Optimization of the Gas Flow in a GEM Tracker with COMSOL and TENDIGEM Development

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Overview

1. Introduction
   - The triple-GEM detector

2. Study and optimization of the gas system

3. Tendigem development

4. Conclusion
Introduction

• The GEM (Gas Electron Multiplier) chambers is currently under development

  • Front Tracker:
    • two 10 x 20 cm$^2$ silicon strip planes
    • six 40 x 150 cm$^2$ GEM chambers (each made up of three adjacent 40 x 50 cm$^2$ triple-GEM modules)

• Energy upgrade of the Jlab CEBAF (Continuous Electron Beam Accelerator Facility): up to 11 GeV in Hall A (2014)
The triple-GEM detector

- **Working Principle**
  - Ionization by the charged particle
  - Charge multiplication in holes of GEM foils
  - Drift of electrons in induction gap induce signal on the anode read-out
  - Excellent intrinsic spatial resolution: ~40 µm RMS

Ionization by the charged particle
Charge multiplication in holes of GEM foils
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The triple-GEM detector

1 cover frame (3 mm)
1 entrance frame (2 mm)
1 drift frame (3 mm, grid)
2 GEM frames (2 mm, grid)
1 induction frame (2 mm, grid)
1 honeycomb frame (6 mm)

20 Cu sectors
20 x 5 cm²
• **GEM foil**

  50µm insulating Kapton coated on both sides with 3 to 5 µm Cu

  Densily perforated:

  D = 70 µm
  d = 50 µm
  P = 140 µm (Lead)
Optimization of the GEM frame design

2 main goals:

1) Improve gas flow uniformity:
   - by optimizing the design of the grid in the frame

   ⇒ Study performed with:
     - a geometry defined in 2D
     - Thin-Film Flow Model
     Model of 1 single frame as if its volume were delimited by 2 solid walls

2) Avoid turbulence:
   - by optimizing the diameter of the tubes leading to the inlets and outlets
   - by optimizing the design of the inlets and outlets
Method

• Finite Element Method using COMSOL Multiphysics

• 2D Geometry & Thin-Film Flow Model
  film thickness: 2 mm in sectors
  1 mm in grid openings, inlets and outlets

• Choice of model & mesh design: influenced by requiring computational capacity
Thin-Film Flow Model:

- The film thickness $h$ remains very small respect to the dimensions of solid structures.
- The channel curvature is small.
- The inertial effects in the fluid are negligible compared to the viscous effects, thus the flow is laminar.
- The pressure $p = p_a + p_f$ is constant over the film thickness $h$.
- The velocity profile over the film thickness is parabolic.
- The fluid is isothermal.

Method (3)

- Reynolds equation:

\[
\frac{\partial (\rho h)}{\partial t} + \nabla_{tg} \cdot (\rho h \vec{U}) - \rho \left( \nabla_{tg} \Delta h_m \cdot \vec{u}_m - \nabla_{tg} \Delta h_b \cdot \vec{u}_b \right) = 0
\]

\[
\vec{U} = -\frac{\nabla_{tg} p}{12 \mu} h^2 Q_{ch} + \frac{\vec{u}_m + \vec{u}_b}{2}
\]

- 3 volume renewals per hour => total inlet flow 60 cm³/min
- constant density \( r = 1.8417 \text{ kg/m}^3 \) (\( U_s = 314 \text{ m/s} \gg U_i = 0.0625 \text{ m/s} \))
- constant dynamic viscosity \( \mu = 1.9696 \cdot 10^{-5} \text{ Pa.s} \) (Reichenberg’s formula)
- immobile solid structures: \( h \) constant, \( \Delta h_m = \Delta h_b = u_m = u_b = 0 \)
- continuum => \( Q_{ch} = 1 \)
• Reynolds equation:

\[ \nabla \mathbf{tg} \cdot \nabla \mathbf{tg} P_f = 0 \]

\[ \mathbf{U} = -\frac{h^2}{12 \mu} \nabla \mathbf{tg} P_f \]

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• **Boundary conditions**

Inlets:
- Uniform perpendicular velocity

Frame surfaces $U = 0$

Outlets:
- $p_f = 0$

(ambient pressure $p_a = 1$ atm)
Mesh Quality

Mesh with only 1 predefined « size »: Fine

Mesh with only 1 predefined « size »: Extra fine
Method (3)

Extra fine Mesh Quality

Statistics

Complete mesh

Element type: All elements

Triangular elements: 399736
Quadrilateral elements: 111244
Edge elements: 18524
Vertex elements: 264

Domain element statistics

Number of elements: 510980
Minimum element quality: 0.06352
Average element quality: 0.7898
Element area ratio: 3.329E-6
Mesh area: 209400.0 mm^2

Element Quality Histogram
Simulation 1

Prototype version:

2 inlets
$U_i = 0.0625 \text{m/s}$

2 outlets

18 sectors

2 large low flux zones
Simulation 2

Modified inlet and outlet configuration

3 inlets
\( (U_i = 0.04167 \text{ m/s}) \)
3 outlets
18 sectors

Six-sector rows:
3 independent and similar flows
Simulation 2 (continued)

Modified inlet and outlet configuration

Simulation 1 (0.04167 m/s)  Simulation 2 (0.04167 m/s)

circular joints 1.5 mm radius at inlets & outlets

=> slight reduction of the high velocities inside sector
& stabilization of the boundary layers
Simulation 2 (continued)

Modified inlet and outlet configuration
Reduction from 18 to 12 sectors:

The idea is to reduce the number of vertical spacers in order to have less «dead angles» (the velocity of the gas is too slow in these corners)

Planarity of the GEM foils

- Normal pressure: 10 N/m²
- Maximum sector area: 265 cm²
- 20µm Maximum deformation
- < 0.074 Geometrical factor
- 9.81 N/cm Circumference force per unit length

⇒ Minimum number of sectors: 9

Conservative choice: 12 sectors

⇒ (sector area = 222 cm²)

⇒ (sector area = 166 cm²)
Simulation 3 (continued)

Reduction from 18 to 12 sectors:
Simulation 4

Enlargement of openings near inlets & outlets

15 mm openings

No significant improvement

20 mm openings

Velocity magnitude (m/s)
Simulation 5

Doubling the openings in the vertical spacers:

6x 15 mm openings

Uniformity improved

9x 10 mm openings
Doubling the openings in the horizontal spacers:

4x 15 mm openings

8x 15 mm openings

No significant improvement
Tendigem machine is a tool for the gem foils stretching.
TENDIGEM

Stretching

Gluing the next frame with spacers
Conclusion

Study and optimization of the gas system

- **Significant improvement of the gas flow uniformity** in the 2 mm gap between 2 GEM foils of a 40 x 50 cm$^2$ module

Final frame design:
- 3 inlets and 3 outlets (with circular joints)
- 12 sectors
- vertical spacers:
  - 9 openings of 10 mm
- horizontal spacers:
  - 4 openings of 15 mm

- **Inlet and outlet pipes cause a very large fraction of the total pressure loss** in a 40 x 50 cm$^2$ module
Thank you for your attention