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EFFECT OF CAPILLARY AS A DYNAMIC IMPEDANCE ELEMENT ON THE DIFFERENTIAL PRESSURE ACROSS RPC DETECTOR IN A CLOSED LOOP GAS SYSTEM

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ABSTRACT

The proposed INO-ICAL detector (INO-Collaboration, 2006) will be instrumented with 28,800 RPCs (Resistive Plate Chamber). These RPCs are of (1.8 x 1.9) m^2 size, consist of two glass electrodes separated by 2 mm and use a gas mixture of R134a ($C_2H_2F_4$), isobutane (iC_4H_{10}) and sulphur hexafluoride (SF_6) in the ratio of 95.3%, 4.5% and 0.2% respectively and are operated in avalanche mode. The INO-ICAL will have set of four RPCs in a road will be connected in parallel for a uniform and equal gas flow in a layer using a suitable gas manifold. This paper highlights the studies done using different capillaries in order to equalize the gas flow in different RPCs, as has been done in large detectors such as ATLAS and CMS (http://iopscience.iop.org/article/ 10.1088/ 1748-0221/8/02/P02014/pdf)

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INTRODUCTION

During the past few years, we have made significant progress in improving the flow and control of gas mixture for the Resistive Plate Chamber (RPC) performance in a closed loop system (CLS). The CLS is designed for 12 glass RPC detectors of size (1.8 x 1.9) m^2 with a gas gap of 2 mm. The RPCs are continuously flushed with a gas mixture of R134a ($C_2H_2F_4$), isobutane (iC_4H_{10}) and sulphur hexafluoride (SF_6) in the ratio of 95.3%, 4.5% and 0.2% respectively, at a steady flow rate of 6 Standard Cubic Centimetre per Minute (SCCM) per RPC to maintain one volume change per day. The design of CLS and effect of ambient pressure variation, optimisation of gas flow rate in a CLS are reported in Refs (Satyanarayana, 2014) and (Bhuyan, 2014). The problem of balancing the flow of gas mixture into the RPCs using a flow resistance viz. capillary is done.

In the following, we describe the design and test carried out with different types of capillaries which were fabricated in an industry.

Design of capillary and testing

A capillary tube is a long, narrow tube of constant diameter and acts as a flow limiter and majoring the chamber impedance so to make the individual flow independent on the chamber impedance. It has applications and widely used gas detectors in large experiments like CMS and ATLAS at CERN. The capillary acts like high impedance source in an electrical system, where the pressure drop is analogous to the voltage and the flow is analogous to current. It follows a linear relationship. Therefore, if we need to supply uniform flow into multiple RPCs from a common source (manifold) which is at high pressure, then a capillary at the input of each RPC would act like a high current source and the flow would be uniform in all RPCs even if the impendences of the RPCs with the connecting tubes is different. A standard flow of 6 SCCM is being used based on the study done in (Bhuyan, 2014), corresponding to about one volume change per day with a safe differential pressure of 2.5 mbar across the input and output. Assuming the input pressure to be 1 bar (which is a requirement of MFC used in the closed loop system), the length of stainless (SS) tube to be 2500 mm, pressure difference required to be say about 2.5 mbar for a flow rate of 6 SCCM and considering the viscosity of the R134a gas (which is the major component), the calculated diameter of the capillary tube using Hagen-Poiseuille Law (as given below), is about 300 microns. The flow is assumed to be laminar, viscous and incompressible.

The flow rate, Q, is given as per the following equation

$$Q = \frac{\pi \times \Delta P \times D^4}{\mu \times 128 \times L}$$

Where D = diameter of tube in meter, L = length of the tube in meter, μ = dynamic viscosity of gas (Pa), ∆P = Pressure Difference (Pa.); Capillary bore is about 300 micron. This capillary is wound on a bobbin for safe handling. To check the designed capillary and also to optimise the parameter of the capillary the following test with various capillaries is carried out.

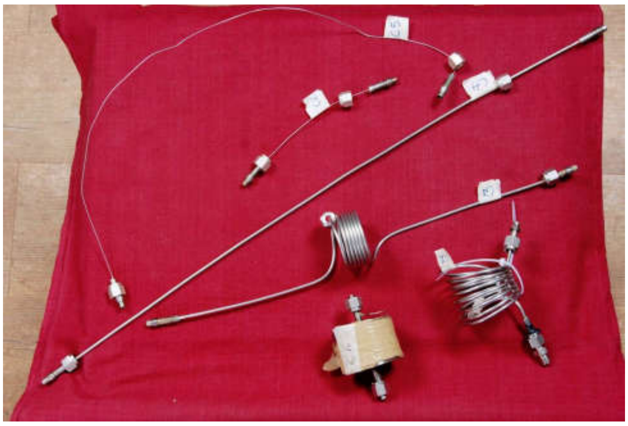

Figure 1. Various Capillaries: C2, C5 and C6: 300 micron (ID); C1, C3, and C4: 1800 micron (ID)

Types of capillaries under test

To study the effect of capillary as a dynamic impedance element on the differential pressure across the RPC detector in a closed loop gas system, two sets of capillaries were fabricated and tested (a) 3 capillaries namely C2, C5 and C6 having inner diameter (ID) of 300 micron and outer diameter (OD) of 1000 micron and having lengths of 150 mm, 600 mm and 2500 mm respectively and (b) 3 capillaries namely C1, C3 and C4 having ID of 1800 micron and OD of 3100 micron and having lengths of 1500mm, 1200mm and 600mm respectively as shown in Figure 1.

Experimental Setup

The experimental block diagram of the setup is as shown in Figure 2 and in the block diagram, under observation test, there is a provision to connect either a capillary or an RPC across a differential pressure.

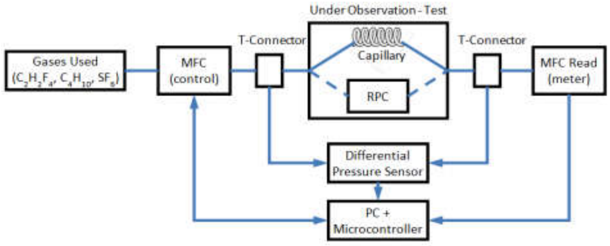

Figure 2. The Experimental Setup

The components in the loop are two Mass Flow Controllers (MFC), differential pressure sensors and a microcontroller (ARDUINO-UNO) board with add on 16 bit ADC (ADC 1115) interfaced via USB to a computer. The studies are performed using 3 gases namely $C_2H_2F_4$ (R 134a), C_4H_{10} (Isobutene) and SF_6 (Sulphur hexafluoride). The data is recorded at a rate of 17 to 20 samples per second in a PC operated in the Linux platform. We had two old MFCs of Tylan made with full scale of 45 SCCM meant for nitrogen gas. The minimum operating pressure is 2 bar abs and one of them is used at the input, to set and control of the flow of gas and is called as the control MFC, while the second MFC function of read only is used and hence we call it as a meter MFC at the output of the capillary. The two MFCs are calibrated using water displacement method for each of the gas and a typical calibration plot for SF_6 gas alone is presented in Figure 3.

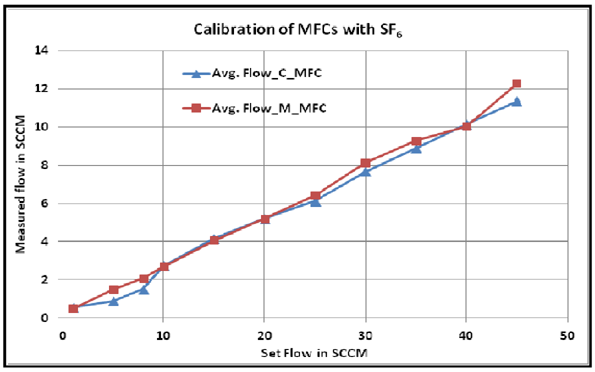

Figure 3. SF6 MFC Calibration

We started the experiment with a pressure sensors namely (a) XLdp, Ashcroft made, which is a diaphragm based, having a differential pressure range of ± 61.3 mbar with a current output of 4mA to 20mA and a resolution of ±0.005 mbar and at the latter stage we used SM5852, Silicon Microstructures Inc. made, a fully amplified, calibrated and temperature compensated sensor having a range of ± 100 mbar, with full scale of 0.5 volts to 4.5 volts (amplified digital output) with a resolution ± 0.1 mbar , are used in the setup. The second pressure sensor had to be used due to the limitation in the range of the first one, as it was getting saturated beyond the range as seen in the plot Figure 4.

RESULTS

The Ashcroft made sensor has an out current of 4 mA to 20 mA and using a multi meter the current is recorded against each flow rate set, and in parallel these current values converted (RCV420) to voltage and calibrated to differential pressure.

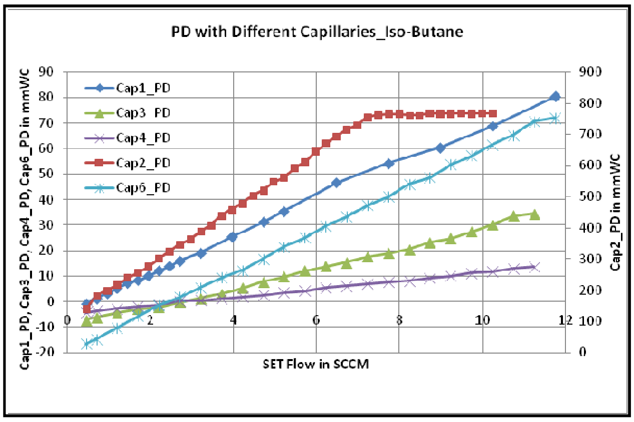

Figure 4. Result with Ashcroft Differential Pressure Sensor

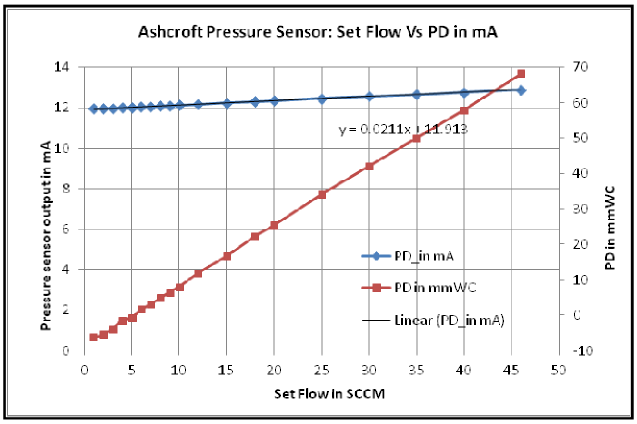

Figure 5. Ashcroft Pressure Sensor: Out 4mA to 20mA

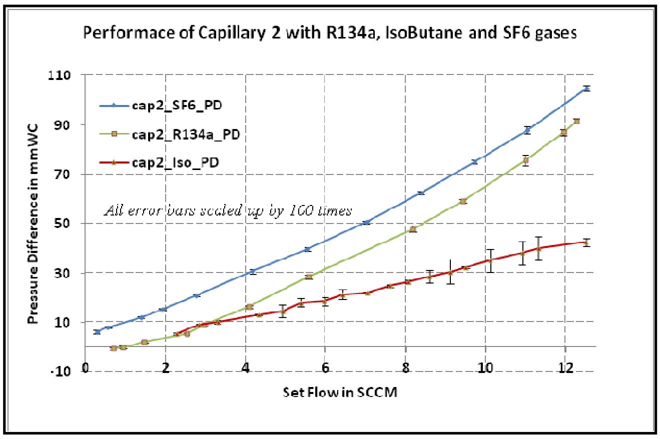

Figure 6. Capillary C2 Results with R134a, Isobutane and SF6 gases

The equivalent current read value to the pressure difference value is also plotted in the same Figure 5.

Flow rate versus pressure difference

In the Figure 6, it is seen that isobutane has the lowest viscosity among the three gases and thus it produces the lowest pressure drop for a given flow rate. The Figure 7 and Figure 8 also show the dependency of the density/viscosity of the gases with capillaries C2, C5 and C6 which are having same diameter (300 micron), but of different lengths. The longest capillary C6, which is wound on a bobbin, shows ideal performance and could be the most suitable one for INO RPCs where the flow rate is about 6 SCCM; it can function well even for the increased flow rate to 25 SCCM.

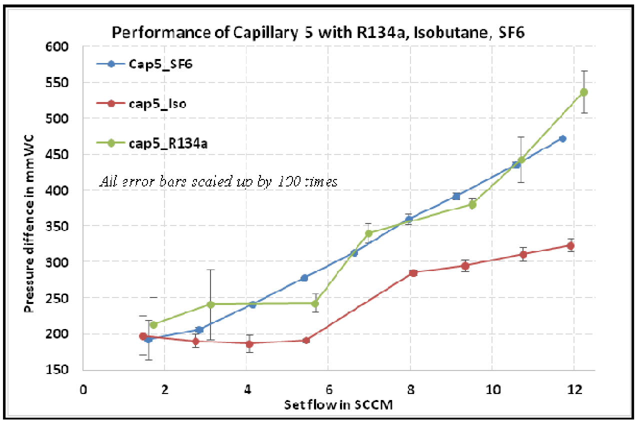

Figure 7. Capillary C5 Results with R134a, Isobutane and SF6 gases

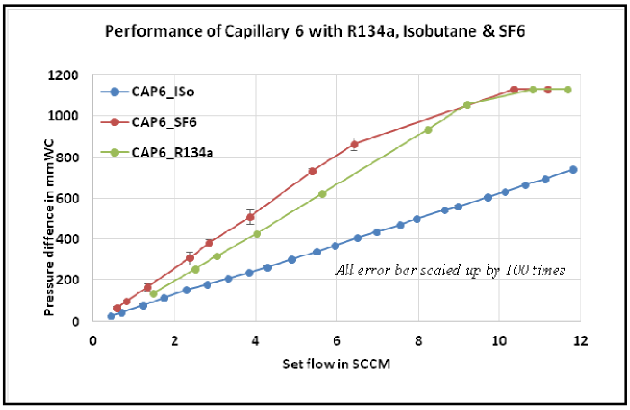

Figure 8. Capillary C6 Results with R134a, Isobutane and SF6 gases

The capillaries C1, C3 and C4 did not show any pressure difference at low flow rates of few tens of SCCM and are not suitable for the glass INO-RPCs in a CLS where in the supply pressure to the capillary is of about 2 bar Abs.

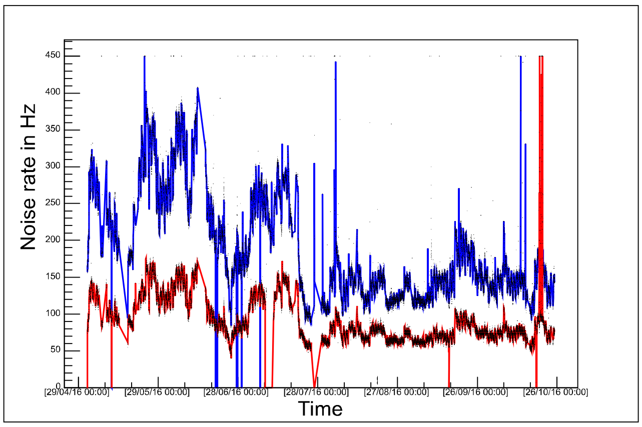

Figure 9. Strip Count (Noise) Rates

RPC pressure difference with various flow rate

To study the pressure drop across the RPC for given flow rate, a RPC of (1 X 1) m^2 in lieu of capillary (as shown in the setup) is connected. An input flow rate of 6 SCCM was applied to the RPC under test and it was observed that, the output flow rate reached the input in few tens of seconds. The pressure drop of about 0.1 mbar across the RPC was observed.

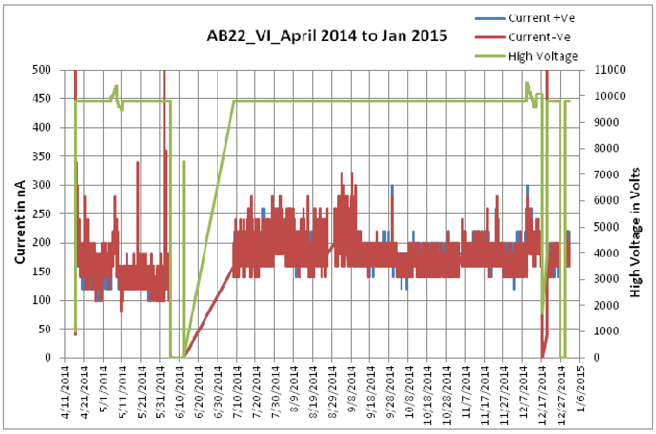

Figure 10. High Voltage current and voltage

The input nozzles have a termination on the side spacer of an RPC with an opening of ((0.7 mm) height X 2.55 mm width X 11 mm length), which would give a resistance to the flow inside the RPC gap. But looks it has marginal effect of the capillary.

Flow balance in a multiple RPCs

It is observed from our studies of the RPC stacks being operated at various locations, with a flow rate of 6 SCCM per RPC, the noise rates for one strip each from X and Y side of the latest data as shown in Figure (9) and the current data for both the electrodes as shown in Figure (10) are almost stable. The flow rate of 6 SCCM per RPC is low as compared to that of Bakelite RPCs at CERN and elsewhere and may cause segregation of SF_6 gas in a closed loop system, whose concentration is very low and hence a longer study may be needed.

Conclusion

The flow resistance depends on type of gas that flows through it. It is very prominently observed that, higher the gas viscosity the higher the pressure difference required. If the plot of flow rate versus pressure difference is linear then the slope is given by $D^4/(nL)$, if it is not a straight line then we have to use the compressible fluid equation and the measurements of input and output has to be on an absolute scale (barometric pressure). With the present setup it could not have been measured. The flow through the capillaries namely C2, C5 and C6 is laminar and hence obeys Poiseuille's principle for fluid and gases. The flow rate of 6 SCCM is in the linear region. In the present CLS, the capillaries C6 and C5 appear to be ideal and could be used inside the RPC tray with a suitable design to accommodate them in an RPC tray and multiple connections to match impedances of the different RPCs. If the above mentioned capillaries are not to be used in CLS (were the input pressure to these capillaries is above 1 bar), then from Figure 4 the best impedances would C1 and C3

Acknowledgment

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