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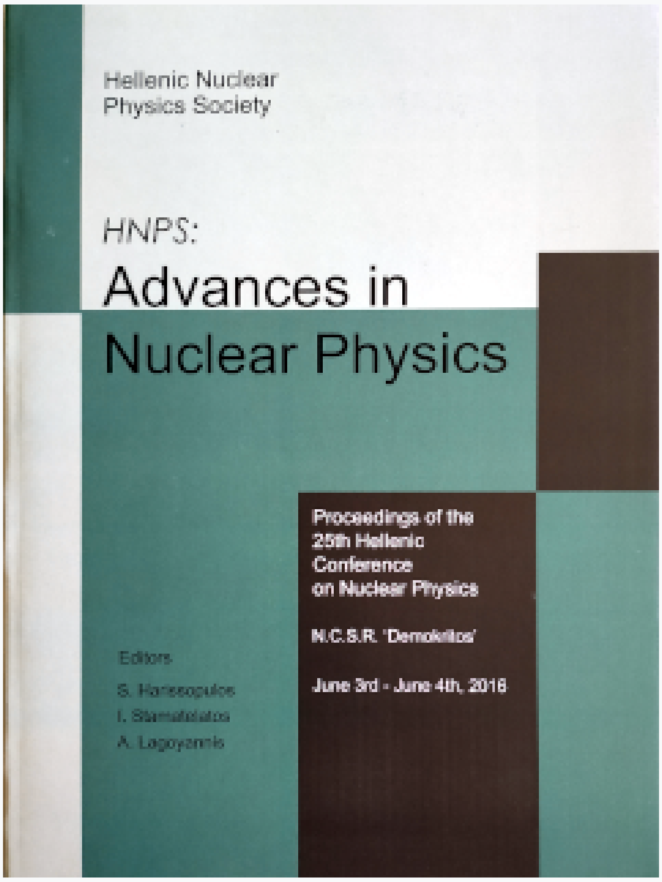

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Gas System for the ATLAS NSW Micromegas Detectors: Design Aspects and Advanced Validation Methods for their QA/QC

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Abstract In this work we present the design aspects of the Gas Distribution System of NSW Micromegas detectors, simulation results and gas flow / pressure uniformity. We also describe the appropriate gas leak test methods, a conventional and an alternative one, being used in the Quality Assurance and Quality Control of the detectors. For the performance studies we used emulated leak branches based on medical needles. We also describe proposed upgrade stages combining the proposed competitive Flow Rate Loss method with the Lock-in Amplifier technique. Further, we describe the baseline setup for the Gas Tightness Station at BB5/CERN.

Keywords ATLAS, Micromegas, NSW, gas system

INTRODUCTION

The Micromegas detector (MM) is one of the two detector technologies for the New Small Wheel (NSW) upgrade phase I of the ATLAS muon spectrometer [1]. By the new detector wheels we aim to provide much better triggering and at the same time a reasonable tracking of the particles in the central region. Each NSW consists of 16 sectors (8 of large type and 8 of small type). Each sector (large or small) includes two Micromegas wedges (one on IP-side and one on HO-side). Each MM wedge consists of two Micromegas detectors, Module 1 (M1) and Module 2 (M2). These detectors are composed of four parallel layers creating a Quadruplet (QP). The gas used is a mixture of Ar + 7% CO_2 and passes through the QPs by using an open gas circuit in a pressure slightly above the atmospheric pressure. During their mass production the MM QPs have to pass quality control and quality assurance via a number of crucial tests. One of these tests is the gas leak test. We also give emphasis to a method based on the flow rate loss and we analyze its benefits, in terms of time and reliability.

UNIFORMITY OF THE GAS FLOW

The main requirement of the gas system has been designed to have 10 renewals of the gas mixture per day, nevertheless, it has been modified to have 4 renewals per day. This leads to a definite gas flow rate for each type of MM detectors. For gas supply, 16 gas channels for each NSW should be used. Each gas channel provides gas input and return to 2 wedges of

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same z-distance, belonging to consecutive, same-type sectors. At the steady state of gas stream, the gas flow rate is determined by the total impedance of the pipe circuit. This in turn, causes major and minor pressure losses along the gas segments. The major pressure losses come from the viscosity of the pipes while the minor ones come from the local resistances of the particular components.

The impedances are components of the gas distribution system which undertake the role of specifying the gas flow rate in each wedge. Assuming the losses are constant, the impedance can determine the desired flow rate. Another use of the impedances is to effectively isolate any leaking region from the neighbouring MM Wedges. The idea for designing such a component comes from the fact that a pressure drop along a pipe segment should be due to kinetic energy or viscous losses or even both.

Let us assume to have a pipe segment consisting of solid cylinder with a capillary channel interposed axially to it, as shown in Fig.1. The pressure drop is calculated at the three separate sub-segments: one with minor losses (sudden contraction), one major loss (in the viscous channel) and one with minor losses again (sudden expansion). The theoretical prediction of the pressure drop caused by these three sub-segments is based on Fluid Mechanics principles obtaining the total pressure drop ΔP by superposition of the three contributions obtaining a quadratic equation for the flow rate Q [2]:

$$\Delta P = (\Delta P)_{tc_1} + (\Delta P)_{cc} + (\Delta P)_{c_2 t} = \frac{8\rho}{\pi^2 D^4} \; k_{LC} + k_{LE} \; Q^2 + \frac{128 L_c \eta}{\pi D^4} Q$$

where, k_{LC} and k_{LE} are the sudden contraction and sudden expansion coefficients respectively. The former coefficient represents the kinetic energy losses due to the sudden decreasing of the diameter. Apart from the turbulence in the two corners a progressive expansion happens again inside the capillary channel. The latter coefficient represents the kinetic energy losses due to sudden enlargement of the pipe diameter. The mechanism mainly concerns the collision of the faster moving gas with the slower one in the larger diameter and can be described analytically by the momentum theorem.

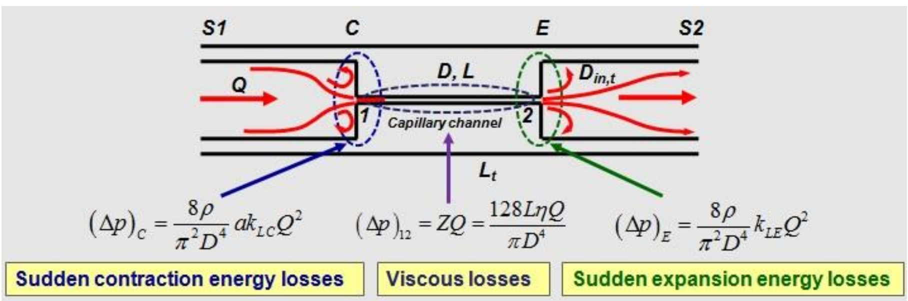

Fig. 1. The shape of a sudden contraction and expansion including a capillary channel.

The impedances we have designed is based on a metallic cylinder with a capillary channel having diameter in the range of 0.5 to 0.8 mm. This cylinder has to be inserted in a plastic pipe of 6 mm external and 4 mm internal diameter. The required pressure drop is deployed basically in three regions: a sudden contraction from the 4 mm pipe to the channel, a viscous capillary channel and a sudden expansion from the channel to again the 4 mm pipe.

The gas distribution to the MM layers in an individual multiplet is not a trivial task. The reason is that the gas volume of two out of four layers are communicated via the interconnected holding screws. As a result the flow rate of the gas has to be shared not equally among three volumes: two in the sides and one in the middle. Because of the double volume of the middle layer, the unequal distribution of the flow has to be as the numbers 0.5, 1.0 and 0.5 with an accepted uncertainty of about ±0.01. Nevertheless, we could use flow control valves to achieve the above distribution we investigated a simple and solution based on passive components like Y-connectors. Another reason to use a simple and compact setup is that the available space among the wedges is limited due to the large number of other components (electronic cables, cooling pipes etc.). In our proposal we use two Y-connectors. This passive, ”pre-balanced” manifold was investigated to share equally the gas to the 4 layers of each wedge.

TWO GAS LEAK TEST METHODS

The Pressure Drop Rate (PDR) Method

The PDR method is a conventional one and mainly demands filling of the vessel and its isolation at time $t = 0$. More details in implementation of this method for the MDTs of Muon Spectrometer are given in [3]. The pressure drop is measured within a specified time interval with respect to a perfectly tight reference chamber. By this technique the variations of the atmospheric pressure can be eliminated. The temperature variations in the chambers has to be reduced at the start and stop stages.

The experimental difficulties in this method primarily are: a) the pressure stabilization at the predefined level by a safety method and the associated procedure, b) the need of thermal stabilization of the measurement area and c) the representative point and the appropriate time for measuring the pressure of the MM QP. Another parameter is the non uniformity of the concentration of the gases inside the QP (air and gas mixture), according to the simulations we have done in other work. Therefore, the equilibrium is not guarantee for a certain time which is yet unknown. Furthermore, the leak rate is a function of the square root of pressure difference inside and outside the MM QP. Therefore, the initial pressure for the leak test has to be adjusted to the desired one, e.g. 3 mbar, for all the testing MM QPs.

The PDR method has to be calibrated because of the strong dependence of pressure on the leak rate. In our application, where the Micromegas modules have fixed volumes, we can use this method determining the leak rate:

$$Q_L = \frac{V_0}{p_0}\frac{dp}{dt} \quad \text{(usually is expressed in bar·L/s or in mbar·L/s)} \quad (1)$$

The Flow Rate Loss (FRL) Method

The leak test using the FRL method [4] can be implemented in two configurations, depending on the cost and time available, during the quality control in the mass production. The first-basic configuration includes: two mass flow sensors (MFS) or other more precise mass flowmeters, one in the input supply line of the MM MP and one in the output line. A by pass pipe (push-in/push-out type could be appropriate) between input and output of the MM MP. The “T” or “Y” connectors allow the flow deviation to a non-leaking part (“tare” term) whose the flow rate has to be subtracted. Four high-tightness on-off switch valves have to be used to isolate alternatively the normal line (branch A) and the bypass line (branch B), as shown in Fig. 2. To speed up the leak test measuring two or more MM QPs at the same time. The idea is to connect a number, let *k*, of QPs in the gas line in series using the appropriate number of MFSs (typically *k*+1). The configuration of such a setup with four MM QPs constitutes the Cumulative FRL (C-FRL) technique.

As an example, but also to study the detection limit of the mass flow sensors, we already purchased for the gas distribution system, we use this type of sensors in the next calculations. A straight line has been fitted to the data given by the manufacturer for argon for obtaining the calibration equation, $V_0 = bQ + a$, where a and b are the two associated parameters which, in principle, could differ slightly. For this reason we use the index 1 and 2. The leak mass rate loss is expressed by the voltage output of the sensors. The corresponding volume flow rate Q is given by the manufacturer referring to the standard conditions (1 bar, 0 ^{o}C) and of course we can covert it for different temperatures.

$$Q_L = \frac{1}{b} \ \Delta V_0^A - \Delta V_0^B \quad (2)$$

It is clear that the leak rate loss is a linear function of the output voltage differences of the MFSs for the branch A and B respectively. The relative error of the Q_L is equal to the one of the slope b which can be considered negligible. The voltage differences can be measured directly (because both are referred to the ground) by a digital voltmeter (with a precision of at least 4.75 digits) or by a bipolar input in a computer equipped by a 16-bit ADC module. In practice, the measurement procedure include a set, indicatively of 10 or more measurements by the MFSs in a flow rate around a selected mean value which preferably has to be as lower as possible (anyway it is much less than the nominal flow rate of the MM MP).

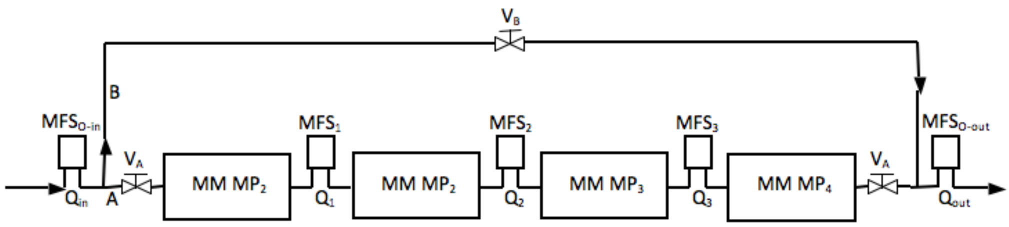

Fig. 2. The configuration of the setup of FRL method measuring four MM MPs in series.

The difference of the first and last MFS concerns the overall leak rate loss while the difference between two successive MFSs concerns the leak rate loss of in between QP. The bypass branch (B) with its isolation valve is used as in the basic configuration.

Both setups are insensitive to the temperature variations because the MFSs themselves are insensitive, therefore a typical Laboratory with elementary controlled temperature could be used. Last but not least, a reference chamber is not required because the principle of operation is based on the mass conservation not affected by the conductance of the branches used.

Therefore, the gas leak test, either by the PDR or the FLR method, in principle, has to be initiated after the complete renewal of the gas (reaching in high enough concentration). However, the FRL method can be used also in the transition stage even if air is still present in the MPs because there is not need to control the pressure. On the contrary, in the PDR method, even it could be also applied in the transition stage, the pressure stabilization has to be done only stopping the gas filling.

BASELINE SETUP AT BB5/CERN

The baseline setup, as is illustrated in Fig. 3, can materialize both methods (PDR and FRL) and is consist of a gas bottle (air or argon), two Flow Controllers, two MFSs, two Digital Manometers, two Reference Tubes, three high-thightness Valves and a Digital Multimeter. The later can be replaced by the Lock-in Amplifier (LIA) setup, described below, according to the first upgrade stage we have proposed.

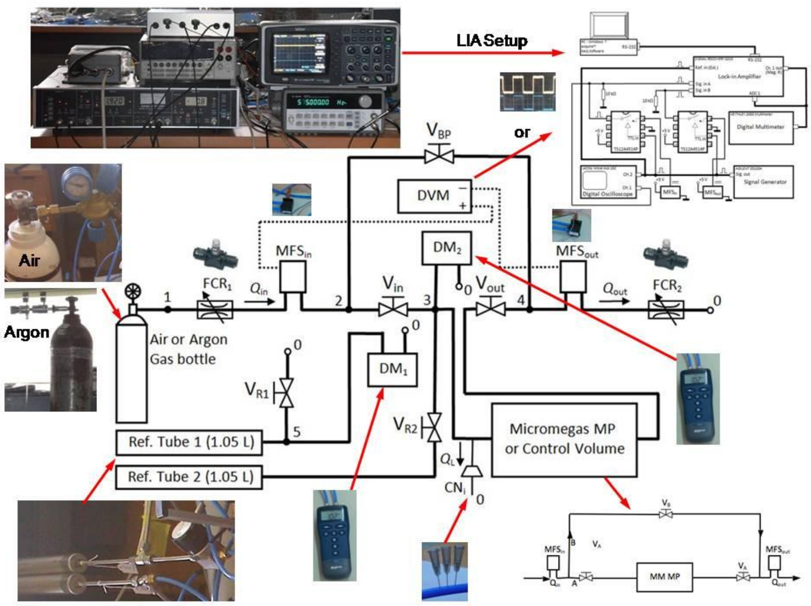

Fig. 3. The baseline and the upgraded setup of the Gas Thightness Station.

The LIA technique [5] is based essentially on the orthogonality property of sinusoidal functions. The resulting mean value of sinusoidal functions of different frequencies, multiplied together over a much longer time than the fundamental period, is zero. Instead, when their frequencies are equal and in phase, the result is the half of the product of the corresponding amplitudes. For a sine-wave reference signal and an input waveform $V_S(t)$, the DC output signal $V_{out}(t)$ may be calculated in an analog Lock-in Amplifier.

The signal $V_S(t)$ may contain superimposed noise components. Furthermore, if the signal $V_S(t)$ is periodic but arbitrary, in its Fourier expansion representation only the fundamental sinusoidal component with frequency equal to the reference can survive in the integration. The produced signal in the PSD output is:

$$V_{PSD,X} = \frac{V_S V_L}{2}\cos(\varphi_S - \varphi_R) - \frac{V_S V_L}{2}\cos(2\omega_R t + \varphi_S + \varphi_R) + V_L n(t)\sin(\omega_L t + \varphi_R) \quad (3)$$

where the first term is constant (DC) and depends only on the cosine of the phase difference (φ_S - φ_R). The second term of the right side contains the frequency $2\omega_R$ while the third term represents the noise $n(t)$ shifted by $\pm\omega_R$. Therefore, the region of the spectrum from 0 to ω_R contains the DC term and the corresponding part of the noise spectrum.

At the BB5 Laboratory area at CERN we have installed the baseline setup of the Gas Tightness Station in April 2016 which should be used for the QA/QC during the mass production of the MM QPs. The setup includes the instruments and components referring to that we call stage-0 setup and can support both methods (PDR and FRL). Additionally, we ppan to test and use the Cumulative FRL technique (testing four MM QPs at the simultaneously). In a subsequent phase we plan to incorporate also the LIA technique.

CONCLUSIONS

The overall configuration of the Gas Distribution System has been finalized and the simulations are more realistic based on the routing solutions. The impedances for 4 renewals/day have been designed and we are investigating the CNC Machinery for their production. Two appropriate methods for the gas leak test have been described and analyzed by means of their sensitivity and feasibility; the classical one (Pressure Decay Rate) and an alternative-novel method (Flow Rate Loss). The Flow Rate Loss method seems adequate and having the required sensitivity to be used for a reliable Pass/Fail decision down to about 10^{-3} st. L/s.

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