Analytical Method to Calculate EMF Induced in Ionic Liquid by Magnetic Field
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Subhashish Dasgupta
Scientist, ABB Corporate Research, Bangalore

K. Ravi Kumar
Scientist, ABB Corporate Research, Bangalore

Philipp Nenninger
Manager, ABB Automation Products, Germany

Frank Gotthardt,
Manager, ABB Automation Products, Germany
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Induced EMF in Fluid: 1D Analytical Calculations

Induced EMF in fluid flowing past magnetic field

Analytical Expression (Electrically Insulated Pipe)

Induced EMF: $\Phi_2 - \Phi_1 = BVD$

$B$: Magnetic Field, $V$: Average Velocity, $D$: Diameter

Assumptions:
- Insignificant 3D effects
- Uniform magnetic and flow fields
- Insulated pipe wall

Analytical Calculation of Induced EMF
Induced EMF in Fluid: COMSOL Multiphysics 3D Model Prediction

Geometry and Meshing

- Model in COMSOL meshing module
- Tetrahedral meshing
- Boundary layers: Resolve near wall physics

Boundary Conditions and Inputs

**Fluid Flow**
- inlet velocity = $u$ m/s
- outlet pressure = 0 atm
- no slip wall ($u = 0$ m/s)

**Electromagnetics**
- Insulated air domain $\nabla \times A = 0$
- DC current and number of coil turns
- *Pipe wall conductivity* $\sim 0$ S/m
Physics Coupling and Governing Equations

**Laminar Flow Module**

**Fluid Flow**
- Continuity:
  \[ \nabla \cdot \mathbf{u} = 0 \]
- Momentum:
  \[ \rho \mathbf{u} \nabla \mathbf{u} = -\nabla p + \mu \nabla^2 \mathbf{u} \]

**Magnetic and Electric Fields Module**

**Electromagnetics**
- Ampere’s law
  \[ \nabla \times \mu_0^{-1} \mu_r^{-1} \mathbf{B} = \mathbf{J} \]
- Ohm’s law:
  \[ \mathbf{J}_i = \sigma \mathbf{E} + \sigma \mathbf{u} \times \mathbf{B} \]

**Method Highlights**
- Multi Turn Coil
- Segregated Solvers
- AMS solver for electromagnetics

\( \Phi \) - magnetic flux density
\( \mathbf{J} \) - current density
\( \sigma \) - conductivity

**Induced EMF**

\[ \text{EMF} = \Phi_1 - \Phi_2 \]
Comparison of 1D Analytical with 3D F.E. Results (Case 1: Electrically Insulated Pipe Wall)

- Analytical Calculations: Almost 1% Deviation F.E. Results
- Case: Electrically Insulated Pipe
- Analytical calculations useful in investigations
Comparison of 1D Analytical with 3D F.E. Results (Case 2: Electrically Conducting Pipe Wall)

**Induced EMF**

\[ \Phi_1 - \Phi_2 = BVD \left( 1 + \frac{t \tau}{r \sigma} \right)^{-1} \]

- **B**: Magnetic flux density
- **V**: Average Velocity
- **D**: Diameter
- **t**: tube thickness
- **r**: tube radius
- **σ**: fluid conductivity

**Drop in EMF**

(Potential Leakage)

**Graph**

- **Non conducting wall**
- **Conducting wall**

**Analytical Calculations:** Almost 1-10% Deviation with F.E. Results
Conclusions

- **Simplistic cases:** ID calculations useful in understanding MEHD phenomenon

- **Complicated cases:** 3D F.E. calculations necessary, Realistic Estimation using COMSOL Multiphysics

- **Future Scope:** 3D calculations can improve 1D results by incorporation of correction factor