Final Evaluation of the Mechanical Precision of the ATLAS Muon Drift Tube Chambers


IEEE Nuclear Science Symposium • October 29 - November 4 • San Diego, California
Precision muon momentum measurement in a toroidal magnetic field:

- Muon chambers (Monitored Drift Tube, MDT)
- Toroid magnetic field: 0.3 – 1.2 T
- 2700 trigger chambers (RPC, TGC)
- 1200 precision chambers (CSC, MDT)

Performance requirements:

\[ \frac{\Delta p_T}{p_T} = 3-10\% \] in a wide momentum range of \( p_T = 10-1000 \) GeV/c

\[ \Rightarrow \] track sagitta resolution in a tower of 3 chambers: 50 \( \mu \)m.
Monitored Drift Tube (MDT) Chambers

Drift tube: Ar:CO\textsubscript{2}(93:7), gas gain $2 \times 10^4$ (3080 V)

- Al tube wall, $d = 29.970$ mm
- W-Re anode wire, $d = 0.050$ mm
- End-plug

- Length: 1–6 m
- Width: 1–2 m
- 3 or 4 layers of drift tubes

- Multilayer

Required wire positioning accuracy within one chamber: 20 $\mu$m (r.m.s)

$\Rightarrow$ elaborate chamber assembly procedure.
Large-scale MDT Chamber Production

88(+13 reserve) MDT chambers produced at MPI during 2001 - 2005.

BOS chambers (Barrel Outer Small):
6 layers, 3920 mm length, various widths:
- $62 \times 2160 \text{ mm}$
- $4 \times 1920 \text{ mm}$
- $6 \times 1440 \text{ mm}$
- $4 \times 1200 \text{ mm}$
- $12 \times 1920 \text{ mm}$ with cut-out

production date of 88 BOS MDT chambers (after replacement of 10 with reserve chambers)

10 of 13 additional reserve chambers were needed as the replacement:
- 4 chambers had multilayers detached from the support frame. (Too large global deformations of multilayers after re-gluing.)
- 6 chambers had tubes with cracks in the end-plug material.
Layers of drift tubes are glued successively to the support frame.

**Assembly procedure for each tube layer:**
- Wire positioning within the tube: 7 $\mu$m.
- Tube positioning on the combs: 5 $\mu$m, glue distribution on the tubes.
- Support frame lowered onto the table, 6 positioning towers allow for the positioning accuracy of 5 $\mu$m.
- Gravitational chamber deformations compensated using pneumatic actuators.
- Mechanical and optical position monitoring with precision of 10 $\mu$m.
Optical Monitoring of the Chamber Geometry

Optical monitoring system "RASNIK":

RASNIK lines-of-sight on the chamber and on the assembly table: (top view)

Legend:
- CCD
- LENS
- LED

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Sensors on the chamber:
measurement of gravitational chamber deformations

Sensors betw. chamber and granite table:
measurement of distances and angles between the drift tube layers
Geometry Monitoring: Neighbouring Tube Layers

Nominal parameters:
\[ \Delta z = 15.018 \text{ mm} \]
\[ \Delta y = 26.034 \text{ mm} \]
\[ \Delta \alpha = 0 \]

Tube layer:
1
2
3
4
5
6

horizontal shift
vertical layer distance

\[ \sigma(\Delta z) = 9 \mu\text{m}, \quad \sigma(\Delta y) = 12 \mu\text{m}, \quad \sigma(\Delta \alpha) = 5 \mu\text{rad} \]
Geometry Monitoring: Multilayer Parameters

Nominal parameters:
\[ \delta y = 346.899, 346.870 \text{ mm} \]
\[ \delta \alpha, \delta z = 0 \]

Tube layer: multilayer distance \( \delta y \)

\[ \sigma(\delta z) = 20 \ \mu\text{m}, \ \sigma(\delta y) = 20 \ \mu\text{m}, \ \sigma(\delta \alpha) = 30 \ \mu\text{rad} \]
Comparison with the X-Ray Measurements

- 15% of chambers measured at the X-ray tomograph at CERN.
- Precision of the wire measurement: $2 \, \mu m$ (stat.) + $2 \, \mu m$ (syst.).
Reconstructed Wire Positions

- optical monitoring parameters + wire position within each tube
  \[ = \text{reconstructed wire position} \quad (y_{opt}, z_{opt}) \text{ within one chamber} \]

All X-rayed chambers:

\[
\begin{align*}
\sigma(P_{Xray} - P_{opt}) &= 11.3 \, \mu m \\
\sigma(P_{Xray} - P_{nominal}) &= 13.8 \, \mu m \\
\sigma(P_{opt} - P_{nominal}) &= 16.5 \, \mu m
\end{align*}
\]

\[\downarrow\]
Accuracy of the wire positions using optical monitors:

\[\sigma_{opt} = \sigma(P_{opt} - P_{true}) = (11 \pm 1) \, \mu m\]

- optical monitoring sensitive to the deviations of geometry
Mechanical Chamber Accuracy

ATLAS software allows for the implementation of the measured multilayer parameters, instead of assuming the nominal geometry.

⇒ improving the knowledge of wire positions using optical monitoring

Mechanical chamber accuracy is well within the tolerances.
Cut-out Chambers

Cut-outs at the barrel ends, to make way for optical alignment rays.

Significant changes in the chamber design and assembly procedure. After one year of development and tests, 3 dummy chambers...

Final design ⇒

- MI cross plate not in the middle.
- Positioning towers moved.
- New RASNIK masks and lenses.
- Position of short tubes very sensitive to gravitational sag compensation.
Mechanical Accuracy of the Cut-out Chambers

- short tubes (cut-out region)
- long tubes

Cut-out region is only slightly shifted w.r.t. the long tubes, within the strict tolerances.
Positioning of Alignment Platforms

Praxial sensors for optical monitoring of chamber positions within one barrel layer:

Measurement of the platform positions

• Precision:
  50 µrad / 5 µm in θ_x, θ_z and y
  100 µrad / 10 µm in θ_y and z

Alignment platforms are glued to the inner layer of drift tubes.
Spread of the measured platform positions exceeds the nominal values by up to a factor of two.

⇒ Position measurement important in order to correct for the deviations.
Challenging longtime production of Monitored Drift Tube Chambers for the ATLAS detector has been successfully completed.

- Optical monitoring during the chamber assembly and the measurements at the X-ray tomograph at CERN certify the mechanical chamber accuracy.
- Installation into the ATLAS detector is well under way. (All 88 BOS chambers already installed.)