3-D Magneto-Structural Analysis of Magnetic Pulse Welding (MPW)

A. Amardas*, Bharat R. Doshi

Institute for Plasma Research
Gandhinagar, India

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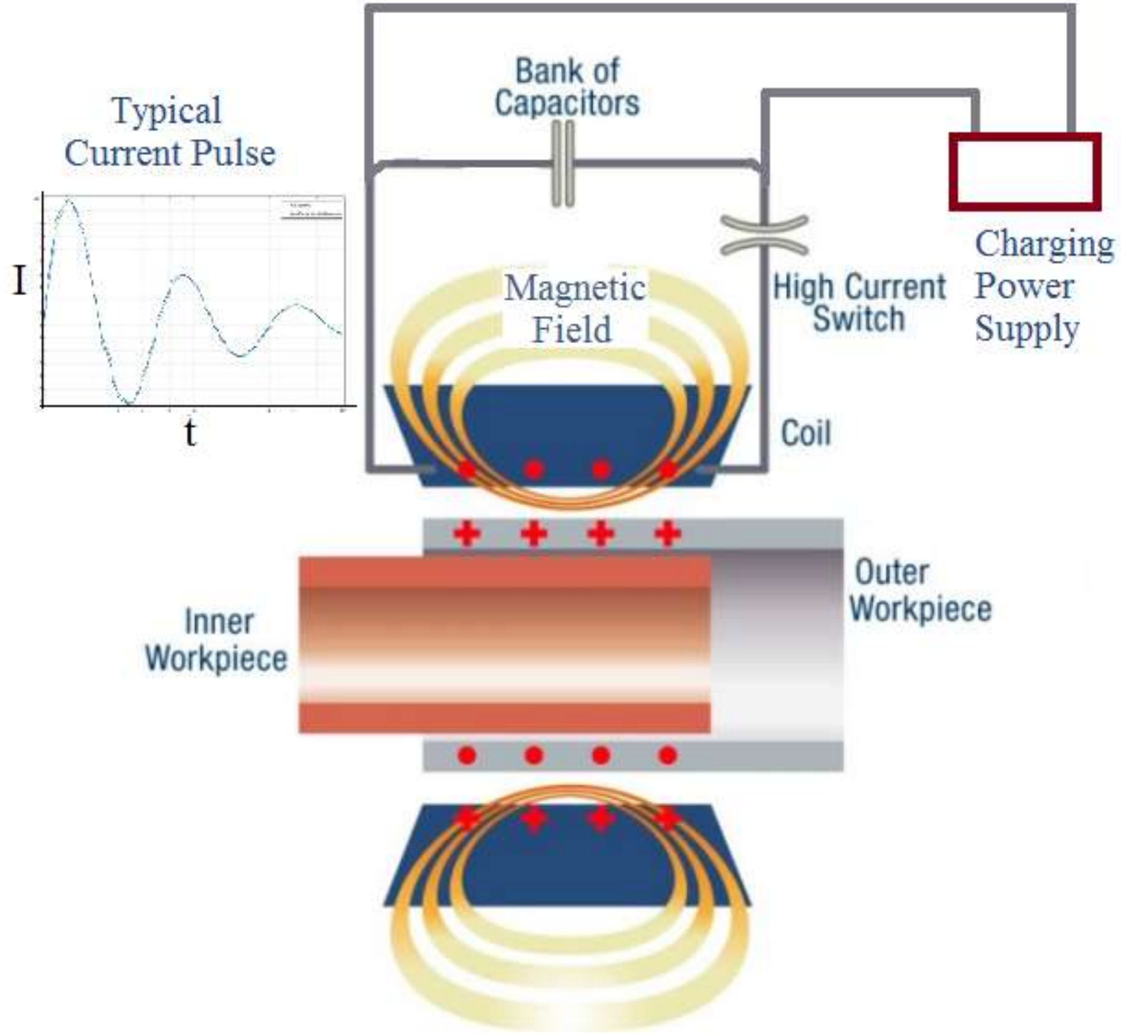
*Corresponding Author: amar@ipr.res.in

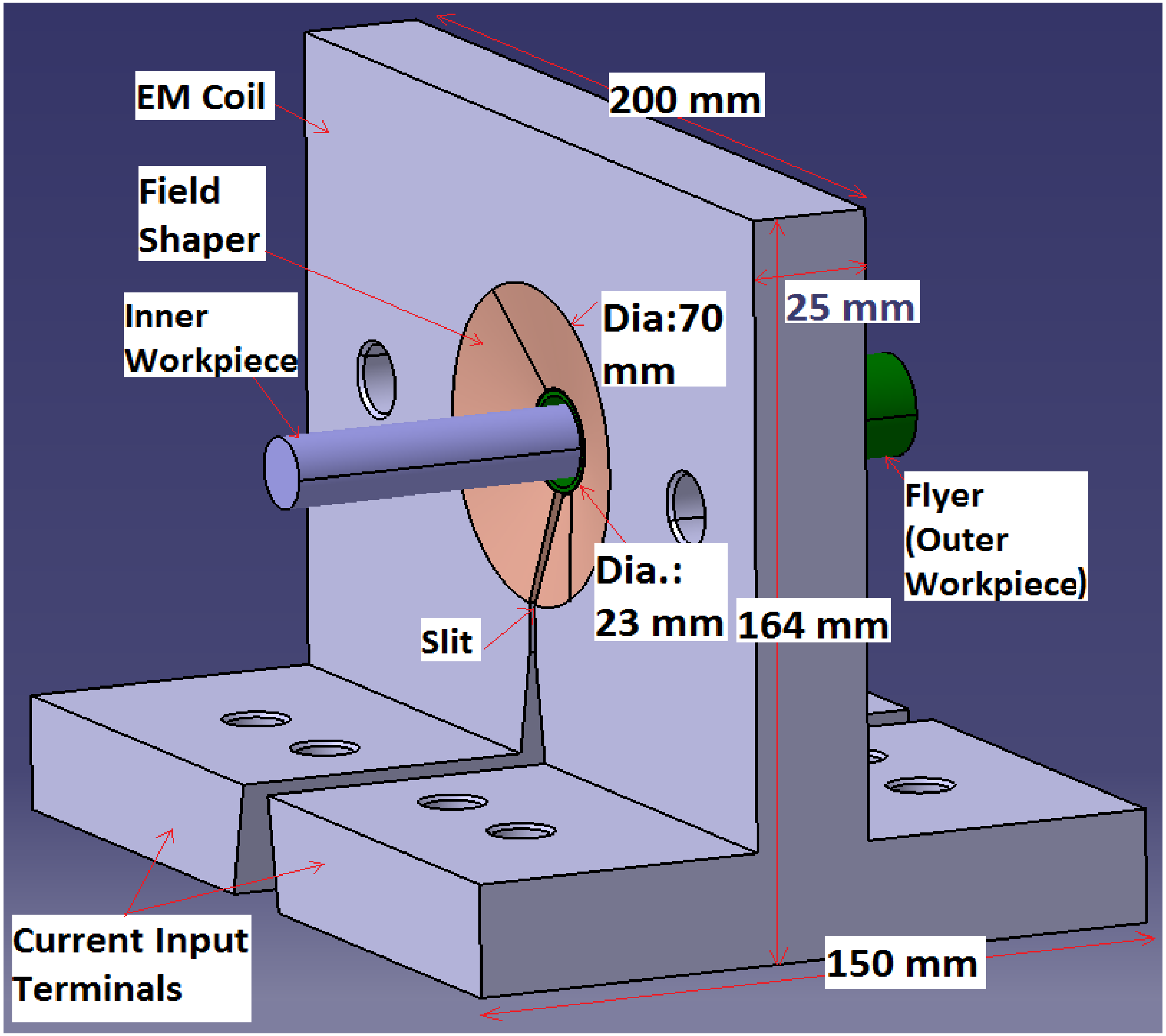
Structure of this talk:

- What is “Magnetic Pulse Welding “?
- Why is it important ?
- Why simulation is required ?
- Why 3-d simulation ?
- What are the Governing equations ?
- How is the simulation done ?
- Results
- Conclusions

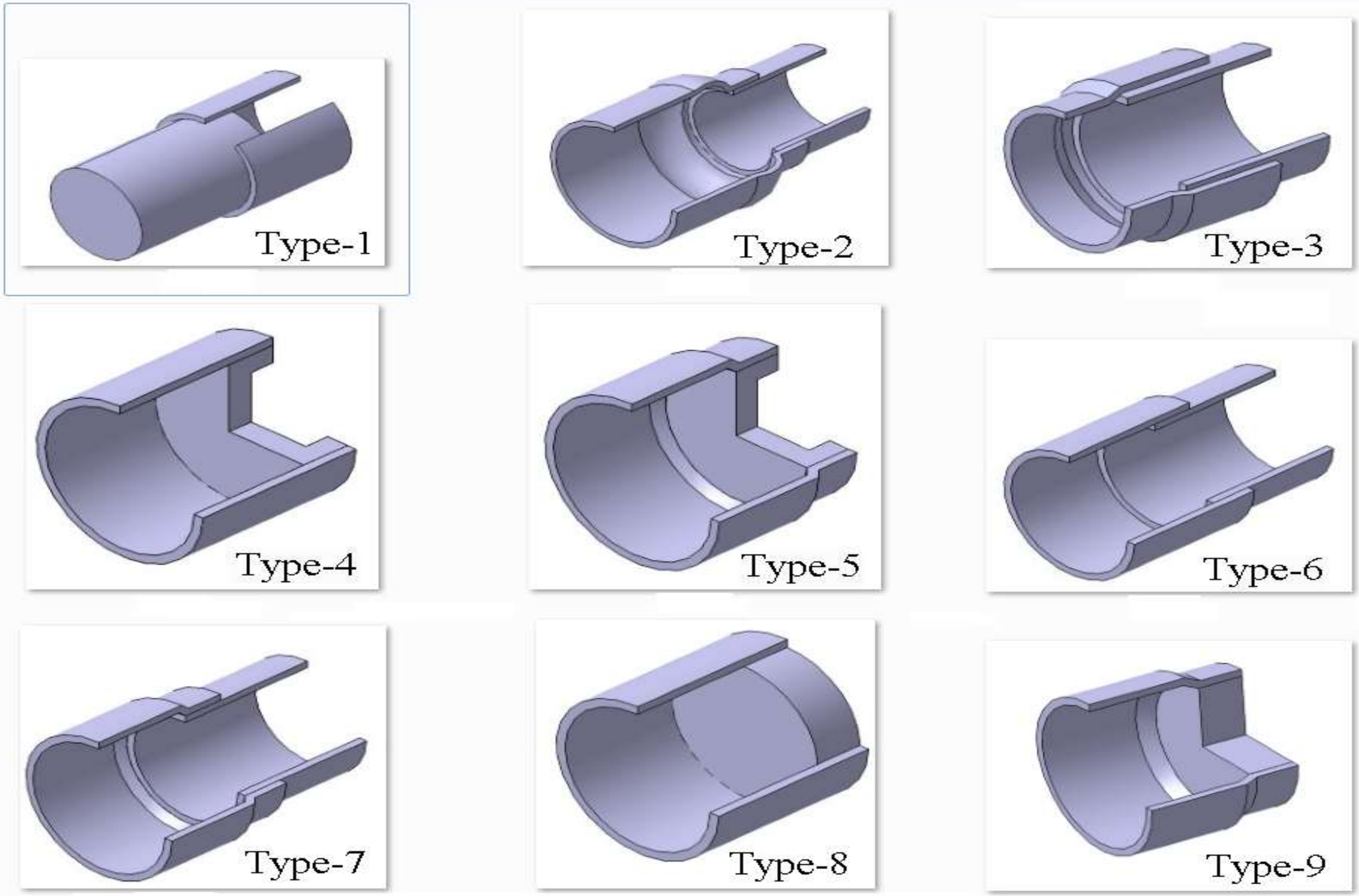
- What is “Magnetic Pulse Welding “?



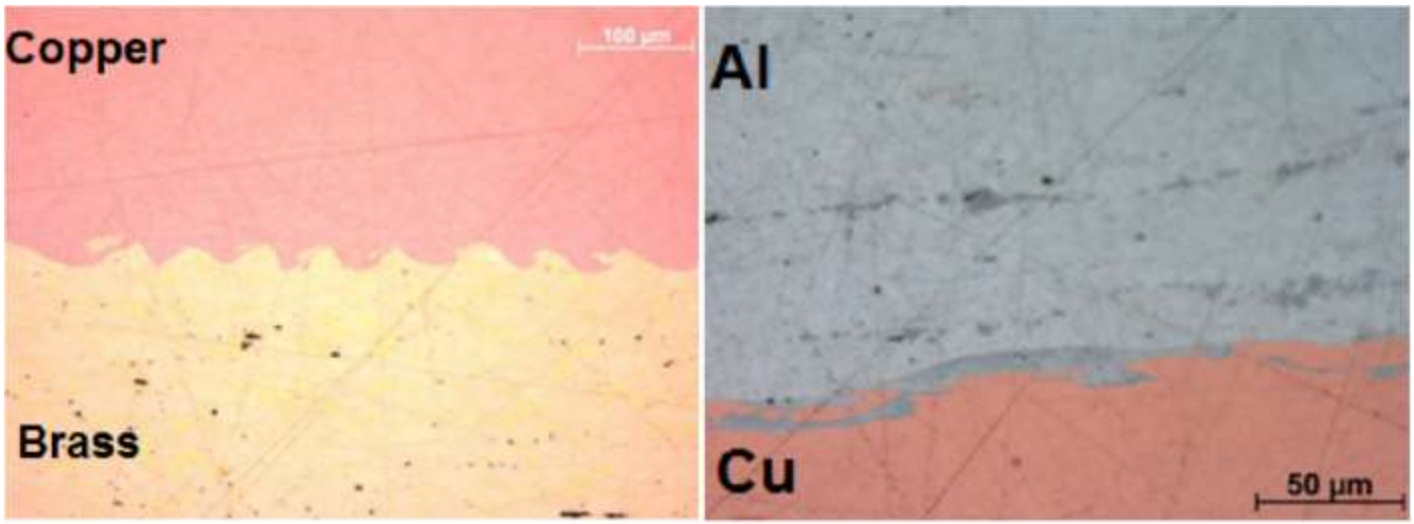
Schematic diagram of Magnetic Pulse Welding System



Geometry of MPW system



Different types of joints for which MPW is suitable



‘Wavy phase’ at the interface of the joint made by high velocity impact in MPW

- Why is it important ?

- It is a fast & clean method (t ~ μs)
- No heat is produced in the process
- No base metal is used
- Can join dissimilar materials with good quality
- Very efficient & cost effective

- Why simulation is required ?

  - To improve the quality of joint with

    less number of experimental trials

- Why **3-D** simulation ?

- MPW system is “fully symmetric”
- Non-uniformity in the joint can be captured only with 3-D
- Results with 2-D axisymmetric model will not give full details
- Of the process.

Governing Equations

Maxwell's Equations:

$$\nabla \times \mathbf{B} = \mu \mathbf{J}$$ (Ampère's circuital law)

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$ (Faraday's law of induction)

$$\nabla . \mathbf{B} = 0$$ (Gauss's law for magnetism)

Ohm's law:

$$\mathbf{J} = \sigma(\mathbf{E} + \mathbf{v} \times \mathbf{B}) + \mathbf{J}_e$$

& using $\mathbf{B} = \nabla \times \mathbf{A}$ ($\mathbf{A}$ is Magnetic Potential)

Magnetic Diffusion type eqn.

$$\sigma \frac{\partial \mathbf{A}}{\partial t} + \nabla \times (\mu_0^{-1} \nabla \times \mathbf{A}) = \mathbf{J}_e$$

Lorentz force:

$$\mathbf{f_v} = \mathbf{J}\mathrm{X}\mathbf{B} = \frac{1}{\mu}(\boldsymbol{\nabla}\mathrm{X}(\boldsymbol{\nabla}\mathrm{X}\mathbf{A}))\mathrm{X}(\boldsymbol{\nabla}\mathrm{X}\mathbf{A})$$

Newton's 2nd law :

(in terms of the Cauchy stress tensor σ)

$$\rho\frac{\partial^2\mathbf{u}}{\partial t^2} = \nabla_{\mathbf{X}}\boldsymbol{\sigma} + \mathbf{f_v}$$

Computational Method

Partial Differential Equations to solve :

$$\sigma \frac{\partial \mathbf{A}}{\partial t} + \nabla \mathrm{X} (\mu_0^{-1} \nabla \mathrm{X} \mathbf{A}) = \mathbf{J}_{\boldsymbol{e}}$$

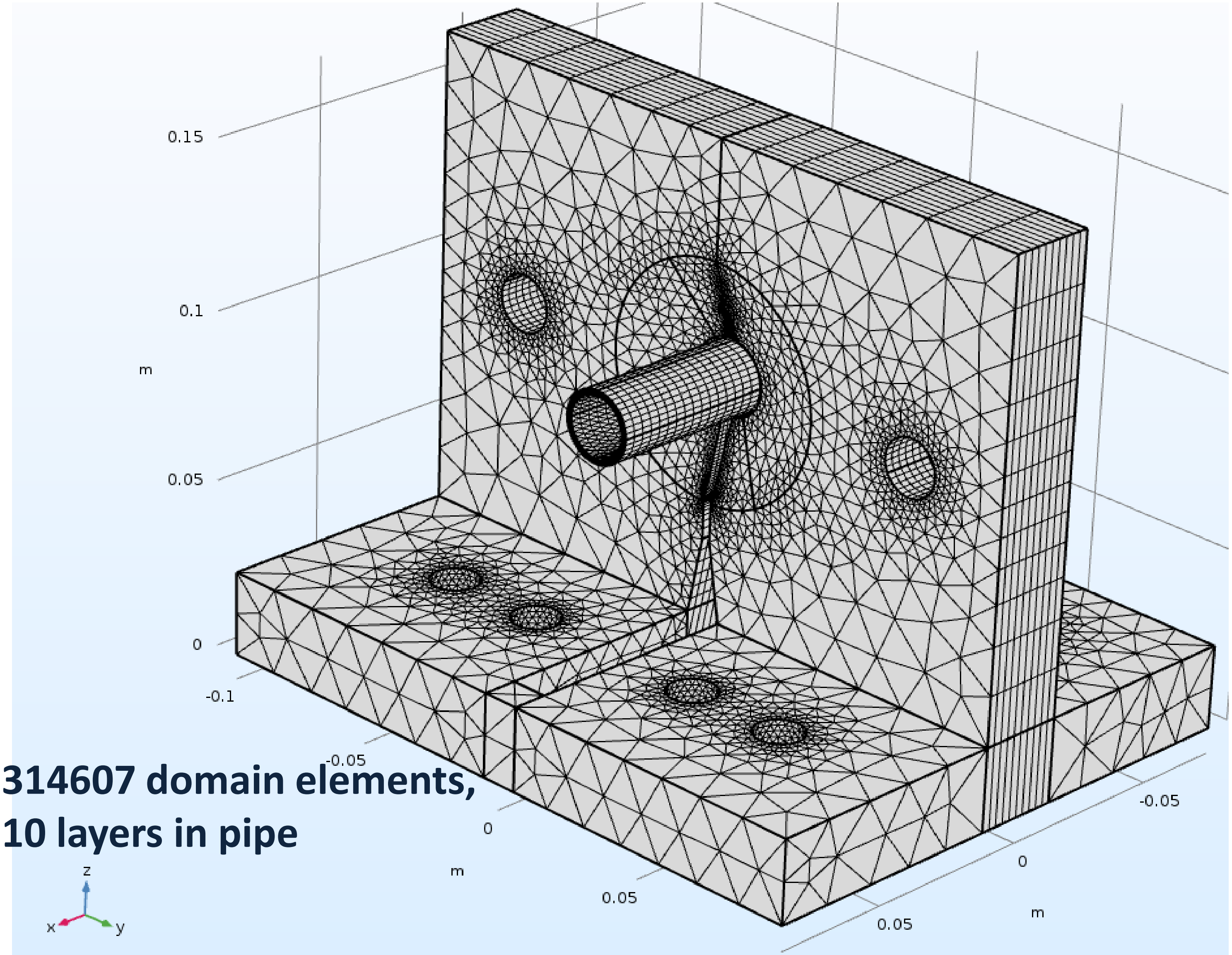
$$\mathbf{f_v} = \mathbf{J}\mathrm{X}\mathbf{B} = \frac{1}{\mu}(\boldsymbol{\nabla}\mathrm{X}(\boldsymbol{\nabla}\mathrm{X}\mathbf{A}))\mathrm{X}(\boldsymbol{\nabla}\mathrm{X}\mathbf{A})$$

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla_{\mathrm{X}} \boldsymbol{\sigma} + \mathbf{f_v}$$

Discretize the Equations by Finite Element Method (FEM)

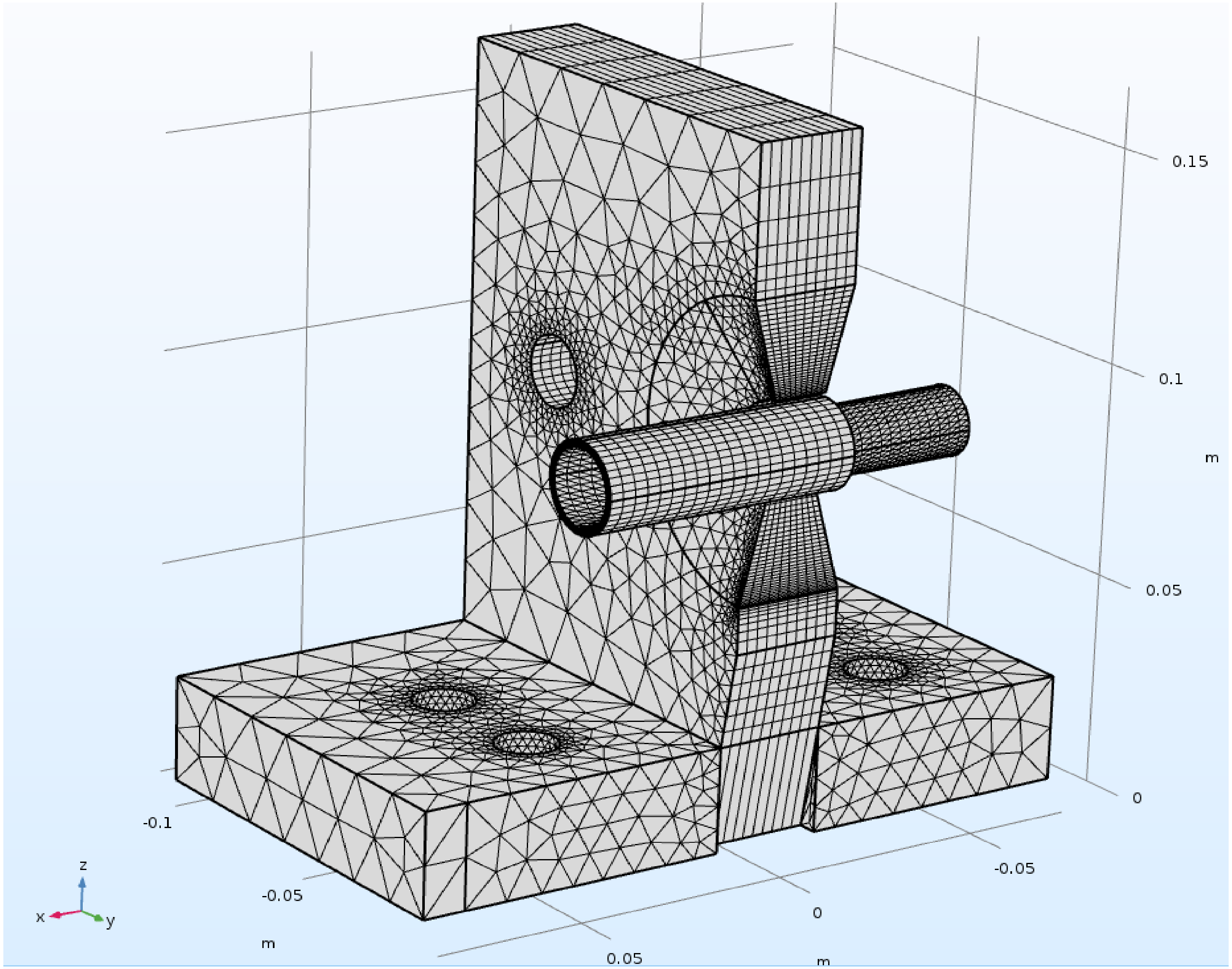
- Finite element method (FEM) is chosen here as it is one of the most powerful and robust methods.
- FEM code meshes computational domain problem into small elements and forms a set of linear equations using weighted residuals (called 'Galerkin method').
- Solve these equations in the form of ‘global stiffness matrix’ to get the solution in any irregular geometries.

“Comsol Multiphysics” is used to solve this problem by above method



314607 domain elements,
10 layers in pipe

Finite element model of MPW system



Finite element model of MPW system (cross section view)

Partial Differential Equations to solved using :

$$\sigma \frac{\partial \mathbf{A}}{\partial t} + \nabla X \left(\mu_0^{-1} \nabla X \mathbf{A}\right) = \mathbf{J}_e$$

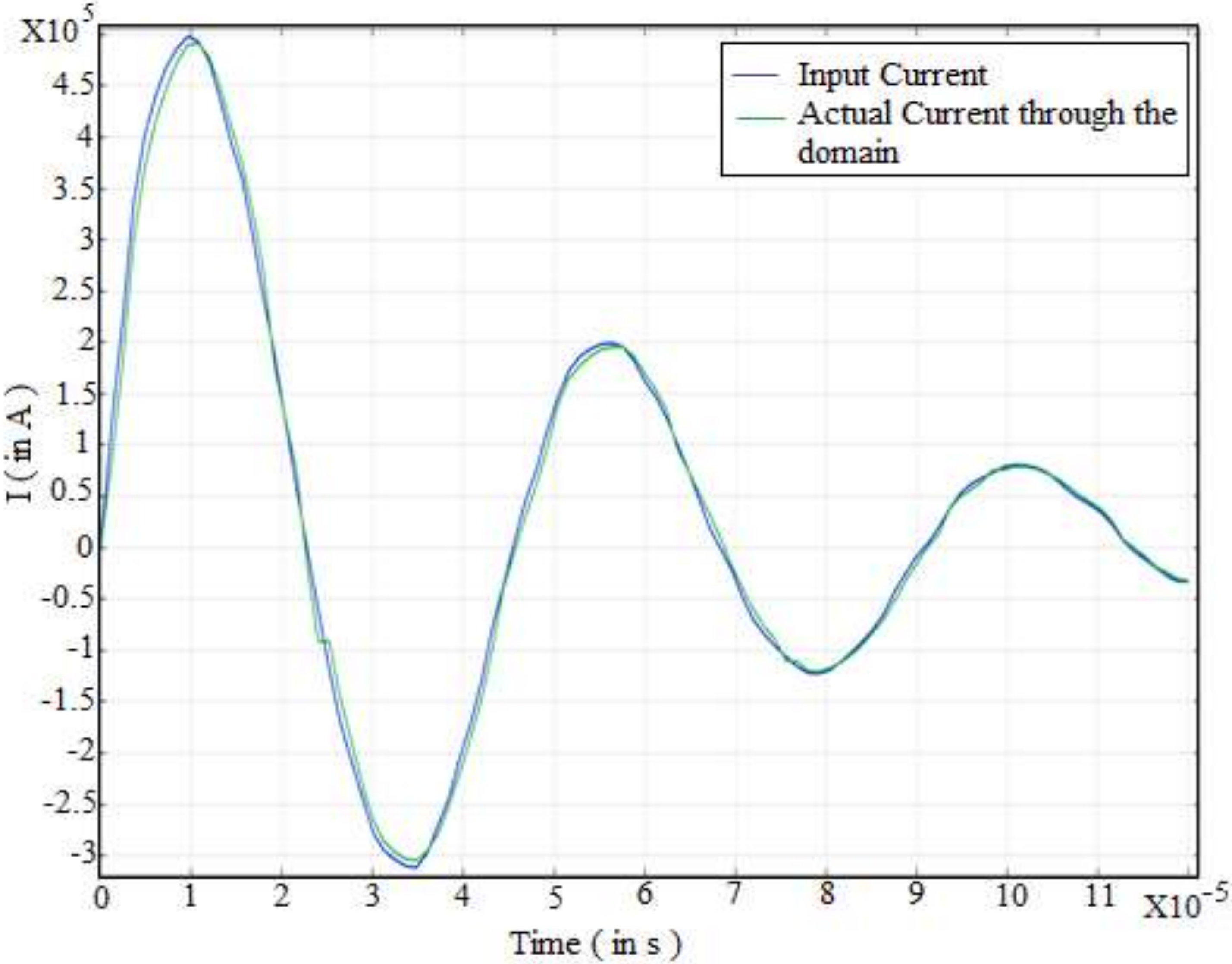
$$\mathbf{f_v} = \mathbf{JXB} = \frac{1}{\mu}(\nabla X(\nabla X A))X(\nabla X A)$$

“Magnetic Field" interface of “AC/DC Module “ ( ) ( )

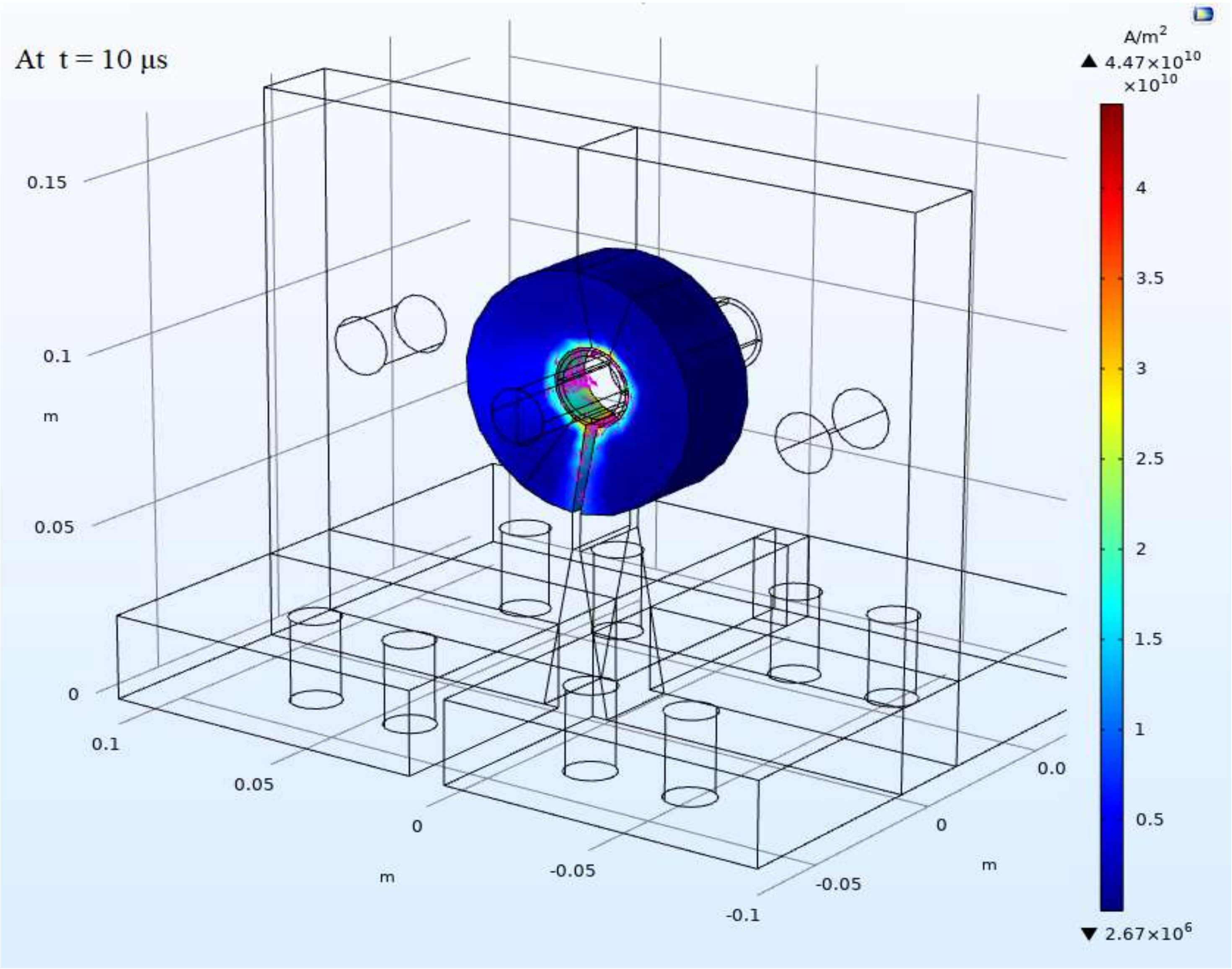
$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla_X \boldsymbol{\sigma} + \mathbf{f_v}$$

→ **“Solid Mechanics" interface of “Structural Mechanics” Module ( ) ( )**

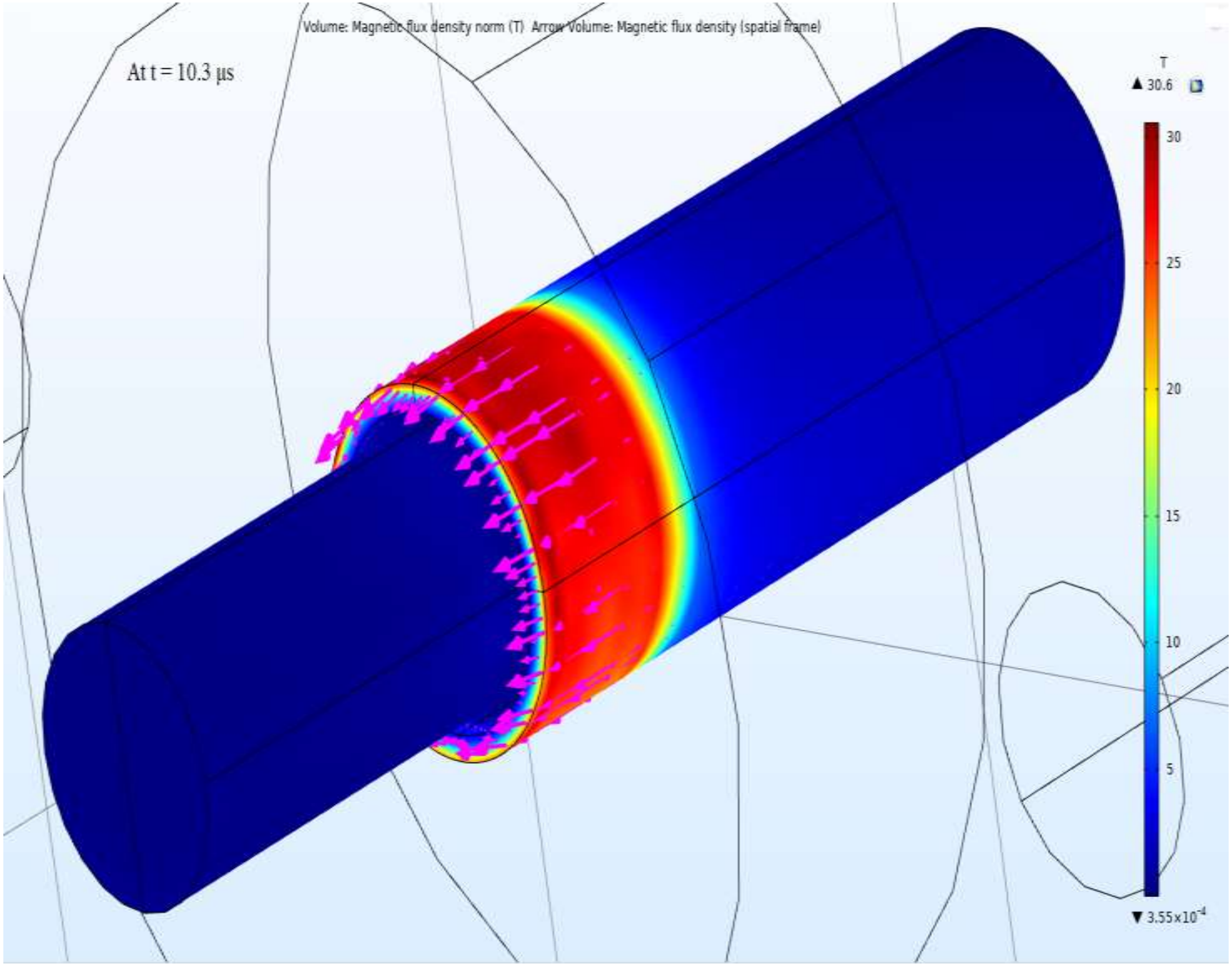
Both physics are “fully coupled” by reading the data of $\mathbf{f_v}$ in to another at every time step.



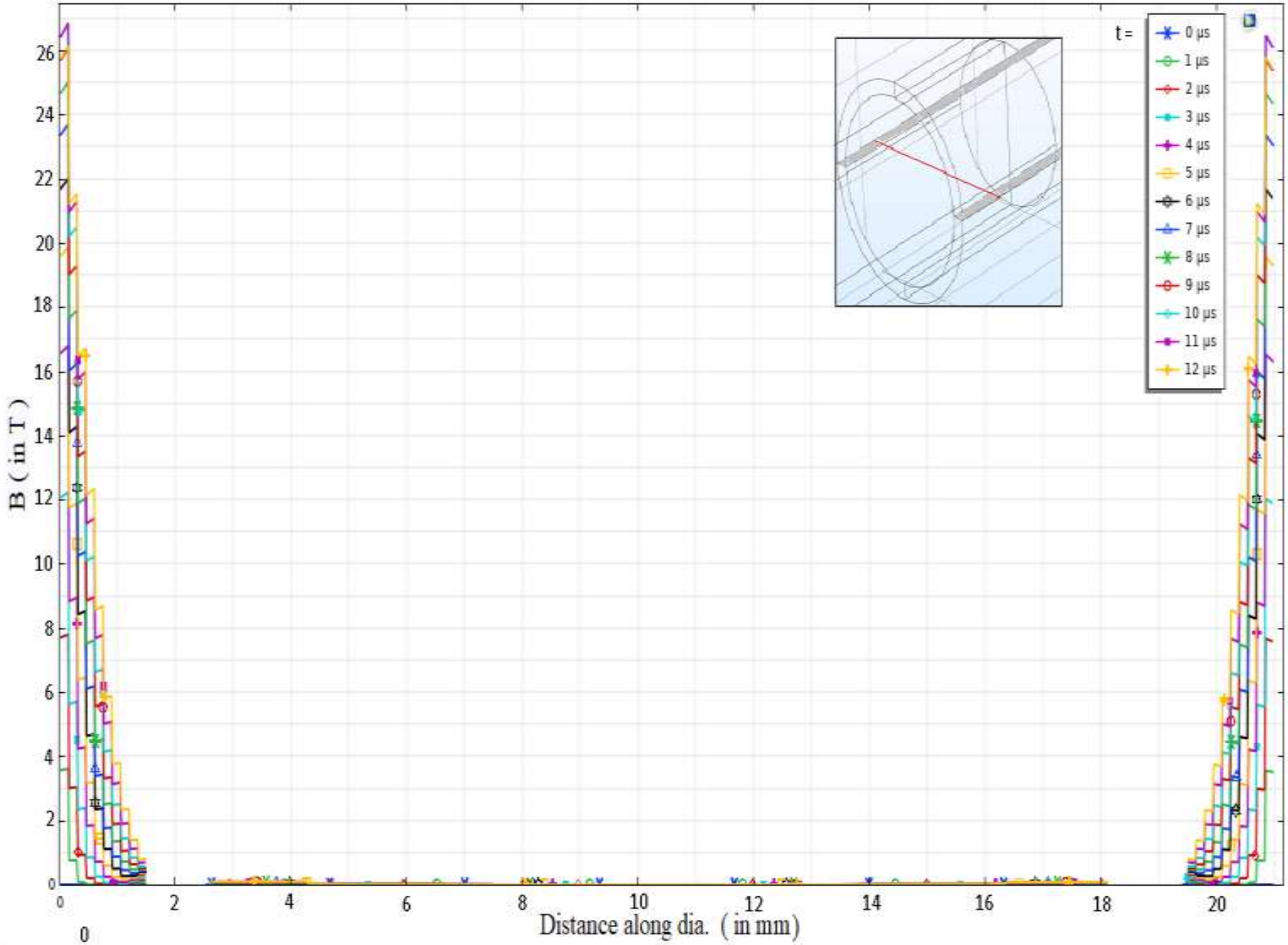
Input Current fed & the actual current generated in the finite element model of the system



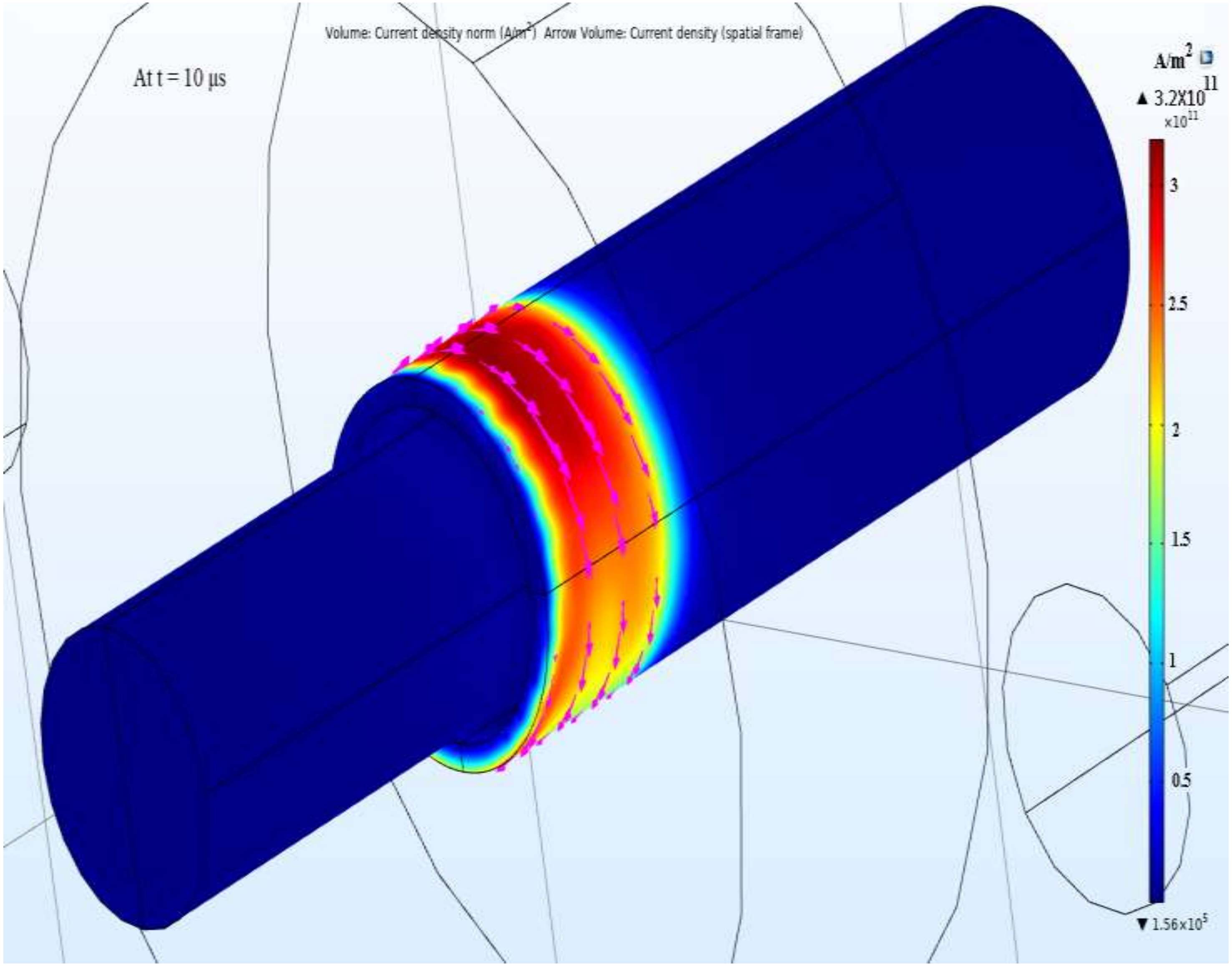
External current density profile in the EM coil



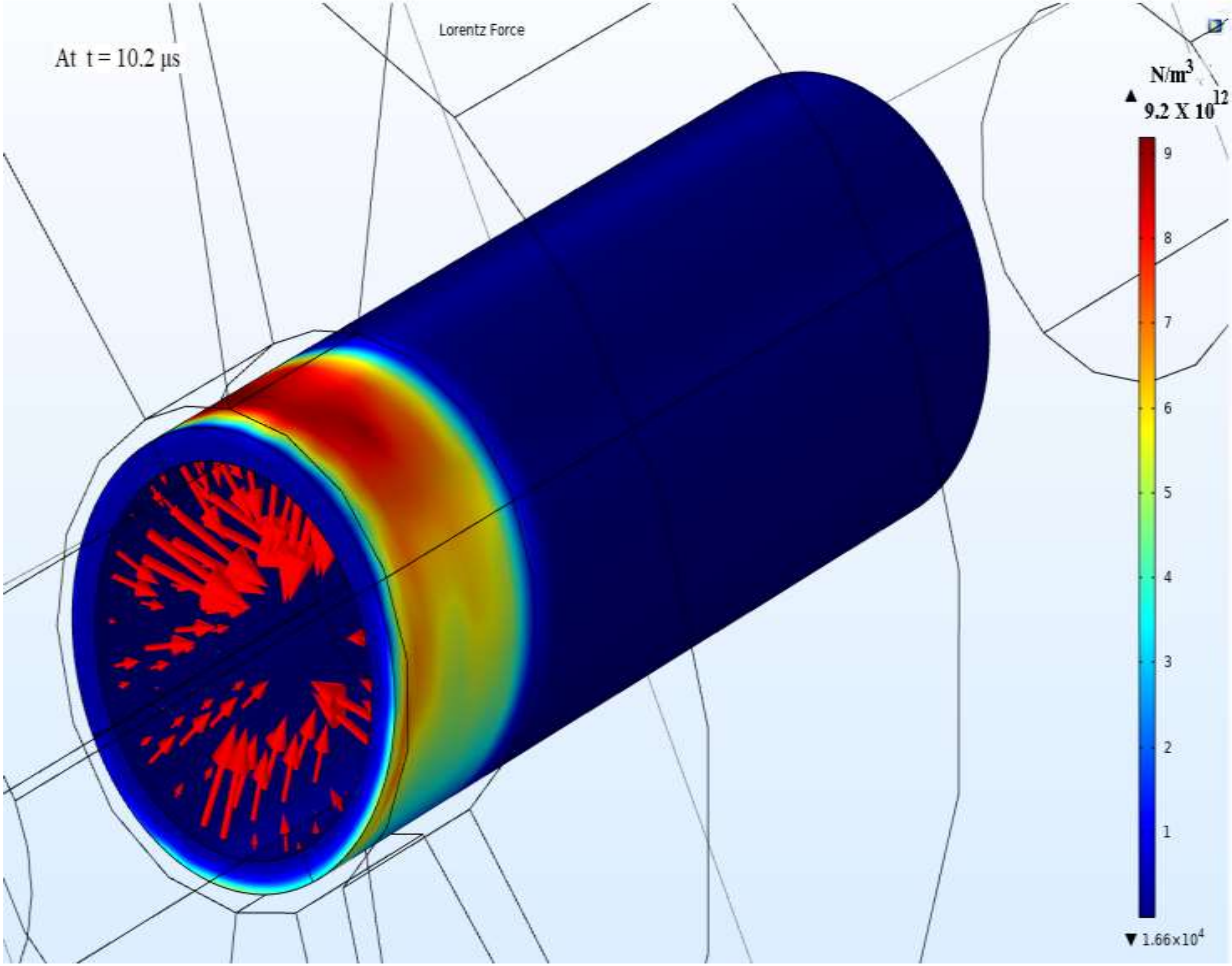
Magnetic field B on work pieces inserted in the system for joining (at peak current)



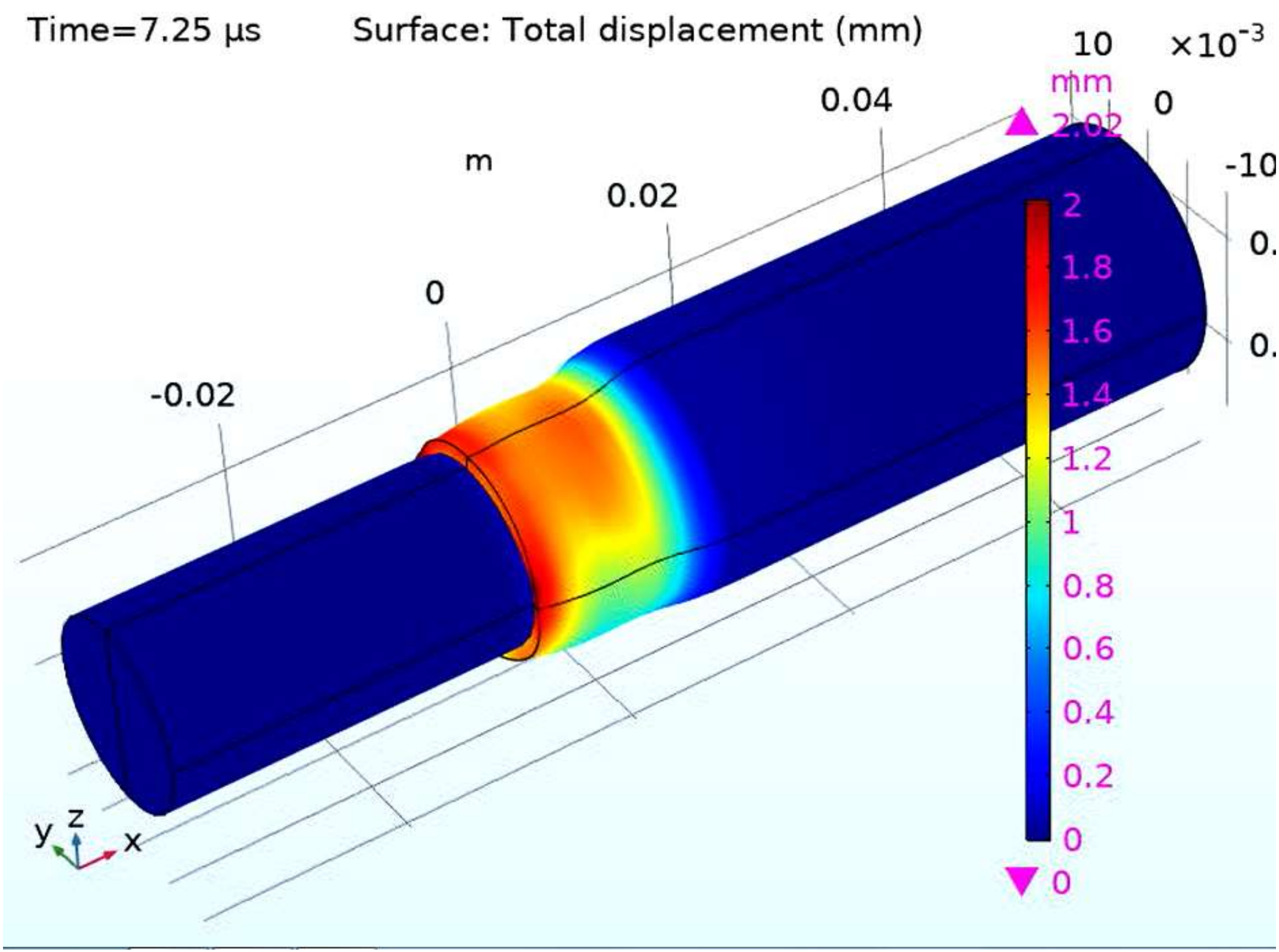
Time evolution of B on work pieces plotted along horizontal diameter (shown inside)



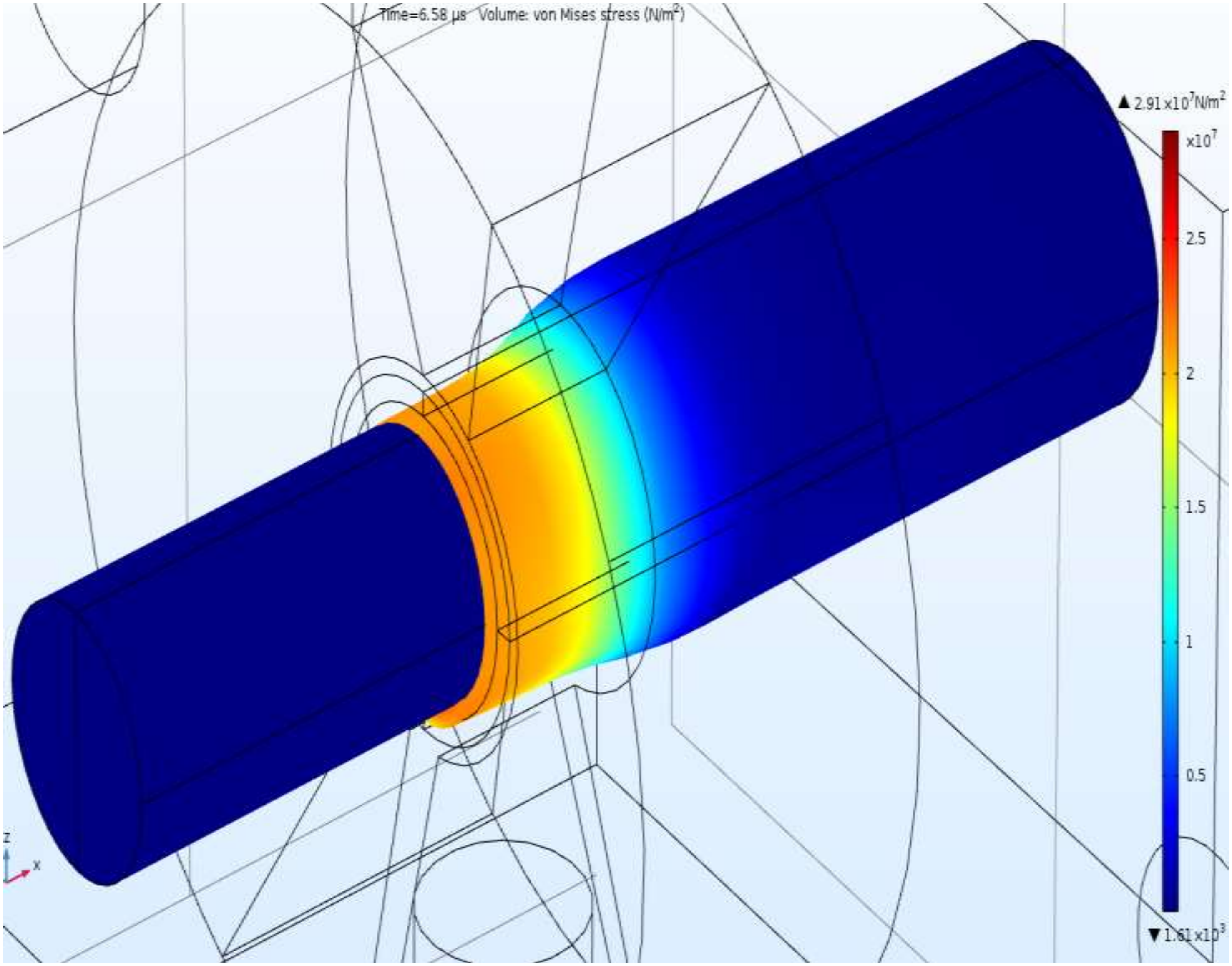
Induced current (J) on the work pieces inserted in the system for joining



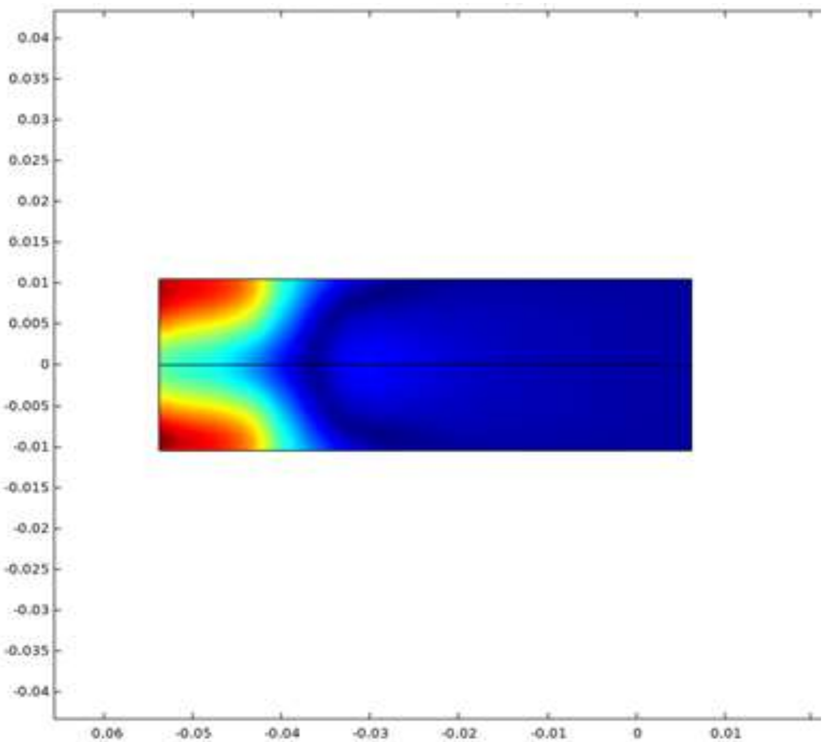
Lorentz force generated that is pinching the outer work piece for joining



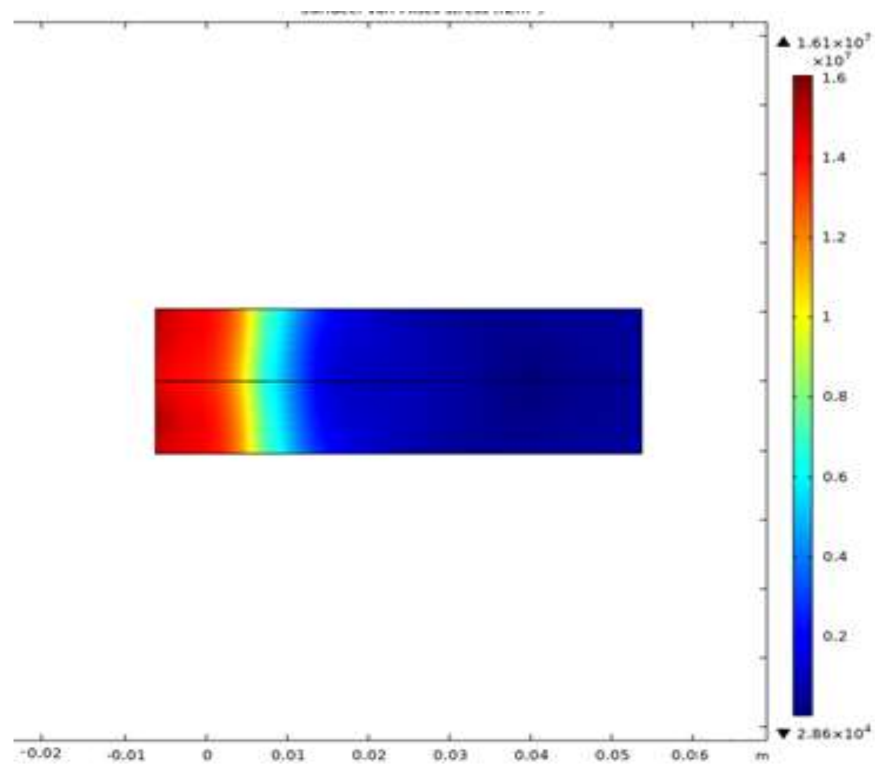
Compression of the pipe due to electromagnetic pinching force



Stress profile on the pipe due to electromagnetic pinching force

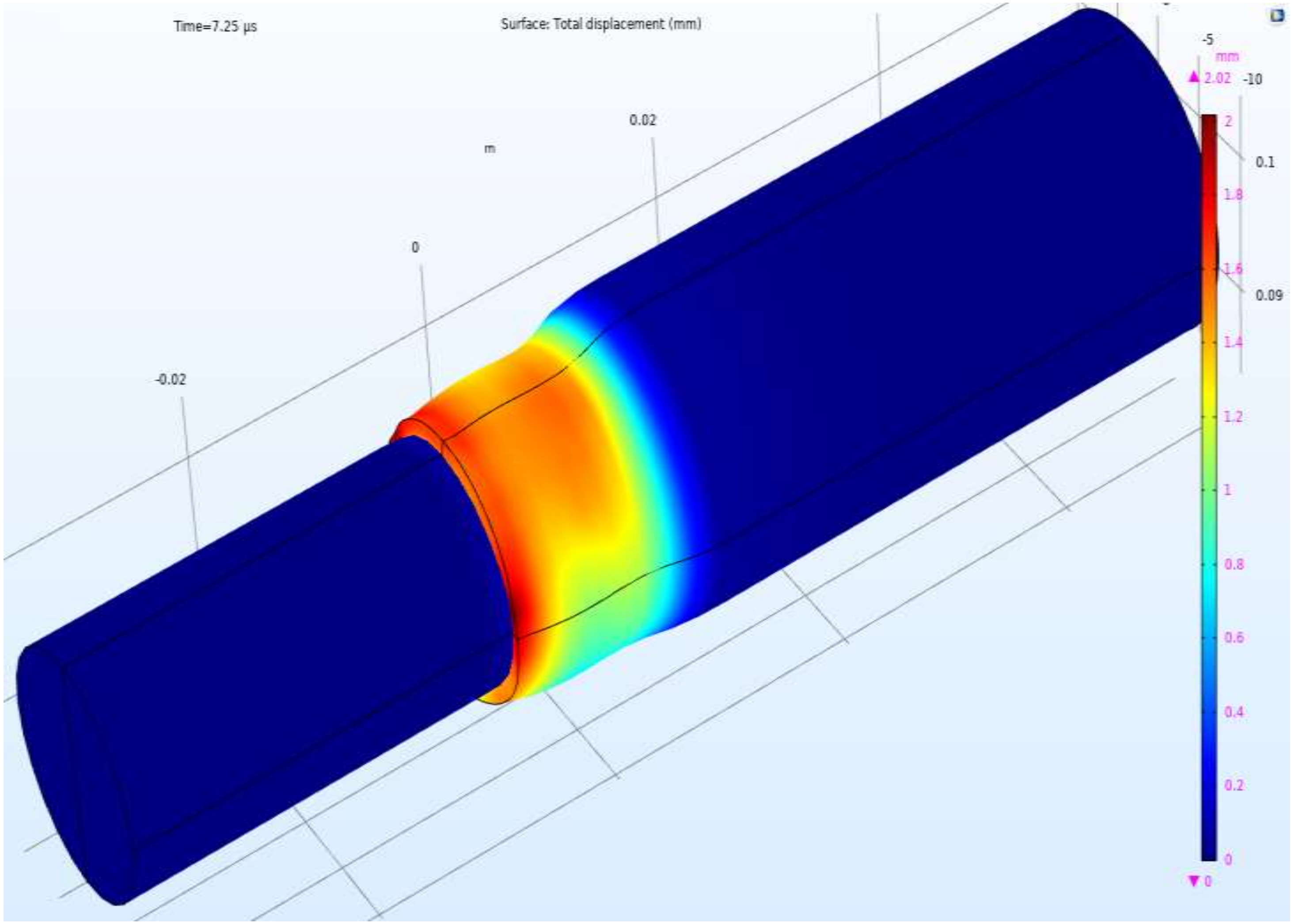


Lower half

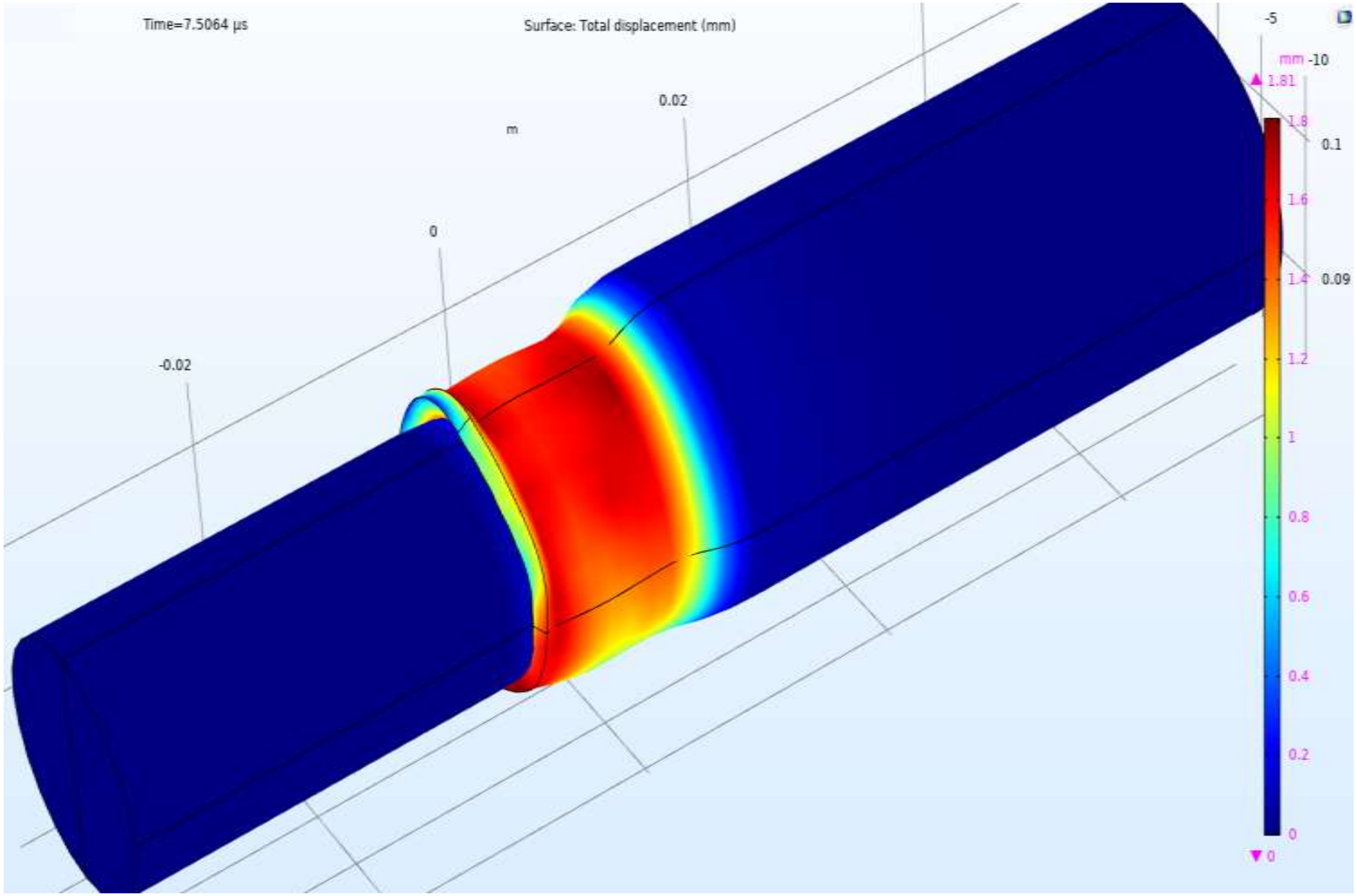


Upper half

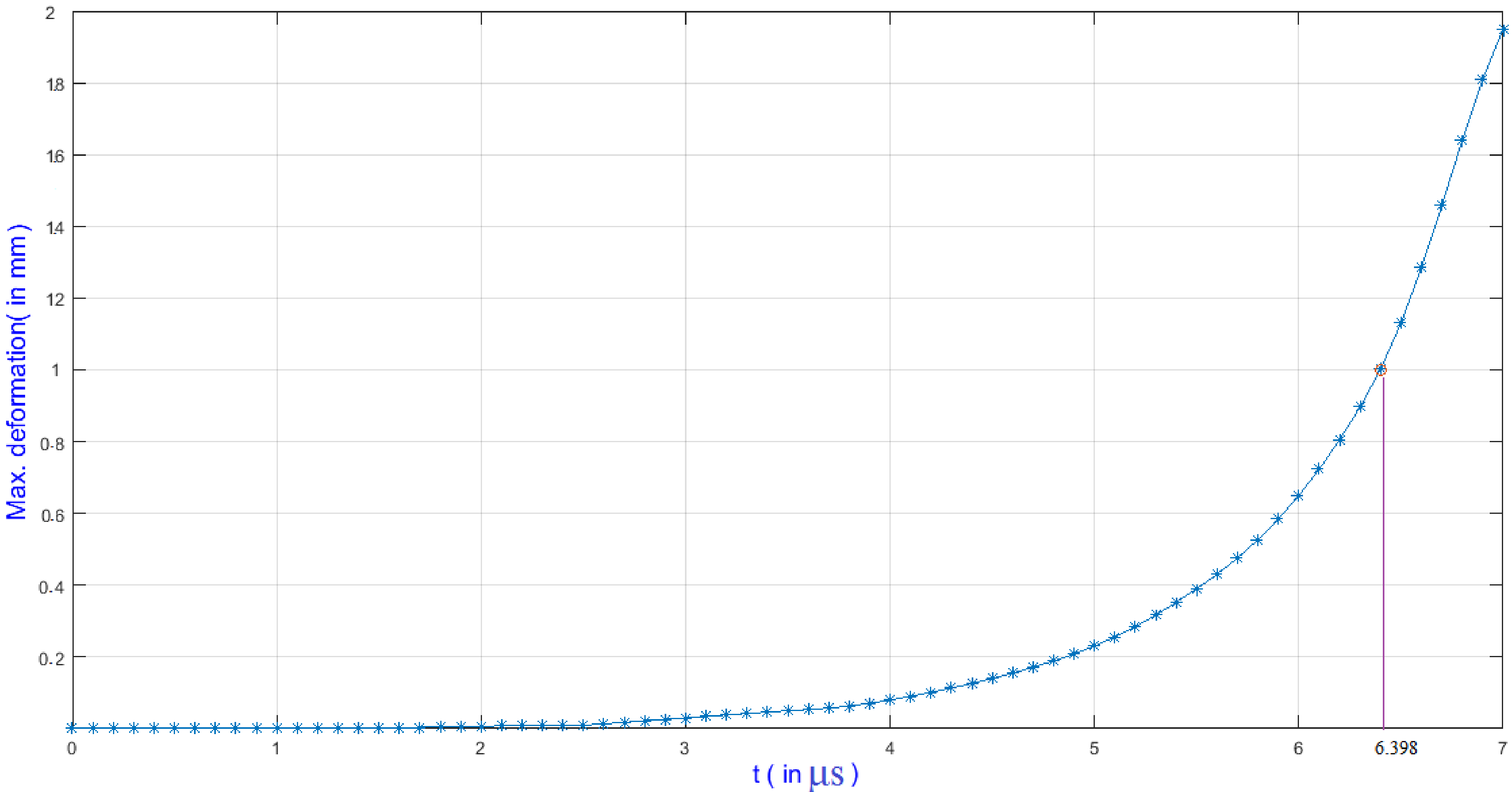
Non uniform Magnetic Pressure on the lower & Upper half portion of pipe



Deformation in the good joint

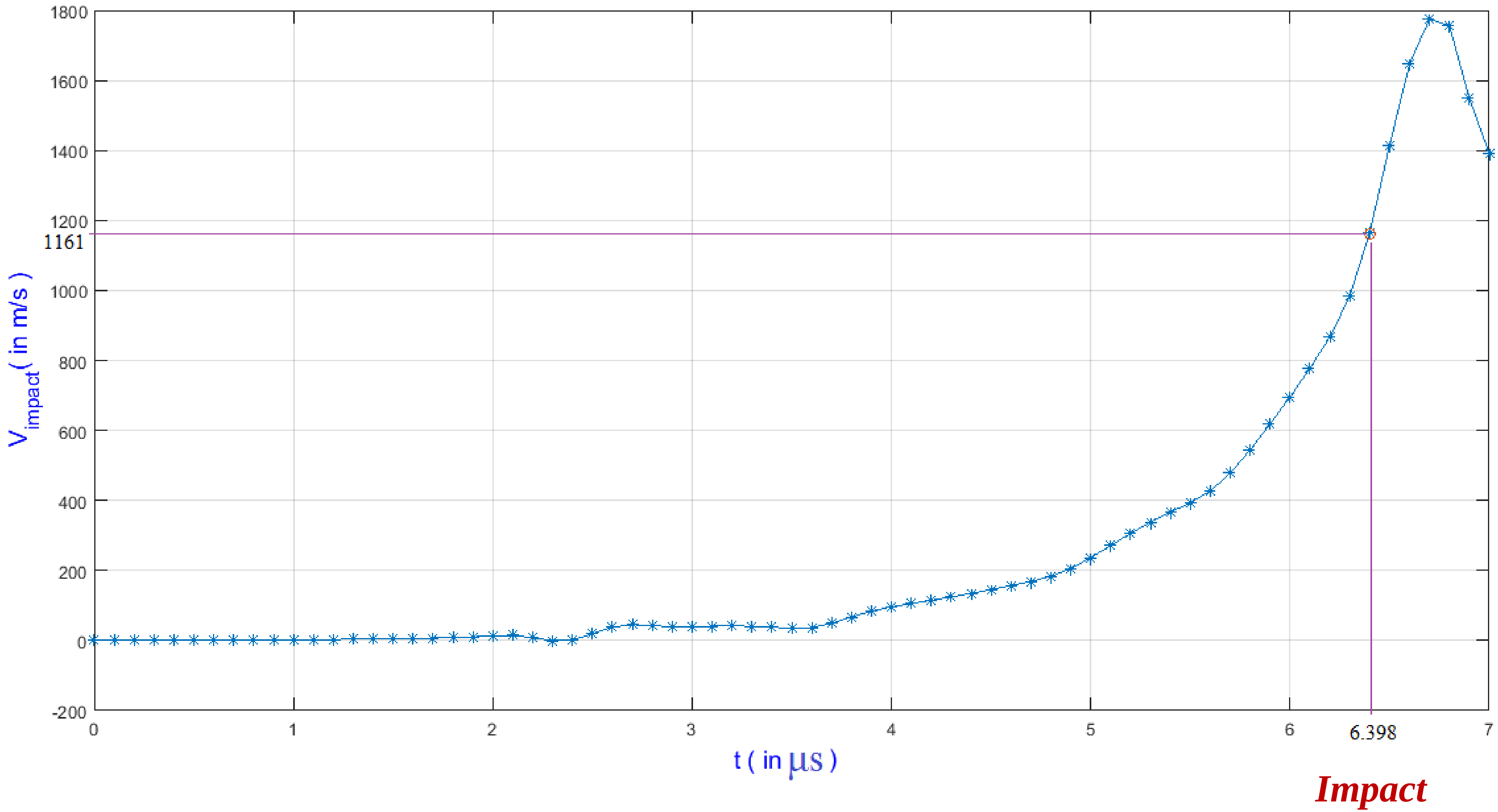


Deformation in the bad joint



Impact

Displacement of Outer tube towards inner work piece



Velocity of Outer tube towards inner work piece

Conclusions

A generalized 3D FEM model of "Magnetic Pulse Welding process" is developed to investigate the 'asymmetric' deformations in the joint (due to narrow slit in EM coil's lower part) and to optimize the various parameters of the process to obtain the best joint for any given work pieces to be joined.

Thank You

Email: amar@ipr.res.in