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The ALICE Vacuum System

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Summary

A design for the ALICE vacuum chambers has been proposed which is based on ion pumping and NEG pumping in baked chambers made from Cu for impedance reasons. A more detailed study of the NEG pumped chamber on one side of the experiment is necessary so that it can be inserted in an aperture of Ø100 mm in the absorber. The vacuum is stable for all gases if the system is baked. Bunch induced multipacting may occur, in which case the inside surface of the chambers may have to coated with, for example, TiN to reduce the secondary electron yield.

1. Introduction

ALICE is the proposed heavy ion experiment for the Large Hadron Collider (LHC) and it will be installed at point 2 [1].

The total length of the vacuum chamber is 39.44 m between sector valves. The chamber is divided into three main sections. The first is the central region, covering a distance ± 1 m on each side of the interaction point (IP) and is made of an alloy of beryllium and aluminium to provide a good transparency. The other two sections are located symmetrically on either side of the IP and are made up of circular section beam pipes. Because of impedance requirements these will be made of Cu. On one side of the IP is an absorber which ideally should have an inner aperture of about Ø100 mm thus limiting the diameter of the vacuum chamber. On the other side there are essentially no space restrictions.

2. Vacuum Requirements

In the warm straights on either side of the insertion the residual gas can contribute to the background in the experiment, however shielding by machine components will reduce this. It was estimated that, to produce an acceptably low background in the experiments [2], the pressure in the ALICE experimental chambers has to be about 1.25 10^{-11} Torr H_2 and 1.25 10^{-12} Torr each of CH_4, CO and CO_2. Since the gases commonly found in vacuum systems are H_2, CH_4, H_2O, CO and CO_2, the above conditions mean that the vacuum chambers must be baked to give the low total pressure and to give a residual gas which contains as high a percentage of H_2 as possible compared to the other gases.

Because the central chamber is closely surrounded by the detector, space for pumping close to the chamber is very limited. In addition, since space in the absorber is also limited, the use of ion pumps in that area is excluded.

The LHC requires that each detector must be able to operate independently. Therefore, the Alice vacuum system should be compatible with normal running of the LHC with proton beams up to 7.0TeV and 0.536 A.

3. Vacuum Chambers

The central chamber is made of an Al/Be alloy for good transparency and will be 2.070 m long, flange to flange, with an internal diameter of Ø60 mm. On each side, to minimise the beam coupling impedance [1], the chambers will be made of OFHC Cu with a wall thickness of 2.5 mm. A normal vacuum chamber will made from one copper tube about 8 m or 9 m in length with a stainless steel conflat flange on each end.

To obtain the low pressure in 10^{-11} Torr region and the good gas composition, *in situ* bake out of entire system at 150°C will be necessary (Cu must not be baked above 150°C for mechanical reasons). Bakeout would be by external jackets which can be removed after use. When baked out at 150°C, a 17 m long copper beam pipe expands longitudinally by about 42 mm. To compensate for this and for alignment purposes RF screened bellows will be installed.

The central chamber should be bakeable to 150°C.

4. Pumping System

In order to pump H_2, CH_4, H_2O, CO and CO_2, the pumping system will consist of a combination of sputter ion and Non Evaporable Getter (NEG) pumps. The sputter ion pumps pump all the above gases but are local. The NEG is distributed along the length of the vacuum chamber and provides a very high linear pumping speed, useful in long thin vacuum chambers, and gives a flat pressure profile, but only pumps the active gases H_2, CO and CO_2. The pumping speed required and pumping locations are determined by the required operating pressure and gas composition, the constraints of detector access and the available space.

5. Outgassing Rates

A Ø131 mm, 3.6 m long OFHC Cu test chamber had been used to study synchrotron radiation induced gas desorption on the dedicated beam line at the e^+ storage ring DCI at Orsay, France and had been baked at 150°C [3].

The vacuum installation at Orsay with its calibrated vacuum gauges and known conductance enabled a precise measurement of the thermal outgassing rates of H_2, CH_4, CO and CO_2 from this baked Cu chamber to be made. This, therefore, provided practical values of the outgassing rates from a baked Cu chamber similar to that proposed for ALICE which could then be used for reliable calculation of the ALICE static vacuum.

The pumping speeds for the ion pumps and the NEG and the thermal outgassing rates after 150°C bake used in the calculation for the various gases are given in Table 1. It must be remembered that thermal outgassing rates are a strong function of the chemical cleaning applied to the chamber and, with inefficient cleaning, large thermal outgassing rates can result. After bakeout H_2O is essentially not present in the residual gas.

Table 1

Gas	200 l s^{-1} Ion Pump Speed (l s^{-1})	NEG Pump Speed (l s^{-1} m^{-1})	Thermal Outgassing Rate (Torr l s^{-1} cm^{-2})
H_2	400	250	1 10^{-12}
CH_4	200	0	5 10^{-15}
CO	200	200	1 10^{-14}
CO_2	200	200	5 10^{-15}

6. Pressure Profiles

A preliminary study of a NEG pumped chamber to be inserted in the absorber indicated that such a chamber can only be inserted if the right hand chamber diameter is 60 mm implying an aperture of diameter 126 mm, somewhat larger than the 100 mm specified. Ion pumps with a nominal pumping speed of 200 ls^{-1} were placed close to the sector valves at ± 20 m from the IP. Some ion pumping is necessary in the centre to pump the CH_4 but detector access and lack of space in the absorber limited the choice of position to 3 m from the IP.

Using these measured outgassing rates, pressure profiles were calculated for a variety of chamber diameters and ion pump speeds in order to find the optimum [4], [5]. Since CH_4 is not pumped by the NEG it was this gas which was the most critical and a nominal 200 ls^{-1} ion pump was necessary near the IP to reduce the partial pressure of the CH_4.

The layout of the pumps, their size and the diameters of the vacuum chambers which gave the lowest pressures are shown in Fig. 1 along with the cross sections of the chambers.

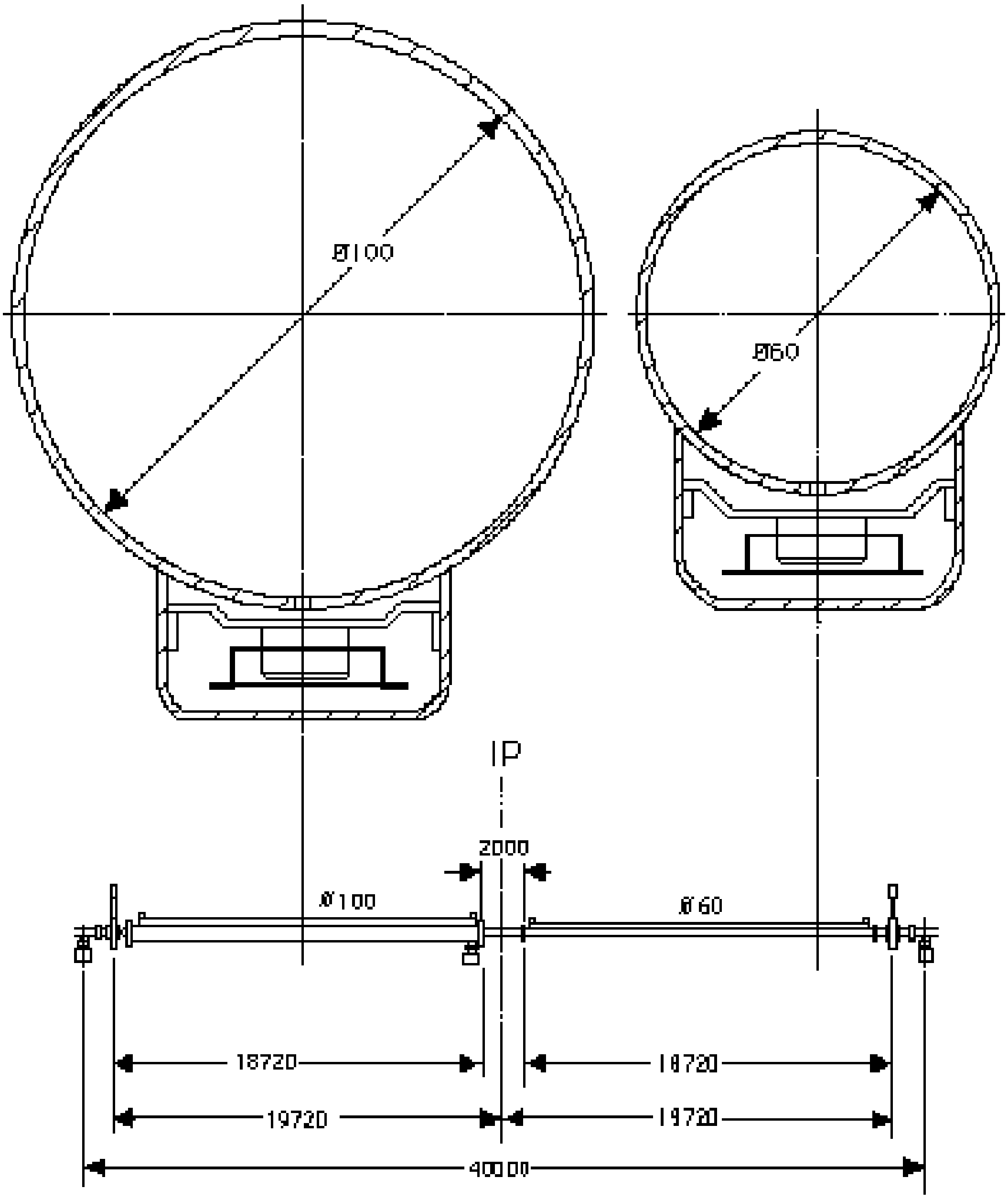

Figure 1. A schematic layout of the optimum design showing the diameters of the chambers and the positions of the pumps.

Fig. 2 shows the optimum pressure profiles for H_2, CH_4, CO and CO_2 obtained with both Cu chambers at Ø100 mm, a 200 ls^{-1} ion pump at ± 20 m from the IP and a 200 ls^{-1} ion pump 3 m from the IP.

The effect of the distributed pumping of the NEG giving a flat pressure profile for H_2, CO and CO_2 is apparent. The localised pumping for CH_4 provided by the three ion pumps results in the parabolic pressure distribution for that gas and the relatively high average pressure. The lack of pumping in the central chamber for H_2, CO and CO_2 is reflected by the bumps in the pressure profile in that area. However to keep things in perspective, it must be remembered that these local pressure bumps have peaks in the middle 10^{-13} Torr range for CO and CO_2 and middle 10^{-11} Torr range for H_2

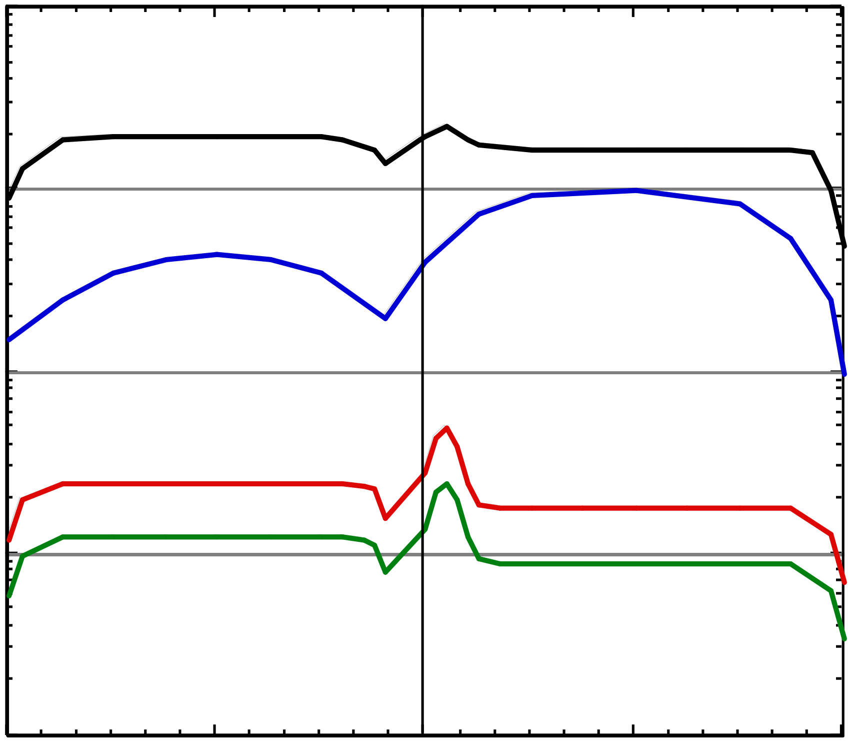

Figure 2. The calculated pressure profiles for H_2, CH_4, CO and CO_2 using the measured baked Cu outgassing rates.

Increasing the ion pump speed does little to decrease the average CH_4 pressure due to the conductance of the chamber. Increasing the conductance of the chamber by increasing the diameter increases the surface area and hence the total outgassing rate and thus the pressure for a given pumping speed.

Table 2

	Warm Straights		**ALICE**	
Gas	**Pressure (Torr)**	**Gas Density (molecules cm-3)**	**Pressure (Torr)**	**Gas Density (molecules cm-3)**
H_2	$1.4\ 10^{-10}$	$4.6\ 10^{6}$	$1.63\ 10^{-11}$	$5.4\ 10^{5}$
CH_4	$2.9\ 10^{-12}$	$9.7\ 10^{4}$	$6.50\ 10^{-12}$	$2.1\ 10^{5}$
CO	$5.3\ 10^{-12}$	$1.7\ 10^{5}$	$2.11\ 10^{-13}$	$7.0\ 10^{3}$
CO_2	$3.3\ 10^{-12}$	$1.0\ 10^{5}$	$1.06\ 10^{-13}$	$3.5\ 10^{3}$

In Table 2 are shown the average partial pressures and gas densities for H_2, CH_4, CO and CO_2 in the ALICE vacuum chamber and, for comparison, in the warm straights between the low β quadrupoles and the outer triplet quadrupoles on each side [6].

7. Dynamic Vacuum

The possibility of the occurrence of ion induced pressure instability [7] and bunch induced multipactoring [8] has been evaluated when heavy ions are stored in the LHC.

The quantity of interest in the ion induced pressure instability is the so-called critical current, ηI_C, which is defined as the product of the ion induced gas desorption yield η (molecules /ion) and the beam current I(A). At beam currents greater than the critical current the vacuum is unstable and large pressure increases are produced.

For bunch induced multipactoring, where a resonant effect with electrons desorbs gas from the walls of the vacuum chamber, it is the threshold beam current above which the effect may occur which is important.

Calculations indicate that both ion induced pressure instabilities and multipactoring in this area will not occur when heavy ions are stored.

When working with 0.536 A of protons at the nominal energy of 7.0 TeV it is calculated that the vacuum in this region is perfectly stable for H_2, CO and CO_2 due to the high linear pumping speed of the NEG.

For CH_4 stability the most critical area is where there is the greatest distance between ion pumps and the diameter of the chamber is least. This is when there is 23 m between pumps and the chambers have a diameter of 60 mm. For this situation the calculated critical current is 0.18 i.e. for stability η times I must be less than 0.18 (for the 17 m distance it is 0.26). Since there are two proton beams in this one vacuum chamber the beam current I=1.07 A (~2x0.536 A). On a baked Cu surface a value of about 0.08 has been measured for the desorption yield η, thus $\eta I=0.086$ which is less than the critical value of 0.18 by about a factor of about 2.

For an unbaked surface η for CH_4 is about 0.25 thus $\eta I=0.27$ which is greater than 0.18 and therefore is unstable. This illustrates the need for bakeout.

Calculations indicate that the beam current threshold for bunch induced multipactoring is 21.8 mA and therefore could be a problem if the secondary electron yield for the Cu surface is sufficiently large.

8. Conclusion

The vacuum system for the ALICE experiment has been designed to meet the various requirements and constraints imposed by impedance, background, space and access.

Using measured values of the thermal outgassing rates for a baked Cu chamber similar to that proposed for ALICE, the optimum pressure profiles were calculated. A combination of 200 ls^{-1} ion pumps and a distributed NEG pump in Ø100 mm and Ø60 mm Cu vacuum chambers baked at 150°C gives average partial pressures for H_2, CH_4, CO and CO_2 of 1.63 10^{-11} Torr, 6.5 10^{-12} Torr, 2.11 10^{-13} Torr and 1.06 10^{-13} Torr respectively.

Due to the relatively small pumping speed for CH_4 provided by the ion pumps, the average pressure of CH_4 is relatively large.

Calculations indicate that with three 200 l s^{-1} ion pumps and Ø60 mm chambers the vacuum is stable for all gases if the system is baked. The critical gas is CH_4 and increasing the vacuum chamber diameter, reducing the distance between pumps and increasing the pumping all increase the pressure stability.

A more detailed study of the Ø60 mm NEG pumped chamber is necessary so that it can be inserted in an aperture of Ø100 mm in the absorber.

Bunch induced multipacting may occur, in which case the inside surface of the chambers may have to coated with, for example, TiN to reduce the secondary electron yield.

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