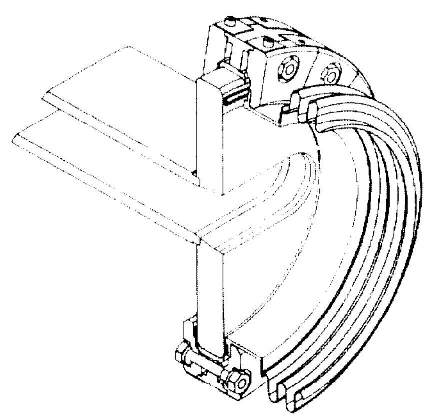

Fig. 4. Clamping system.

Metallization

General

Titanium has been chosen as coating material for it's high resistivity, it's high melting point and it's reactivity, which leads to chemical bonds with the silicate phase of the ceramics, a guarantee for good adhesion. For the electrical end contacts to the adjacent metallic beam tubes a 100 µm thick platinum layer is fired onto the ceramic which is slightly overlapped by the metallization.

A higher resistivity in the curved parts of the chamber is of interest because the image currents of the beam circulate mainly in the centre while most of the eddy current losses due to the pulsed magnetic field are created in the curved region.

The Magnetron

In collaboration with the Battelle Research Centre a technique has been developed to metallize the ceramic vacuum chambers by magnetron sputtering.

Because of the restricted space in the chamber conventional diode sputtering with purely electrostatic ion production would be very inefficient. Only a very slowly growing layer could be produced in this way, bearing the risk of high impurity and poor adherence. Therefore magnetron sputtering is preferred.

The magnetron is shown in fig. 5. The 3 mm thick hollow titanium target embracing the inner profile of the chamber is clamped vacuum tight between two supports. A samarium cobalt permanent magnet is mounted inside the target as near as possible to it's wall. The field at the target surface has been measured to be 0.07 T. Coaxial tubes provide the electrical power supply. The inner pipe conducts the cooling water for the evacuation of the target heat. The target acts as a cathode and is connected to the negative dc voltage via the inner tube. The anode screens are on earth potential and close the electrical circuit via the outer pipes. The curved parts of these anodes are formed in such a way as to limit the titanium deposition in this areas, resulting in a higher resistivity. During sputtering the magnetron is slowly moved through the chamber which is gradually metallized in this way.

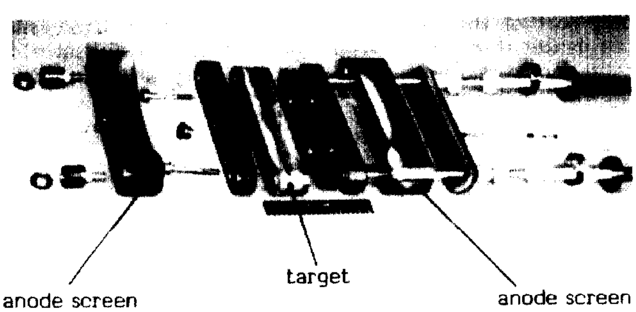

Fig. 5. Magnetron (exploded view).

Vacuum System and Moving Mechanism

The chamber is assembled vertically between two vacuum vessels. The upper vessel is connected to a 250 l/s turbomolecular pump and holds the longitudinal translation feedthroughs which are designed with shaft joints using a differential vacuum. The lower vessel is equipped with a regulated gas inlet valve. The ceramic chamber acts as it's own vessel and is baked by means of a heating jacket to 110 °C during sputtering in order to force the water vapour to the cooler parts of the vacuum system. Fig. 6 gives an overall view of the sputtering installation.

The Sputtering Procedure

Before sputtering the chamber is clean fired in air at about 500 °C to eliminate organic contaminations, followed by micro glass-ball blasting to remove all ceramic dust sticking to the surface to be metallized. The chamber

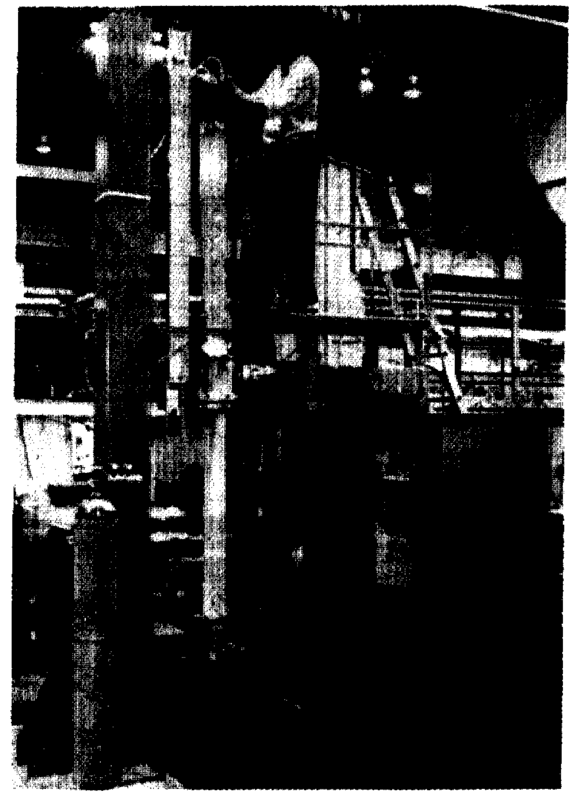

Fig. 6. Sputtering installation.

is then mounted and aligned in the sputtering installation and baked at 110 °C with a programmed temperature increase of 10 °C/h. To verify the absence of any organic contamination a gas analysis is carried out at a pressure of $2 \cdot 10^{-4}$ Pa. Then argon is injected in the lower vessel at a flow rate of 80 cm³/min raising the pressure to $2 \cdot 10^{-1}$ Pa. During sputtering the power supply is stabilized to 1 kW at 400 V. The magnetron is moved against the gas flow with a velocity of 3 mm/min metallizing the chamber in about 6 hours.

Conclusion

A large metallized ceramic vacuum chamber has been manufactured. The clamping system which has been developed, is an economical alternative to the technically difficult brazing technique. Extensive tests have proven its reliability at temperatures of up to 200 °C. Magnetron sputtering has been used to provide a homogenous metallization with excellent adherence to the chamber wall.

Acknowledgments

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We acknowledge furthermore the contribution of P.Faure who assembled and leak tested the clamping device and the magnetron and who carried out the metallization.

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