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INDUSTRIAL FABRICATION OF ULTRA-HIGH VACUUM QUADRUPOLE CHAMBERS FOR LEP

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ABSTRACT

CERN has constructed a Large Electron Positron Storage Ring (LEP) for colliding beam experiments, located in an underground ring tunnel of approximately 27 km circumference. Particle (e^+ & e^-) storage requires an evacuated (UHV) beam pipe. The global design goal for the total pressure was $p < 3 \times 10^{-7}$ Pa, nitrogen equivalent pressure. The quadrupole vacuum chambers are made of aluminium alloy and not equipped with their own pumping system, hence they must have a very low outgassing rate. Most of them are equipped with a block for 4 pick-up electrodes, which must be very accurately positioned (0.05 mm) for beam diagnostics. The welding of aluminium is difficult operation, especially for UHV components with very low outgassing rates. For the present case, which concerns the manufacture of 2635 metres of quadrupole vacuum chambers, the Plasma arc process was chosen. After vacuum commissioning at 150°C, no leak was found in the 742 quadrupole vacuum chambers thus manufactured, and all chambers had a vacuum limit corresponding to a specific outgassing rate lower than 2×10^{-13} Pa m³ s⁻¹ cm⁻².

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1. INTRODUCTION

CERN has completed the construction of a Large Electron Positron Storage Ring (LEP) for colliding beam physics. It is installed in an underground ring tunnel of approximately 27 km straddling the border between Switzerland and France near Geneva. Particles travelling in LEP require an evacuated beam pipe. The global design goal for the total pressure is $p < 3 \times 10^{-7}$ Pa (about 3×10^{-9} torr) nitrogen equivalent pressure [1]. Vacuum in this range is not particularly difficult to obtain but the size of LEP, accessibility and the strong synchrotron radiation [2] are restricting factors.

Reliability was therefore of prime importance and a system as simple as possible was required, which would also help to keep the cost of manufacture by industry at a reasonable level.

2. THE QUADRUPOLE VACUUM CHAMBERS IN THE VACUUM SYSTEM

The vacuum system of this machine [3] consists mainly of dipole and quadrupole chambers made from aluminium alloy. The quadrupole vacuum chambers (VCQ) are installed inside their magnets (Fig 1) which makes further intervention very difficult. This meant finding a highly reliable method of production and control.

Due to lack of space in the magnets, the quadrupole vacuum chambers are not equipped with their own pump, i.e. they are pumped only from the ends. Therefore they must have a very low outgassing rate. It was considered that the most suitable materials for the LEP chambers were aluminium alloys, for reasons of good thermal conductivity and low outgassing under vacuum, as well as ease of extrusion of the tubular components.

Most of the quadrupole beam pipe (90%) consists of extruded aluminium tubes of elliptical cross-section 131 mm wide and 70 mm high in which the beams circulate, and 2 channels for cooling or heating the vacuum chamber. More than half of the VCQs are equipped with a block to house 4 pick-up electrodes which must be very accurately positioned (± 0.05 mm) with respect to the theoretical axis of the chamber (Fig 2).

To cover the 2.6 km (total length of quadrupole chamber), despite a deep concern for standardization, it was necessary to create 22 different types of quadrupole vacuum chamber. The total number of quadrupole chambers installed is 742 of which the lengths vary from 500 mm to 5822 mm and the quantities from 1 to 237.

3. MANUFACTURING PROCEDURE

The main sequence of operations for the manufacture of a VCQ may be summarized as follows: machining of components, geometrical checking, cleaning, welding, final cleaning, vacuum leak testing (subsequently combined with hydraulic pressure testing of the cooling channel), lead shielding, and UHV test at 150°C.

The VCQs have between 2 and 8 weld beads in contact with UHV. While the surface of these weld beads represents only a little less than 0.6% of the surface of the VCQs, this is still a total of 5 m². This is why it was necessary to be careful with the execution of welds, the follow-up of all operations of manufacture, cleaning and checking.

With the aim of avoiding porosities (interconnecting or not) and lack of penetration - the main sources of real and virtual leaks - the choice of welding technique turned to the Plasma procedure for welding the tubes of 6060 alloy to the forged parts in 6082 alloy (flanges and blocks). This "Plasma Key-hole" technique offers the advantages of being relatively insensitive to variations of arc length and of having a self-cleaning effect. With "Plasma Key-hole" the cleaning of the surfaces and the rejection of alumina towards the transition zones allows welds of 5 mm thick to be carried out. The one-pass execution (thus one weld run without restarting) allows a production which should avoid the formation of gas pockets which could prove harmful to the vacuum.

Furthermore, it had been decided from the outset to implement an automatic welding procedure which was justified by the elliptical geometry and by the large number of welds (2642 for the total production).

To guarantee constant quality throughout the entire production, an assembly procedure and a metallurgical examination protocol were drawn up. Checks of samples taken before and after the production of each batch of 50 chambers showed that very or no little porosities were present even when parameters such as the humidity in the assembly area varied [4]. To the specific UHV aspects came the additional constraint (from beam dynamics) that steps of 0.3 mm maximum between two successive components were allowed. This precise alignment was obtained by means of a self-centering device situated inside the tubes (Fig 3). The 30 mm distance between the axis and the tube wall meant that the plasma touched at the central shaft of the device causing geometric deformations of the tooling and thus of the vacuum chambers. A heat shield was therefore required, and several different materials (metallic and non-metallic) were envisaged and some were tested (titanium, tantalum, ceramic, macor^{TM}.....). Only graphite resisted the thermal shocks and was thus adopted. However, surface analysis (by Auger analyser) of weld samples showed an abnormally high carbon content (carbon 90%, chlorine 4%, potassium 4%), not compatible with the requirements of an electron/positron beam machine. By increasing the duration of the cleaning operation by 50 % the weld bead showed 18% of carbon (atomic). This value is considered good for UHV standard [5]. Another problem caused by the Plasma process was the creation of nitrous

vapours due to the high temperature of the Plasma. This generated ozone which then combined with the ambient humidity and could have led to corrosion of the chamber [6]. Argon shielded welding can eliminate this problem, but requires special care because argon is not a desirable gas in an electron machine due to its mass and furthermore it is not pumped by the NEG (Non-evaporable Getter) [7]. However argon is already used in the Plasma arc torch as a gas shield (mixed 75% He and 25% Ar) ; therefore it was decided to shield the welding with a non-turbulent circulation of argon inside the tube. Spectrum analysis and pressures obtained have shown that no argon remained in the chambers.

4. VACUUM PERFORMANCE

Taking into account a pumping speed of 100 l s^{-1} for the ion pump the total outgassing (N_2 equivalent) per chamber 24 hours after stopping the bake-outs about $3 \times 10^{-10} \text{ Pa m}^3 \text{ s}^{-1}$, which corresponds to a specific outgassing rate of $3 \times 10^{-14} \text{ Pa m}^3 \text{ s}^{-1} \text{ cm}^{-2}$ (about $2 \times 10^{-13} \text{ torr l/s}^{-1} \text{ cm}^{-2}$). The total pressure in the chamber was the difference between the global pressure and the pressure in the measuring dome (fig 4). The composition of the residual gas after bake-out shows that hydrogen is still the principal component of outgassing. On Fig. 5 part 1 gives, 24 hours after bake-out, the average of the partial pressures of 295 VCQs without pick-up blocks, and part 2 the values for 447 VCQs with pick-up blocks fitted with their stainless steel pick-up electrodes. Argon, which could have come from the welding process, was not detectable within the limits of sensitivity of the detector ($\text{Ar} = 5 \times 10^{-12} \text{ Pa}$) with a flux of $Q < 5 \times 10^{-10} \text{ Pa l/s}$ [8].

5. CONCLUSIONS

Automatic welding by Plasma key-hole is one method [9] of obtaining good quality welds, but in our case, has the inconveniences of requiring graphite for the tooling and argon as a shielding gas. Examinations and analysis made throughout the manufacture showed no harmful consequences.

At the end of fabrication, and after the bake-out at 150°C none of the 742 vacuum chambers were found to have leaks. The degree of cleanliness and the performances were excellent since the outgassing was $3 \times 10^{-14} \text{ Pa m}^3 \text{ s}^{-1} \text{ cm}^{-2}$, or a factor of 10 lower than the limit imposed in the basic specification. CERN and an industrial firm [10] showed their capability and willingness to co-operate by executing a large number of vacuum chambers conforming to the LEP machine specification.

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REFERENCES

- [1] LEP Design Report, CERN Internal report N° CERN-LEP/84-01, June 1984.
- [2] C. Benvenuti, R. Calder and O. Gröbner, "Vacuum for particle accelerators and storage rings" Vacuum, 37, N° 8/9, 699 (1987).
- [3] LEP Vacuum Group (R. Calder) "LEP Vacuum System: Present Status", presented at this conference, in September 1989.
- [4] J-C. Brunet "The influence of moisture of TIG and Plasma welding in aluminium alloy", 4th International Conference on Aluminium Welding, Tokyo, Japan, 1988.
- [5] A. Grillot, A. Mathewson, private communication.
- [6] J-P. Bacher and N. Hilleret "Corrosion of accelerator vacuum system: risks and prevention" presented at this conference, in September 1989.
- [7] H-P. Reinhard et al., Proceed. IX Int. Vac. Congress, Madrid, 1983.
- [8] J-P. Bojon, private communication.
- [9] Kazuyuki Tsuchiya et Al., "Automatic welding process for thin and small diameter pipes of aluminium alloy", Doc. N° XII-C-059-83, Meeting of International Institute of Welding, IIW Committee XII, 1983.
- [10] Romabau AG, Weinfelden Switzerland.

Fig. 1: LEP machine, general view (CAD) in the LEP tunnel

Fig. 2: P.U. Block with electrodes

Fig. 3: Vacuum tube during the welding operation with the self-centering system

Fig. 4: Vacuum Test Set-up

Fig. 5: Total and partial pressure without (1) and with electrodes (2)