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Modeling and Simulation of Load Controlled Noise of Power Transformers

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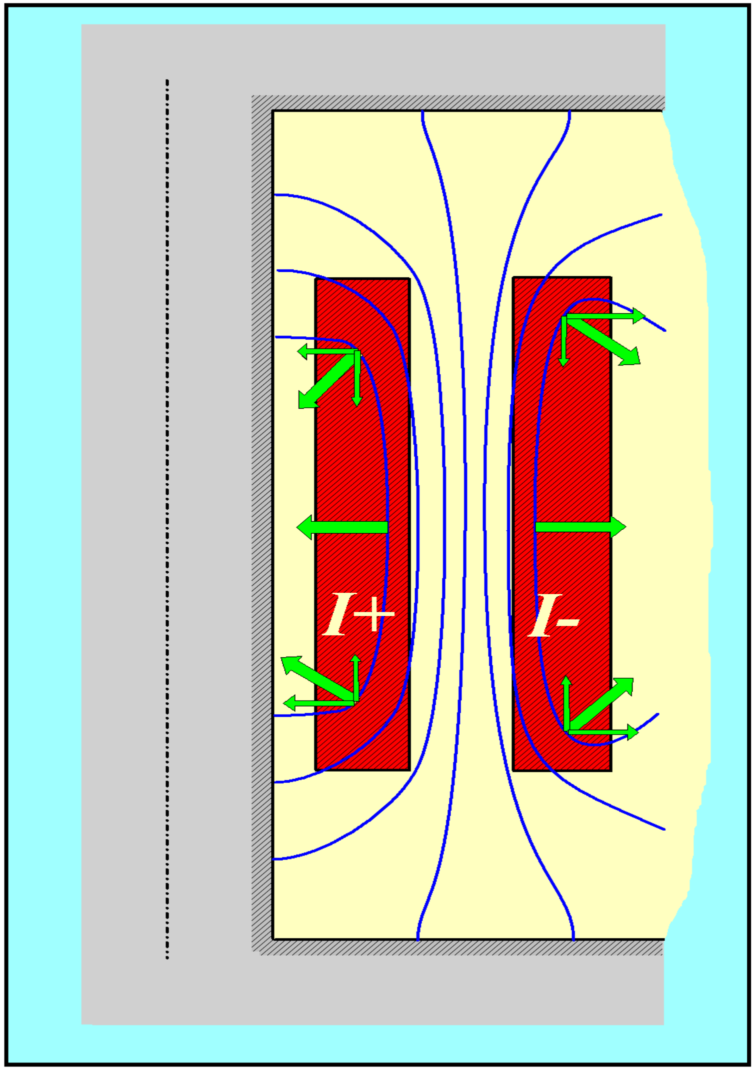
Overview

- Introduction
- Important steps for Load Noise simulation
- Results
- Summary

Introduction

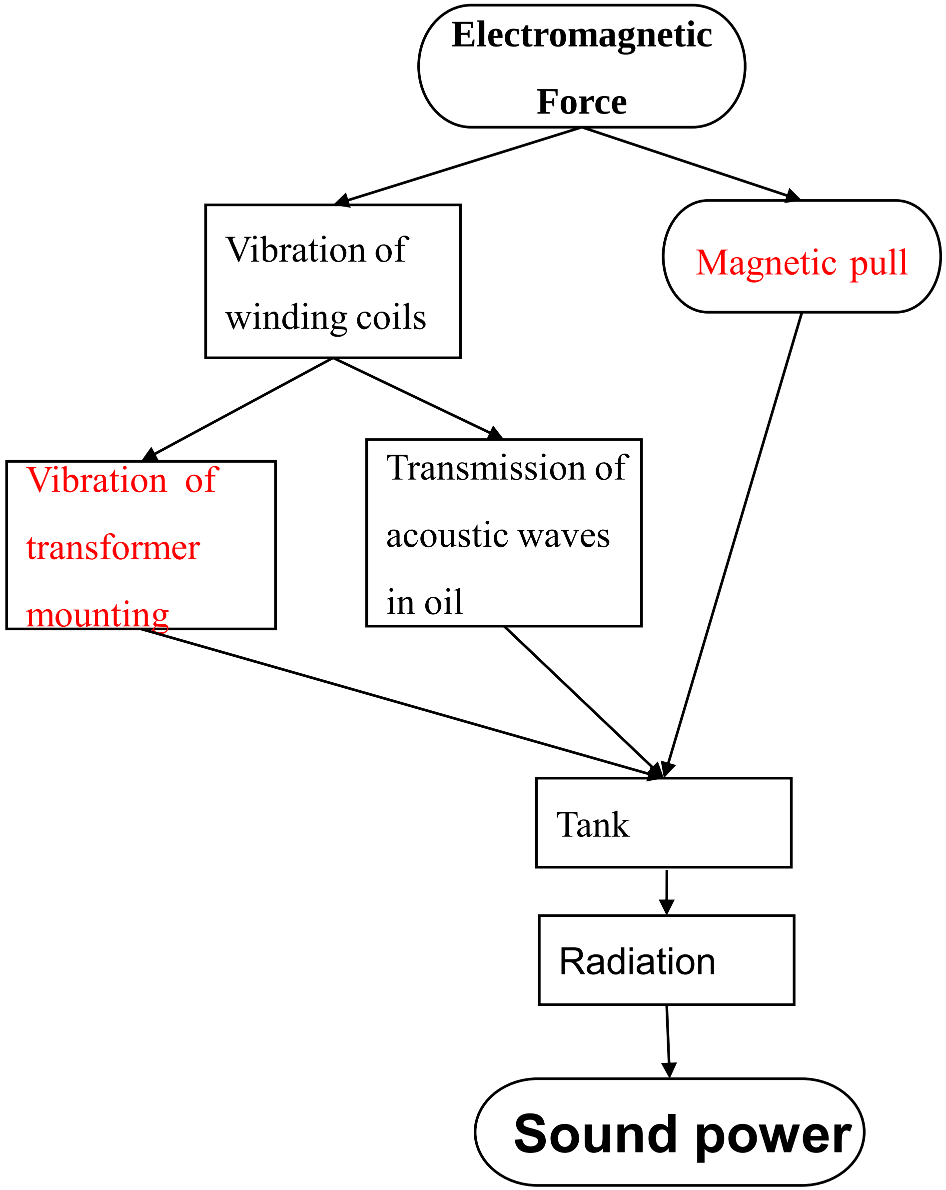
- Transformers exhibit vibrations while operating, and generate a characteristic **hum noise. The noise, being of a marked tonal character, causes irritation and discomfort.**
- Transformers are moved nearer to the working and living districts. Many countries have stipulated maximum permissible noise levels.

Load noise – Its Source



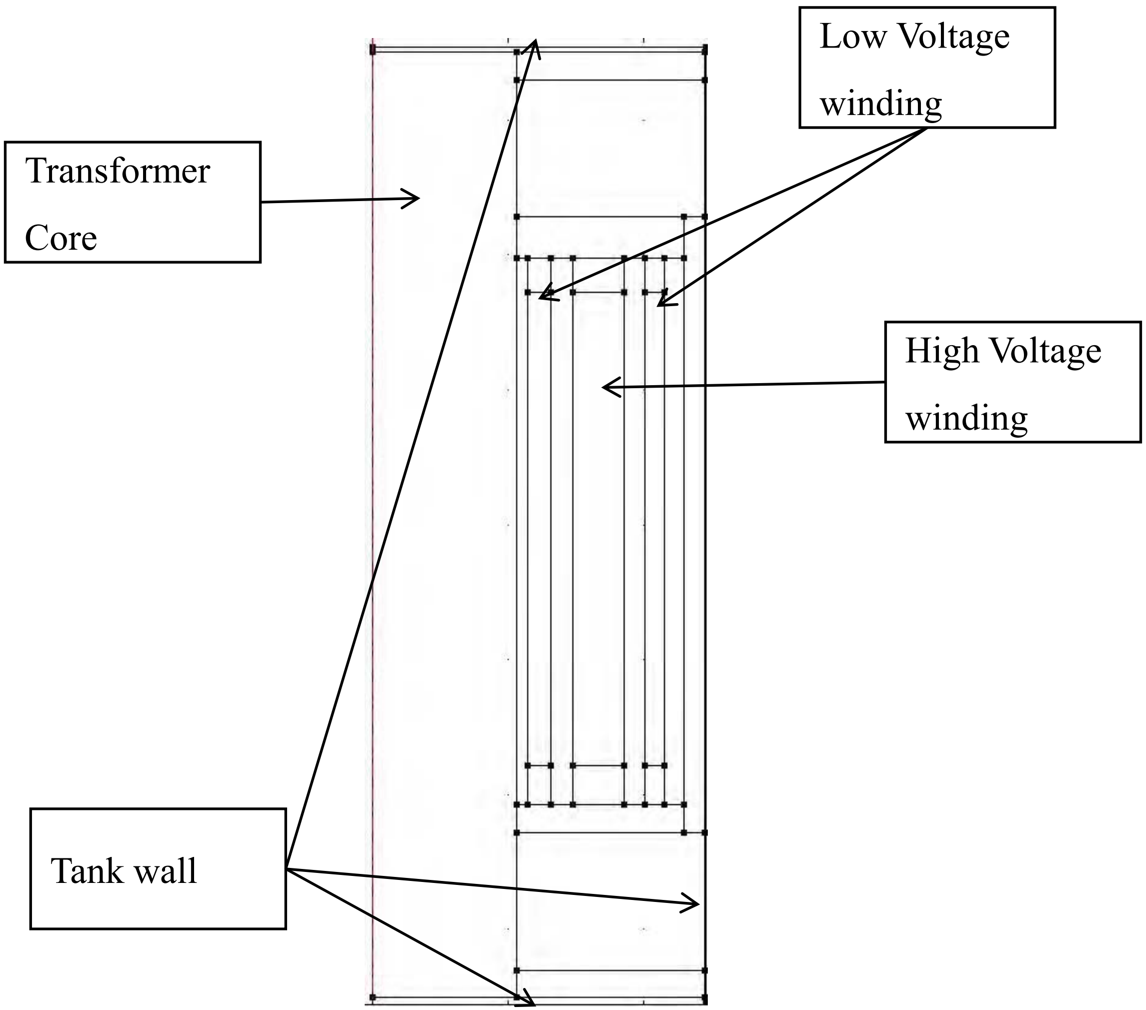
- Winding vibrations
  - Axial flux leading to radial forces and vibrations
  - Radial flux leading to axial (compressive) forces and vibrations

Transformer Winding Sound – Generation



- Radiated sound power is the end result of a series of mechanisms
- Each step is influenced by a number of factors
- Here we are not looking at core noise or ventilation noise.

Electromagnetic Model- Geometry



Electromagnetic Model- Equations

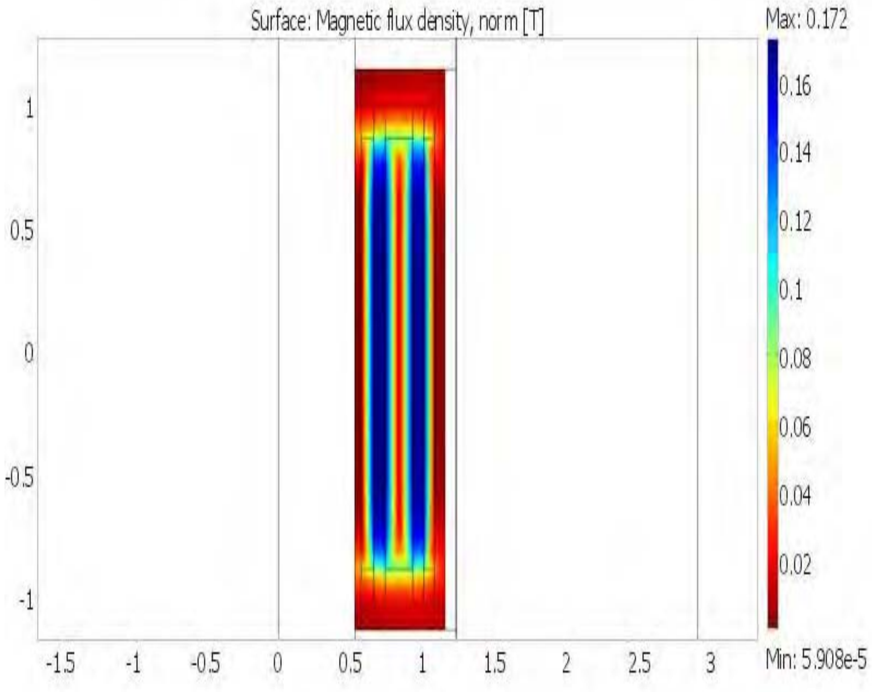
- In the electro magnetic model our main interest is Lorentz Forces

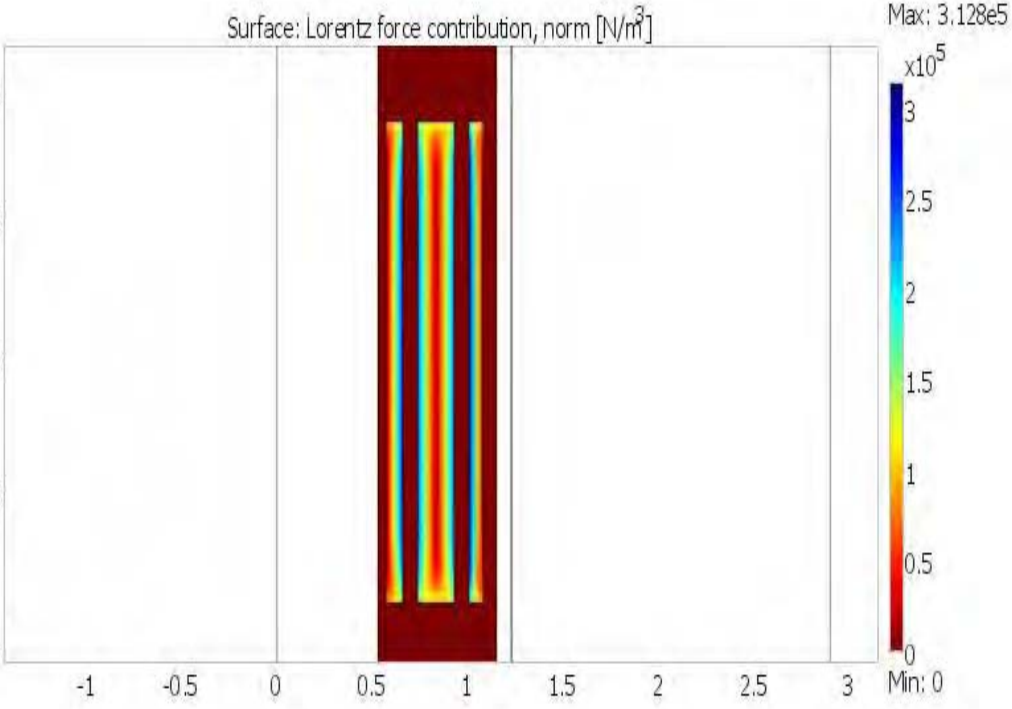
$$f_v = J \times B$$

- We are deriving these variables using magnetic vector potential formulation.

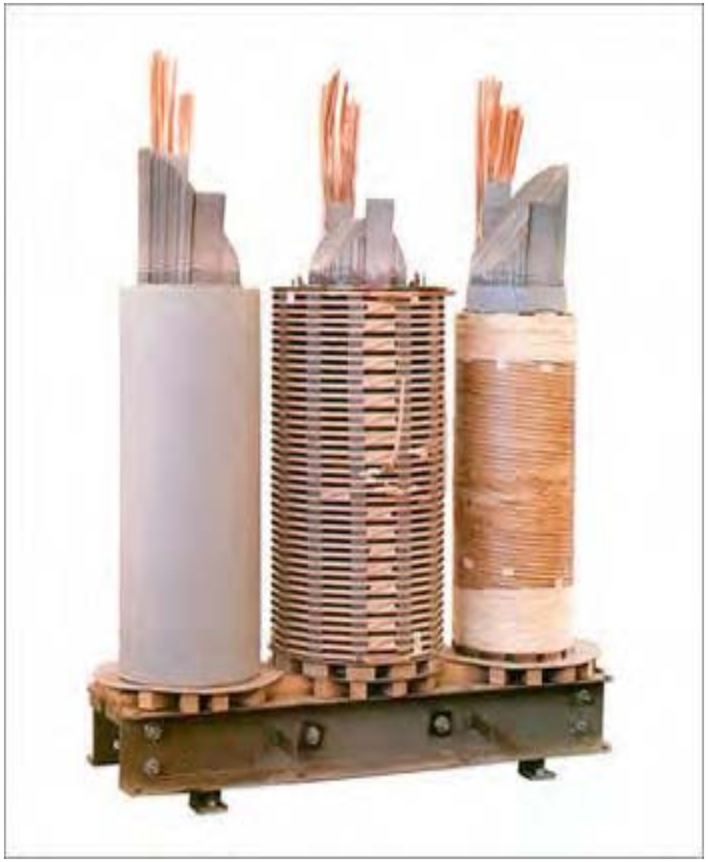
$$\nabla \times \upsilon \nabla \times A = J_i - \gamma \frac{\partial A}{\partial t} + \gamma (v \times \nabla \times A)$$

Electromagnetic Model -Results



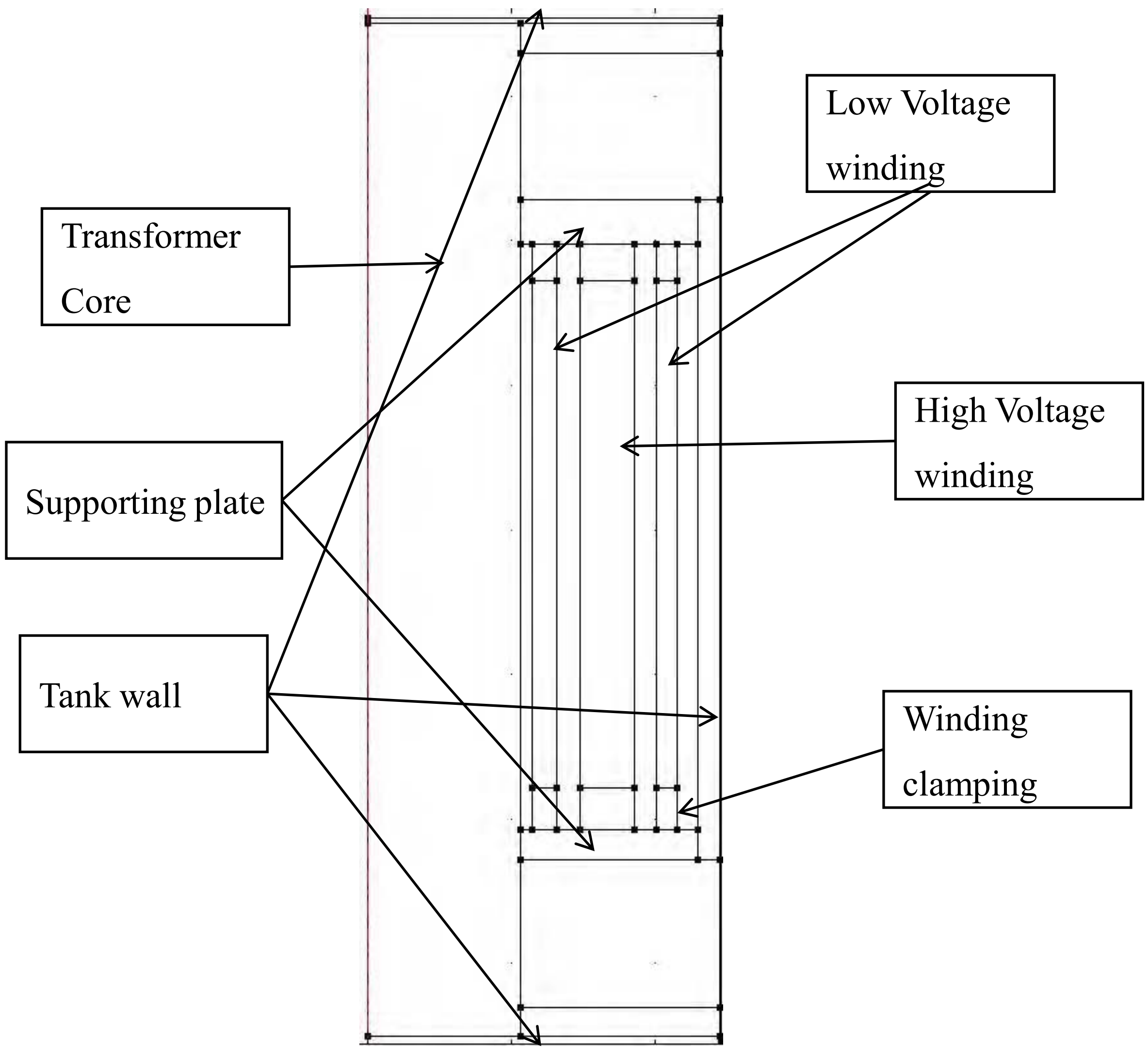


Mechanical Model

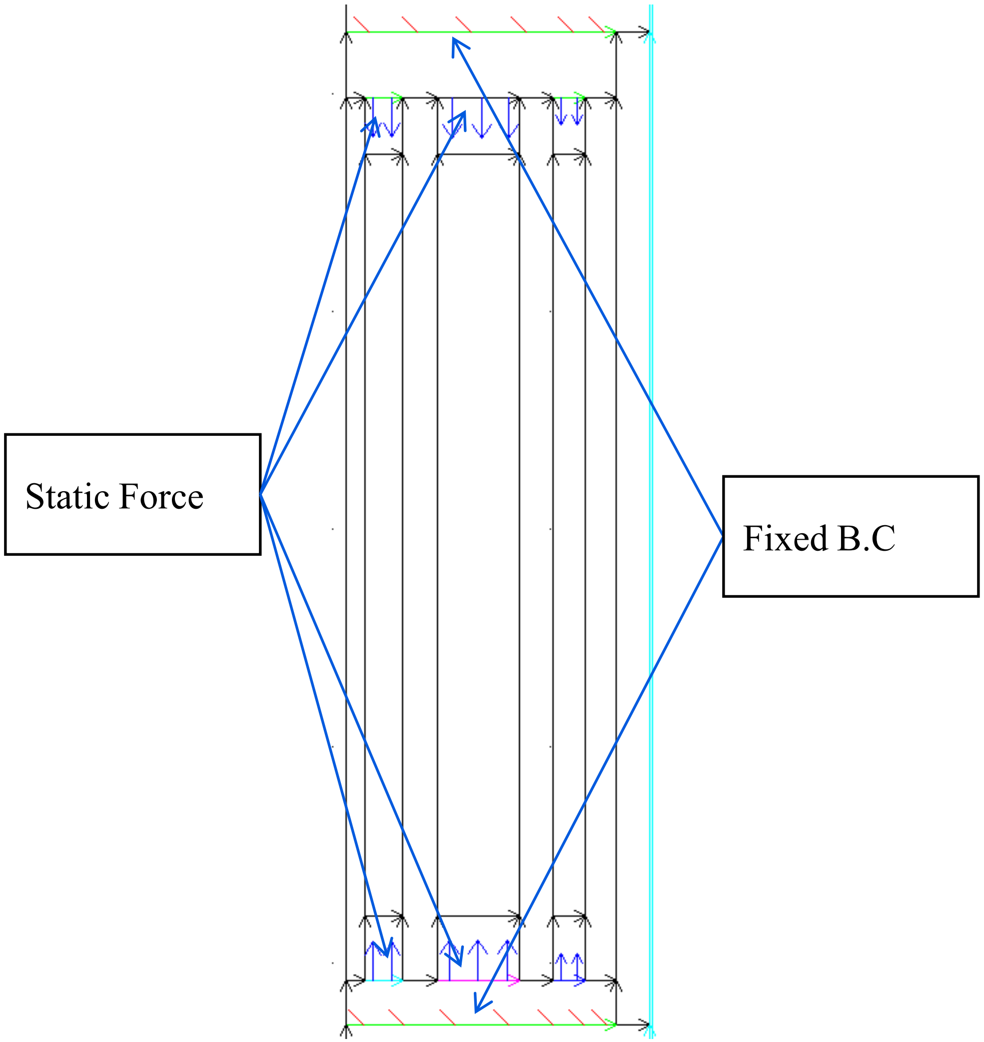


- Aim of the mechanical model is getting correct vibration levels.
- Transformer windings are complex structures made of copper, pressboard and insulation paper
- This structure is simplified in the model.

Mechanical Model- Geometry



Mechanical Model- Equations

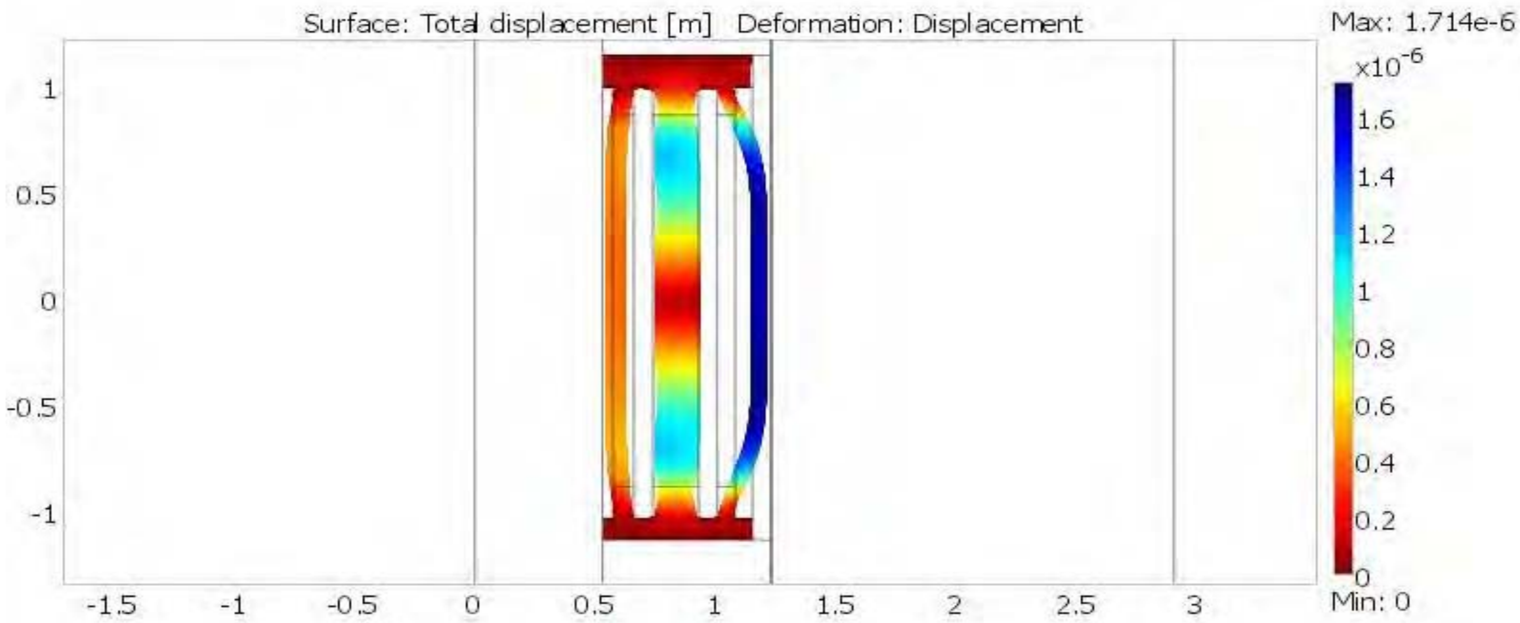


- We are using the Navier's equations to describe the dynamical behavior of mechanical systems

$$f_v + B^t[c]Bu = pa$$

- Even though static forces do not change the dynamic behavior of windings they alter the mechanical properties of pressboard

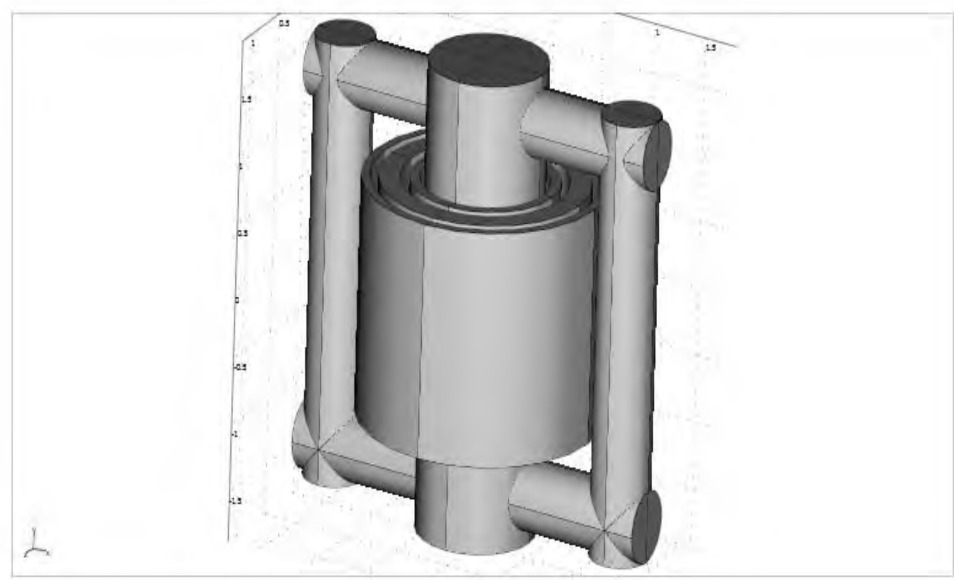
Mechanical Model- Result



Radial Disp	Winding A	Winding B	Winding C
Empirical Formula	5E-7[m]	6E-8[m]	1.9 e-6[m]
Simulation Results	3.9E-7[m]	9E-8[m]	1.71E-6[m]

Acoustic Model

- Aim of this simulation is calculating sound radiation outside the tank
- Transformer tanks are generally rectangular structures with stiffeners



Acoustic Simulation -Equations

- In acoustic simulation we are solving wave equations which read as

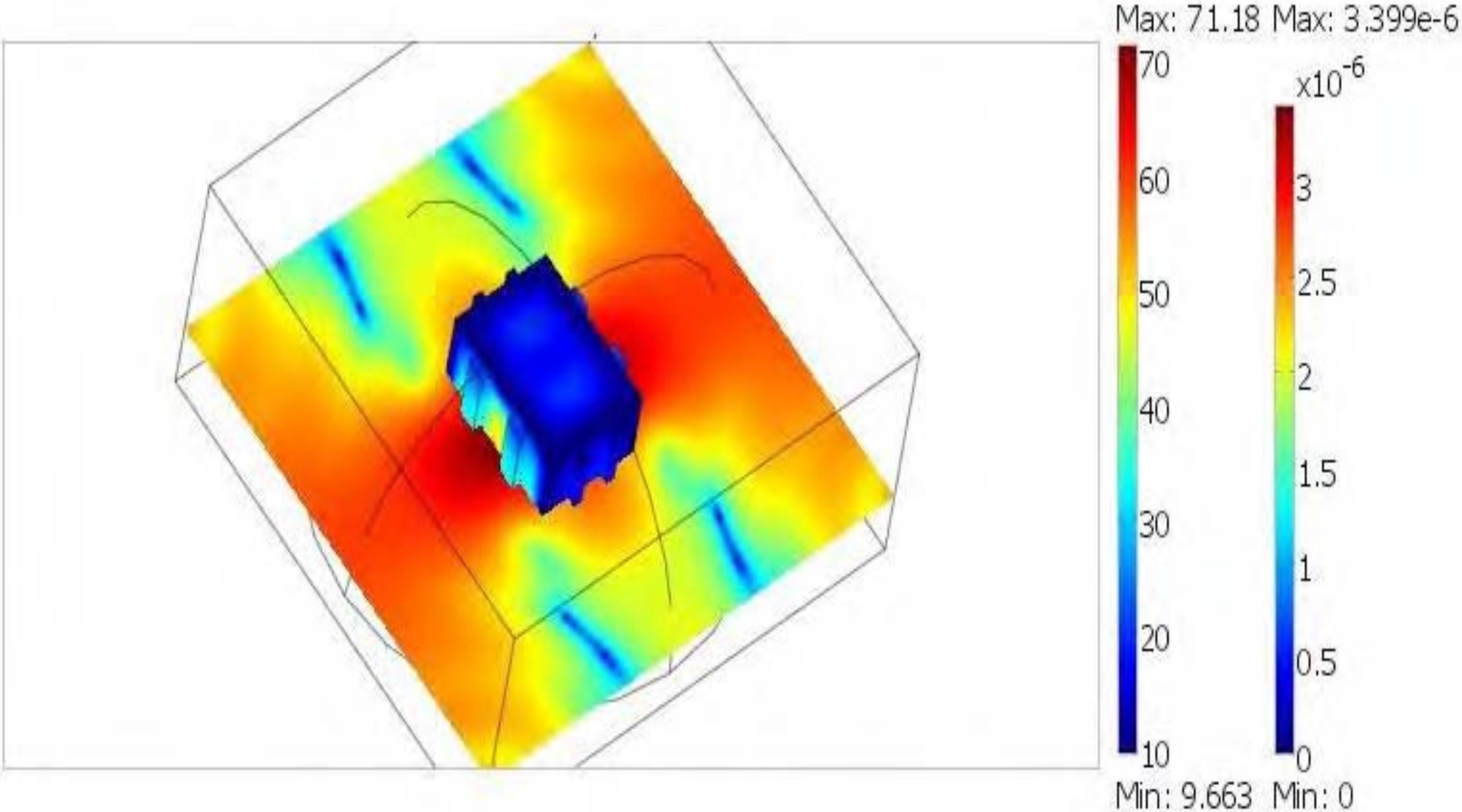
$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = 0$$

- We are using following boundary conditions for acoustic mechanic coupling on winding and tank boundaries

$$\mathrm{n}\frac{\partial^2 \mathrm{u}}{\partial \mathrm{t}^2} = \mathrm{n.a}_{\mathrm{fluid}}$$

$$-np = \sigma_n$$

Acoustic Simulation -Result



Verification of the model

dBA levels for 20 measurement points

	1	2	3	4	5	6	7	8	9	10
0.75m	61.	52.	53	57.1	65.5	67.8	65.5	57.1	53	52.4
2.25m	58.	52.	53.0	58	64.5	66.5	64.4	58	53.1	52.6

Due to perfectly symmetric results just half of the transformer is measured.

- Calculated Overall SPL is 61.6dB(A) where the actual measurement results are 62.4dB(A)

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Summary

- 3D Acoustic model is built to understand radiated noise from transformer tank.
- Electromagnetic and mechanical simulations are done in 2D axisymmetric geometry
- Results are carried by extrusion coupling to the 3D geometry.
- Measurement and simulation results show good agreement

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