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Finite Element Analysis to Investigate Electromagnetic Flowmeters of Diverse Cross sectional Shapes

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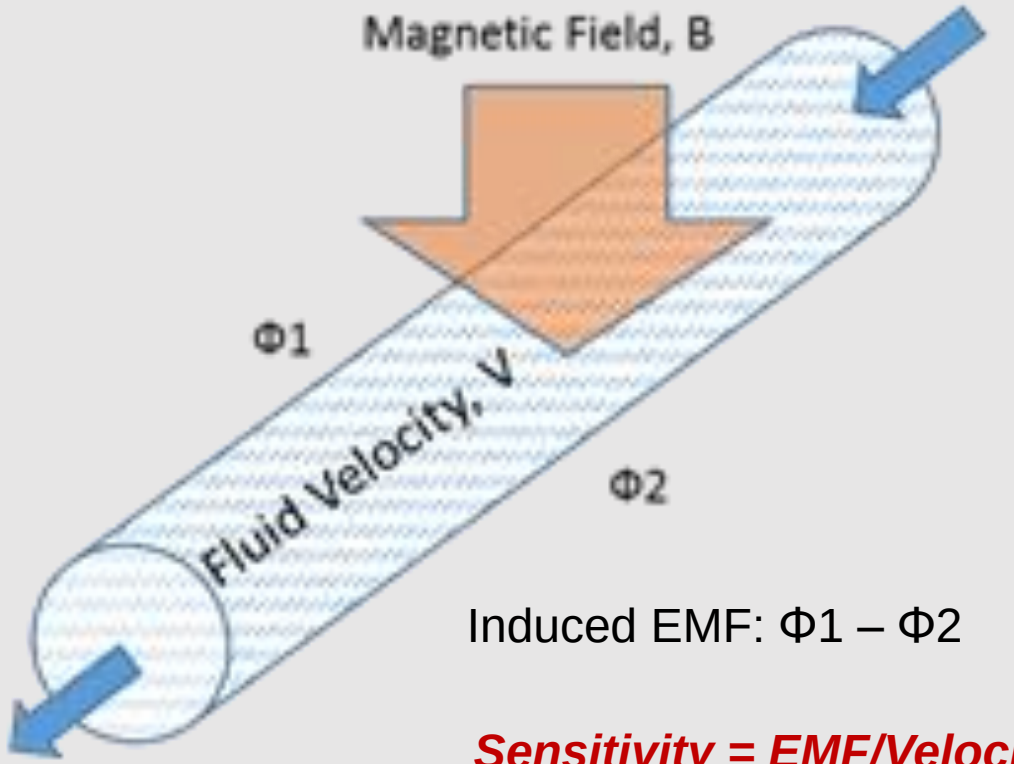
Electromagnetic Flowmeter: Working Principal

Faraday's Law in action



Induced EMF: Φ1 – Φ2

Sensitivity = EMF/Velocity

EM Flowmeter

- Ionic liquid flows across magnetic field
- EMF induced in accordance with Faraday's Law of electromagnetic induction
- Induced EMF is proportional to velocity

Scientific model required to improve understanding of complexities - design improvement

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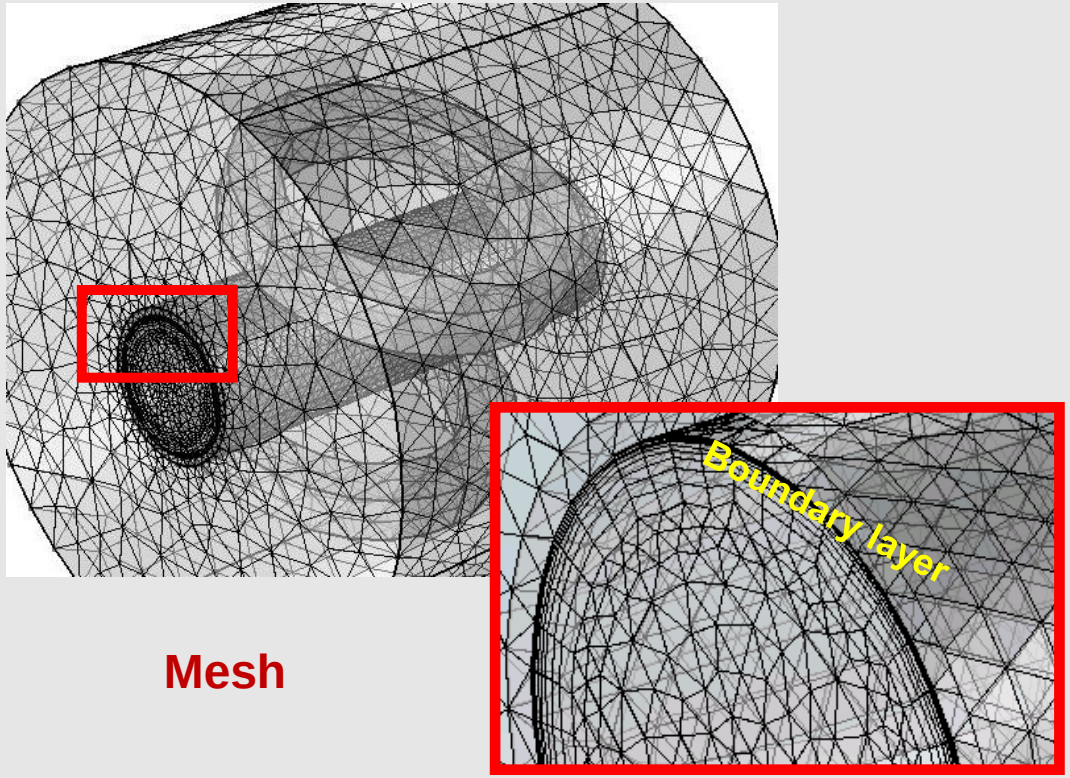
Finite Element Model of Flowmeter

Domain Discretization



Mesh

- Tetrahedral meshing scheme
- Mesh resolved in zones of complicacy: Boundary layer
- Mesh independence study performed

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Finite Element Model of Flowmeter

Governing Equations

Fluid Flow

Fluid flow module

Mass Conservation

$$\nabla . u = 0$$

Momentum Conservation

$$\rho u \nabla u = -\nabla p + \mu \nabla^2 u + F$$

u – Velocity
p – Pressure
μ - Viscosity

Electromagnetics

Magnetic and Electric Fields

Ampere's law

$$\nabla \times \mu_0^{-1} \mu_r^{-1} B = J$$

Current Conservation

$$\nabla . J = 0$$

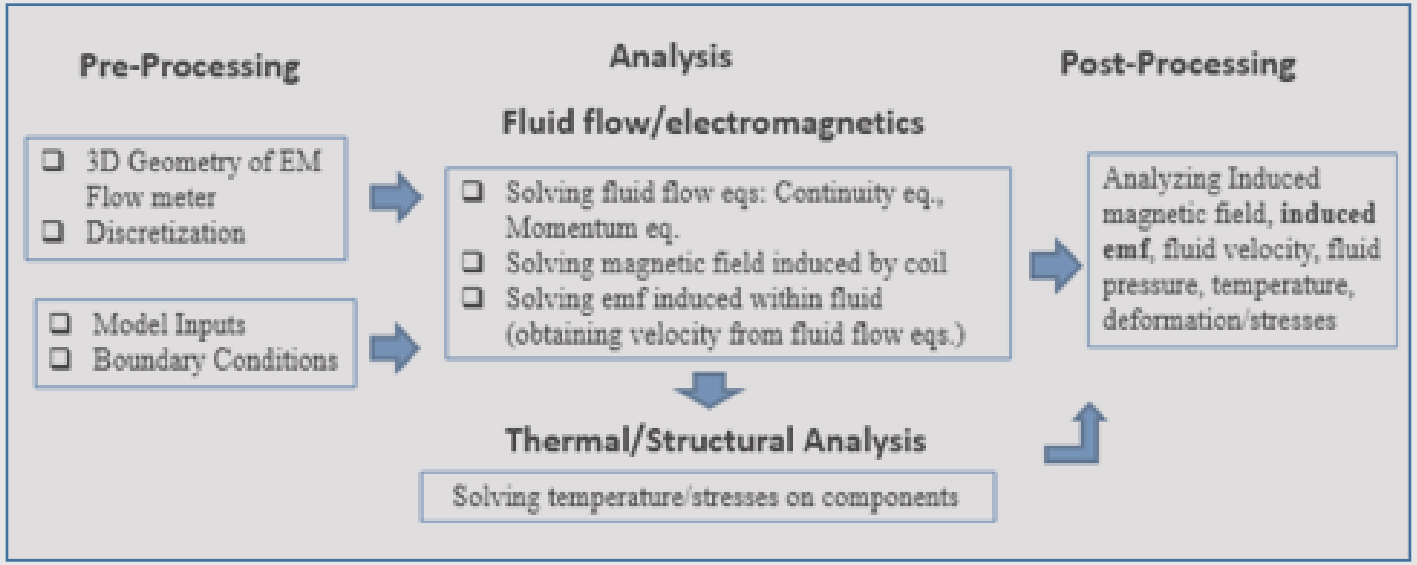
Lorentz Term (Faraday's Law)

$$J_i = \sigma E + \sigma u \times B \Rightarrow \boxed{E = -\nabla \emptyset}$$

B – Magnetic flux density
J – Current
E – Induced electric field

- ***Interaction of flow and magnetics***
- ***Integration provides induced potential***

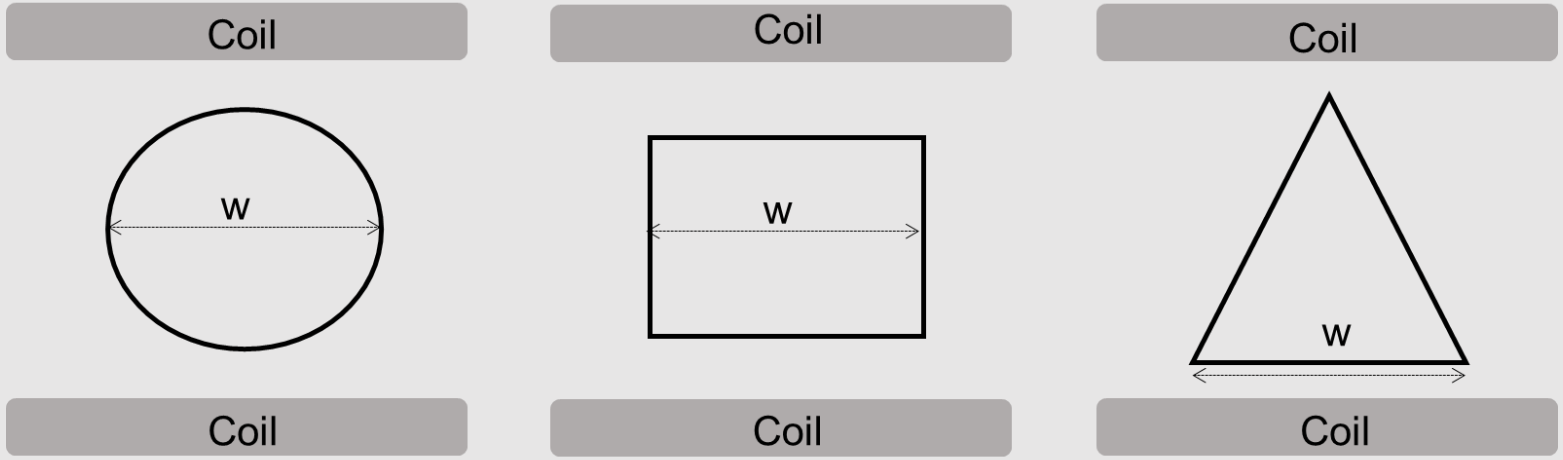
Model Structure



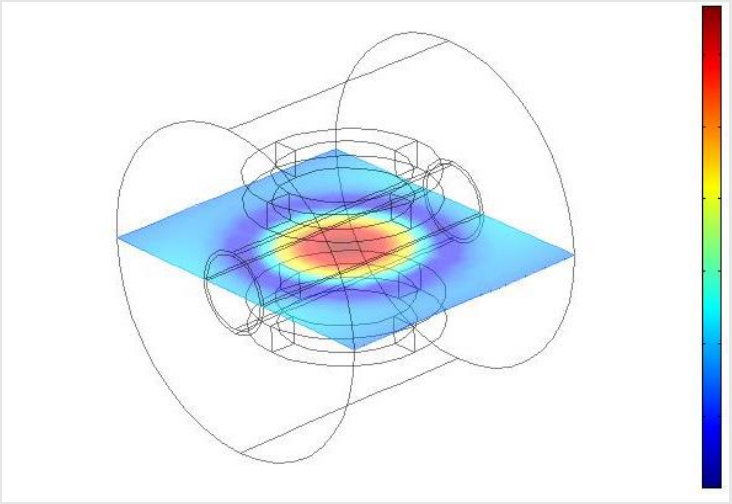
- Steady state simulation
- Segregated Direct Solvers for fluid flow
- Iterative solver for electromagnetics
- Solvers interaction between velocity and magnetic flux

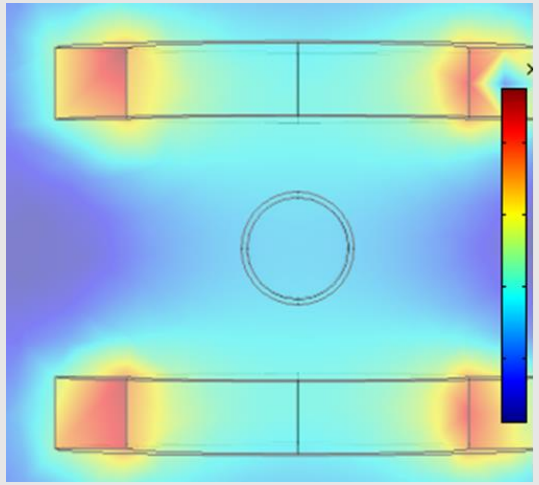
Influence of Pipe Cross Sectional Shape

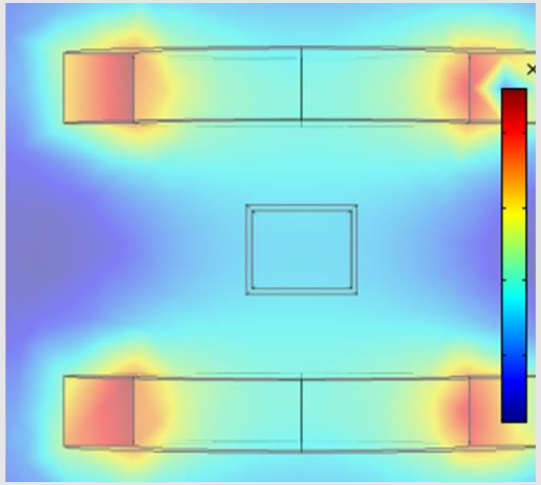
- Circular, square and rectangular cross sectional shapes chosen
- Constant area and width
- Varying height

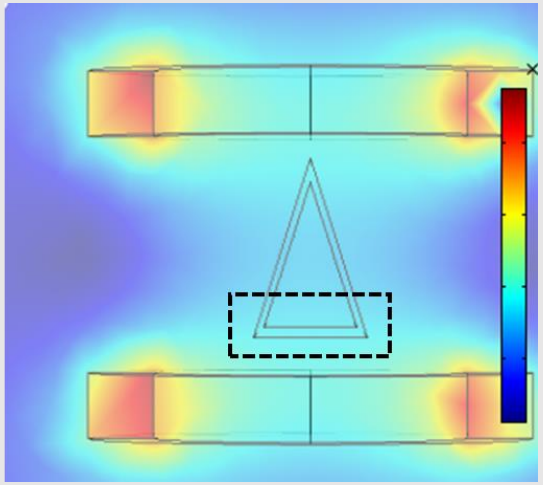


Magnetic Flux Density

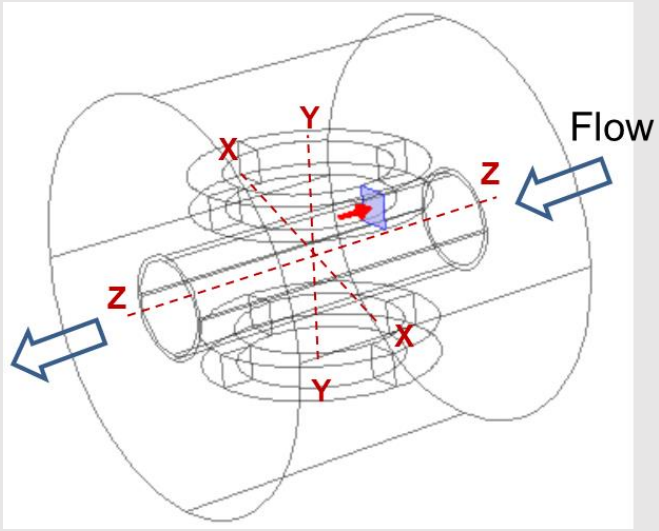




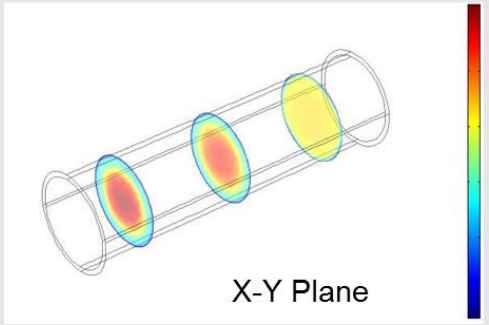




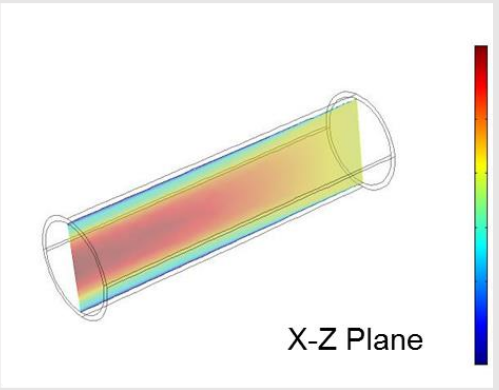
Influence of Pipe Cross Sectional Shape



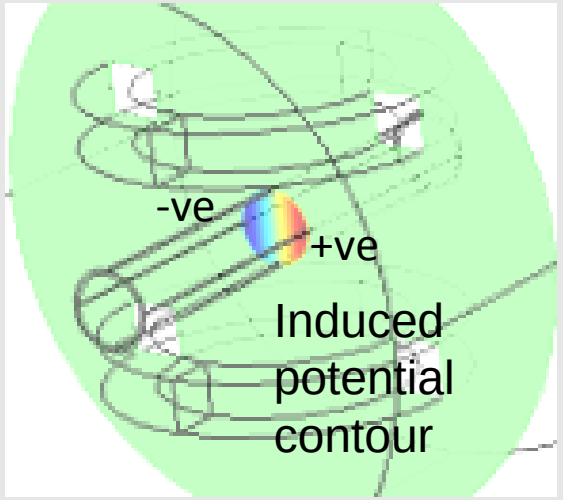
Fluid Flow

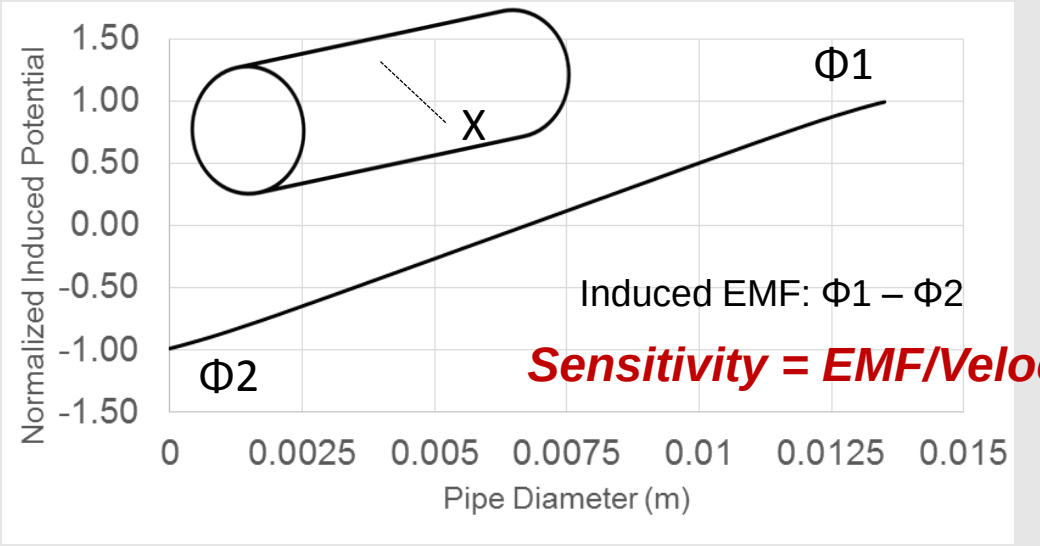


Indicates developing flow

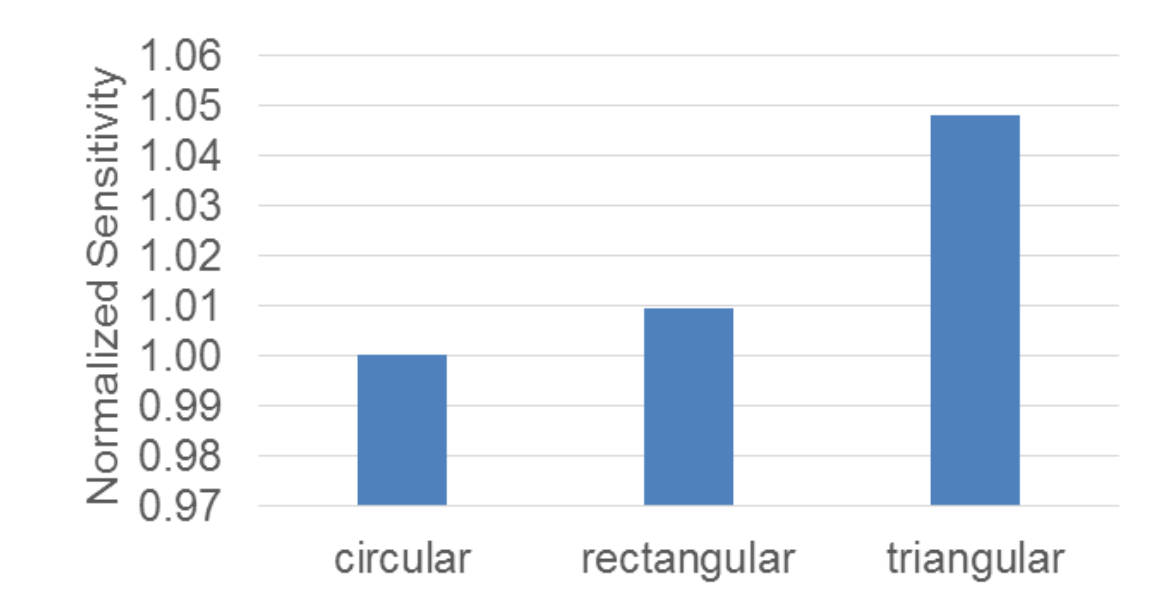


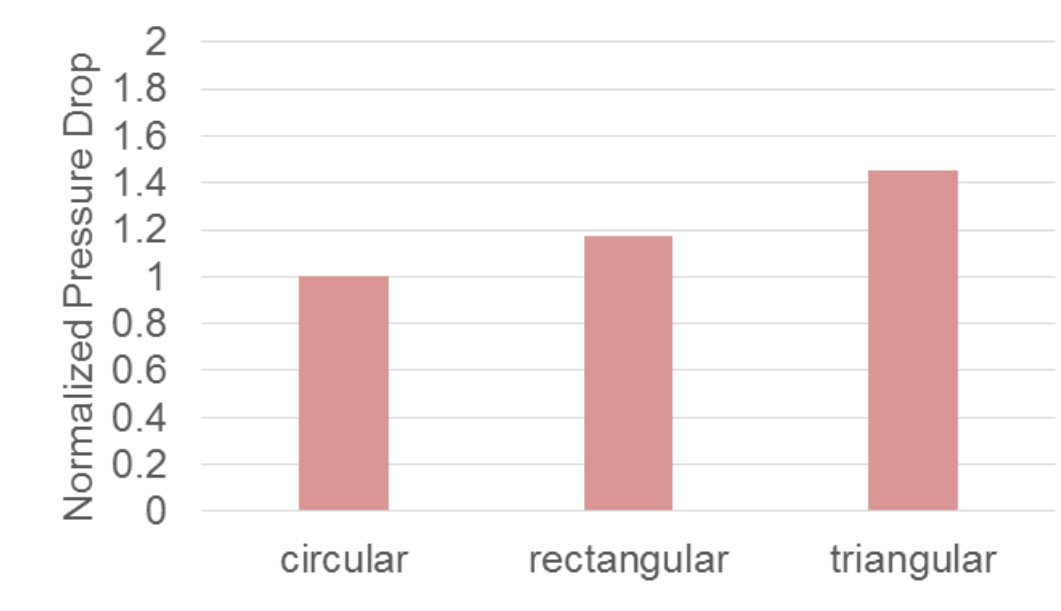
Induced Electric Potential





Influence of Pipe Cross Sectional Shape





- Triangular shaped flowmeter yields best sensitivity
- Pressure drop 45% higher in triangular shaped flowmeter
- Conclusion: Circular shaped flowmeter yields overall best performance

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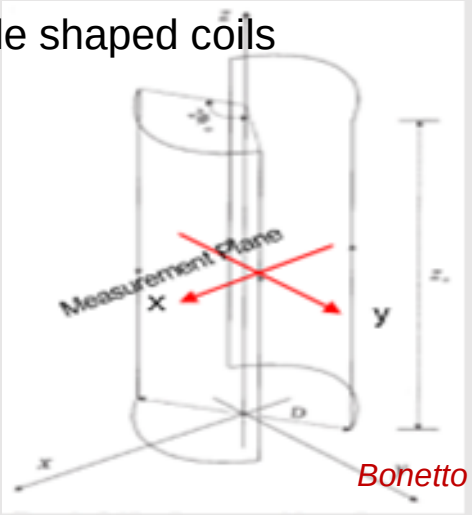
Model Validation

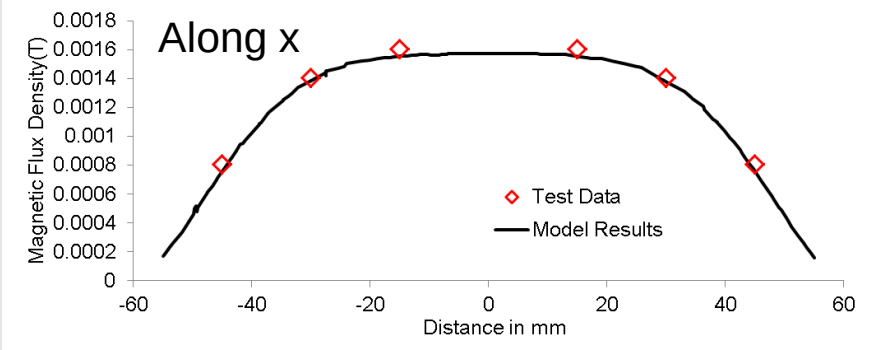
1. Magnetic Flux Calculation Method

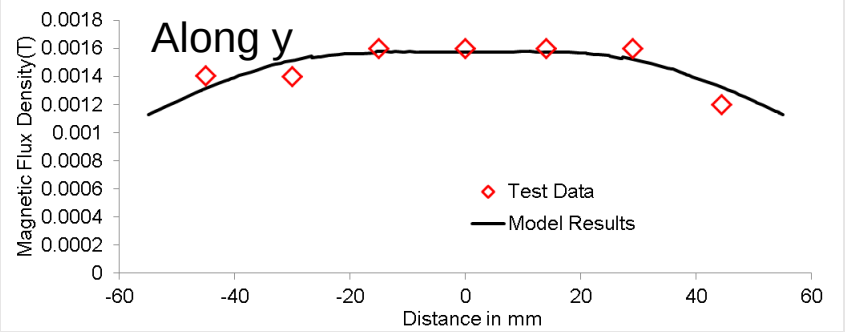
Saddle shaped coils



Bonetto et al. 2006

Model vs. Test data

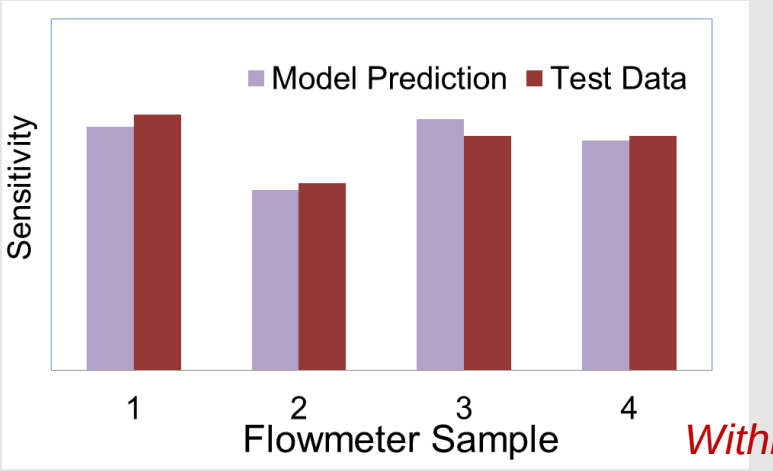




Magnetic flux density measured along x, y directions

- *Within 95% agreement*
- Validates magnetic flux modeling method

2. EM Flowmeter Sensitivity Calculation



Within 95% agreement

- **Model validation:** 2 step process
- Magnetic flux modeling method validated using literature data (test)
- Flowmeter sensitivity validated against in-house test data
- *Overall model predicts with acceptable accuracy: ~ 95%*
  - Useful predictive tool for industry