Development of scanning technique for sTGC detectors production quality control

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Abstract. The innermost station of the ATLAS muon end-cap system will be replaced during the forthcoming Phase-I upgrade of the ATLAS detector. The small-strip Thin Gap Chambers (sTGC) are supposed to operate at harsh radiation conditions of super LHC. X-ray scanning technique for production quality control is proposed to ensure long-term reliability of these chambers. It allows to reveal different types of technological defects critical for sTGC chambers operation.

1. Introduction

The Large Hadron Collider (LHC) was designed to operate with two proton beams of 7 TeV energy in each direction with maximum luminosity of $10^{34}$ cm$^{-2}$s$^{-1}$. However in order to increase statistics of rare events, an upgrade of the LHC machine (super-LHC) is foreseen. Average luminosity of LHC will reach a level of $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$ after upgrade. In order to operate in these conditions, all LHC experiments develop now corresponding upgrade programs. One of them is the upgrade of the ATLAS muon spectrometer. In the first phase of the ATLAS upgrade (2018-2019) a new muon end-cap system New Small Wheel (NSW) will be installed [1, 2]. It is based on two technologies: small-strip Thin Gap chambers (sTGC) and Micromegas chambers. The sTGC is mainly devoted to the Level-1 trigger function and also provides track measurement with a precision of about 100 μm for each chamber plane. The trigger detectors should provide bunch-crossing identification, which requires good time resolution and track angle measurements with an accuracy better than 1 mrad [1].

A general concept of the sTGC chamber is based on the technology of Multi-Wire Proportional Chambers, which was developed in 1983 [3]. The sTGC chamber consists of a layer anode wires of 50 μm made from gold plated tungsten spaced by 1.8 mm, which is sandwiched between two cathode graphite-sprayed G10 planes at a distance of 1.4 mm from the wire plane. Behind the graphite there are precision strips on one side (which run perpendicular to the wires) and large pads on the other side [2]. Chambers are filled with the n-pentane+CO$_2$ (45/55%) gas mixture and operate with a voltage of 2.9 kV applied to the anode wires.

sTGC detectors will work in a harsh radiation environment and will be practically inaccessible during run periods. This implies a requirement of very strict quality control procedures during chamber production. One of the most important tests, which insures robust operation under large ionizing particle fluxes, is the one with different types of radioactive sources. It is very important to
carry out these tests at early stages of production in order to be able to introduce corrections in the production process and to eliminate any technological defects before the chambers are fully assembled. Various technological defects, such as missing wires, wires lost tension, cathode strip and gap thickness defects, dust particles inside the gap and on the wires, gluing defects, etc. result in gas gain non-uniformity and may cause discharges or wrong interpretation of the measurement results.

Very often techniques used for multi-wire chamber qualification under irradiation require front-end electronics to be installed on a chamber and radioactive source [1, 4]. In this paper the technique based on the X-ray scanner with direct measurement of the chamber current is described.

2. Experimental set-up and test results

The X-ray scanner is an X-Y CNC machine designed to scan the entire sTGC area with X-ray tube and to measure the current from anode wires shown in figure 1.

![Figure 1. X-ray scanner prototype.](image)

Few different types of scans are foreseen for the sTGC quality control. One of them is a search for hot spots and global gas gain uniformity measurement. These types of tests are performed with a wide X-ray beam of 3-30 cm in diameter depending on the goal. Another type of the scans are precision scans with the beam of about 1 mm and less, which allow to localize and study in details observed defects without equipment of the detector with a complex readout system.

The X-Y scan machine can operate in both directions in a continuous movement mode with a speed, which can be set in the range of 0.5 -100 mm/s or in step mode with steps 0.5 mm or larger. The scan area is 2220x1410 mm and covers the maximum sTGC chamber size. The positioning accuracy is less than 1 mm at the maximal distance and it is much below 1 mm at smaller distances. The scanner is equipped with X-ray tube Amptek MINI-X with working parameters 40-50 kV and 75-80 μA. Tests were performed with different sTGC prototypes. CAEN NI471H high voltage power supply was used for the test. It allows to measure the current with a precision up to 50 pA. Both n-pentane+CO₂ (45+55%) and CO₂ were used as working mixtures. A special graphical user interface and visualization tool described in [5] was used to perform the scans and to analyze the results.

2.1. Current stabilization during irradiation

One of the critical parameters, which has an impact on the scanning technique, is the time needed to obtain correct current measurements after turning on X-ray irradiation or changing irradiation area position. Figure 2 shows the current response of the sTGC filled with CO₂ after irradiation start. One sees that the current stabilizes after 0.3 seconds after turning the X-ray tube on. This time includes X-
ray tube reaction and all transition processes inside the chamber. This time can be considered as a limit, which should be taken into account when programming scanner operation modes.

**Figure 2.** The current response of the sTGC prototypes on irradiation with X-ray tube when it was turned on and off. The chamber was filled with CO$_2$ gas. Lines connecting points are guide to the eyes only.

2.2. *Scans of defective areas*

For the identification of the defective areas a whole area of the sTGC quadruplet was scanned with X-ray beam of 3 cm in diameter with step of 2.5 cm. The scanning results are presented in these proceedings [6]. Quite many defective areas were found. Detailed analysis of these areas requires more precise scan with a thin beam. For this purpose, a collimator with a slit of 1 mm was used. This collimator reduces the chamber current, however, it is enough to obtain the results with good accuracy.

**Figure 3.** Current profile of a defective vertical area in the sTGC chamber. Lines connecting points are guide to the eyes only. Inset: current map of the first chamber with marked defective region.
In figure 3 the results of the detailed scan of the defective area corresponding to one of the anode wires in the first chamber of sTGC quadruplet are shown. X-ray tube operated with the following parameters: 40 keV and 75 μA. In the figure insert the current map of the chamber is shown. Wire on tested chambers are oriented in vertical direction and strips – in horizontal direction. The vertical red area corresponds to the wire defect. For detailed studies, 1 mm wide X-ray beam was moved across the wire with a step of 1 mm. The current profile corresponding to a read area on the map is presented in figure 3 as main plot. One sees that significant current modulation corresponds to the position when X-ray beam covers the wires. These modulations tell that a significant part of the gas ionization comes from interaction of X-rays with the wires. Since the distance between the wires is 1.8 mm and the beam width and the step is 1 mm, some beating of the current modulations is observed. It is clearly seen that one wire has a gas gain by a factor of 1.5 larger than the adjacent ones, which tells about its displacement from the anode plane.

Another type of the anode defect was found in the second chamber of the sTGC quadruplet. A “cold” vertical area shown in the insert of figure 4 corresponds to the case of low gas gain. This area was scanned with the thin X-ray beam and the results are shown on the main plot in this figure. The current value close to the dark current was observed in the area between 8 and 10 mm. This area corresponds to missing wires or most likely to the absence of HV on a group of wires.

![Figure 4](image)

**Figure 4.** Detailed scan of the defective vertical area in the second chamber of sTGC quadruplet. The current drop between x=8 mm and x=18 mm reflects the fact of either absence of HV on the group of wires or missing wires. Lines connecting points are guide to the eyes only. Insert: current map of the second chamber with marked defective region.

Horizontal rows on the current maps reflect orientation of the cathode strips. In the insert in figure 5 the “cold” horizontal area manifests a strip problem. A scan of this area across the strips was performed with 2 mm X-ray beam and with a step of 2 mm. The distance between strips is small with respect to the size of the beam and one should not expect significant current modulation. Reduction of the gas gain in area between 5 and 10 mm manifests some issue related to the cathode strips. As the coordinate of a particle is calculated by weighting the signals from several strips, this defect will lead to a significant degradation of the coordinate accuracy in this region.

2.3. Precise scan mode

All the experiments described above were carried out in a step-scanning mode. A continuous scanning mode can give more precise information about defect locations and a mechanical layout of chamber components.
The HV power supply (CAEN N1471H) used in the tests allows to perform current measurements with a frequency of 1 Hz or less. This actually defines the maximum speed of X-ray beam movement. The movement should not be faster than a half of the collimator width times 1 Hz. Detailed step mode is very time-consuming and from that point of view continuous operation is much more preferable. To compare the continuous measurement method with the step mode, a scan with 1 mm collimator along the wire was performed. This type of scan allows to obtain information concerning the strip structure of the chamber. The chamber with two different strip sizes of 3 and 4 mm was used. The results are presented in figure 6. Contrary to the anode wire effect, the X-ray interactions with Cu-strips reduce X-ray flux and hence the total ionization of the working gas [7]. The peaks in the plot correspond to the place between the strips where Cu is absent and deeps to centers of Cu-strips. One sees that position and amplitude of continuous and step modes of the scan are in good agreement.

The plot was compared with exact strip layout. Change of the cathode strip structure is clearly seen in the figure.

Figure 6. Comparison of current profiles obtained with a continuous and a step scan modes. Continuous mode parameters: collimator 1 mm; scan speed 0.5 mm/sec; 1 measurement/s. Step mode parameters: collimator 1 mm; scan step 0.4 mm; measurement time 5 sec. Lines connecting points are guide to the eyes only.
3. Conclusion
X-ray scanning technique offers a possibility to measure gas gain uniformity and to find hot spots in sTGC chambers. It also allows to perform detailed studies of found defects and to obtain information related to strips and wires, which are not accessible after chamber assembly. Further development of the technique will be important to finalize the sTGC quality control procedure.

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