Study of the tightness of ATLAS MDT chamber

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About ATLAS

At CERN in Geneva a protons accelerator (LHC) will replace the electrons and positrons accelerator (LEP), which has stopped operating in 2000. LHC is a ring of about 27 km with eight intersections where the particles could collide. The ATLAS collaboration is working to build a large detector in correspondence with one of these intersections. ATLAS (A Toroidal Lhc ApparatuS) is composed of a complex system of tracking of charge particles surrounding the intersection point, a calorimeter and a spectrometer for muon tracking, being muons charged particles that pass very easily through matter. This spectrometer is constituted by a large toroidal magnetic field produced by 8 coils plus a large quantity of very precise chambers for muon tracking. There are about 1100 of these chambers. They have different dimensions and the overall layout provides three chambers for each track (fig.1). 94 of these 1100 chambers that are produced in different parts of the world are in production at the LNF.

Chamber description

One chamber is constituted principally of three layers (multilayer) of drift tubes, which are stuck on both parts of a support structure called spacer. The tubes and the spacer are made of aluminium. The length of each tube is 3.55 m, its external diameter is 30 mm and its thickness is 400 µm. Inside there is a wire (50 µm diameter) made of tungsten (97%) and rhenium (3%) gold plated, it is operated with a mixture of Argon (93%) and carbon dioxide (7%) pressured at 3 bar abs and an operating voltage of 3080 Volts.

The principle of functioning of the tube is based on the fact that a muon, being a charged particle, ionises gas and the electrons produced in this process move towards the wire. The electrons of the ionised gas, going towards the wire, when they arrive in the proximity of the wire (300 µm), switch on a chain reaction and in this way the electron signal on the wire is amplified. Knowing the electron speed and the time that it employs to reach the wire, it is possible to calculate the distance between the wire and the muon track. Unfortunately it isn’t possible to individuate the angle of incidence but it’s only possible to track a circle where it is presumed that the muon has passed. After this operation, having a lot of tubes, we can individuate the trajectory of the particle tracking the tangent of all the circles. To have a good signal it’s necessary to choose a gas that at the same time ionises very easily and has a good power of quenching i.e. it must naturally stop the electrons production process. Hydrocarbons could match these requirements very well but they have been excluded from the choice to avoid the chamber ageing. Indeed the repeated passage of muons make the hydrocarbons leave some residuals on the wire. The mixture chosen is composed of Argon (93%), a noble gas that ionises very easily, and CO_2 (7%) that increases the quenching of the mixture.

My work

Each tube has to satisfy several quality control checks before being assembled: length, wire tension, high voltage and gas leak. After assembly also the chamber must be tested for the gas leak. My work is to measure the gas leak of a chamber. The limit of the leak rate, established by the collaboration, is 10^{-8} bar l/ sec for a single tube and $2*N*10^{-8}$ bar l/ sec for the whole chamber, being N the number of tubes.

Theoretical calculations

The starting point to solve the problem is ideal gas law:

A variation of moles in time, due to a leak, corresponds to a variation of pressure, assuming volume and temperature a constant.

$$\Delta pV=\Delta nRT$$

But it's important to know not only the leak in function of the pressure but also in function of time, which produces the following relation:

$$\Delta pV/\Delta t=\Delta nRT/\Delta t,$$

where Δt is a unity of time.

The second member of the equation evidently represents the border limit of leak.

$$\Delta p/\Delta t=\text{border leak}/V=1.38\ \text{mbar/day}$$

Then to verify if a chamber fulfils the requirement we have to measure a pressure drop less than 1.38 mbar/day.

Problems of measurements

Even if it's easy to calculate the border leak things in real life are not that easy. Indeed temperature isn't a constant and a variation of 1°K causes a variation of pressure of 10 mbar, and this fact disturbs the measure. Moreover, each multilayer is very large and the temperature changes from place to place. To solve this problem it's necessary also to have information about the temperature of the multiplayer therefore the instruments I used were a digital manometer (sensibility 0.2 mbar) and 8 temperature sensors (sensibility 0.1 °C) put in different positions of the same multilayer.

Calibration of sensors

To be sure that the measurements are exact it's necessary to calibrate the sensors of temperature. To do this the 8 sensors have been put between two little bars of aluminium together with a thermometer with two sensors, which gives the standard temperature. The 10 temperatures were recorded every 2 minutes and after the graphics were done and, on the bases of the angular coefficient of the line, the sensors were calibrated.

Measurement and analysis of data

The measurements, in order to obtain significant results, last three days during which a computer program (in the framework of the commercial package LabView) running on a PC records every 5 minutes the 8 temperatures from the sensors and the relative pressure from the manometer. Data are transferred to EXCEL where the analysis is made.

First of all it's necessary to do the average of the temperatures, fig.2 shows the behaves of pressure and temperature which are similar, as we can foresee from the ideal gas law. In the same figure the day-night cycle is clearly visible.

Following the same law also the volume increases and volume augmentation had been calculated with the thermal expansion formula $V=V_0(1+\alpha t)$. Of course this variation is very little because the coefficient of thermal expansion is very small and then this effect can be negligible.

First it's necessary to transform the temperature measured in absolute temperature, adding 273.15, then to transform the pressure measured in absolute pressure, adding the atmospheric pressure, which is of about 1013 mbar, and expressing it in bar. Having done these simple operations we can correct pressure with temperature following this equations derived from the ideal gas law, assuming volume a constant, the corrected pressure=$P/T*T_0$ where T_0 is the average of all temperatures measured. The result of application of this formula is shown in fig.3.

The ideal graphic of the pressure in function of time would a descendant line which slope represents the leak rate. Fig. 3 instead shows relatively large fluctuation around the trend line that make us understand that the correction with temperature is not completely done. This happens because the measured temperature is not the real gas temperature because sensors are in contact with aluminium. The leak measured is 1.9 mbar/day that is bigger then our limit but this measurement is influenced by a large error caused by the fluctuations.

Description and testing of the gas distribution system

Another part of my work consists in testing the system to distribute the gas to a single tube (fig.4). The distribution is based on an aluminium tube (rectangular section) called gas-bar, where the gas enter from a mixer, on the gas-bar there are several black plates each one with three small tubes to connect corresponding tube of the three layers. The tubes that aren't connected to the gas-bar are connected with the neighbours through an object called jumper clearly visible in fig.4.

To simplify the operations of leak detection the gas-bar are mounted on a special tool visible in fig.5.

From similar considerations on the ideal gas law we can calculate also the border leak of gas-bar, which is of about 3 mbar/h. To reach results in the fastest way the leak of the gas-bar isn't tested with a manometer and the sensors of temperature, but with a Helium spectrometer and a differential manometer.

Testing of a gas-bar with the differential manometer

In this case the differential manometer measures the difference of pressure between the gas-bar, which is put on about 3 bar as the gas will be in the chambers, and a reference tube, which at the beginning is at the same pressure of the gas-bar. The tube and the gas-bar are in contact and they are made of the same material, then temperature can't influence the measure because they behave in the same way. From the increment of the difference the leak could be determined. The layout of the test system is also shown in fig.5. An example of test result is shown in fig.6 where the differential pressure, defined as the pressure of the reference volume minus the pressure of the gas bar, is plotted Vs time. The slop of the trend line is 0.4063 mbar/hours that is much smaller than the limit.

Testing of a gas-bar with the Helium spectrometer

The Helium spectrometer measures little quantities (with a sensitivity of 10^{-11} bar l/sec) of helium thanks to a pump that aspires what enter inside the gas-bar. This way of detection is useful to us to locate small source of leak. With a small tube, Helium is spread outside the gas-bar near the connections and if a small quantity of it enters in a gas-bar the spectrometer detects it. Helium is chosen because is a very small molecule, which can penetrate also in very small holes, because is relatively cheap and because it's easy to find Helium spectrometer on the market.

Functioning of the Helium spectrometer

A fraction of what is aspired by the pump passes through a small cell where some electrons emitted by hot wire ionise the gas molecule that are around and this process produces ions. These ions are accelerated by some electrodes and they pass through a magnetic field. After this passage only the ions with the correct ratio of masse and charge arrive to the detector. The amount of ions measured by the spectrometer is proportional to the partial pressure of Helium.

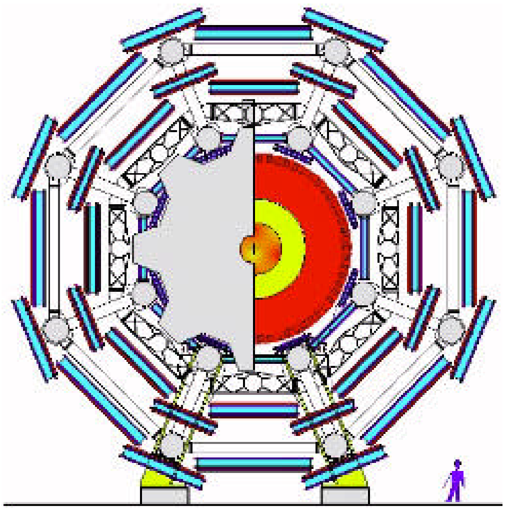


fig.1: cross section of ATLAS detector. In light blue the three stations of the muon chambers are clearly visible. A man is also plotted for comparison.

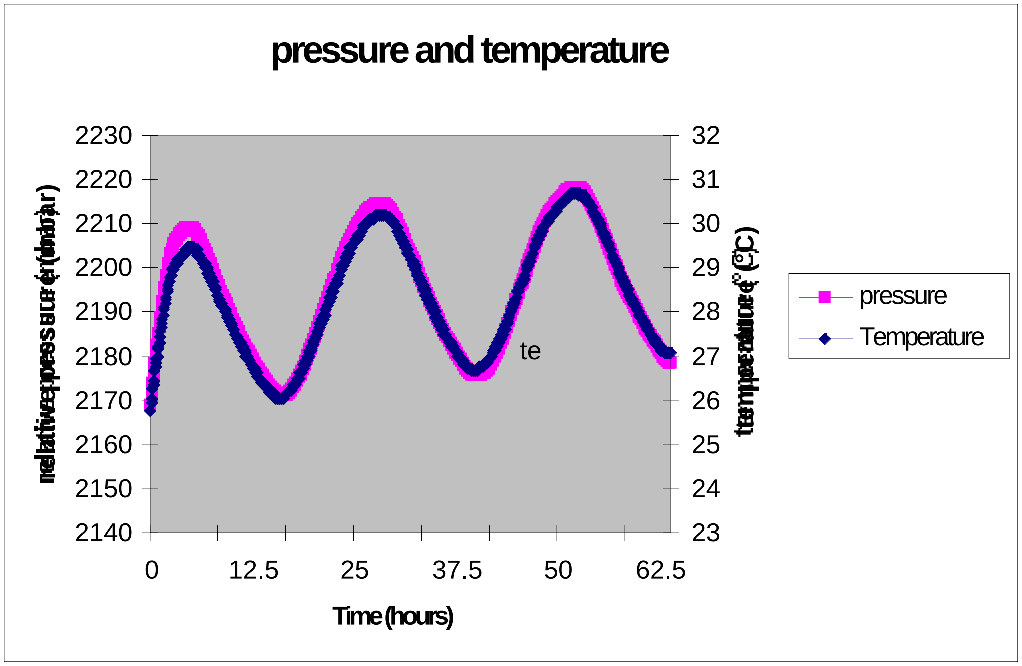


fig.2: raw data of pressure and temperature

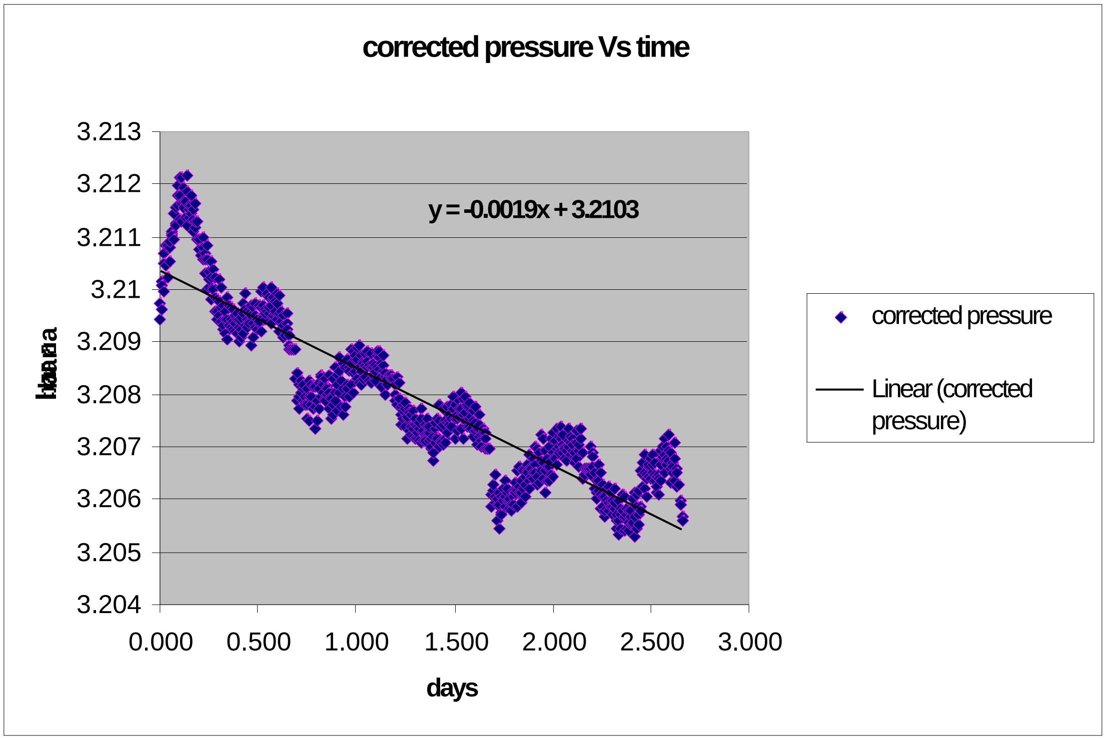


fig.3: behaviour of the corrected pressure Vs time after the analysis

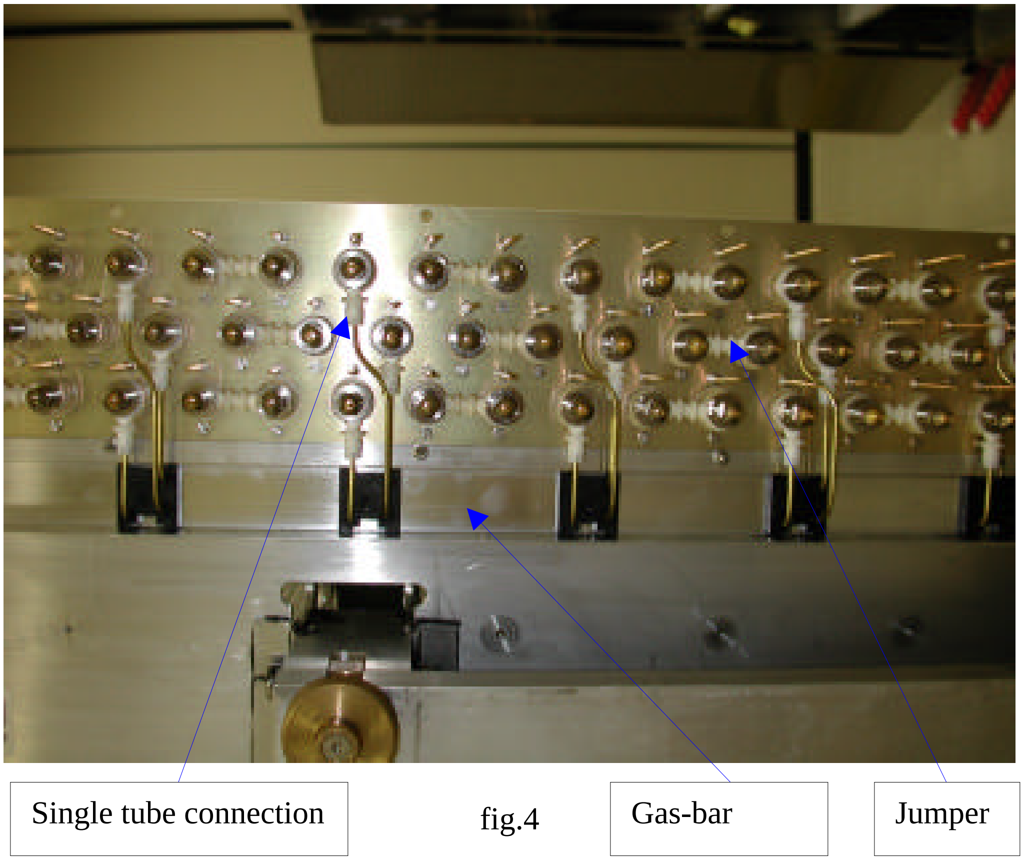
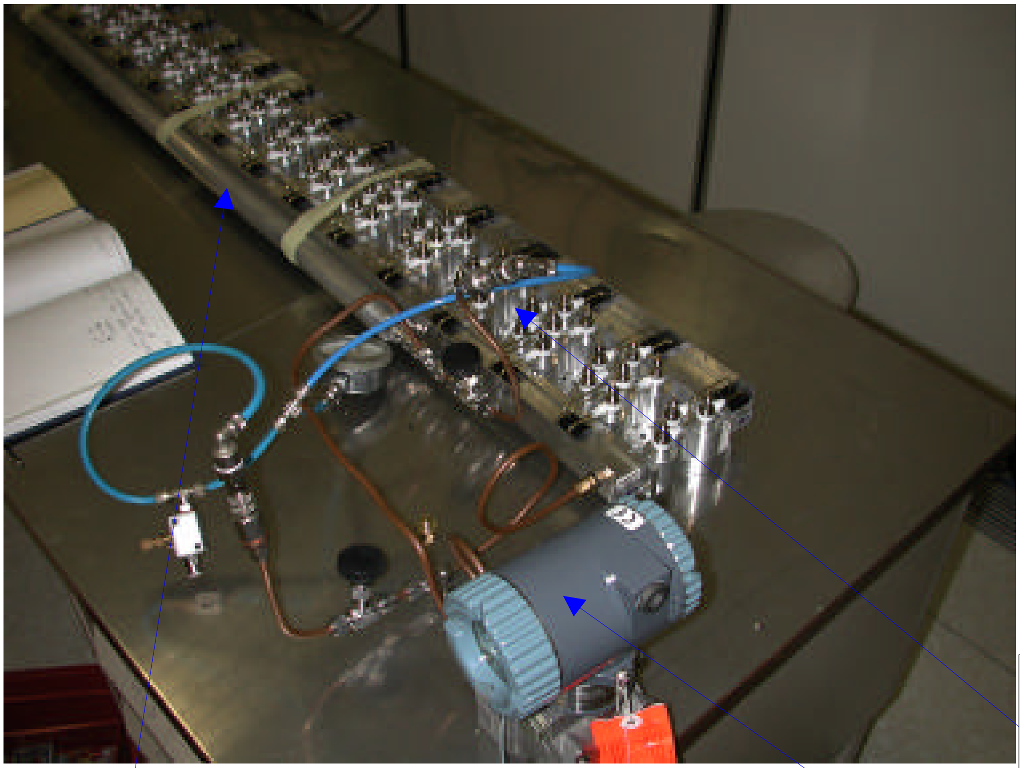


fig.4



Gas-bar mounting tool

Reference tube

fig.5

Differential manometer

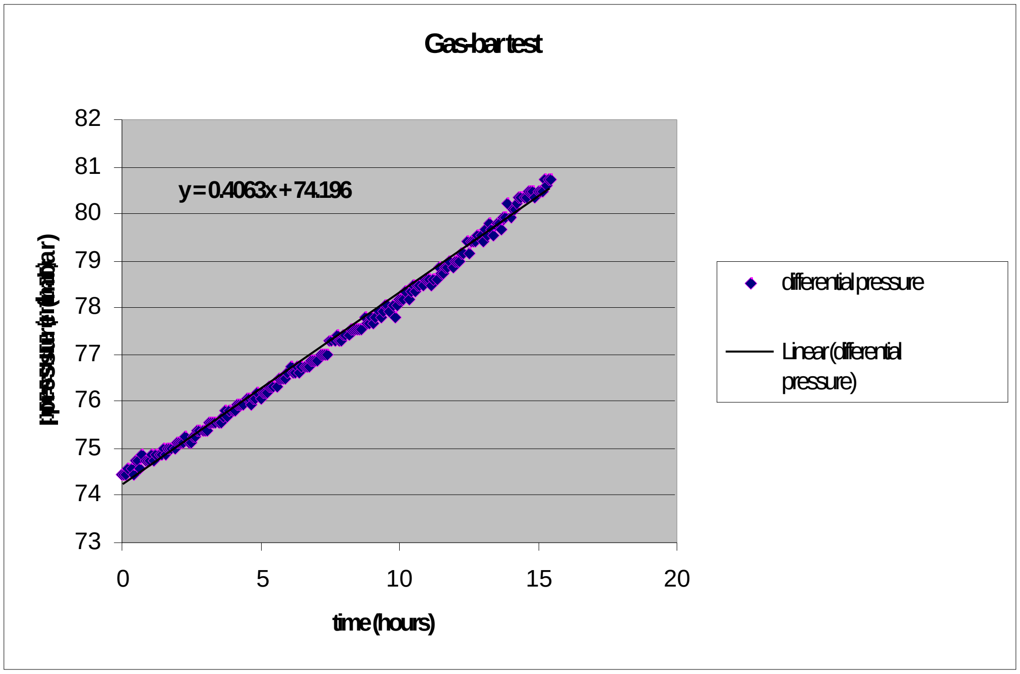


fig.6: Differential pressure Vs time, also shown result of the trendline.