Insight into the realistic behaviours of magnetic pulse forming and welding processes using numerical simulations

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Introduction: Project COILTIM

- Produce efficient welding of similar / dissimilar metal pairs
- Joint quality analysis with process parameters
- Joint quality analysis of the effect of metal dissimilarity
- Modeling and simulation of the MPF/MPW
- Feasibility study and development of processing tools

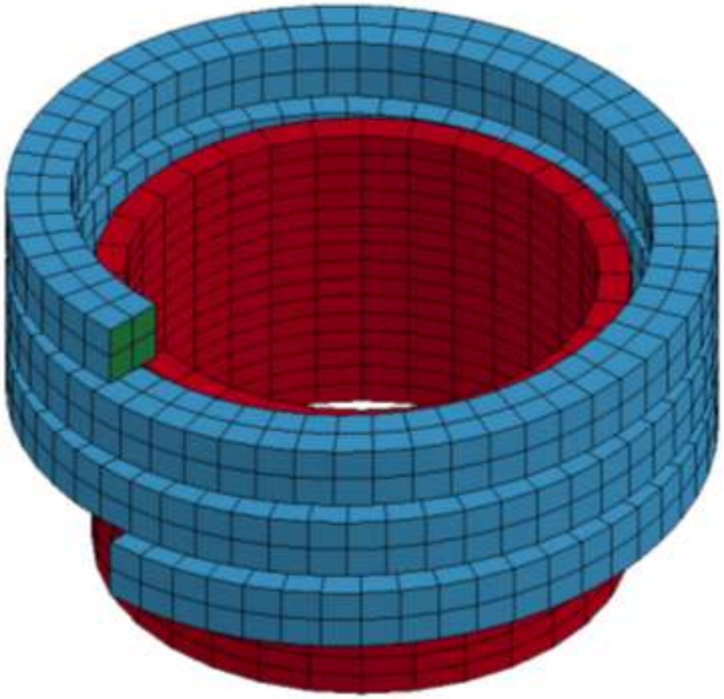
[MPF/MPW: Magnetic Pulse Forming / Magnetic Pulse Welding]

Outline

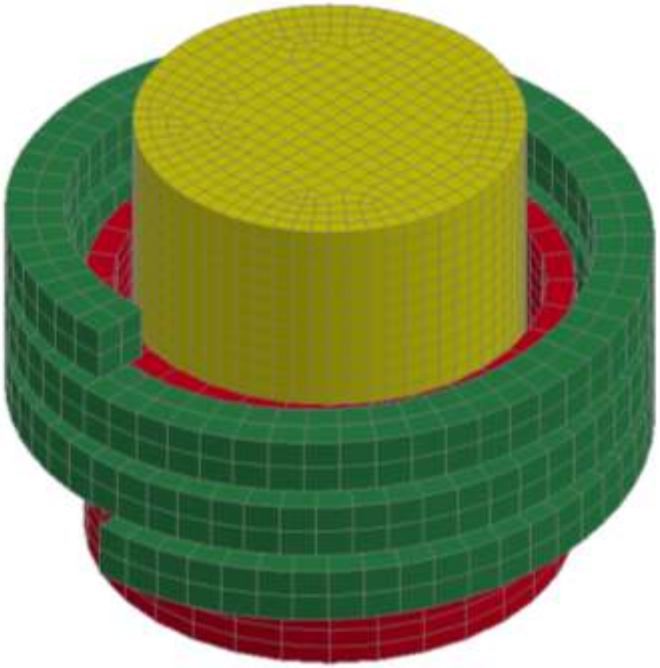
- Methods about the EM numerical modelling, investigating the influence of the cylindrical rod in a MPW
- Main focuses on the numerical modelling of MPW
    - *EM component*
    - *Interfacial behaviour*
    - *Contact behaviour*
- Field shaper effect in forming and welding
- Change in force direction, during MPF/MPW
- Development of negative velocity and spring back effect in ring expansion process
- Identification of material models for MPF/MPW processes

[EM: Electromagnetic; MPF: Magnetic Pulse Forming; MPW: Magnetic Pulse Welding]

Preliminary models: Tube compression with and without rod using helix coils

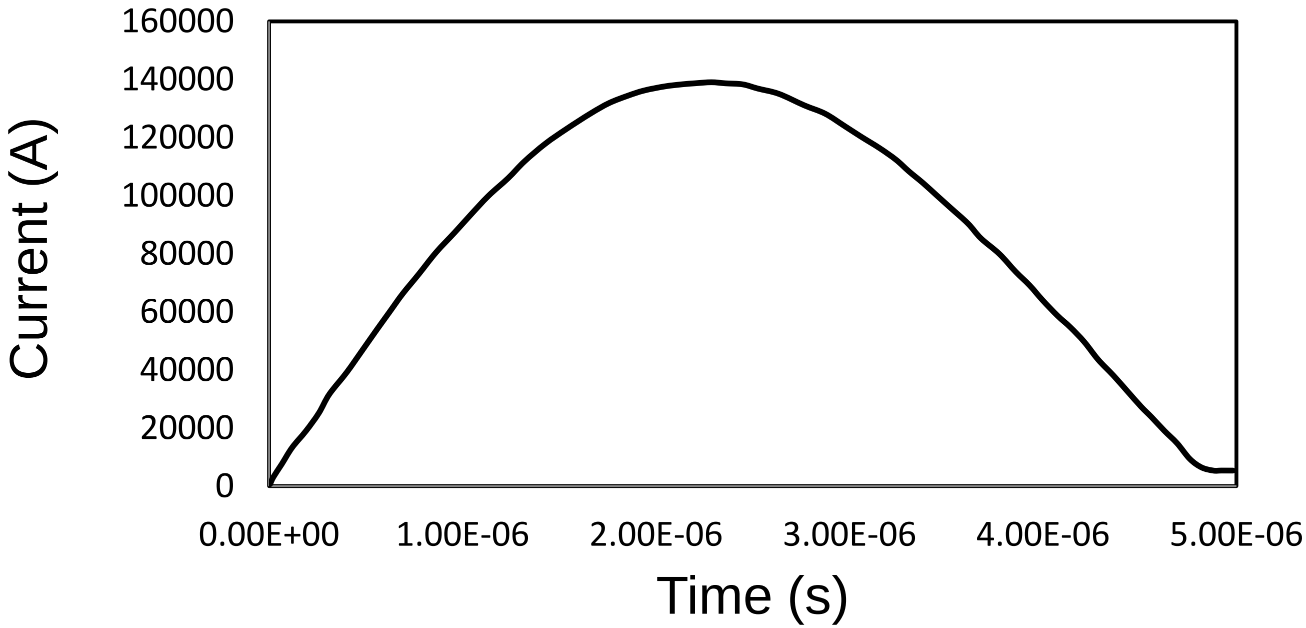


Tube without cylinder rod model



Tube with cylinder rod model

Input current used in those preliminary models



(I. Henchi et al, 10th International LS-Dyna User Conference)

Material Model

Table 1
Johnson– Cook parameter values used to simulate the behaviour of A2024-T351 [17]

A	*B*	*N*	*C*	*m*
352	440	0.42	0.0083	1

Table 2
Workpiece and tool physical parameters [18]

Physical parameter	Workpiece (A2024-T351)	Tool (tungsten carbide insert)
Density, ρ (kg/m^3)	2700	11900
Elastic modulus, E (GPa)	73	534
Poisson's ratio, ν	0.33	0.22
Specific heat, C_p (J/kg/°C)	$C_p = 0.557T+877.6$	400
Thermal conductivity, λ (W/m/C)	$25 \leqslant T \leqslant 300$: $\lambda = 0.247T+114.4$ $300 \leqslant T \leqslant T_{melt}$: $\lambda = 0.125T+226.0$	50
Expansion, α_d (μm.m/°C)	$\alpha_d = 8.9 \times 10^{-3}T+22.2$	×
T_{melt} (°C)	520	×
T_{room} (°C)	25	25

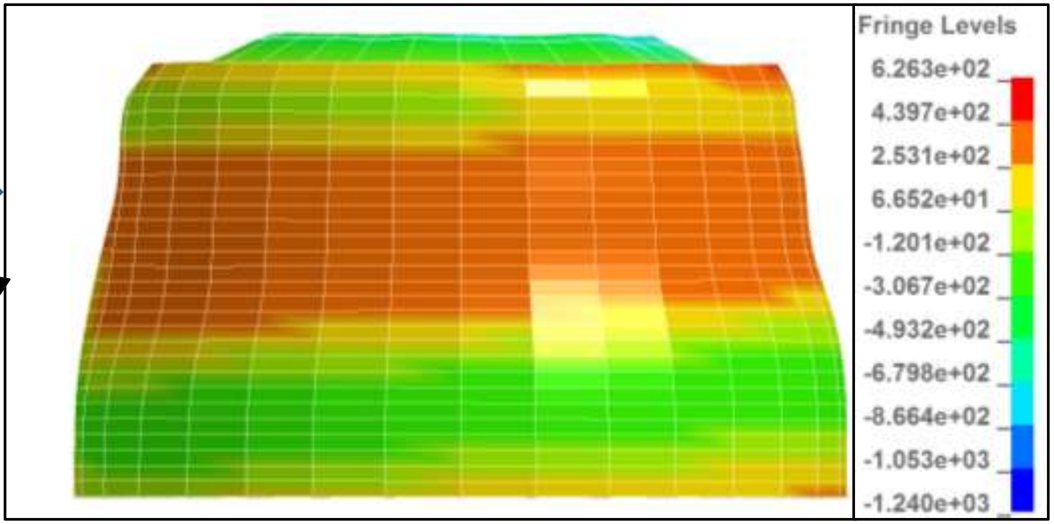
(T. Mabrouki et al. 2008, Int. Journal of Machine tools & Manufacture)

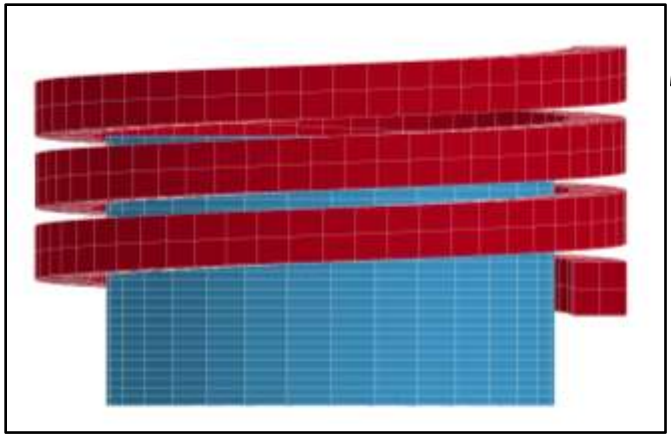
Electromagnetic properties of material

- σ of the work piece: Aluminum alloy – 30% IACS (1.74×10^4 S/mm)
- Copper helix coil – 70% IACS (4.06×10^4 S/mm)
- Steel coil – 7% IACS (4.06×10^3 S/mm)
- $\mu_r = \mu / \mu_0$, for copper alloy, steel and air are considered to be ~ 1
- However this μ_r may significantly vary with the type of steel

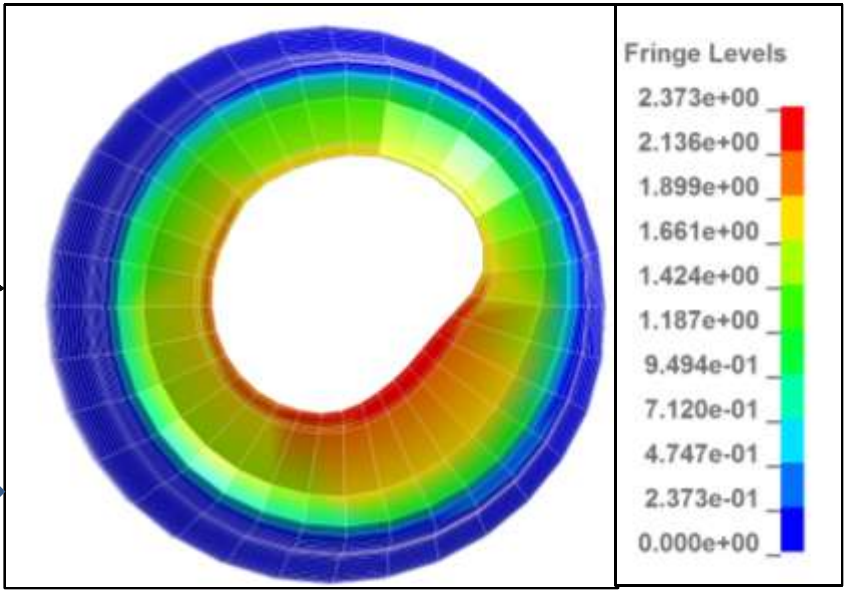
Coil geometry and non axisymmetric deformation

Pressure distribution



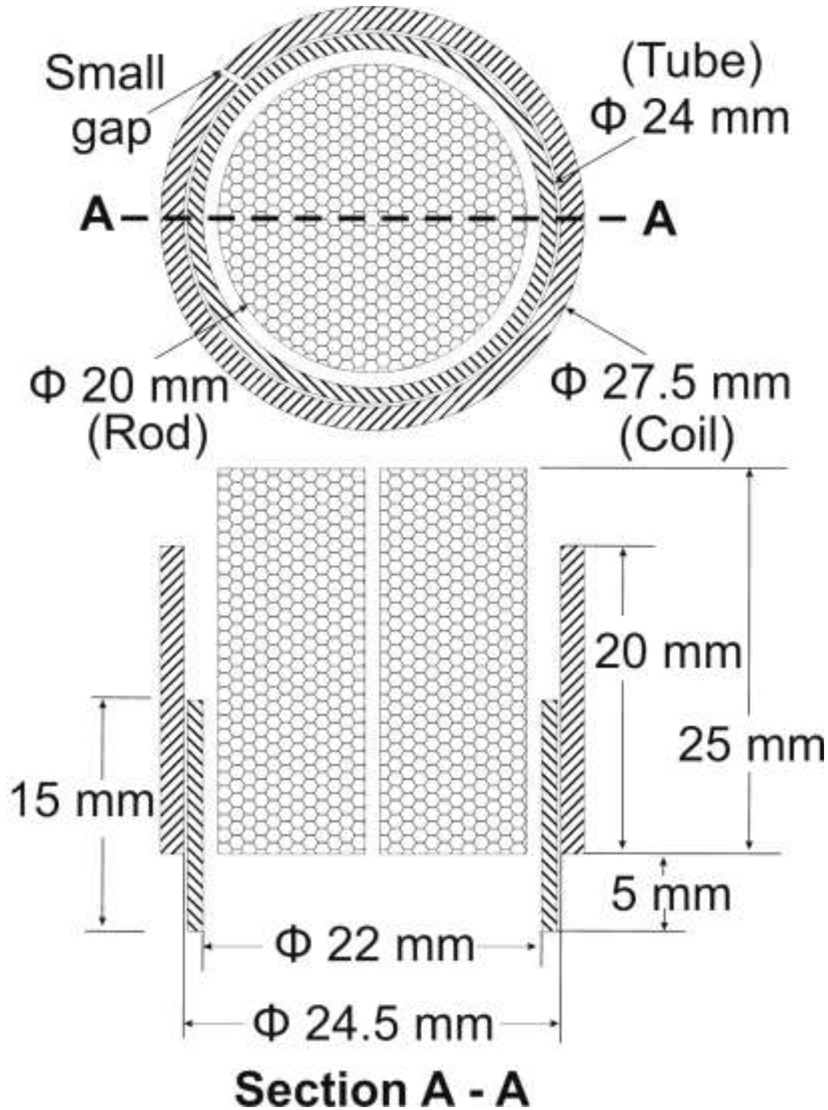


Model Geometry



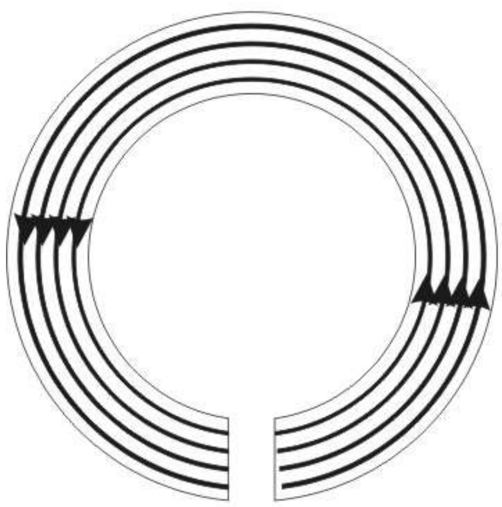
Effective plastic strain distribution

Model with one turn symmetric coil

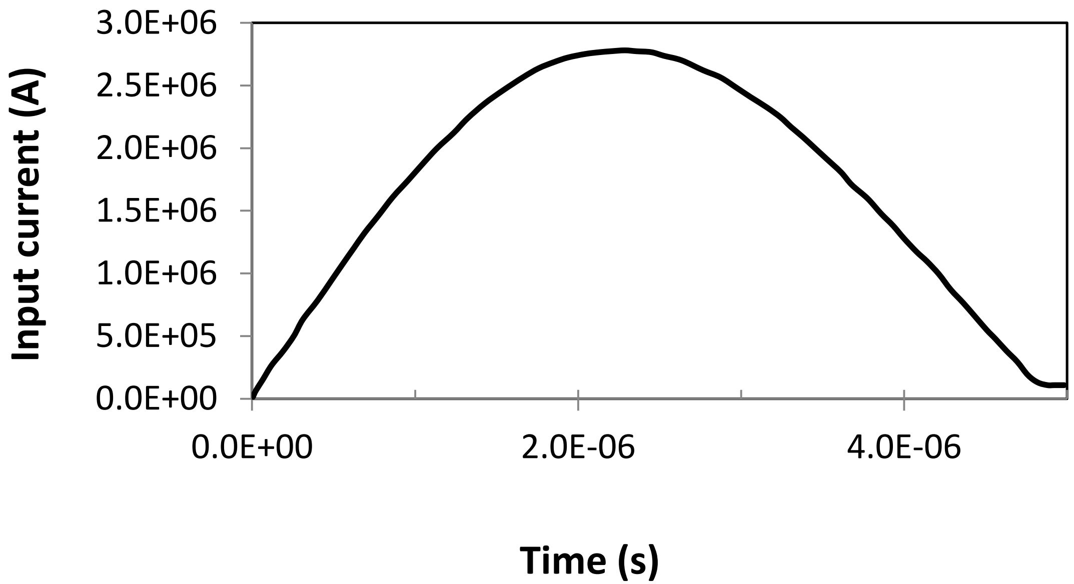


Material and other parameters

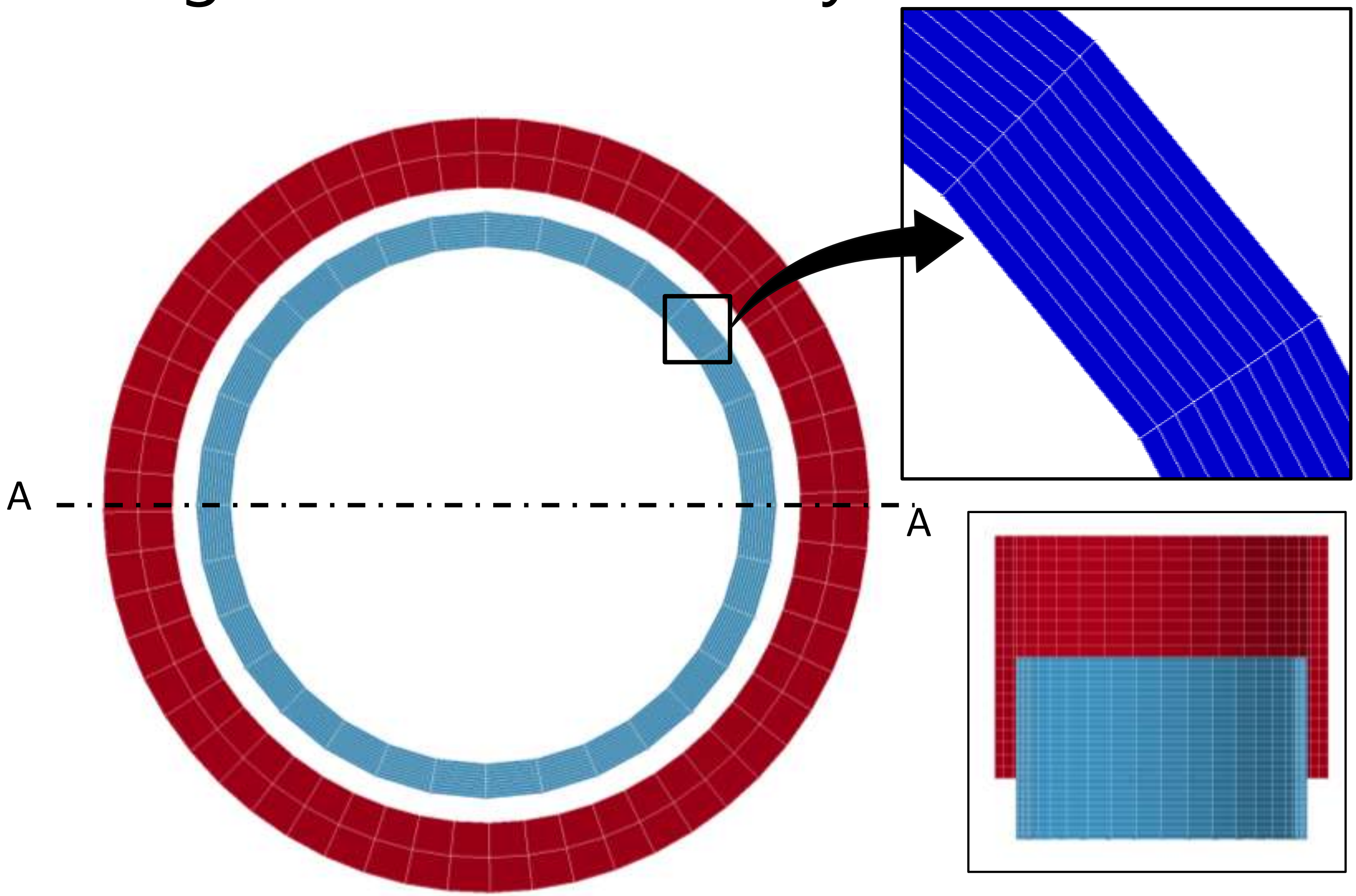
- Core and solid made from aluminium A2024 – T351
- One turn coil with axis-symmetric geometry used and a symmetric current flow expected



Expected a symmetric current flow

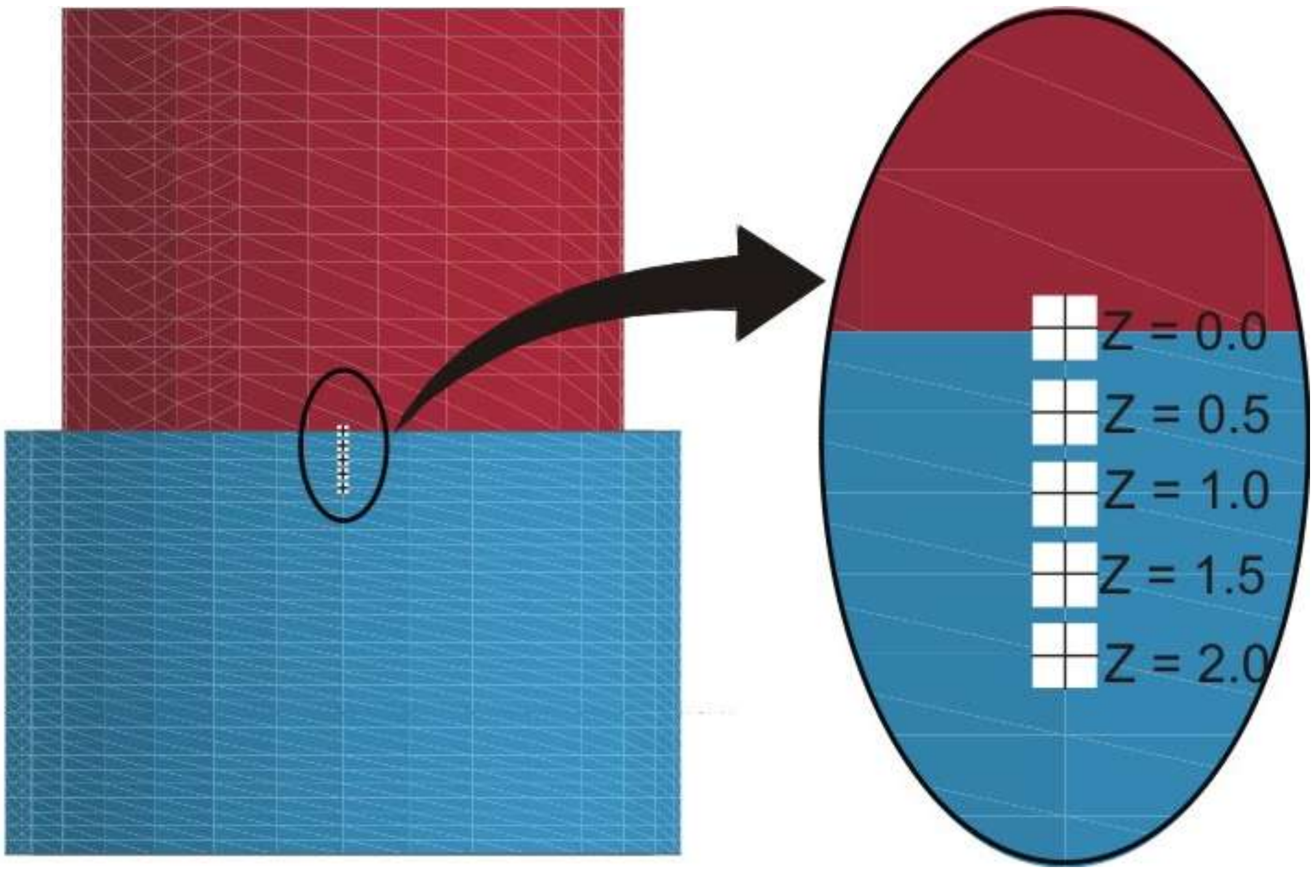


The multi-layered mesh to capture the gradient of the eddy current

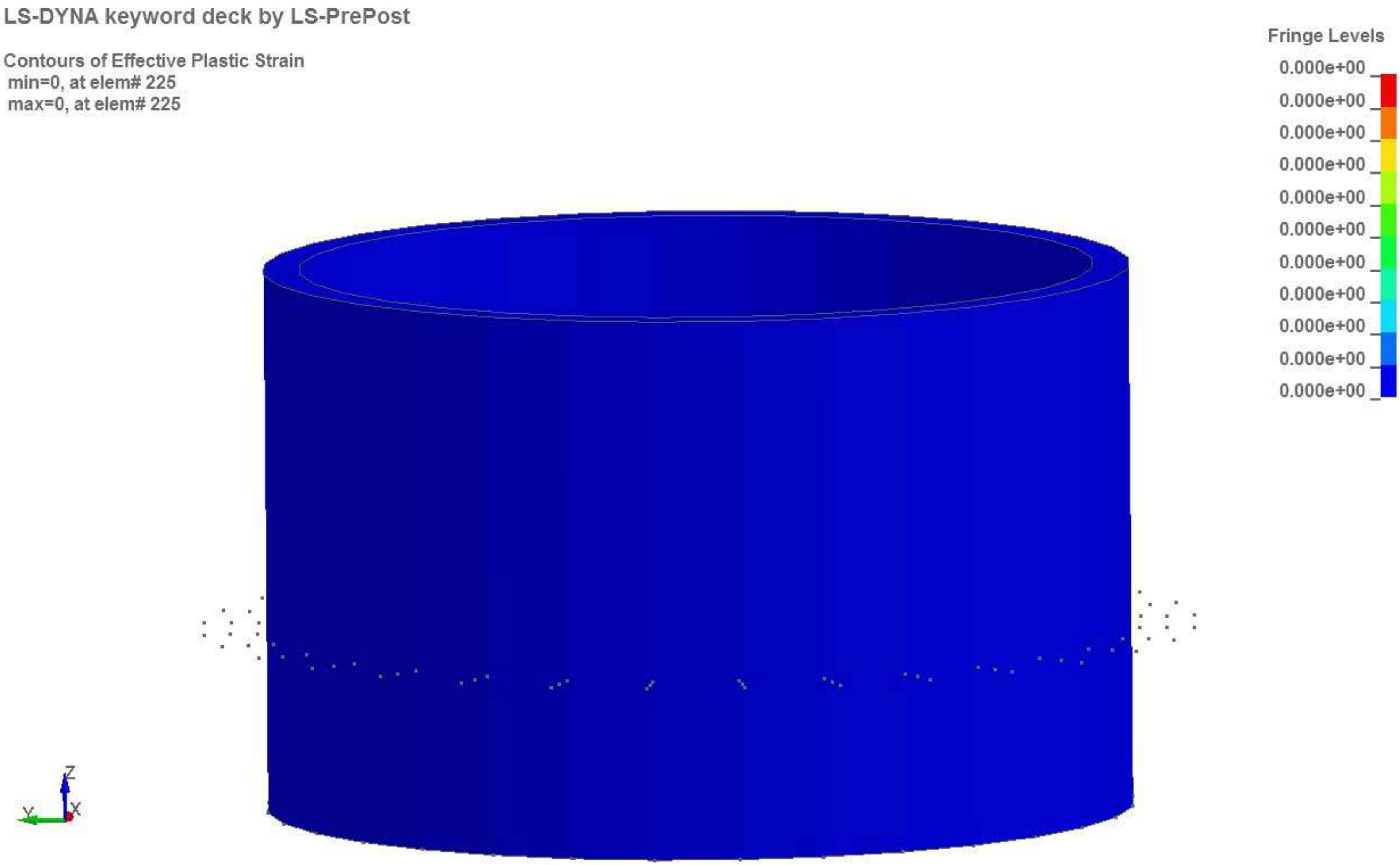


Section A-A

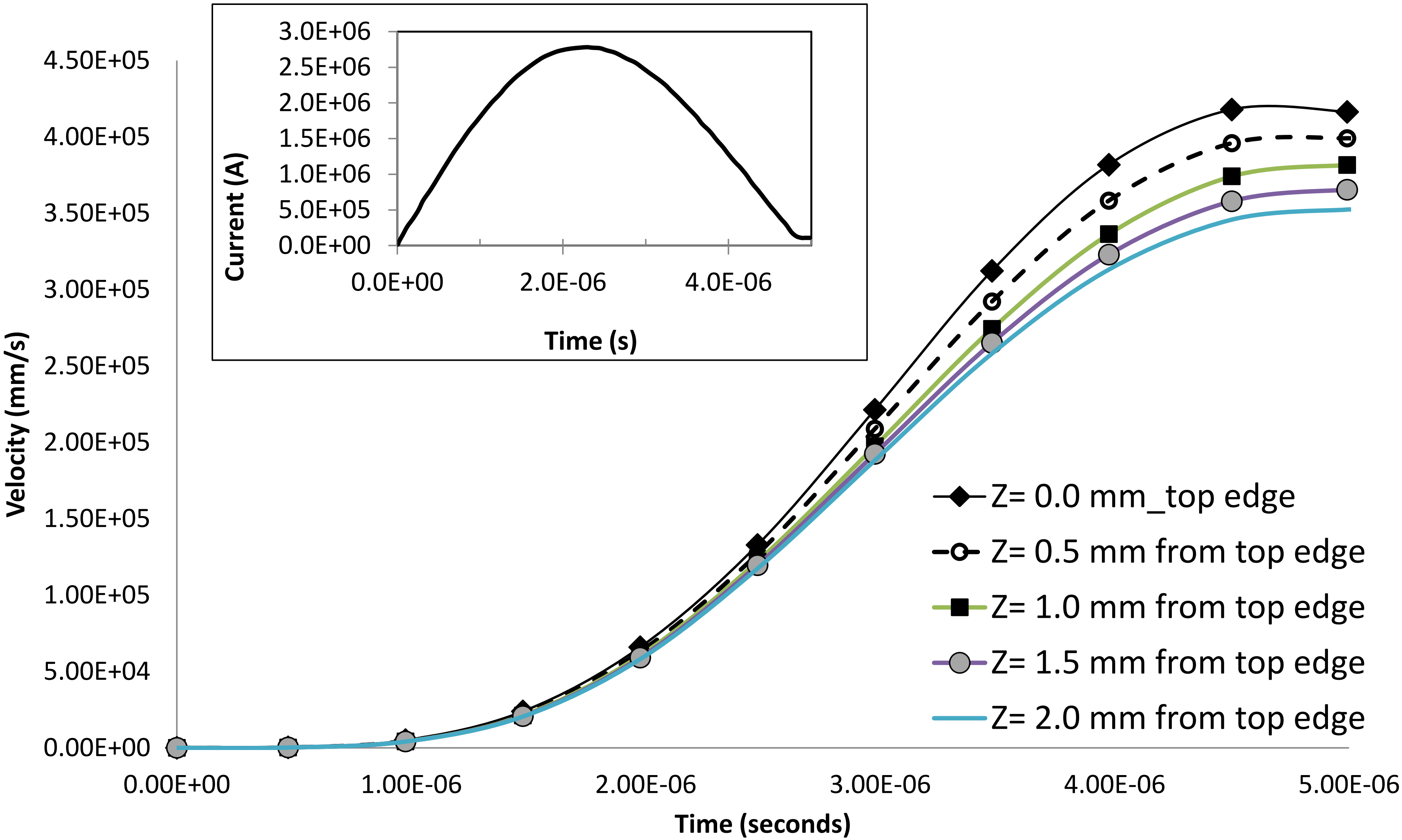
Investigation of nodal velocity



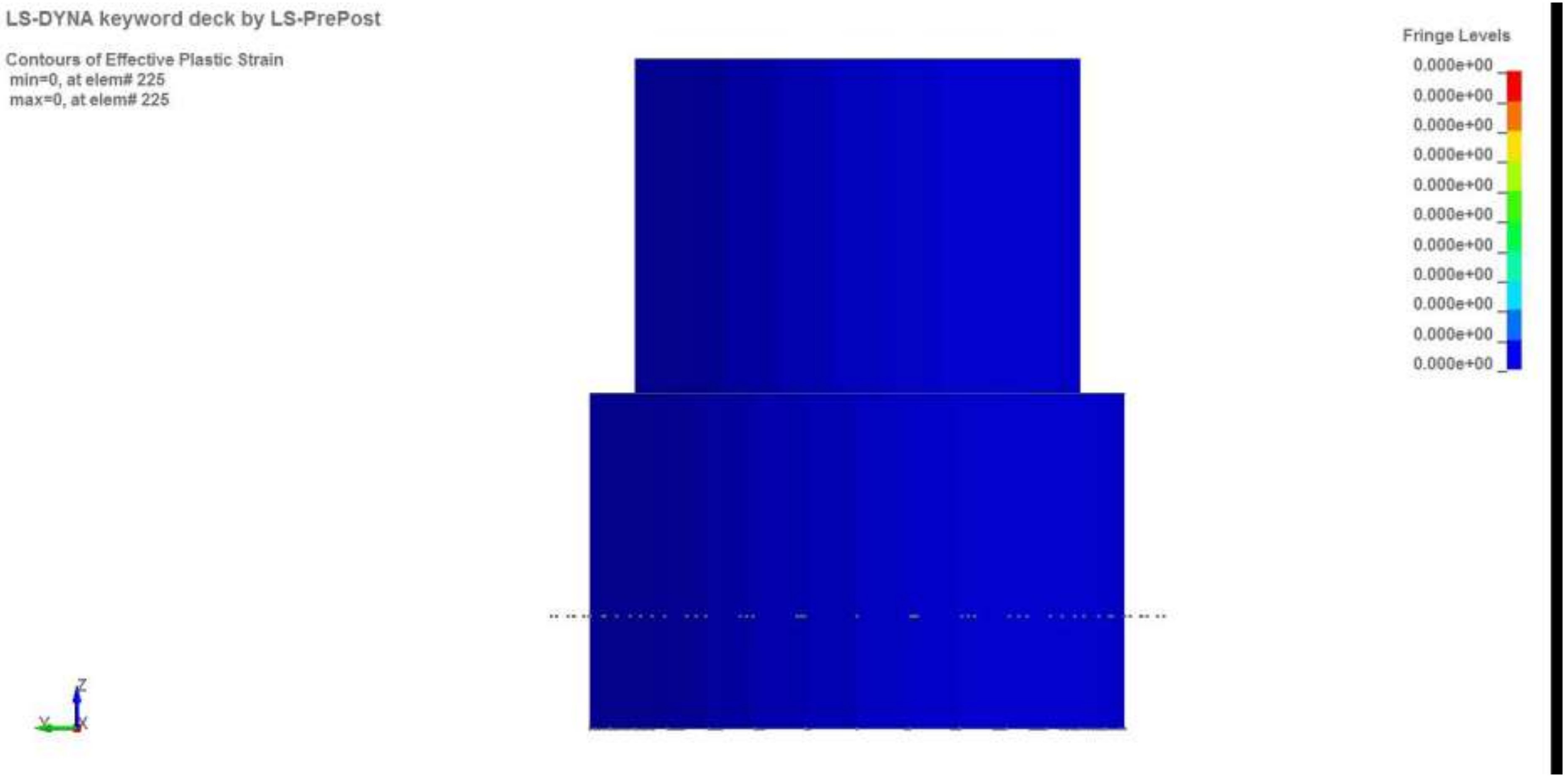
Model without the cylinder rod



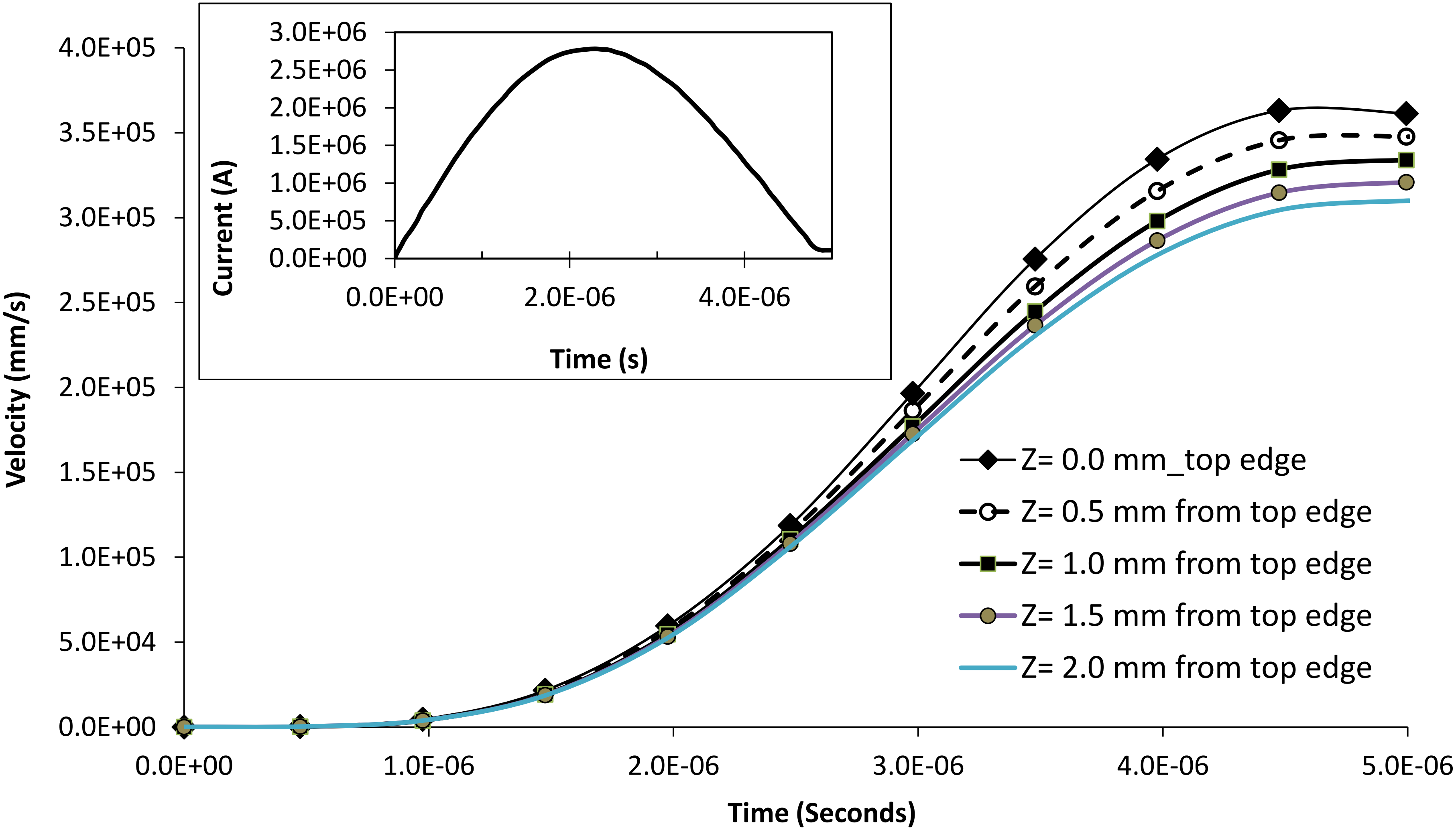
Nodal velocity from the top edge



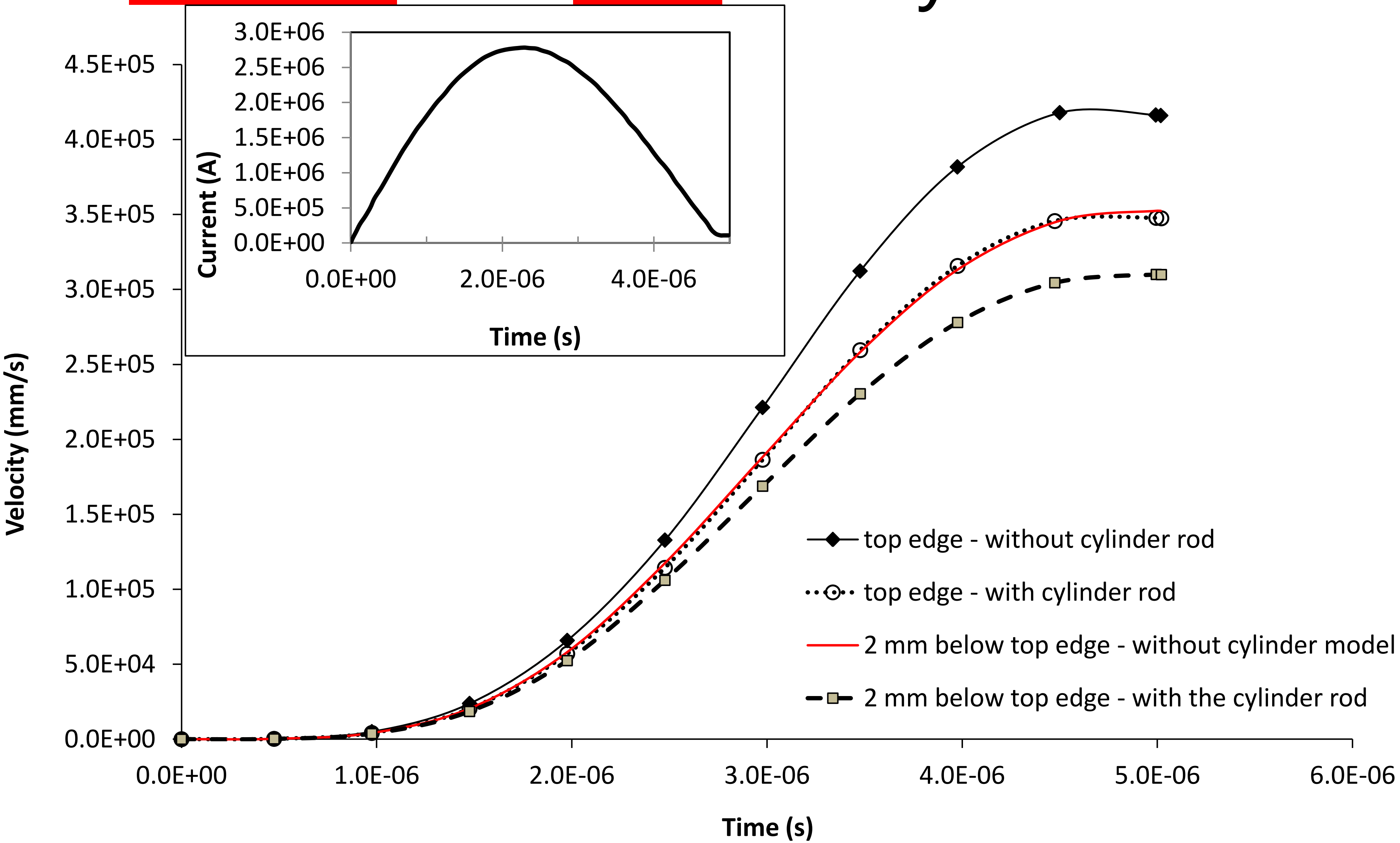
With Solid rod in the model, but without contact



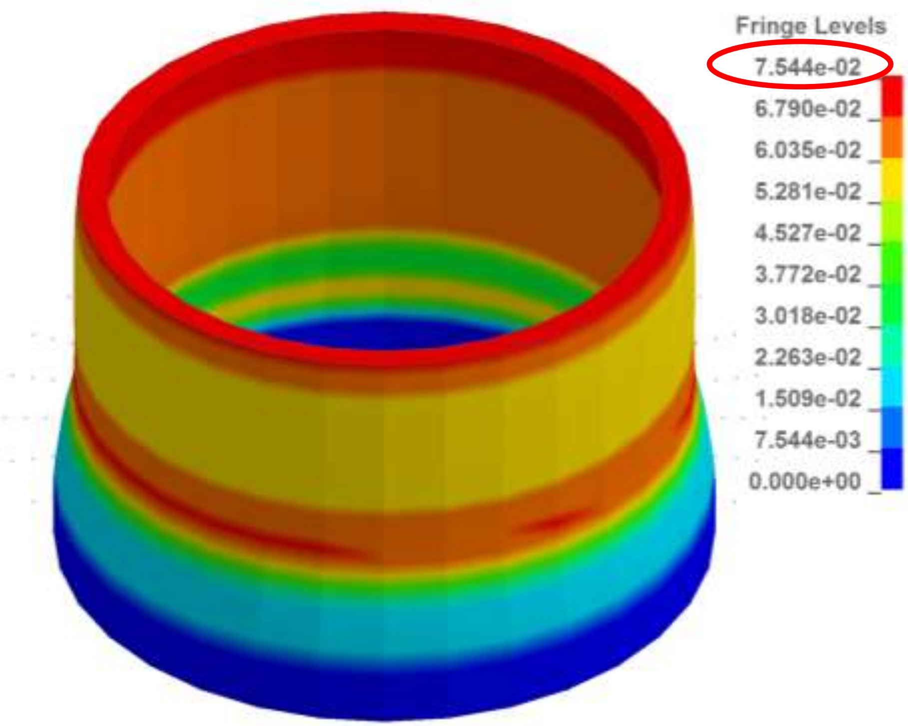
Nodal velocity from top edge for the model with the cylinder rod



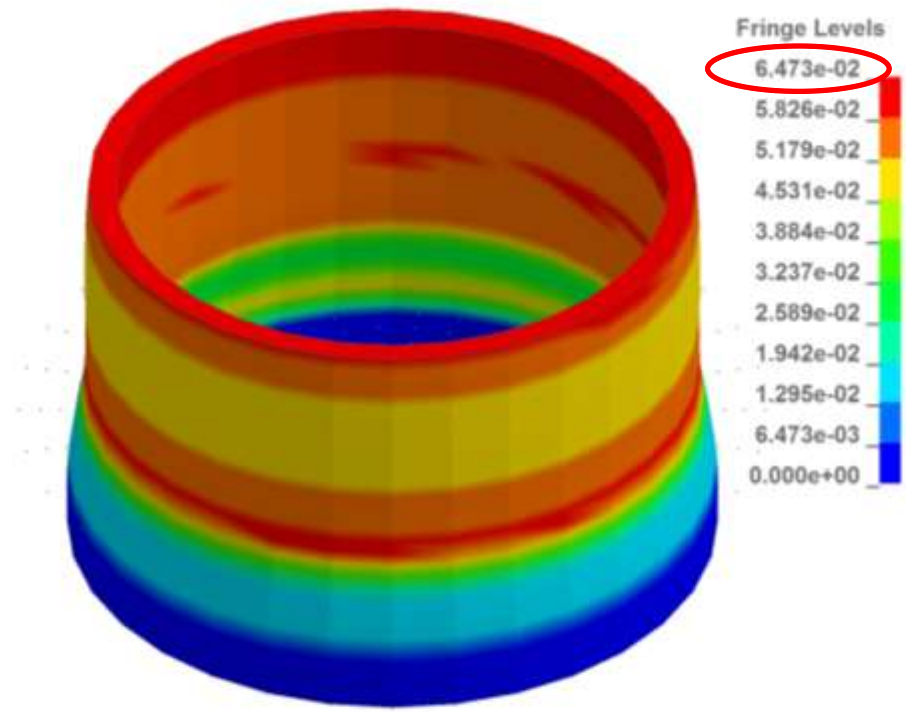
Comparison of velocity without and with the cylinder rod



Comparison of plastic strain without and with the cylinder rod



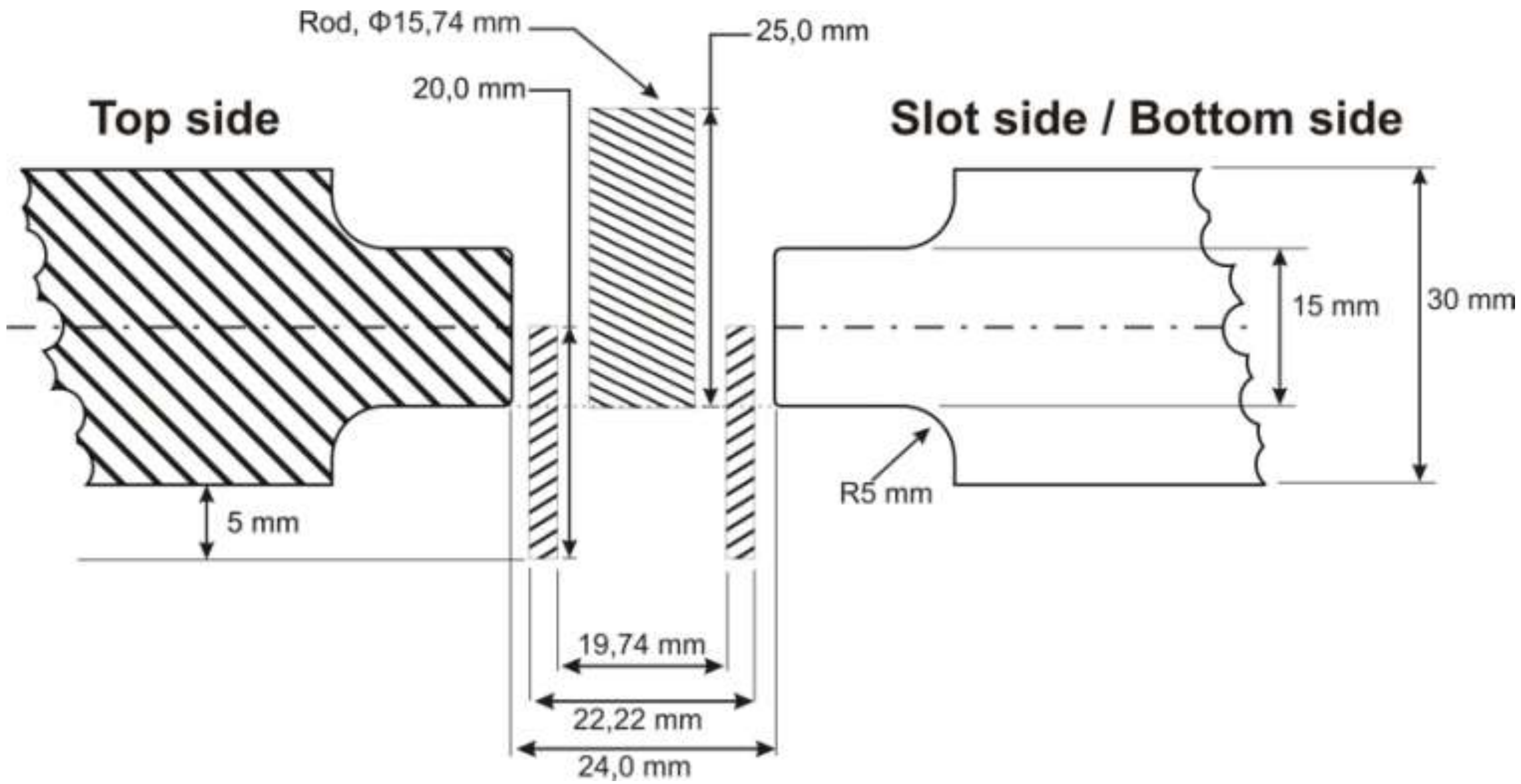
Plastic strain without the cylinder rod
Maximum : 7.54%



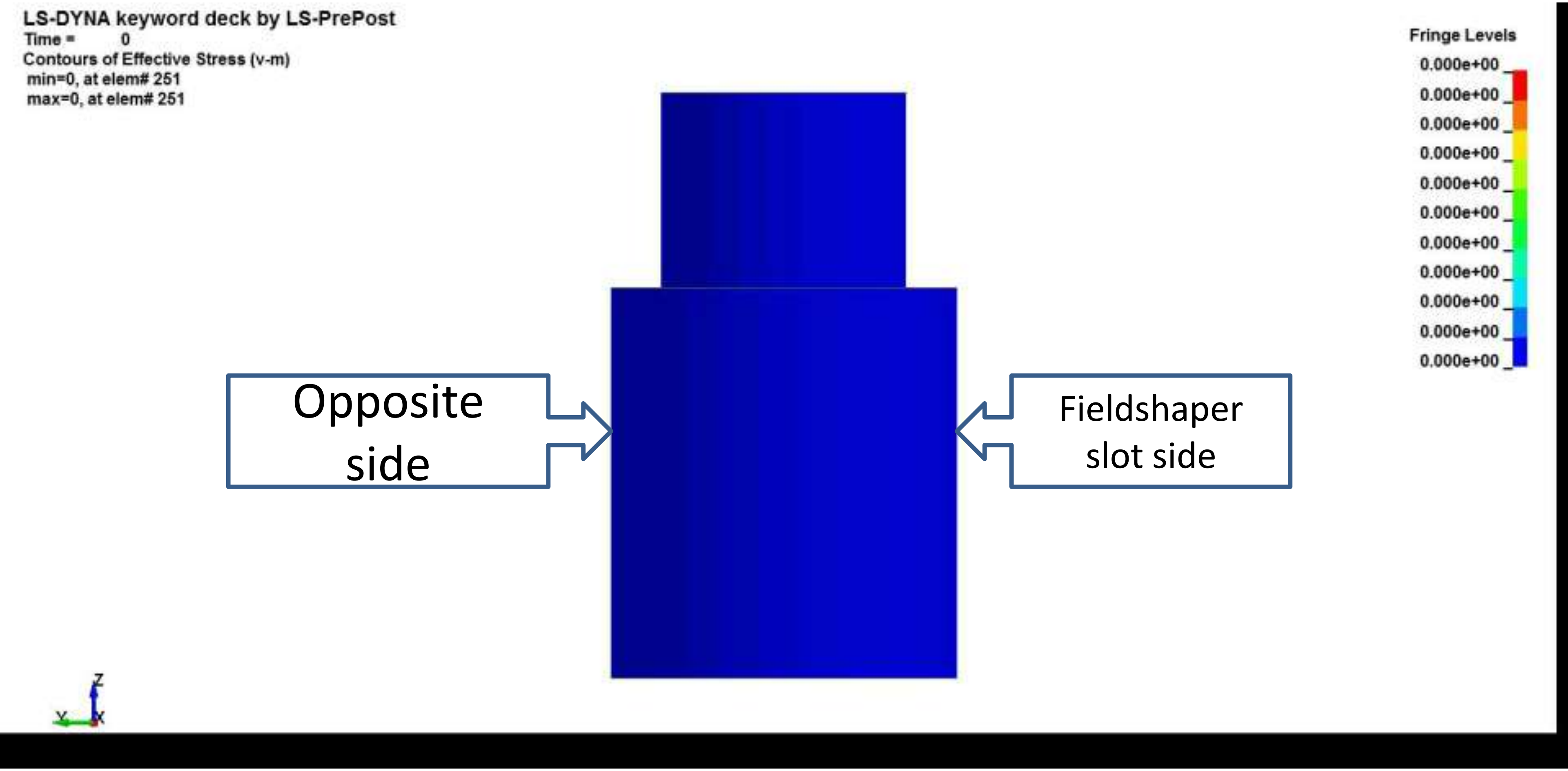
Plastic strain with the cylinder rod
Maximum: 6.47%

Welding and contact models

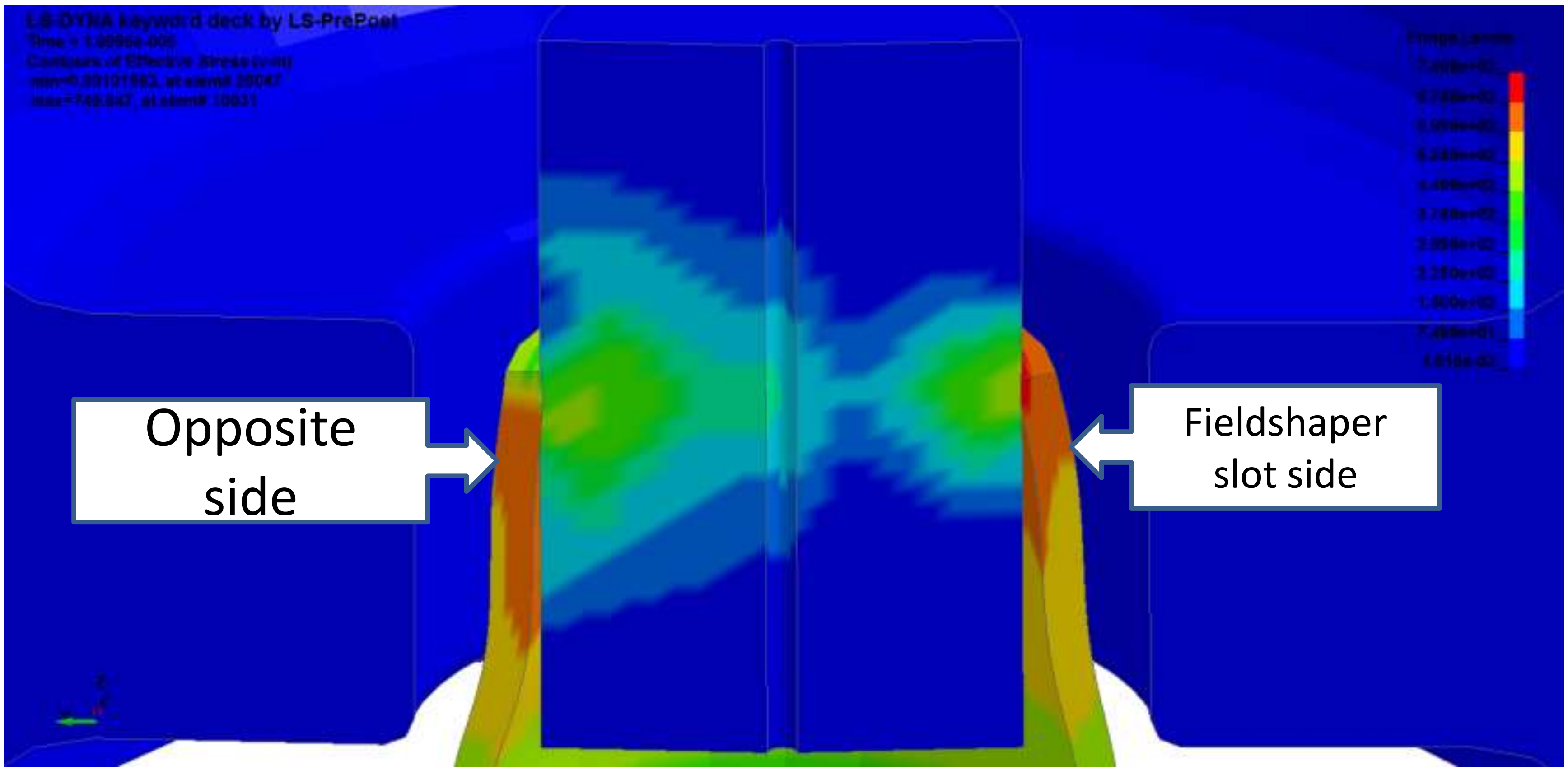
- Mechanical + Electromagnetic contact algorithms used in these models



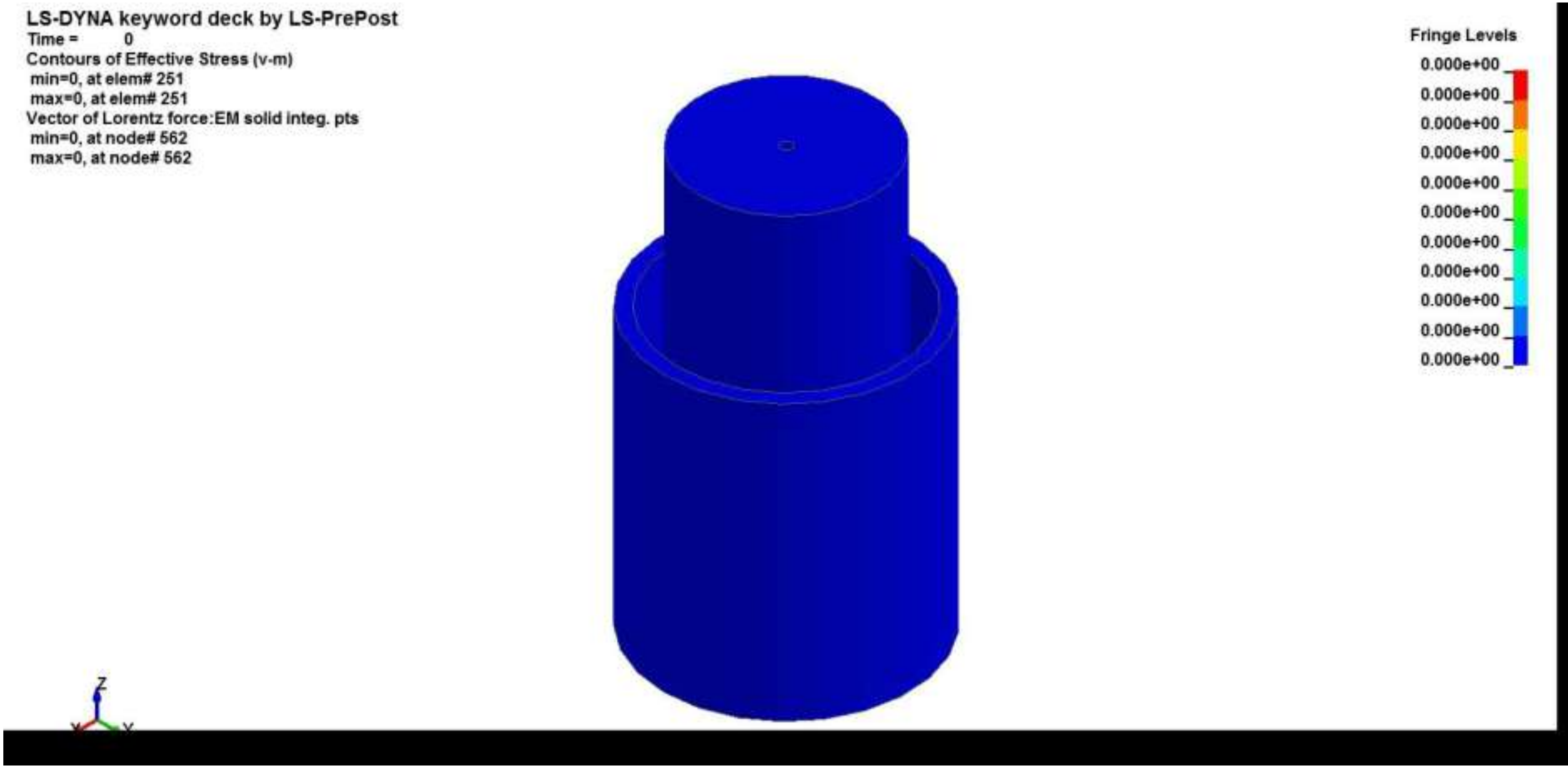
von Mises stress distribution (MPa)



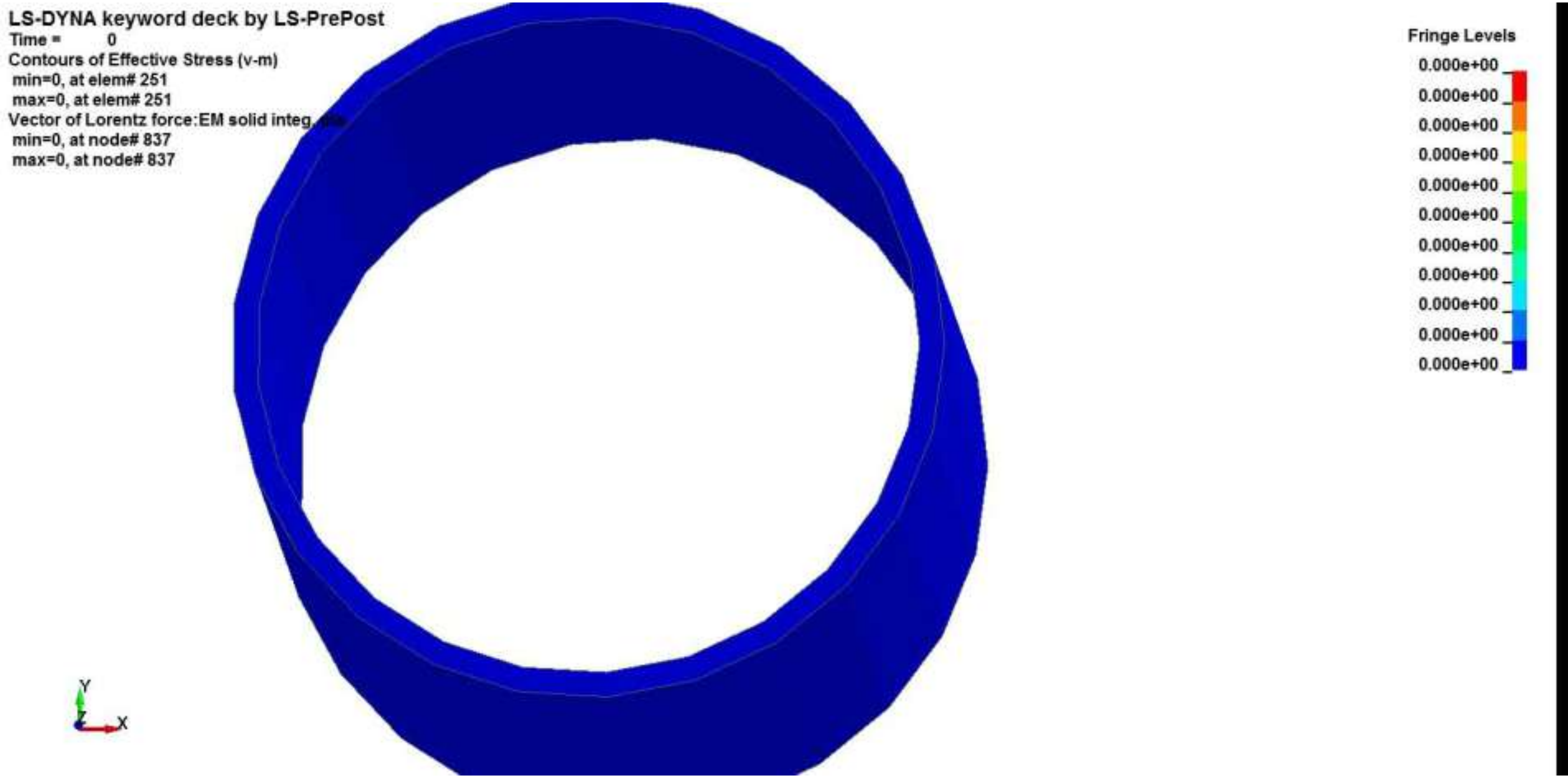
Effective stress at the beginning of the impact (MPa)



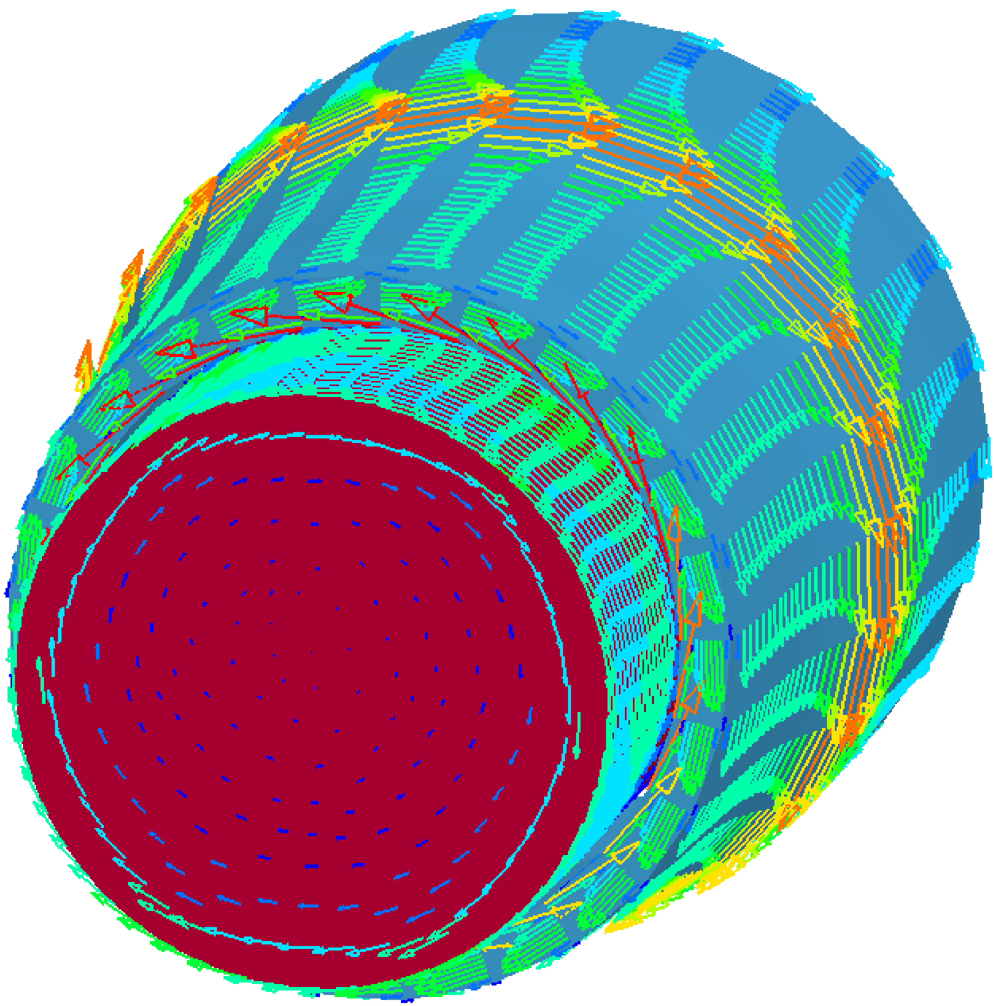
von Mises stress and Lorentz force (N/mm^3)



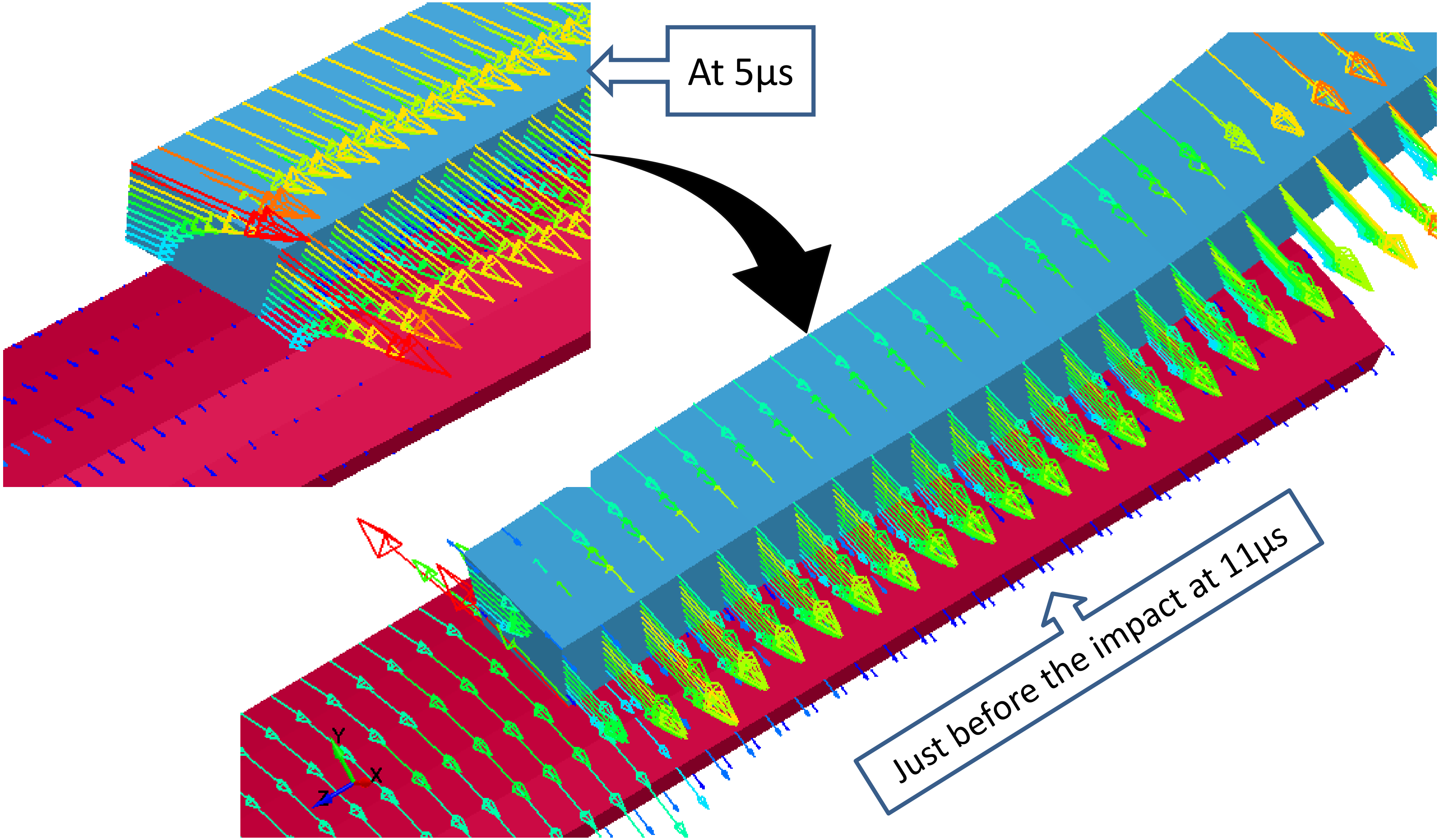
direction of force without the solid rod, in a tube only model



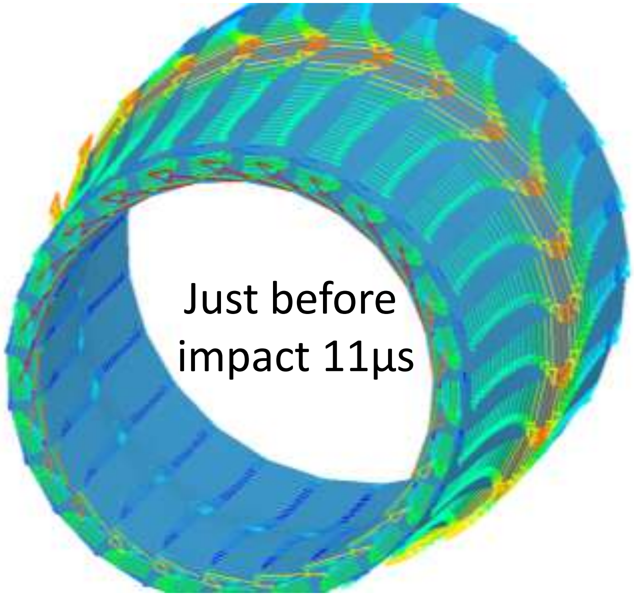
Eddy current changes in welding model, just Before the impact at 11μs

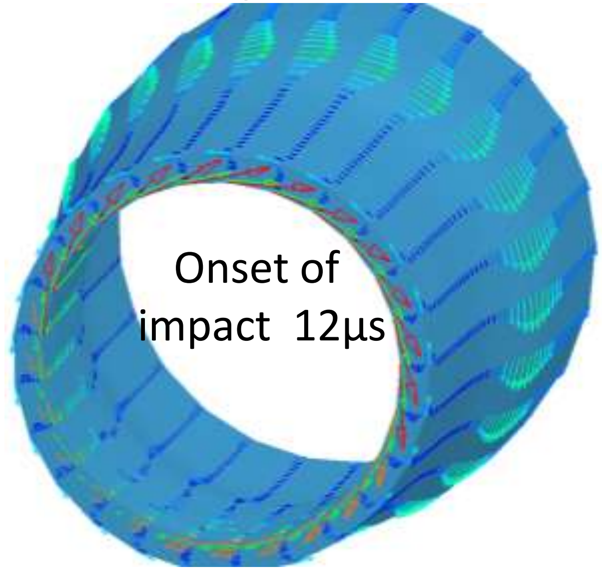


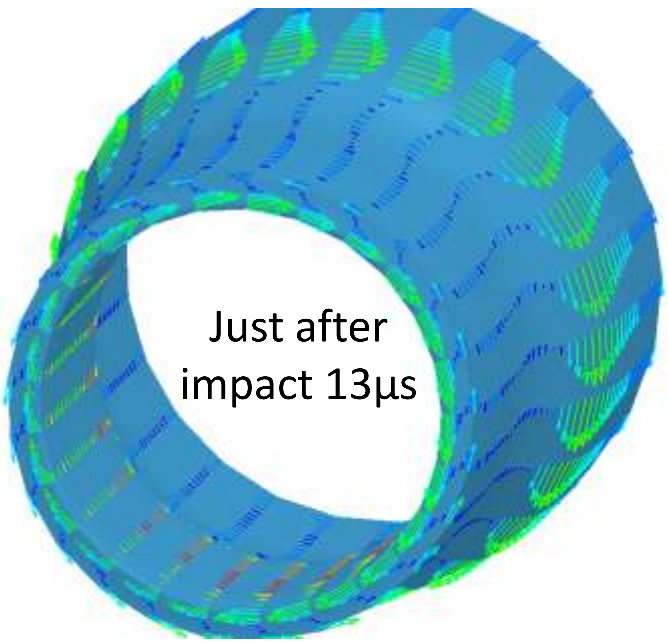
Eddy current changes in welding model, at 5μs and just before the impact at 11μs

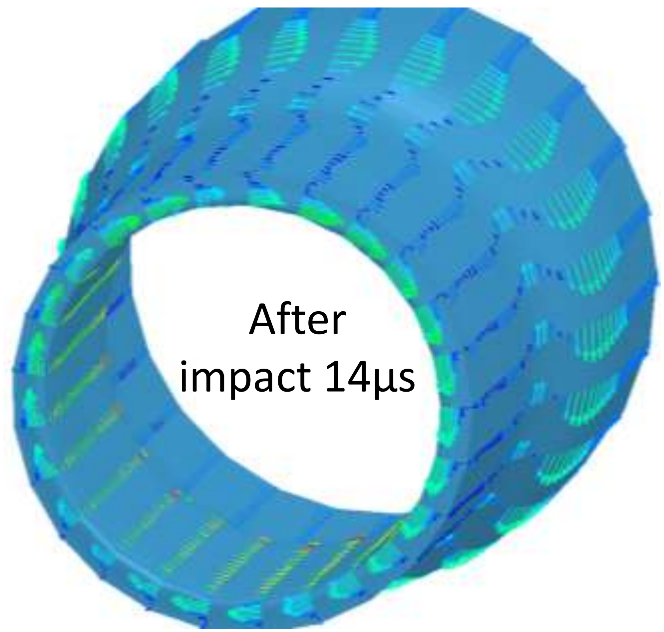


Eddy current changes in flyer tube



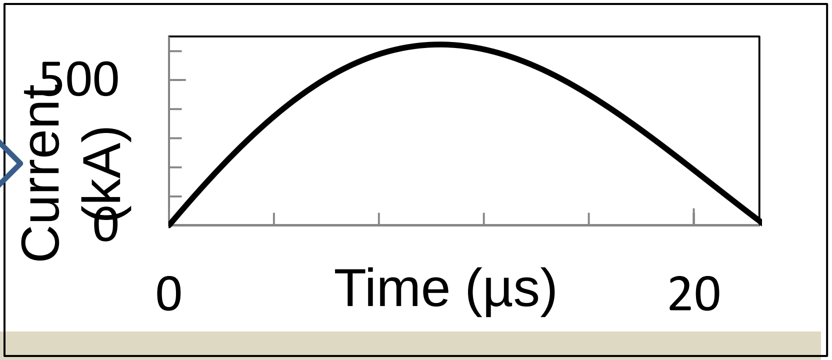


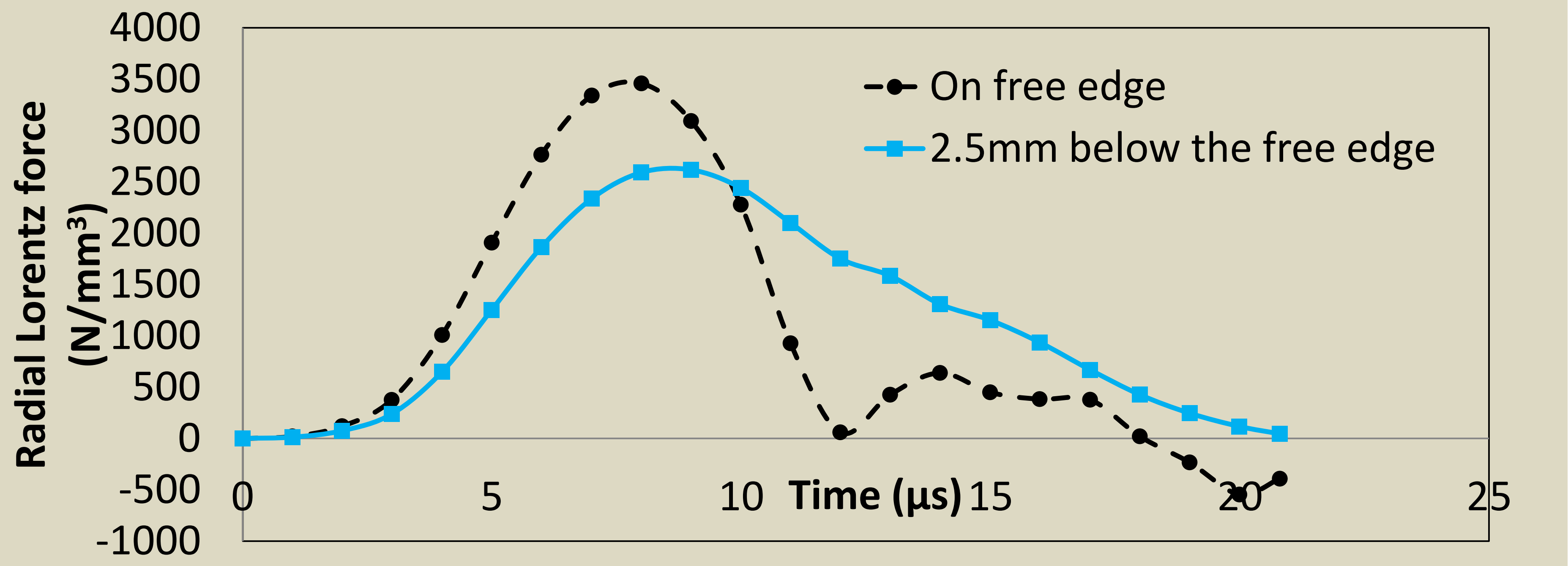




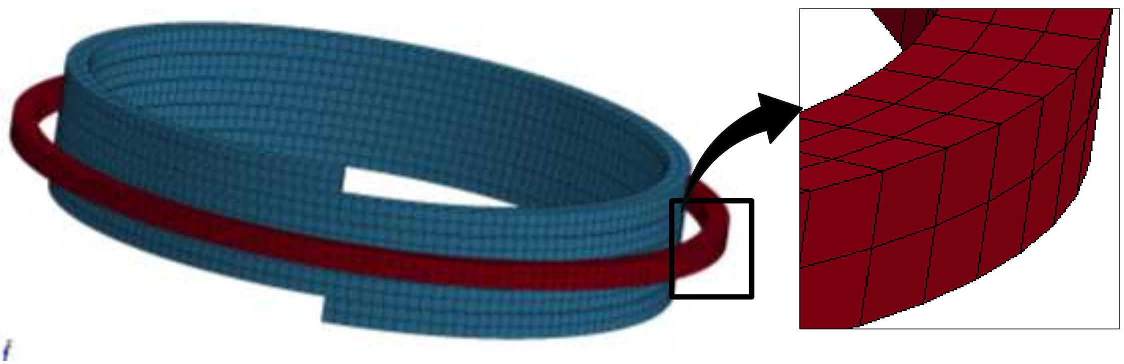
Average radial Lorentz force near free edge and 2.5mm below the free edge

Source Current

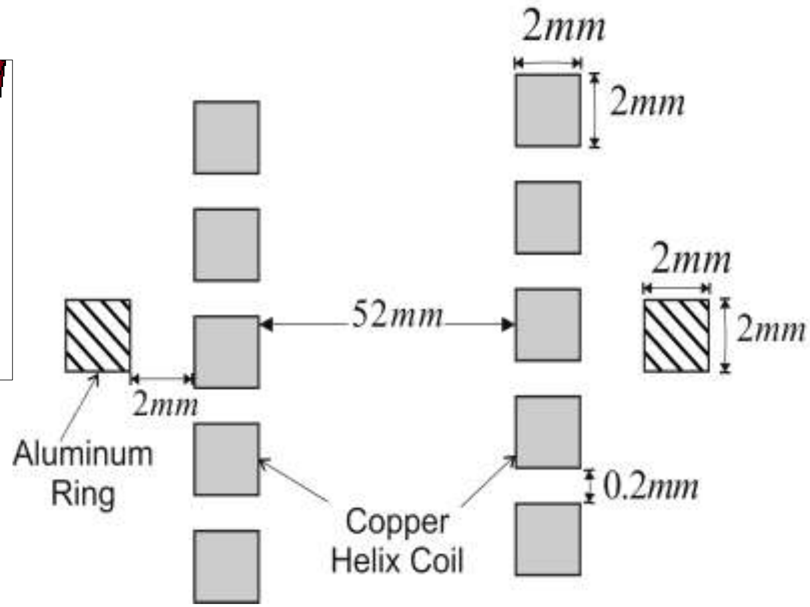




Ring expansion simulation test



3D model in LS-DYNA

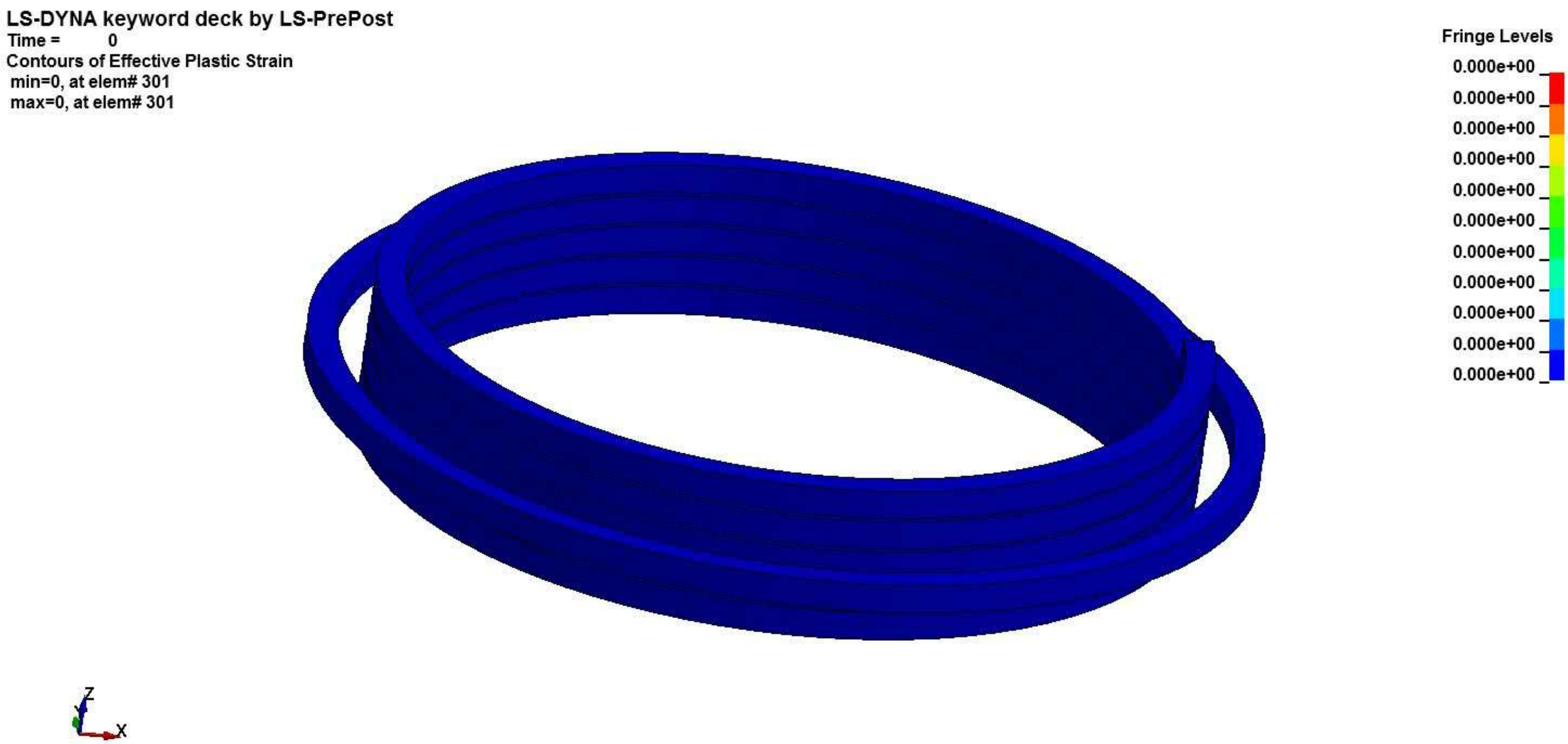


schematic cross-section(Initial state)

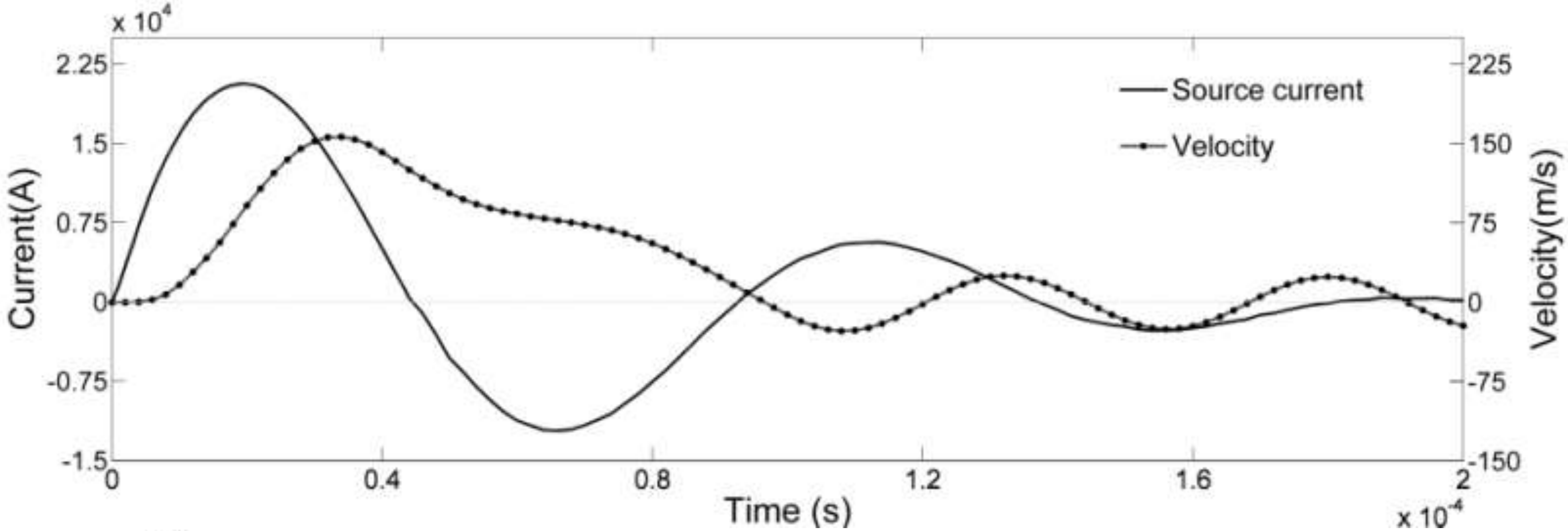
Johnson-Cook parameters used for ring (AA6061-T6)

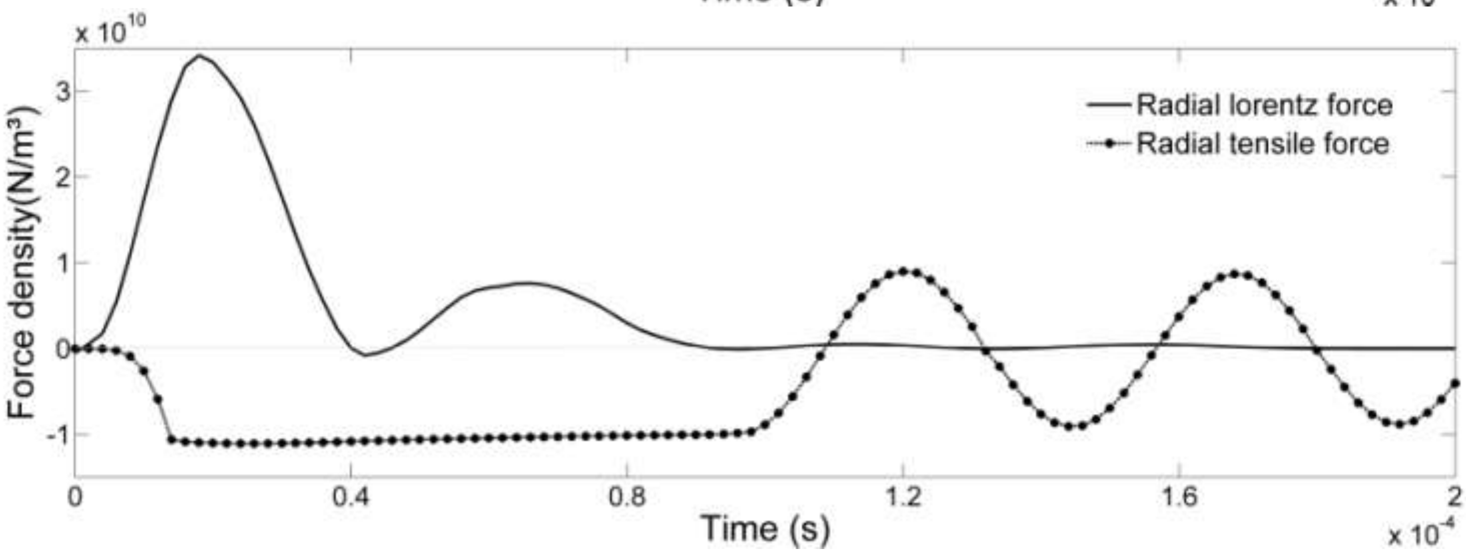
A (MPa)	*B* (MPa)	*C*	*n*
324	114	0.42	0.002

Plastic strain in the ring expansion

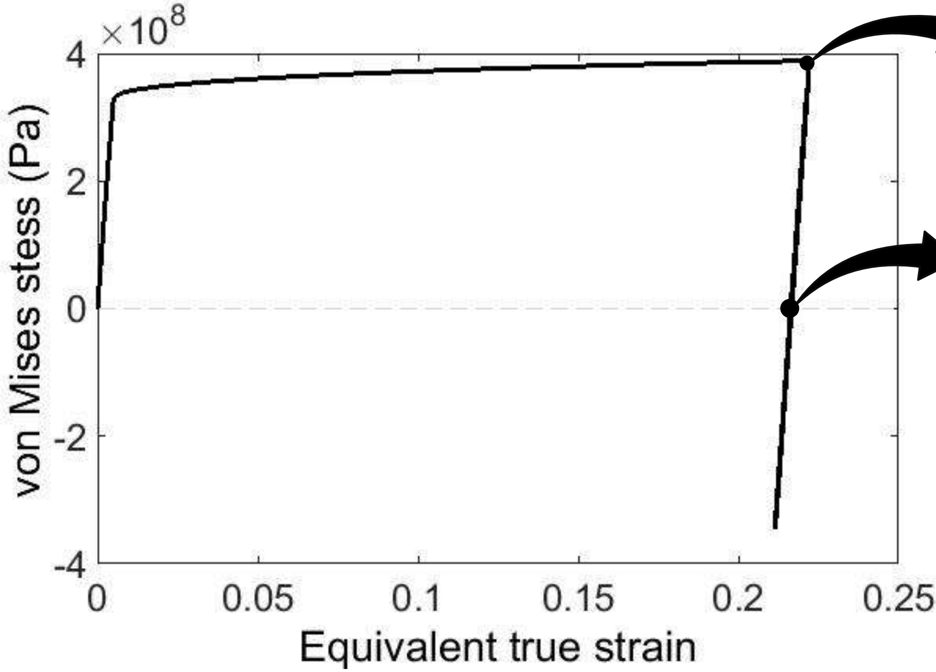


Analysis of process parameters





Spring back effect



Stress here is denoted as σ_1

Ring radius here is denoted as r_i

Max spring back radius:

$$\Delta r \approx \frac{\sigma_1}{E} r_i$$

Vibration frequency:

$$f \approx \frac{1}{2\pi r_i}\sqrt{\frac{E}{\rho}}$$

Max spring back velocity:

$$v_{max} \approx \frac{\sigma_1}{\sqrt{\rho E}}$$

Identification of suitable material models for MPF/MPW

Viscoplasticity:

$$\sigma = \sigma_s \cdot f(\dot{\varepsilon})$$

- σ_s is the von Mises stress in quasi-static deformations. It could be determined by quasi-static tensile test;

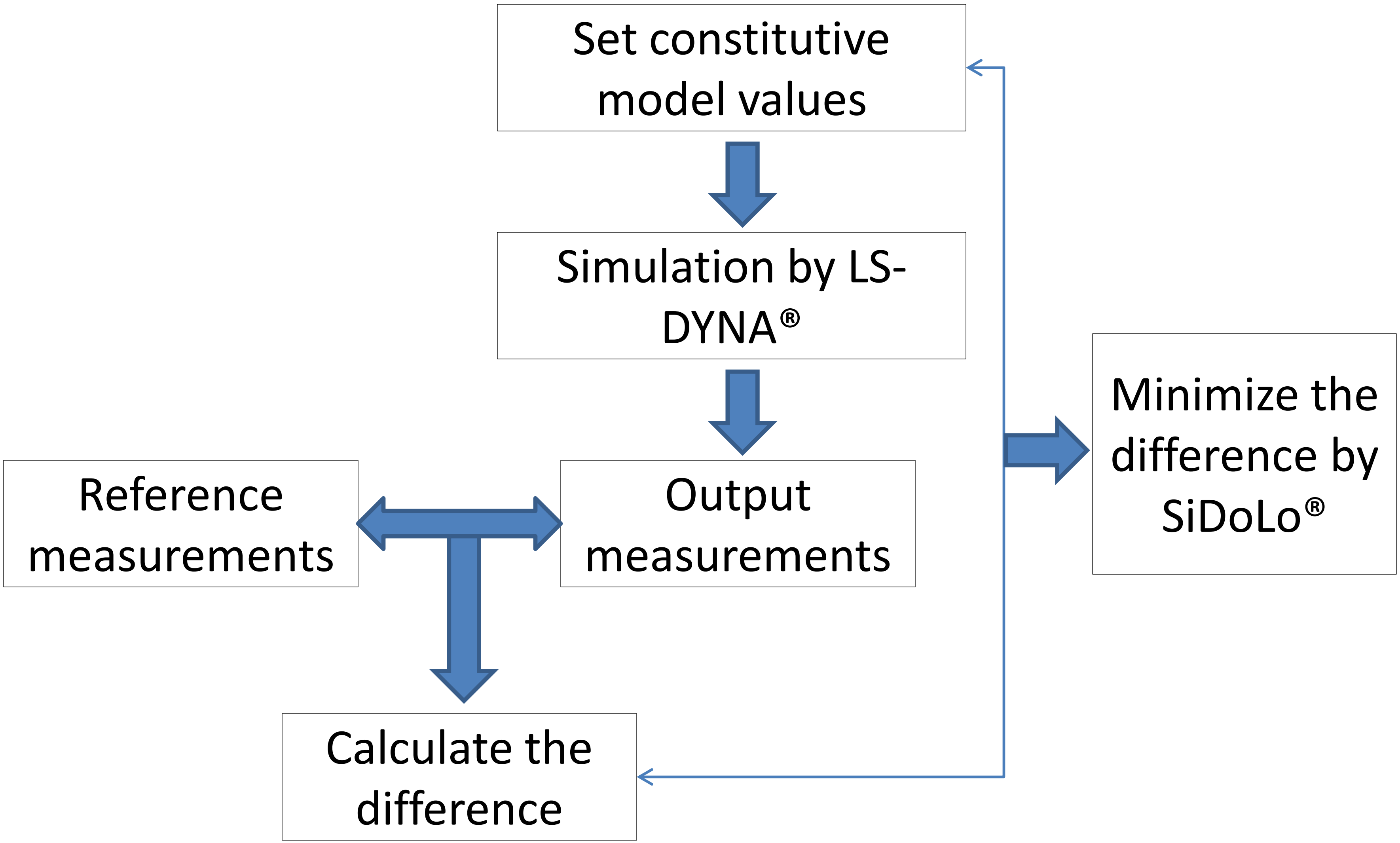
- $f(\dot{\varepsilon})$ is the viscoplasticity factor. Two most common models:

a) Johnson-Cook model: $f(\dot{\varepsilon}) = 1 + Cln\dot{\varepsilon}$

b) Cowper-Symonds model: $f(\dot{\varepsilon}) = 1 + (\frac{\dot{\varepsilon}}{C})^{\frac{1}{p}}$

[MPF/MPW: Magnetic Pulse Forming / Magnetic Pulse Welding]

Diagram of identification steps



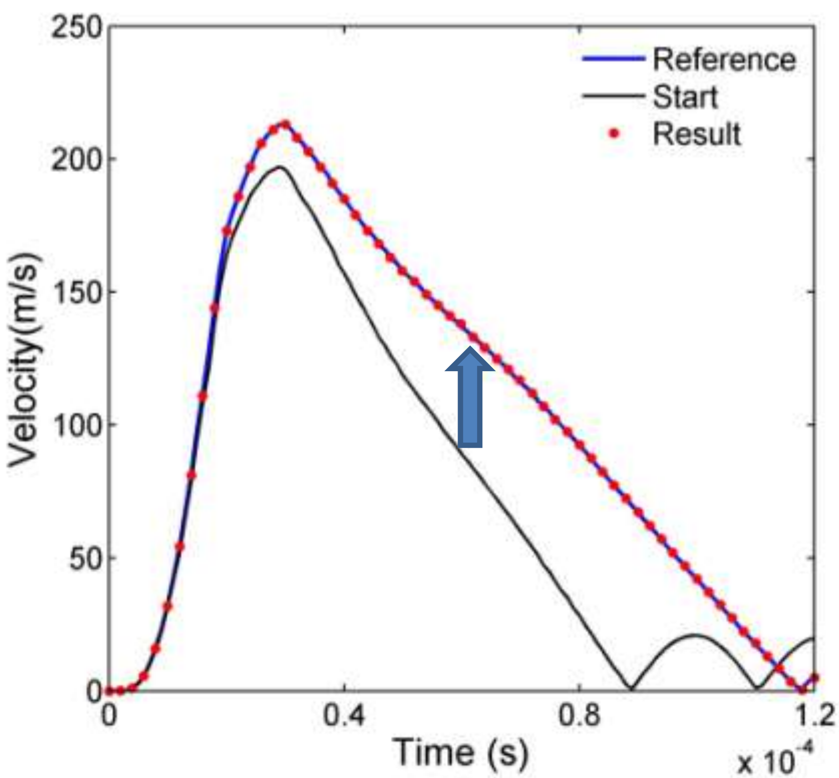
[SiDoLo®: Software toolbox used for identification]

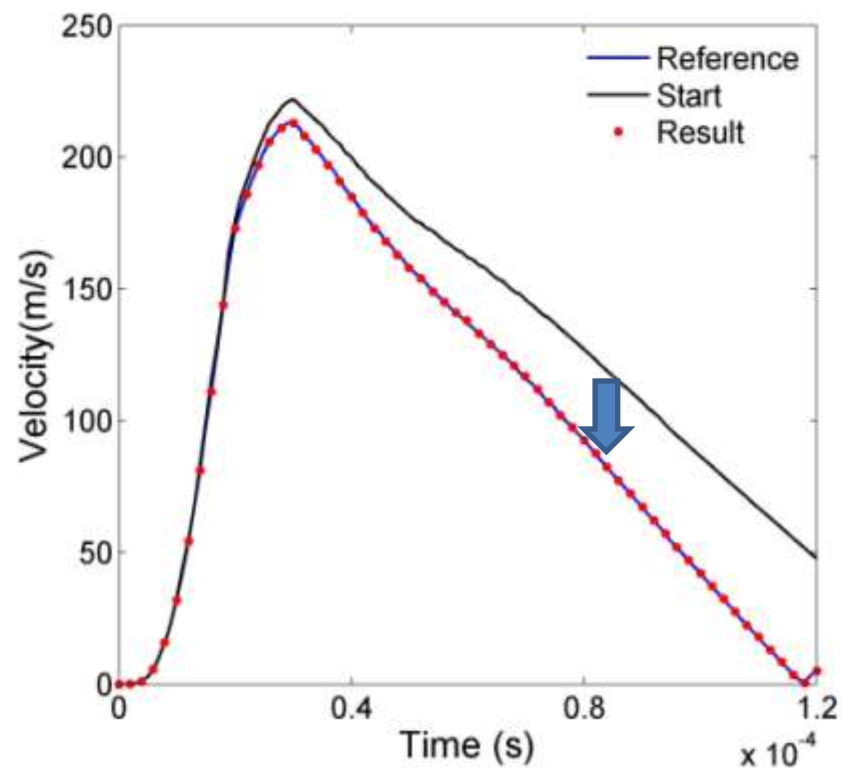
Result for Johnson-Cook model

Determination of C, with $\sigma_s = (170 + 423\varepsilon^{0.42})\mathrm{MPa}$

Target	Start	Result
0.0335	0.09	0.033503

Target	Start	Result
0.0335	0.005	0.033383

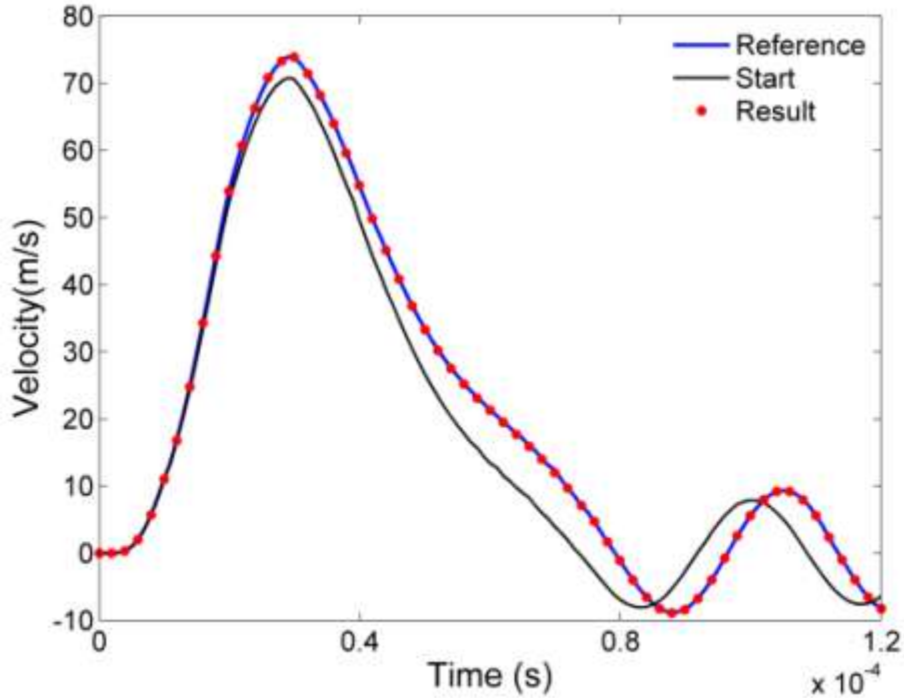




Result for Cowper-Symonds model

Determination of C and p, with $\sigma_s = (170 + 423\varepsilon^1)\mathrm{MPa}$

	Target	Start	Result
C	20000	10000	19778.6
p	4.0	5.0	4.0



Conclusions

- Predictive numerical models were developed for MPF/MPW
- The changes in the deformation behaviours with additional components were investigated
- Fieldshaper slot effect was investigated
- Change in Lorentz force direction and eddy current were also studied
- Changes in electromagnetic field significantly influence the deformation behaviours
- Vibration due to spring back was studied in a ring expansion test
- Numerical models developed for the purpose of identification of material's constitutive models in MPF/MPW

[MPF/MPW: Magnetic Pulse Forming / Magnetic Pulse Welding]

Thank you for your attention

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International Impulse Forming Group

Insight into the realistic behaviours of magnetic pulse forming and welding processes using numerical simulations

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Questions!

International Impulse Forming Group

Insight into the realistic behaviours of magnetic pulse forming and welding processes using numerical simulations

Thank you!

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