Gas mixtures for quality control of the sTGC chambers

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Abstract. sTGC chambers are designed to operate at super–LHC conditions and will be installed in place during Phase-I upgrade of the ATLAS muon spectrometer. These chambers will provide precise coordinate measurements of the charged particle tracks and level 1 trigger for high $p_T$ muons. It is critical for the ATLAS detector to ensure a robust operation of these chambers during entire sLHC period. A quality control procedure based on X-ray scanner is being developed. Choice of the active gas for these tests is a very important issue. On one hand it should allow to find different types of chamber production defects, on the other hand one has to be sure that found problems are essential for the detector operation in future. Studies of the operation of the sTGC chamber prototype under X-ray irradiation with two gas mixtures (n-pentane/CO$_2$ and CO$_2$) were performed. The prototype was irradiated by X-rays with energy up to 50 keV. Particular attention was paid to the study of the “hot” chamber regions.

1. Introduction

The small-strip Thin Gap Chambers (sTGC) were specially designed for conditions of super LHC when luminosity may reach values up to $7 \times 10^{34}$ cm$^{-2}$s$^{-1}$. The ATLAS detector is expected to run about 10 years under these conditions and will accumulate total integral luminosity of 3000 fb$^{-1}$ [1]. The main features of sTGC technology are:

- Very good spatial resolution (around 100 µm).
- Ability to operate at high loads (20 kHz/cm$^2$).
- High resistance to radiation damage.
- Trigger and coordinate measurement capabilities.

In order to ensure long time operation stability in high radiation environment a very strict quality control procedures must be applied. One of them is a direct operation test under high radiation. For this a scanning technique with using X-ray tube is proposed. This technique is based on irradiation of the chamber with a flux of gamma-ray photons with the energy 40-50 keV. The X-ray tube is installed on the moving carriage of the specially designed scanner, which can work in different modes and make irradiation of entire surface of the chambers (2.2x1.4 m$^2$). Irradiation tests of TGC detectors
were performed in the past using \(^{60}\)Co and \(^{90}\)Sr radioactive sources and have shown very high efficiency. These quality control procedures allowed to find operation defects and helped to make a decision whether to cure them using chamber training under HV and irradiation, or to remove defective wires [2]. However these tests were carried out after the chambers were produced and assembled. Tests with X-ray scanner will complement these procedures allowing to find out defects at early stages of the production process. In addition precision scans with different type of collimators can be performed to check technical alignment of the chamber components [3]. In this paper results of studies of different gas mixtures for the X-ray scanning technique are presented.

2. Test set-up.

The tests were carried out at CERN with the first prototypes of sTGC chambers assembled in quadruplet (figure 1). The first chamber had dimensions 1232 mm wide and 723 mm high. The total gas volume of the quadruplet was about 9 litres.

Two types of gas mixtures were used for the tests: \(\text{CO}_2\) – 100\% and n-pentane/\(\text{CO}_2\) – 45\%/55\%. The first one is a safe non-flammable gas, which allows to operate chambers at voltages close to the nominal. The second gas mixture is the one used during sTGC operation at LHC. Amptek X-ray tube [4] was used for the tests. Scans were performed in manual mode with 25 mm steps using the collimator of 30 mm in diameter and 15 cm long head fixed on the tube (figure 1). The X-ray tube was running at 40 kV with a current of 80 \(\mu\)A. For \(\text{CO}_2\) gas mixture the voltage on chamber was set to 2.9 kV and for n-pentane/\(\text{CO}_2\) to 2.8 kV.

The main goal of the tests was to measure gas gain uniformity across the chambers and to study sensitivity of different gases to the sTGC chamber defects.

3. Test results

Figure 2 shows the current in two chambers as a function of applied voltage in logarithmic scale for two gas mixtures. The current is shown in arbitrary units. Because of X-ray attenuation in the first chamber the currents from the second chamber are scaled to overlap the curves. One sees that even at the highest voltages the gas gain is linear for \(\text{CO}_2\) mixture. For n-pentane/\(\text{CO}_2\) mixture gas gain saturation is observed above 2800 V. At this voltage (the nominal operating voltage) the slope of the curves is smaller than for \(\text{CO}_2\) gas. This means that if the chamber operates with this mixture one should expect lower sensitivity to the electric field uniformity across the chamber.
Figure 2. Current (arbitrary units) as a function of applied voltage in two chambers for two gas mixtures.

Map of the currents after the scan of entire chamber operating with CO$_2$ gas is shown in figure 3. This map was obtained using a special visualisation program developed for the X-ray scanner [5]. One sees a presence of some number of the hot spots where current reaches a level of 5-10 µA. During the tests the chambers were mounted in such a way that the strips were oriented in horizontal direction and wires – in vertical directions. A clear wire defect causing higher gas gain is observed in the right part of the chamber. Low current areas in horizontal direction correspond to the wire supports (see description of the sTGC design in [1]). There is also a significant reduction of gas gain at the bottom left corner of the chamber which has still unknown origin.

Figure 3. Currents map for the chamber operating with CO$_2$ gas.

Figure 4 shows similar current map for the first chamber filled with the n-pentane/CO$_2$ mixture. No hot spots except one were found in that case. The discharge in this spot was quickly cured after training under irradiation. This spot is not shown on the map because scan was done after the problem had been fixed. Less contrast but similar behaviour of the gas gain across the chamber was observed.
Figure 4. Currents map for the chamber operating with n-pentane/CO$_2$ gas mixture.

Wire supports, an area with decreased gas gain, as well as defect associated with strips (in black ellipse on the picture) are well visible.

For the second chamber the results are shown in figures 5 and 6. Since the vertical size of this chamber was smaller than that of the first one, no current above Y=620 mm was observed. Similar to the first chamber no hot spots were registered in n-pentane/CO$_2$ gas mixture.

Figure 5. Currents map for the second chamber operating with CO$_2$ gas.
Figure 6. Currents map for the second chamber operating with n-pentane/CO\textsubscript{2} gas mixture.

Many hot spots found in CO\textsubscript{2} gas are related to a surface current on insulators supporting the wires and holding the cathode planes. They are not observed in n-pentane/CO\textsubscript{2} gas mixture because of its excellent quenching properties. Quite a few hot spots in two chambers had a self-sustaining discharge. Figure 7 shows evolution of the current in CO\textsubscript{2} gas mixture during X-ray irradiation of one of the spots with continuous discharge in chamber 2 (coordinates X=900 mm and Y = 25 mm). At the time of about 100 sec the X-ray irradiation was turned on. The current reached the level of about 250 nA and shortly after jumped up to 2500 nA. It did not change significantly during 10 min of irradiation and remained at the level of 1100 nA even after X-ray irradiation had been turned off. A few steps in current after 1400 sec correspond to the moments of lowering down HV on the chamber. The current went down to zero when the voltage had been set to 2700 V.

Figure 7. Time evolution of the current in the chamber filled with CO\textsubscript{2} during X-ray irradiation of one of the spots with continuous discharge.
Most likely the reason for this behavior is the Malter effect [6] happening in CO₂ gas mixture. This effect takes place when a thin layer of insulator covers the cathode. Positive ions are accumulated on the surface of this insulator and create a strong electric field being able to provoke electron emission. No discharges were observed in these points in the n-pentane/CO₂ mixture. Absence of the Malter effect in this mixture might be explained by a modification of a surface conductivity by n-pentane gas.

The uniformity of the gas gain measured with two gas mixtures is compared in figure 8. Plots in the left show the current profile measured with CO₂ gas in slices of 25 mm wide along X and Y directions for the crossing point with coordinates X=1000 and Y=175 in the first chamber. Right side plots show similar results for n-pentane/CO₂ mixture. For this mixture the gas gain variation is at least by factor of two less. Significant difference in the gas gain variation at smaller Y coordinate for the tests with CO₂ gas most likely indicate a presence of a mechanical deformation of the chamber.

![Image](image_url)

**Figure 8.** The current profiles along X and Y directions for CO₂ (a) and n-pentane/CO₂ (b) gas mixtures at the point with coordinates X=1000 and Y=175 in the first chamber.

4. Conclusion
The tests of sTGC chambers irradiated with X-ray source carried out with different gas mixtures demonstrated that the chamber defects are more pronounced when the chamber is filled with CO₂ gas. Quite a few hot spots can be associated with wire or cathode supports. Self-sustaining discharges were found in many places indicating some problem with the cathode surface of the chambers. However, the chambers filled with n-pentane/CO₂ gas mixture showed much higher operation stability and lower sensitivity to the electric field non-uniformity. No areas with self-sustaining discharge or hot spots except one were found for this mixture. This particular spot was cured after a few minutes of radiation at different voltages.

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