

COMSOL
CONFERENCE
2015 GRENOBLE

Multiphysics Analysis of a Thermo Acoustic MHD Inductive Generator

Carcangiu Sara - Forcinetti Renato - Montisci Augusto



University of Cagliari - Sardinia - Italy

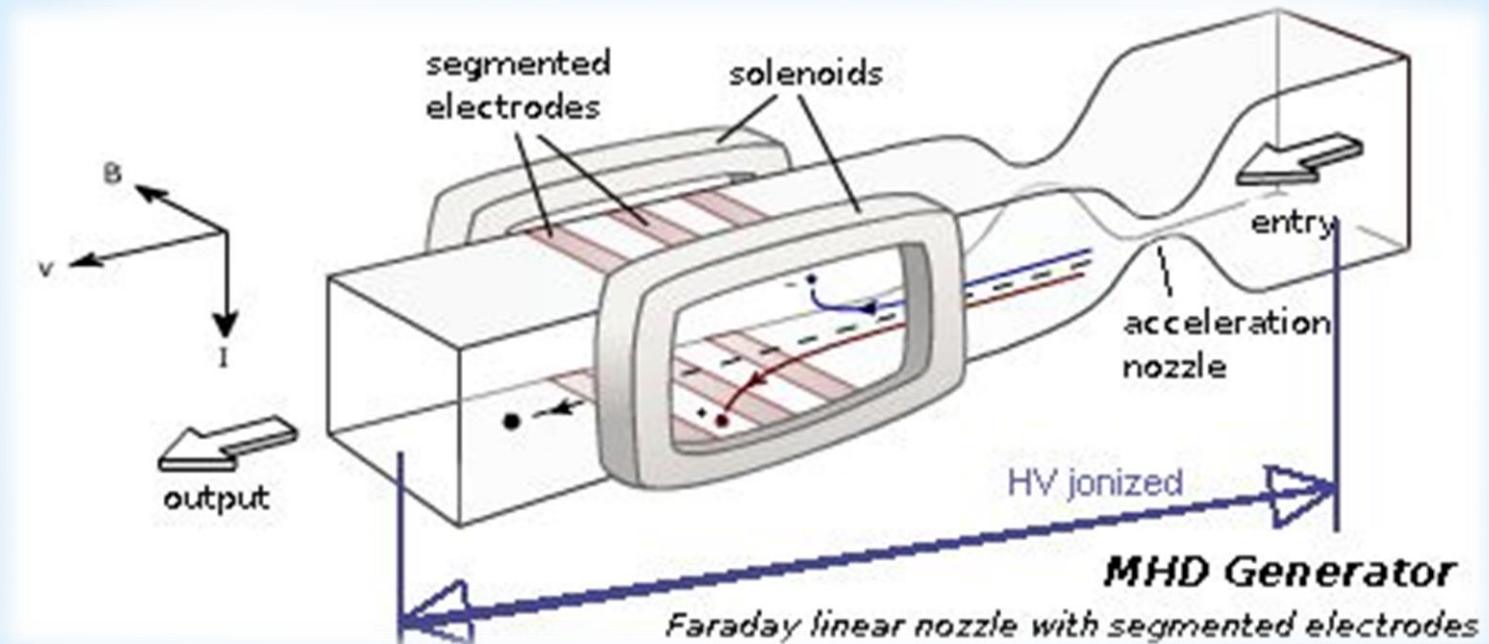


Outline

- Introduction
 - Main problems of known MHD generators
 - Main features of the proposed device
 - Principle of functioning
- FEM analysis
- Numerical Results
- Conclusions & Future work



Introduction



WIKIPEDIA

[https://en.wikipedia.org/wiki/Magnetohydrodynamic_generator#/media/File:MHD_generator_\(En\).png](https://en.wikipedia.org/wiki/Magnetohydrodynamic_generator#/media/File:MHD_generator_(En).png)

Schematic view of the MHD conversion principle

- **Drawbacks of classical MHD generators:**

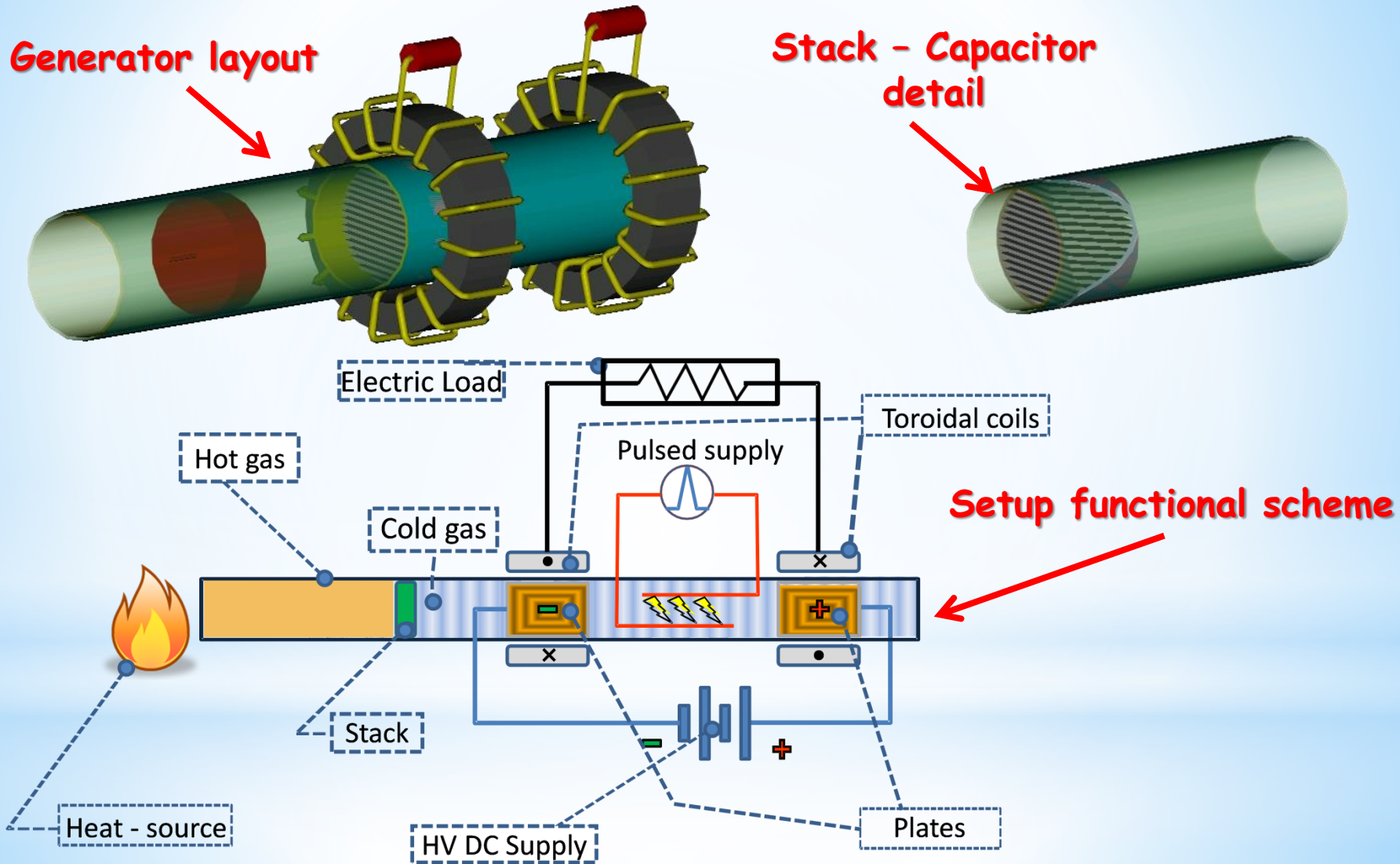
- Need of very high external Magnetic Field
- High temperatures are needed to ionize fluid
- Seeding Recovery
- Deterioration of electrodes
- Need for flowing working fluid

- **Advantages of the proposed device**

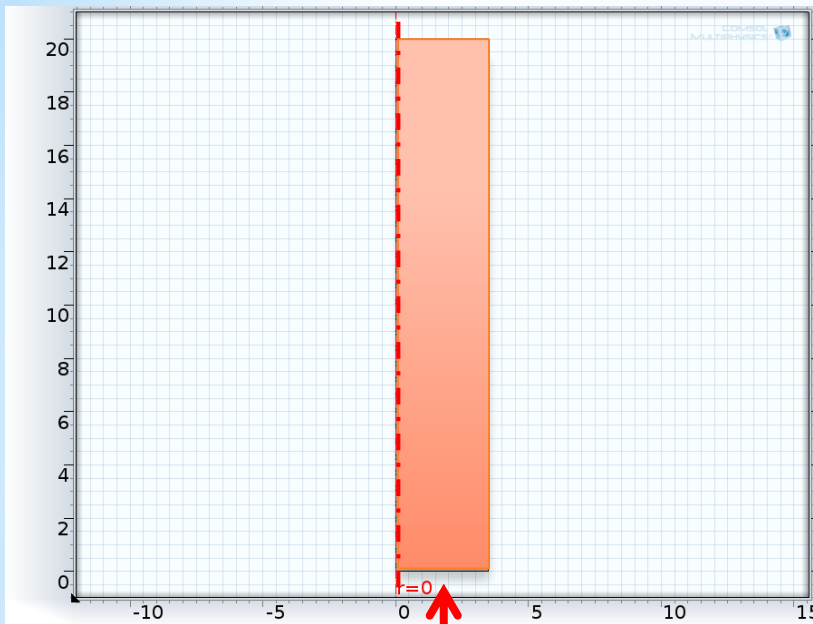
- No external Magnetic Field
- No Superconducting Coils
- High Performance at Low Temperatures
- No seeding
- Quasi - Static working fluid



Principle of functioning



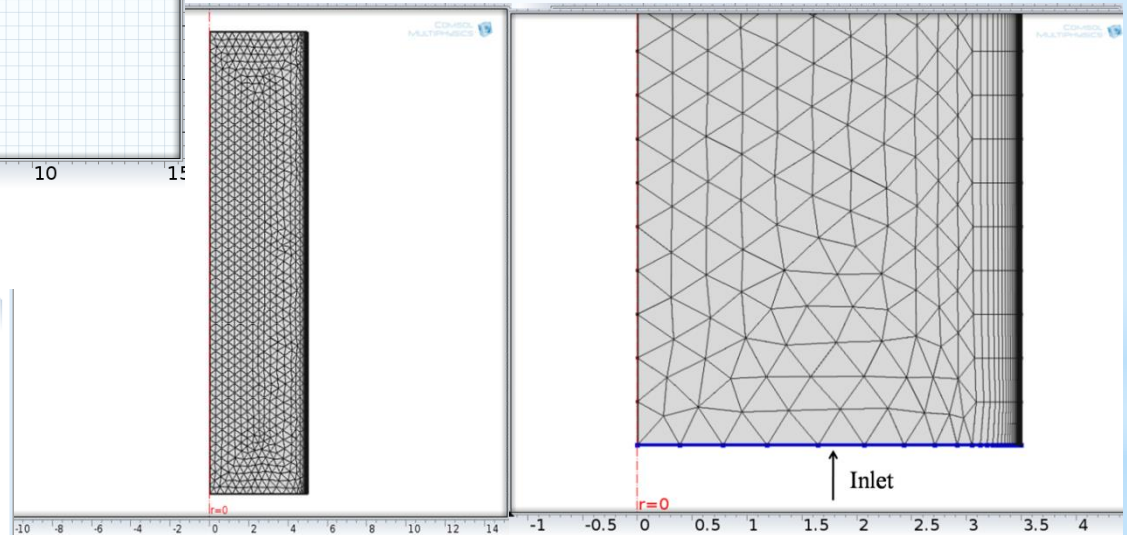
FEM Thermo - acoustic analysis



Inlet Pressure

$$\delta_v = \sqrt{\frac{\mu}{\pi \cdot f \cdot \rho_0}}$$

Viscous layer



Meshed model with boundary layer detail

Boundary Layer Properties

Number of boundary layers:

Boundary layer stretching factor:

Thickness of first layer:

Thickness: cm

Governing equations

Variables

- Acoustic pressure (p)
- Particle velocity (\mathbf{u})
- Temperature (T)
- Density (ρ)

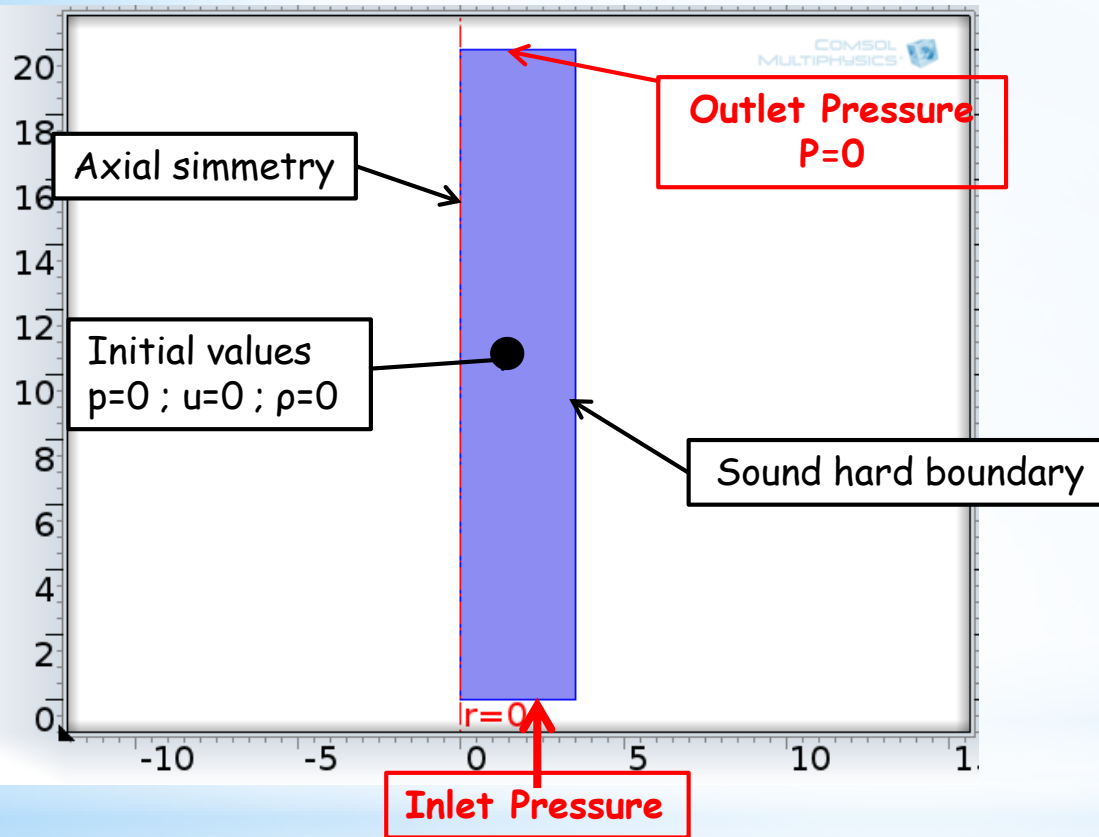
$$i\omega\rho_0\mathbf{u} = \nabla \cdot \left(-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \left(\frac{2\mu}{3} - \mu_B \right) (\nabla \cdot \mathbf{u})\mathbf{I} \right)$$

$$i\omega\rho + \rho_0(\nabla \cdot \mathbf{u}) = 0$$

$$i\omega\rho_0 C_p T = -\nabla \cdot (-\mathbf{k}\nabla T) + i\omega p T_0 \alpha_0 + Q$$

$$\rho = \rho_0(\beta_T p - \alpha_0 T)$$

Boundary conditions & Study



Variables

- Acoustic pressure (p)
- Particle velocity (u)
- Temperature (T)
- Density (ρ)

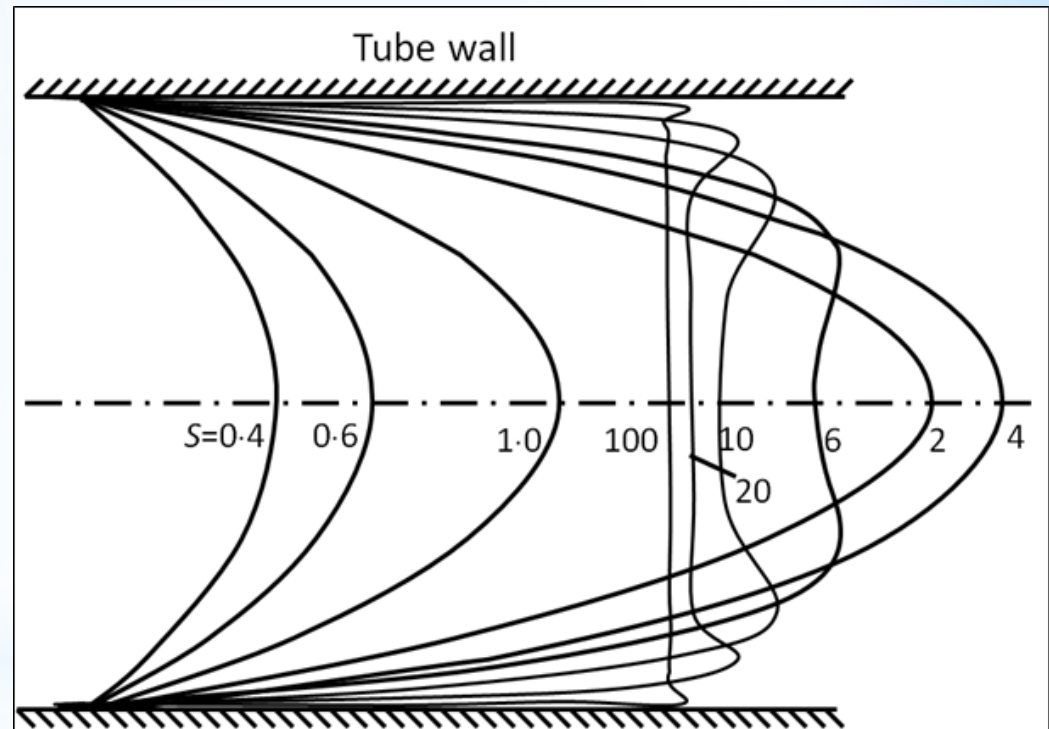
FEM Thermo - acoustic analysis

Meaningful parameters
for a given gas

- Frequency
- Radius of the duct
- Pressure

$$s = R \sqrt{\frac{\rho \cdot \omega}{\mu}}$$

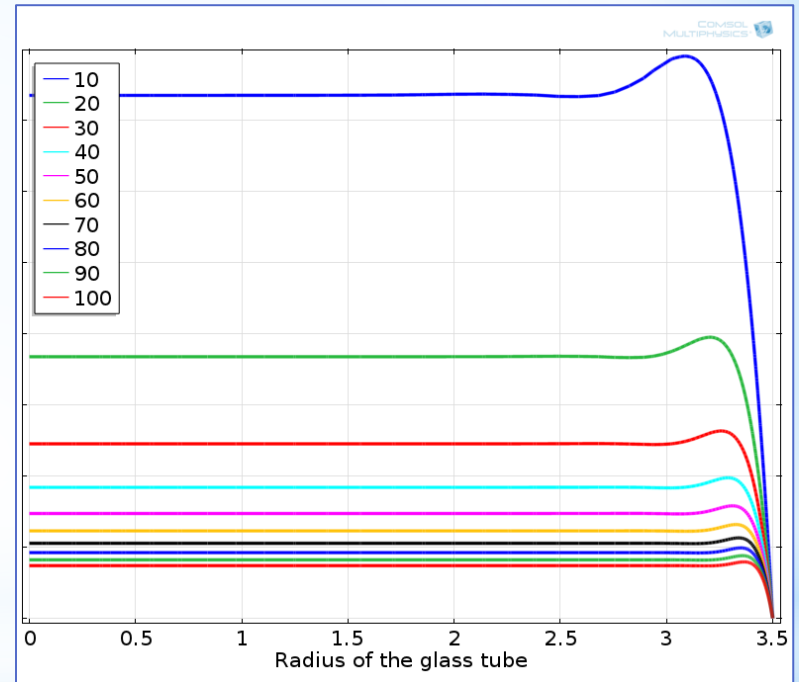
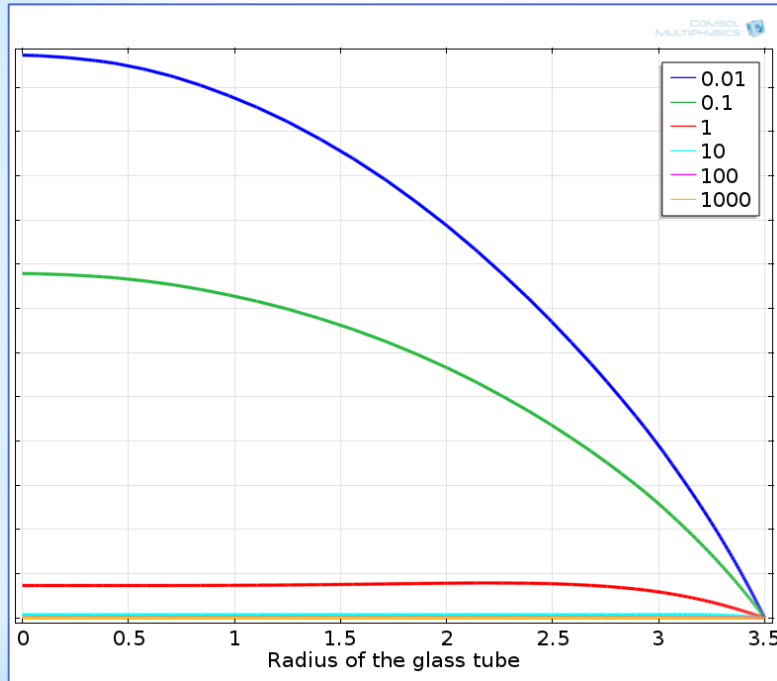
Shear wave number



Velocity profiles from literature

H. Tijdeman. On the propagation of sound waves in cylindrical tubes.
Journal of Sound and Vibration, Vol. 39 (1975), pp. 1-33.

FEM Thermo - acoustic analysis



Velocity distribution (Rd=3.5cm; f=0.01 - 1000 Hz)

FEM Thermo - acoustic analysis

Post-processing

The screenshot displays the COMSOL Multiphysics software interface for a FEM thermo-acoustic analysis. The main window is titled "newThermo-Particle-ok.mph - COMSOL Multiphysics".

Model Builder (Left Panel): Shows the project hierarchy including Global Definitions, Model 1 (mod1), Study 1, Study 2, Results, Data Sets, Views, Derived Values, Tables, Acoustic Pressure (ta), Velocity (ta), Surface 1, Arrow Line 1, Temperature (ta), Velocity field, Particle Trajectories (cpt), Export, Player 1, Animation 1, and Reports.

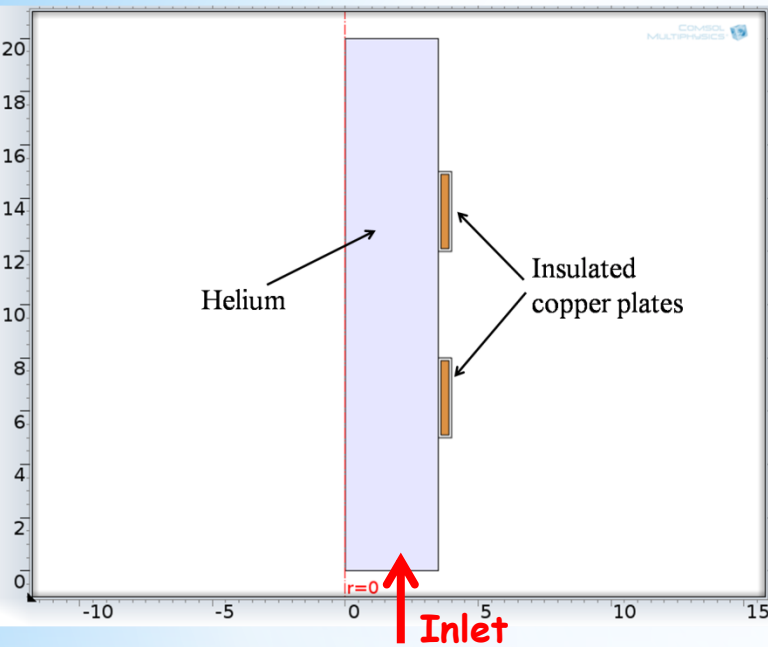
Animation Panel (Center): Contains settings for the animation of the "Velocity (ta)" subject. The "Output" section is set to "Movie" format, "GIF" format, and filename "velocita". The "Frame Settings" section is set to "Manual" size, "Lock aspect ratio" checked, "Width: 640 px", "Height: 480 px", and "Record in reverse order" unchecked. The "Parameter Sweep" section is set to "Sweep type: Dynamic data extension" (highlighted by a red arrow), "Cycle type: Full harmonic", and "Number of frames: 20".

Graphics Window (Right): Displays the "Instantaneous local velocity (m/s)" and "Arrow Line: Velocity field". The plot shows a velocity field with a color scale from 0 to 7 m/s. The x-axis ranges from 0 to 4, and the y-axis ranges from 3.5 to 7. The plot shows a dark blue region with a vertical rainbow-colored line on the right side.

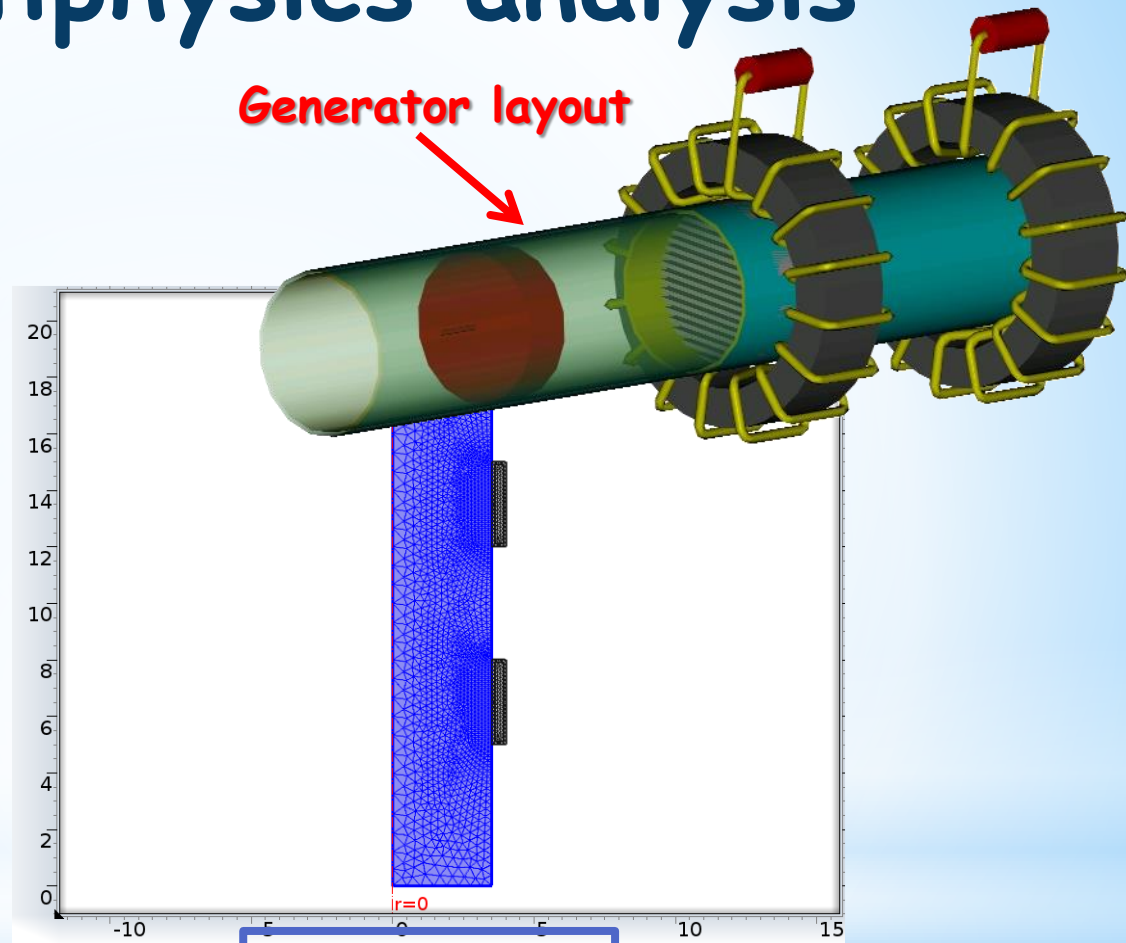
Messages Panel (Bottom Right): Shows the export status: "COMSOL 4.3.0.151", "Exported animation: C:\Users\Sara\Desktop\velocita.gif", and "Exported animation: C:\Users\Sara\Desktop\velocita.gif".

System Information (Bottom): Shows "282 MB | 350 MB".

FEM Multiphysics analysis



Geometry and materials used



Meshed Model

Physic-controlled mesh
Extra fine (2091 elements)

Governing equations

Variables

➤ Acoustic pressure (p)

➤ Particle velocity (\mathbf{u})

➤ Temperature (T)

➤ Density (ρ)

➤ Electric potential (V)

➤ Particles position

$$i\omega\rho_0\mathbf{u} = \nabla \cdot \left(-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \left(\frac{2\mu}{3} - \mu_B \right) (\nabla \cdot \mathbf{u})\mathbf{I} \right)$$

$$i\omega\rho + \rho_0(\nabla \cdot \mathbf{u}) = 0$$

$$i\omega\rho_0 C_p T = -\nabla \cdot (-\mathbf{k}\nabla T) + i\omega p T_0 \alpha_0 + Q$$

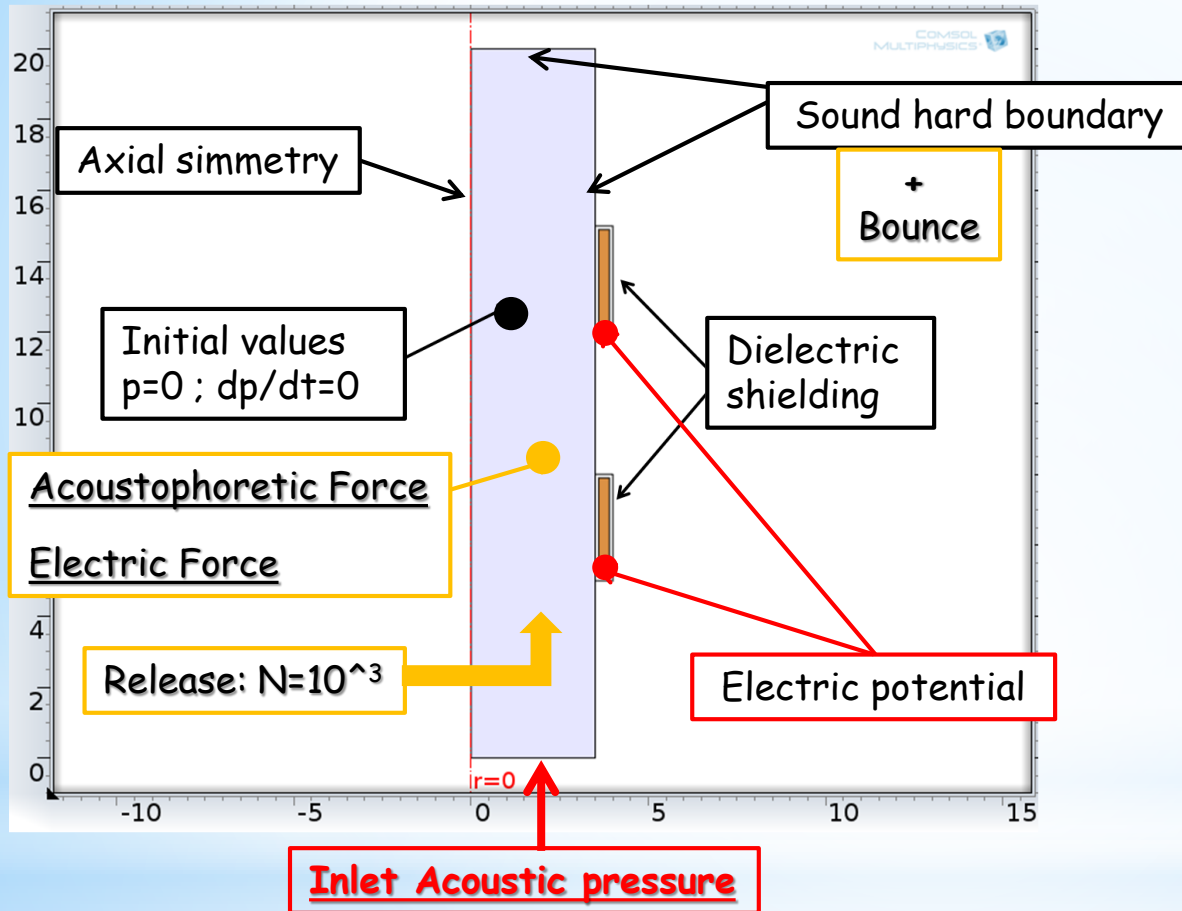
$$\rho = \rho_0(\beta_T p - \alpha_0 T)$$

$$-\nabla \cdot (\epsilon_0 \nabla V - \mathbf{P}) = \rho$$

$$\frac{d}{dt}(m_p \mathbf{v}) = \mathbf{F}_D + \mathbf{F}_g + \mathbf{F}_{\text{ext}}$$



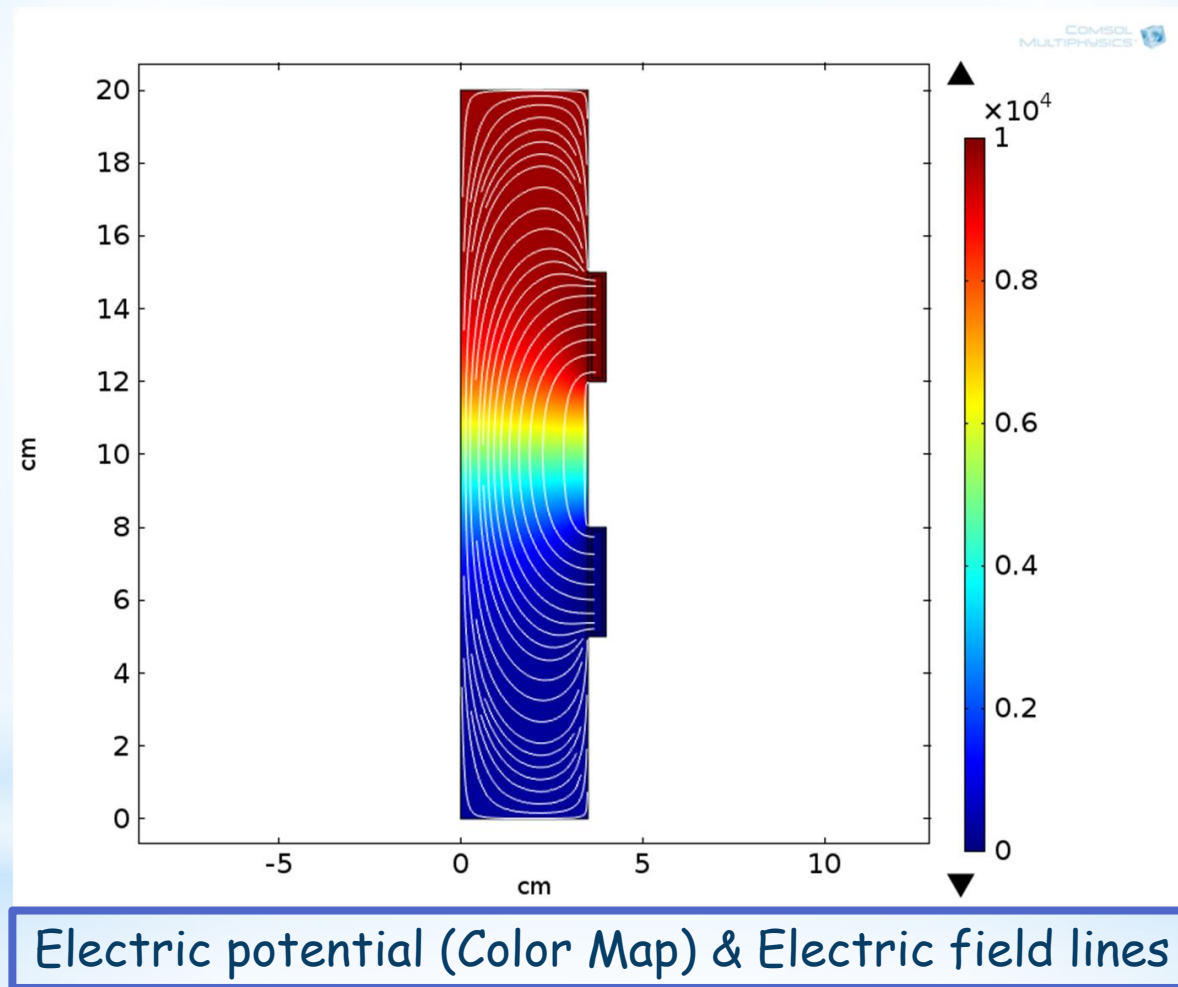
Boundary conditions & Study



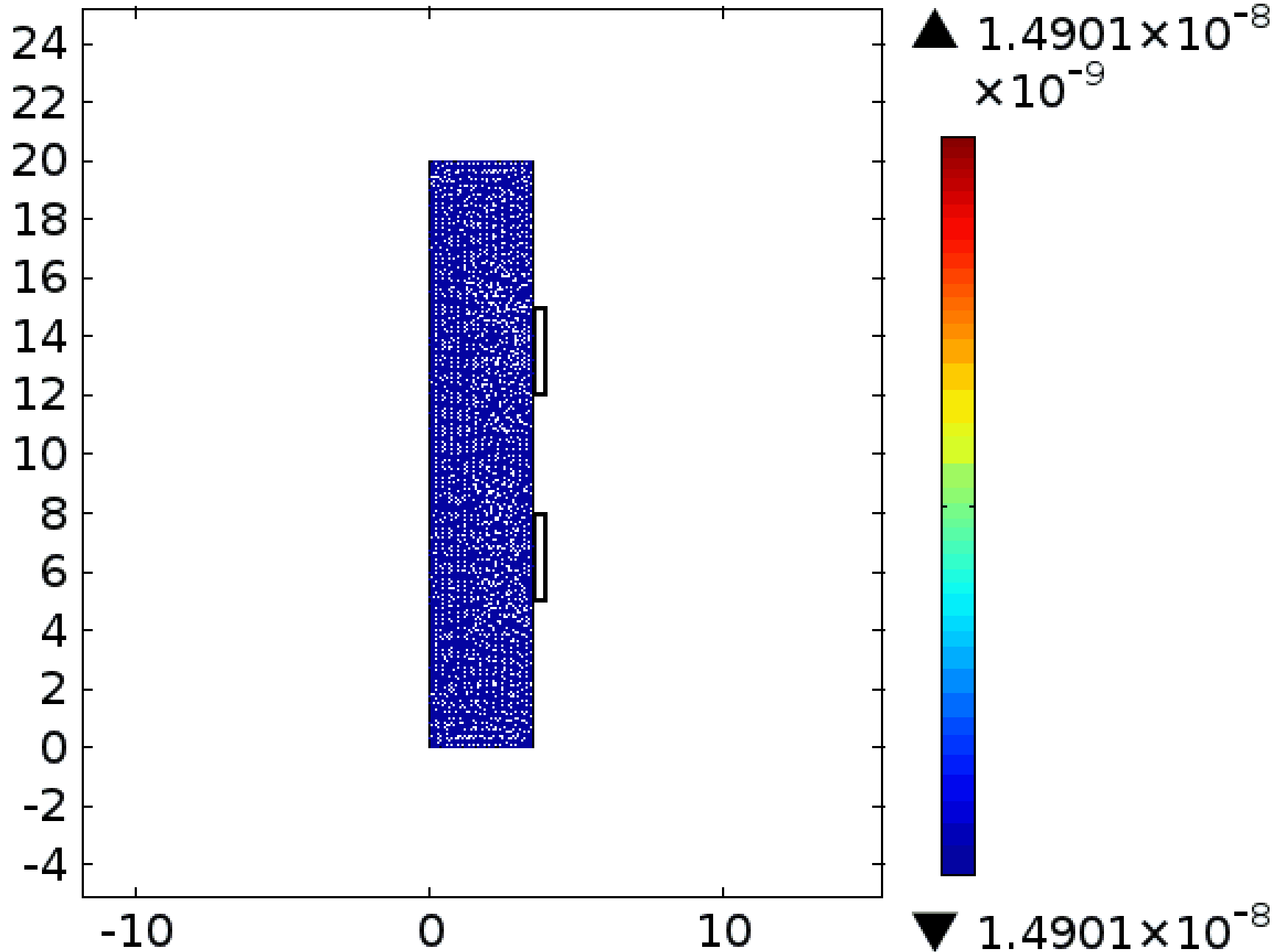
Variables

- Acoustic pressure (p)
- Particle velocity (u)
- Temperature (T)
- Density (ρ)
- Electric potential (V)
- Particles position

FEM Multiphysics analysis



Time=0 Particle trajectories



CONCLUSIONS

- Simplified study about the device
- FEM analysis of 2 distinct problems
- Best velocity profile (acting on frequency or radius)
- Equilibrium condition for charge distribution
- Encouraging preliminary results

FUTURE WORKS

- Reduce simplificative hypothesis
- FEM analysis of the complete system
- Develop a prototype



THANK YOU

COMSOL CONFERENCE 2015 GRENOBLE
OCTOBER 14-16, 2015

