ATLAS Note

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BIS small-Diameter Drift Tube Quality Assurance for the ATLAS Muon Spectrometer Phase II-Upgrade

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This note documents the means of quality assurance and quality control of the small-Diameter Drift Tubes for the Phase-II upgrade of the ATLAS muon spectrometer in the BIS sectors.

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1 Introduction

For the Phase-II upgrade of the ATLAS detector, 96 new precision muon tracking chambers are needed for the barrel inner small (BIS) sectors covering the longitudinal sectors 1 to 6 [1]. In total, these chambers will consist of 46 080 drift tubes of 1615 mm length and 15 mm diameter. Given the preceding BME, BMG and BIS7/8 chambers, there is ample experience regarding the construction, quality assurance and operation of these drift tubes within the ATLAS collaboration [2]. In the following, the means of quality assurance taken during the drift tube construction are described.

2 Drift tube assembly

The drift tubes consist of injection-molded endplugs on both ends which allow to precisely position the 50 µm diameter tungsten-rhenium sense wires with respect to the external reference surface on the central brass insert by means of a spiral wire locator 1. The drift tube walls are made of aluminium with a thickness of 0.4 mm. They are chromatised in order to ensure reliable electrical ground contacts.

Before the drift tube assembly, all endplugs are cleaned in a three-step procedure. In each step, the endplugs are exposed to ultrasound in a bath with a temperature of 50 °C. In the first step, the soapy water Tickopur R30 is used for 15 minutes. In the second step, water is used for another 15 minutes. In the last step, flushing water is used for 3 minutes.

All drift tubes are assembled in a clean room with a constant temperature of 23 °C and a relative humidity of 50 %. First, one endplug is crimped to the tube wall and a semi-automated wiring station is used to insert the sense wire into the drift tube and endplug by means of clean, in particular oil-free air flow. Then the wire is fastened to the endplug using a copper tubelet. The second endplug is crimped to the tube wall as well, yet without fixing the wire in it. Sense wires are only touched using clean gloves. The wires are tensioned first to 400 g. After 10 seconds, this tension is removed and the wire is re-tensioned to 350 g. This tension is fixed using another copper tubelet on the second endplug. A bar code is attached to each drift tube wall and a MySQL database is used to registrate the tube and keep track of the tube test result and the assignment of tubes to chambers.

All drift tubes are tested as described in the following section. Subsequently they are stored in boxes in which they are separated from each other by foam material with a dedicated profile. Protection caps are mounted on each end plug for the storage period. The boxes remain in the clean room until the drift tubes are used for the chamber construction.

3 Tests of the drift tube quality

For every drift tube the sense-wire tension, the gas tightness and the dark current under high voltage are tested. In order to keep track of the test results, they are stored in an online MySQL database so they can be checked in real time. To assign each drift tube to its identification number in the database easily, a barcode scanner is used. For every drift tube, every test result must be positive. Otherwise the drift tube cannot be used to construct a chamber.

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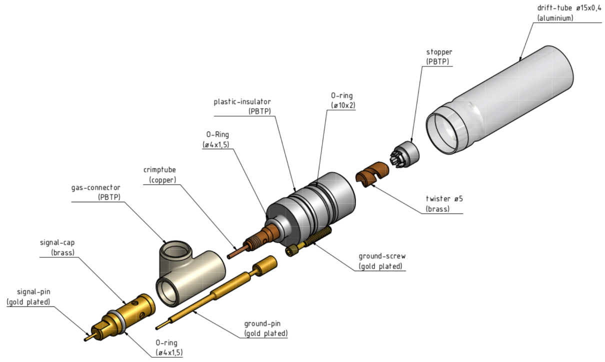

Figure 1: Composition of sMDT drift tube endplugs. The spiral wire locator (twister) precisely positions the sense wire with respect to the external reference surface. The injection-molded gas connector and the gold-plated electrical connections, namely the signal pin and the ground pin connection to the tube walls, are also shown.

3.1 Wire tension measurement

The wire tension is checked by applying a magnetic field to the wire, and passing an alternating current across the wire, which vibrates it. By noting the vibrational amplitude of the wire, the fundamental frequency of the wire can be found, which is directly related to the tension of the wire:

$$T = \frac{\pi L^2 d^2 f^2 \rho}{g} \tag{1}$$

where T is the tension, f is the frequency, d is the diameter of the wire, L is the length of the wire, and ρ is the density of the wire. Tab. 1 show the values used in the calculation. Furthermore, this measurement can be done without breaking the airtight seal on the tube endplugs and can be repeated multiple times. Multiple measurements are necessary as the wire relaxes in the tube over time, which leads to a decrease in the tension. On average, the tension decreases by approximately 5–10 g within the first few days (see Fig. 3) before stabilizing. The tubes are therefore checked for tension at least one week after the initial tensioning process to ensure that the wire tension remains within the specified range. The final wire tension is required to be between 335 g and 370 g.

Constant	Value
L [mm]	1597
d [mm]	5×10^{-2}
ρ [g·cm^{-3}]	19.3
g [m/s^2]	9.81

Table 1: Wire parameters used in the calculation of the wire frequency using Eq. 1. Here L denotes the effective length of the sense wires within the drift tubes, contrary to the total tube wall length of 1615 mm.

After a second measurement is done (at least one week after the first test), the tension loss is recorded. Tubes which have a tension loss of more than 18 g are rejected. The second tension measurement is required to be at least one week after the first test as after one week as the tension stabilizes after approximately seven days have passed. This was seen in the previous construction of sMDT tubes for the BMG chambers.

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Figure 2 shows the measured tension the second measurement. Figure 3 shows the average tension loss and the tension loss per tube as a function of time.

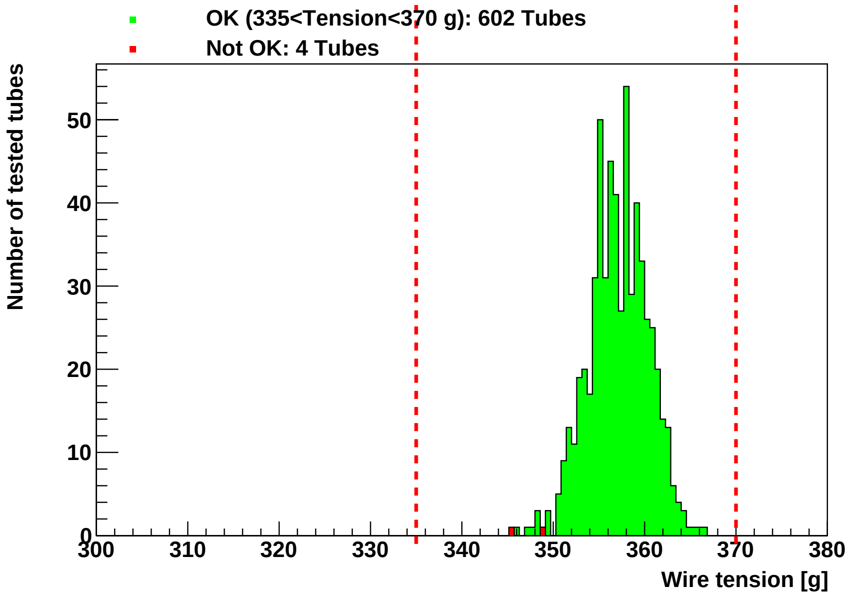

Figure 2: Tension measurements for all tested tubes produced for the BIS1 prototype module -1. The required tension limits are shown in dotted red. The tubes which pass are in green, while the tubes which fail are in red. Tubes within the limits but shown in red have lost > 18 g over time

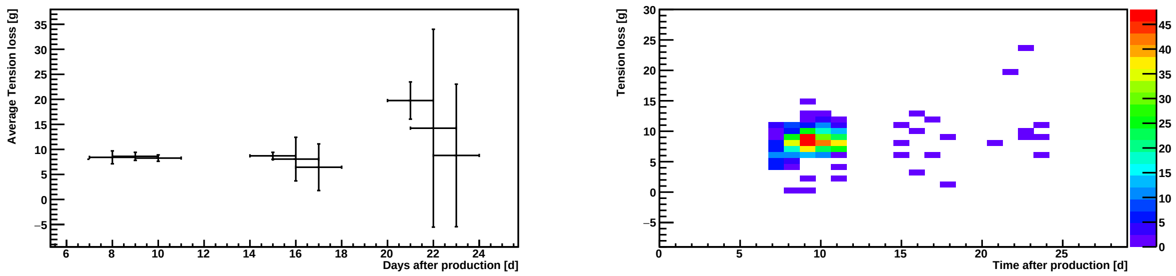

Figure 3: Average loss in tension (left) and the tension loss per tube (right) as a function of time. On average, the tension decreases by approximately 5–10 g.

3.2 Gas leak test

Once the endplugs have been crimped, the gas seals are tested on the tube. The tubes are placed in an evacuated testing cylinder, which is also known as a “Torpedo”. The sMDT tube is then filled with a mixture of 95% Ar, 5% He and pressurized to 3 bar. A He leak detector, installed on the Torpedo, measures the amount of gas which escapes into the Torpedo from the tube. The measurement is then corrected for the difference between the gas mixture used and an all-argon gas. This leakage is required to be less than 10^{-5} mbar·l/s of argon.

The results of the gas leak test can be seen in Fig. 4. As before, the red dotted line shows the acceptable leak rate limit of 10^{-5} mbar·l/s. The leak detection unit has a minimum detection sensitivity of 3×10^{-8} mbar·l/s,

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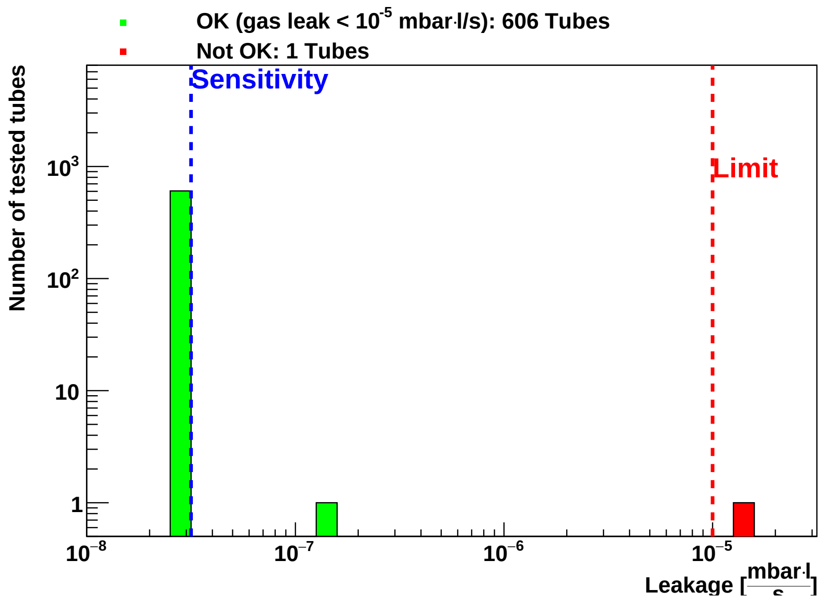

Figure 4: Measured gas leak rates for tubes produced for the BIS1 prototype (Modul-1). The limit (10^{-5} mbar·l/s) is shown in red, while the sensitivity of the leak detector (3×10^{-8} mbar·l/s) is shown in blue. The tubes which pass are in green, while the tubes which fail are in red.

which is indicated by the dotted blue line. A large fraction of the tubes not only pass, but have a leak rate below the sensitivity of the detection unit, indicating that the construction and crimping process on the tubes is not only sound but reliably results in tubes which are in essence completely gas tight.

3.3 High Voltage Test

After the gas seals have been tested, the sMDT tube is taken to HV testing. The tubes are filled with the nominal working gas (93% Ar, 7% CO_2) at 3 bar. The voltage is then slowly raised to 3,015 V, which is above the working voltage of 2,730 V. The dark current from the tube is continuously measured, and recorded after it stabilizes, which takes approximately 10 minutes. The measurement device can test up to 15 tubes at a time, each with a separate HV source and current measurement device. The maximum allowed dark current is 2 nA per tube.

The results of the HV test can be seen in Fig. 5. The limit of 2 nA is denoted by a dotted red line. The measurement device has a minimum sensitivity of 0.5 nA, which is shown by the dotted blue line. While most of the tubes are under the limit, there is a larger distribution of tubes which are above the allowed dark current.

Table 2 summarizes the requirements for tubes to pass all tube tests.

Wire tension [g]	335 <Tension< 370
Tension loss [g]	< 18
Gas leak [mbar·l/s]	$< 10^{-5}$
Dark Current [nA]	< 2

Table 2: Summary of the required measurement values for tubes to pass all tube tests.

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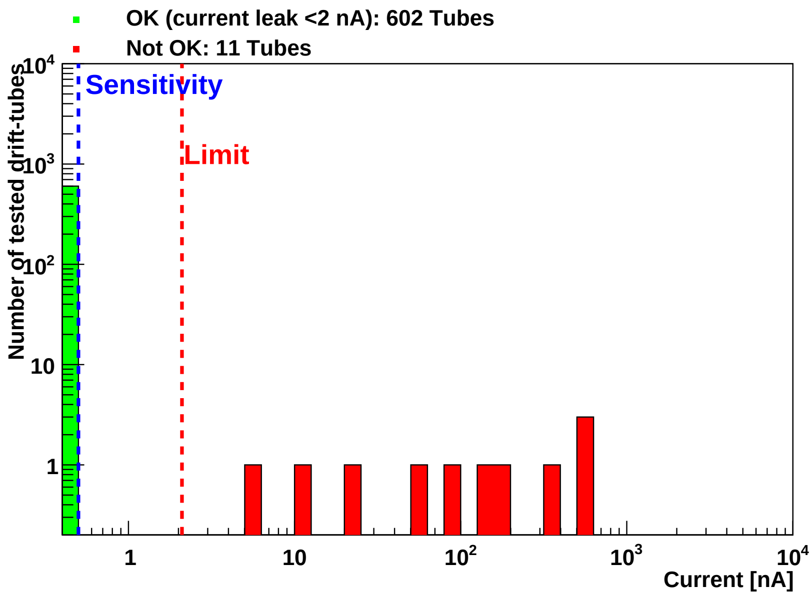

Figure 5: Measured dark current for tubes produced for the BIS1 prototype (Modul-1). The limit (2 nA) is shown in red, while the sensitivity of the dark current detector (0.5 nA) is shown in blue. The tubes which pass are in green, while the tubes which fail are in red.

3.4 Length test

The length of the tubes can vary. This may cause problems for installing the gassystem and the electronics. Therefore it is considered for the future to measure the length of the tubes before assembling them into the chambers.

4 Gluing of drift tubes

The protection caps screwed on both endcaps of each drift tube are removed right before the tube is incorporated into the chamber. Also at this point the barcode attached to the drift tube wall is scanned such that the tube is assigned to its chamber in the chamber database. When drift tubes are glued together to construct a chamber, they are aligned along the Readout-side of the chamber in order to avoid clashes with the Readout-electronics mounted later on.

References

[1] A. Collaboration, *Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer*, tech. rep. CERN-LHCC-2017-017. ATLAS-TDR-026, https://cds.cern.ch/record/2285580: CERN, 2017, URL: `https://cds.cern.ch/record/2285580` (cit. on p. 2).

[2] E. H. Takasugi, O. Kortner, K. R. Schmidt-Sommerfeld and H. Kroha, *Small-Diameter Monitored Drift Tube (sMDT) BMG Chamber Construction and Testing*, tech. rep. ATL-COM-MUON-2017-008, CERN, 2016, URL: `https://cds.cern.ch/record/2254940` (cit. on p. 2).