An MPP version of the Electromagnetism module in LS-DYNA for 3D Coupled Mechanical-Thermal-Electromagnetic simulations

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Outline

- General presentation of LS-DYNA.
- Presentation of the electromagnetism (EM) module.
- Recent and future developments.
- Presentation of the MPP version of the EM module.
- Examples:
  - Electromagnetic free forming.
  - Electromagnetic bending.
  - Rail gun.

General presentation of LS-DYNA

Finite element code for non linear transient dynamics

- 2-D and 3-D simulations with explicit/Implicit time integration
- Deformable & rigid bodies
- Numerous element types and formulations
- Around 150 constitutive (material) models
- 14 equations-of-state
- More than 35 contact algorithms
- Coupled thermal analysis
- Coupled fluid/structure analysis (Euler/ALE/Lagrange element formulations)
- Smooth Particle Hydrodynamics (SPH)

Some Applications of LS-DYNA

- **Automotive**
  - Crash
  - Airbags
  - Occupant safety
- **Aerospace**
  - Bird strike
  - Blade containment
  - Crash
- **Manufacturing**
  - Stamping
  - Forging
  - Casting
- **Structural**
  - Earthquake safety
  - Concrete structures
- **Electronics**
  - Drop analysis
  - Package design
  - Thermal
- **Defense**
  - Weapons design
  - Blast response
  - Penetration

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Some Applications of LS-DYNA: Metal Stamping

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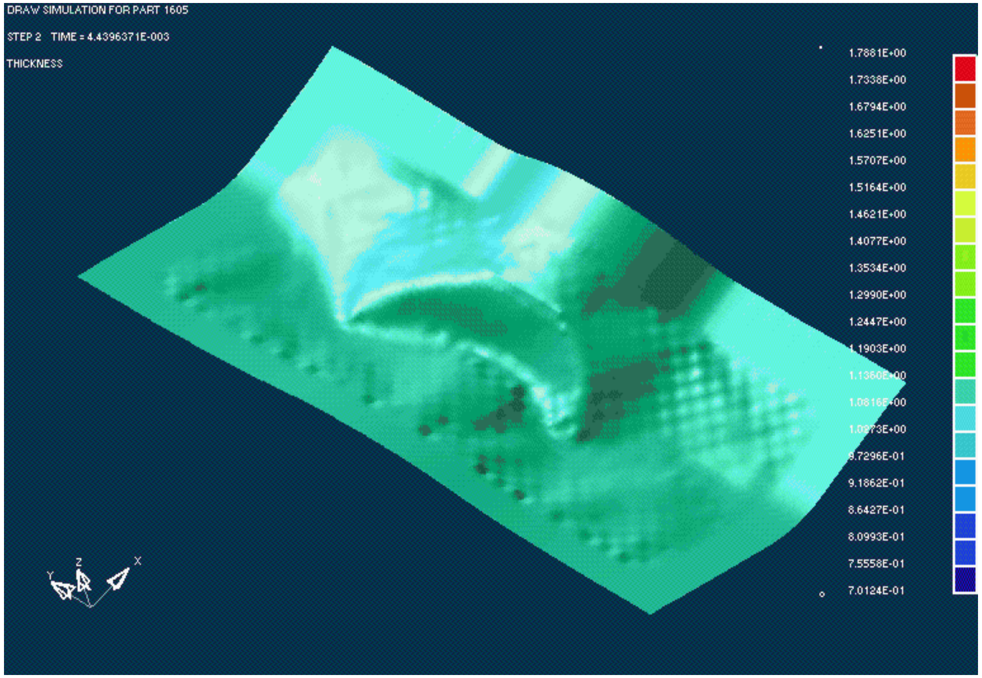
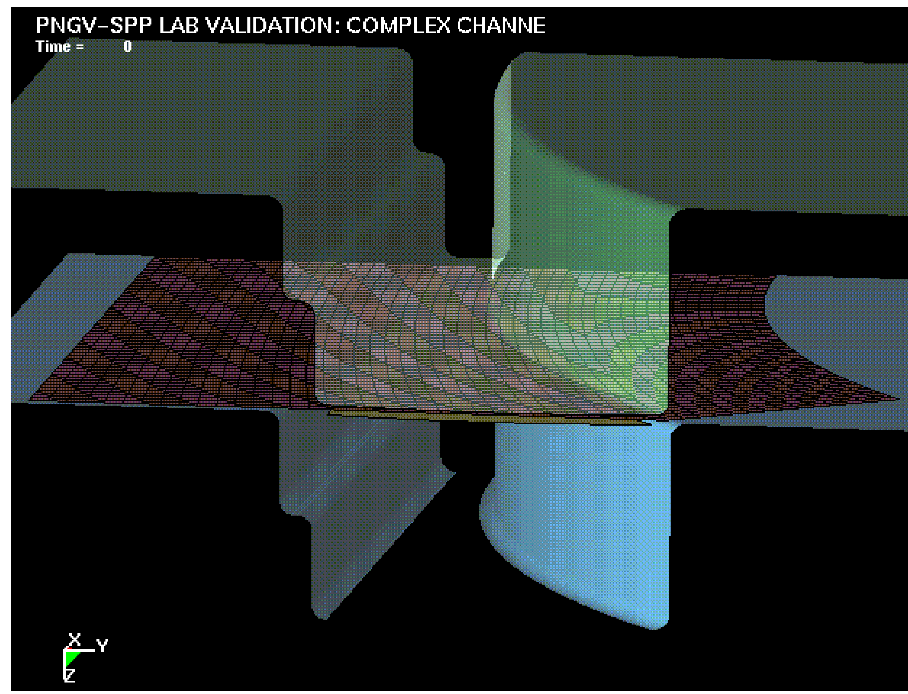




LS980-Electromagnetism module: General presentation

- Electromagnetism module for 3D eddy-current problems, coupled with mechanical and thermal solvers (typical applications: magnetic metal forming and welding).
- Boundary element method in the air coupled to finite elements in the conductor is used to avoid meshing the air.
- The EM fields, as well as EM force and Joule Heating can be visualized with LSPREPOST.

Electromagnetism module: typical applications

- **Magnetic metal forming.**
- **Magnetic metal cutting.**
- **Magnetic metal welding (impact welding).**
- **High magnetic pressure generation.**
- **Computation of the stresses/deformations in coils.**

More recently:

- **Induced heating (Joule effect).**
- **Resistive heating.**
- **Electromagnetic contact capability: rail-gun.**

LS-980 Electromagnetism module: update

- MPP version now available.
- Electromagnetism contact capability now available (rail gun, …).

Future:

- Extension of the module to tetrahedral, wedges elements, triangular faces, as well as shells.
- Introduction of other solvers than eddy-current (magnetostatics,…).
- Mesh adaptivity.

MPP version of the electromagnetism module

- Allows sharing the computation as well as the memory between several processors.
- Large gains in run time.
- Makes it possible to simulate much larger cases.
- Especially true for the BEM part of the EM solver which is the most demanding both in memory and CPU.

Run time vs # procs for typical EMF case:

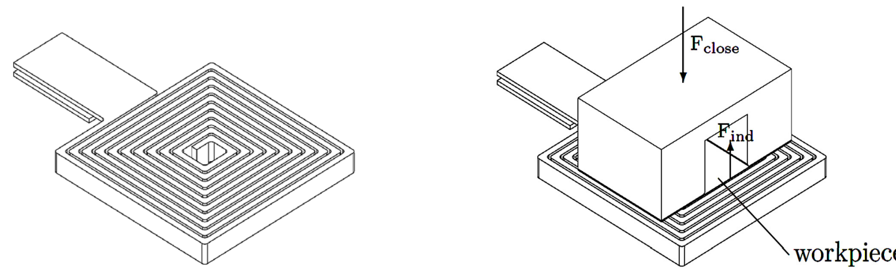
#proc	1	2	4	8	16	32	64
Run time	24h16mn	12h16mn	6h28mn	3h56mn	2h29mn	1h36mn	1h09mn

Maximal mesh (#elements) size vs # procs (typical)

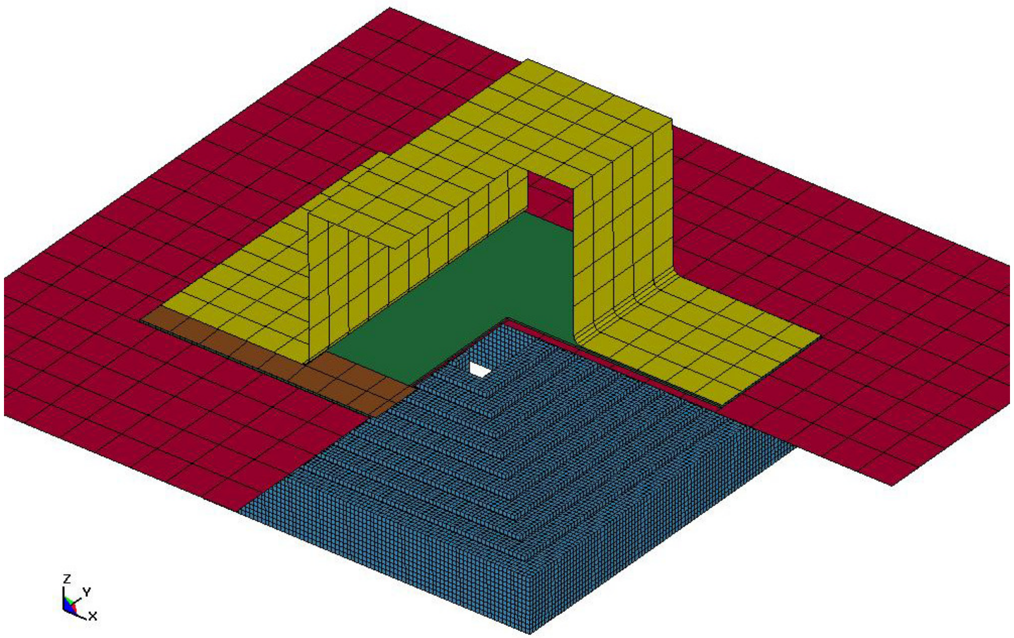
#proc	1	8
# elem	100,000	500,000

Electromagnetic free forming case

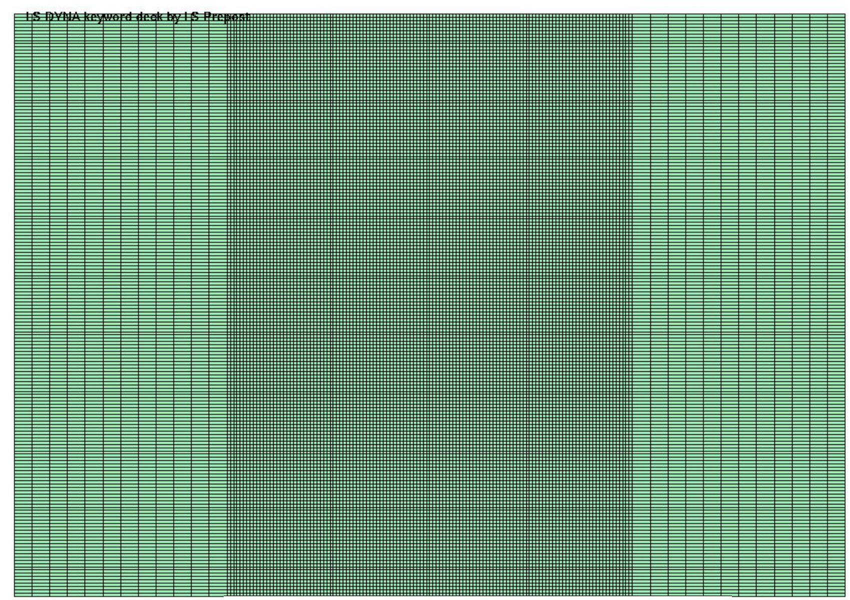
AZ31B magnesium alloy sheet



Coil and die used

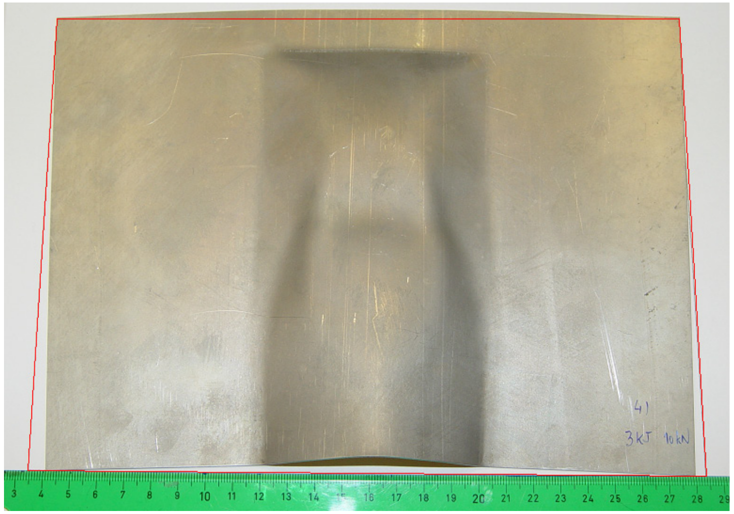


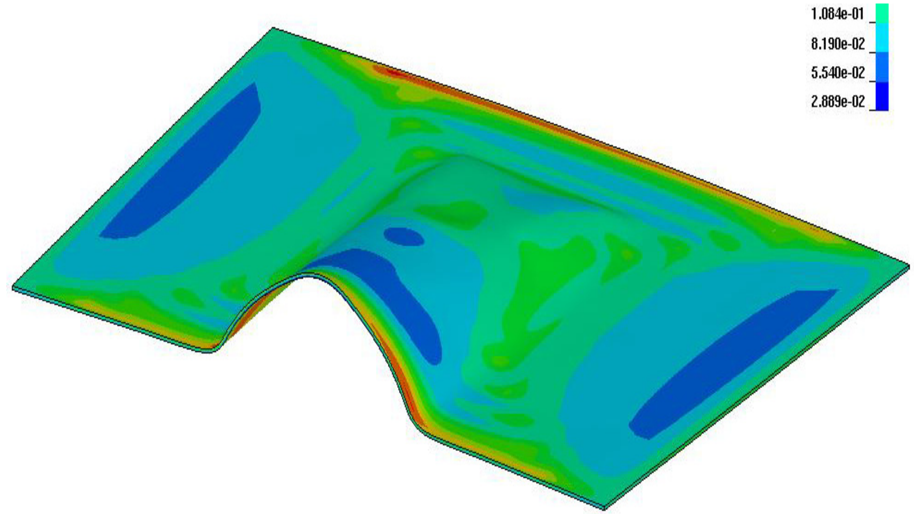
Mesh (general view- ¼ represented)



Mesh (sheet)

Comparisons experimental/numerical

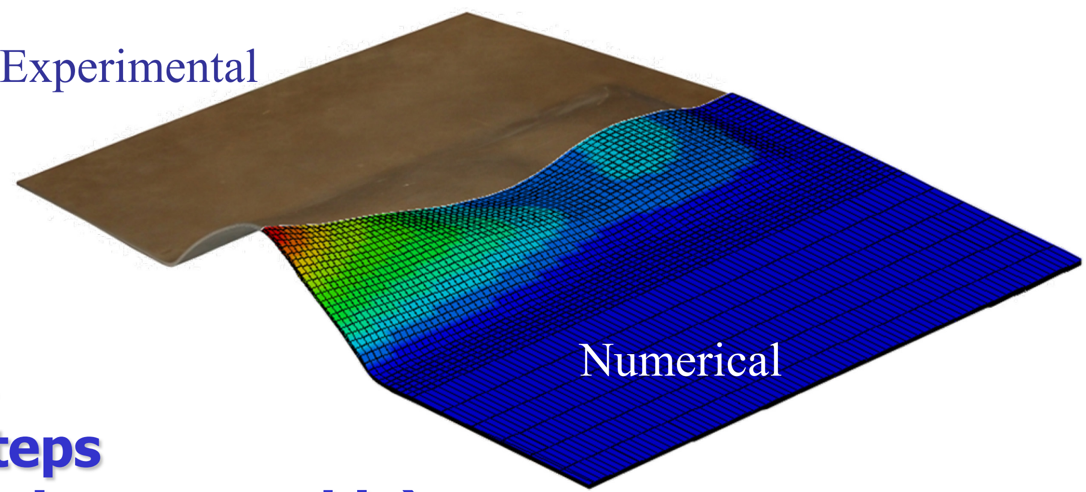




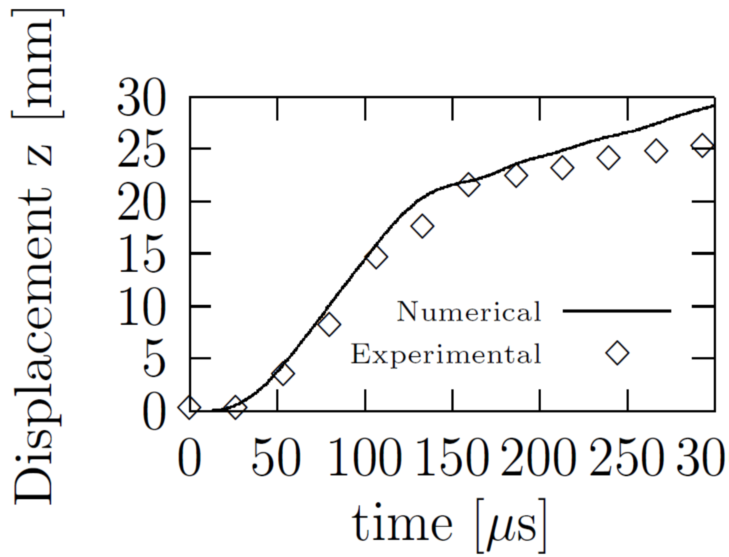
Num. and Exp. Final shapes

Total run time: 300µs
Time steps:
- **Mechanical: 30ns**
- **Thermal: 2µs**
- **EM: 1.5µs**

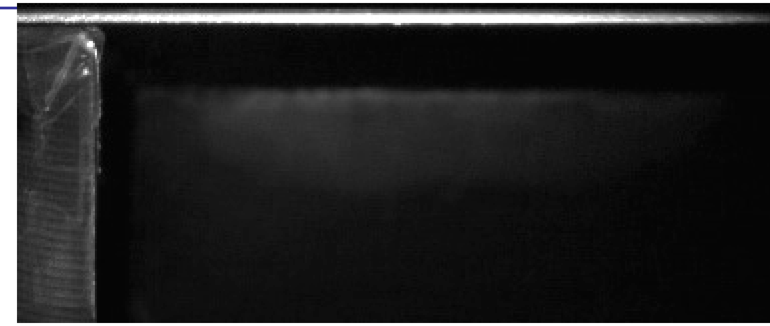
with FEM and BEM matrices reassembly every 10 time steps (=200 EM time step, 20 matrix reassembly)



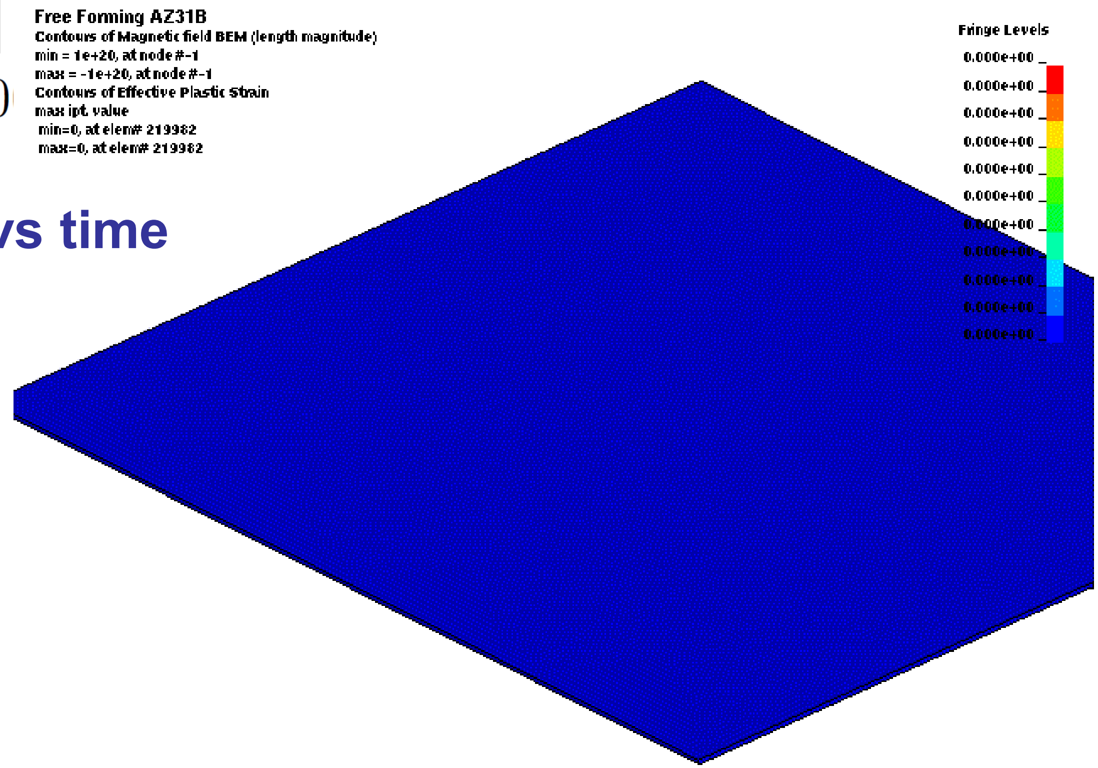
Comparisons experimental/numerical



Num. and Exp. Z displacement vs time



PHOTRON High speed camera



B field

(numerical)

MPP run time versus number of processors for different mesh sizes

case	mesh1	mesh8	mesh16	mesh32	mesh64
#nodes	39,504	63,759	86,537	131,747	420,478
#elem	28,595	43,568	62,600	98,744	343,224
#BEM P	19,851	36,971	44,279	62,363	147,843
#BEM Q	39,688	73,920	88,532	124,688	295,648

Mesh sizes

# processors	*Mesh1*	*Mesh8*	*Mesh16*	*Mesh32*	*Mesh64*
1	*24:16*	*55:41*			
2	*12:16*	*27:42*			
4	*6:28*	*14:13*			
8	*3:56*	*8:49*	*12:14*		
16	*2:29*	*5:15*	*7:34*	*15:53*	
32	*1:36*	*3:07*	*4:22*	*8:57*	*42:16*
64	*1:09*	*2:01*	*2:46*	*5:32*	*26:31*

Run time (hours:minutes)

Run time versus number of processors for mesh1 and mesh8

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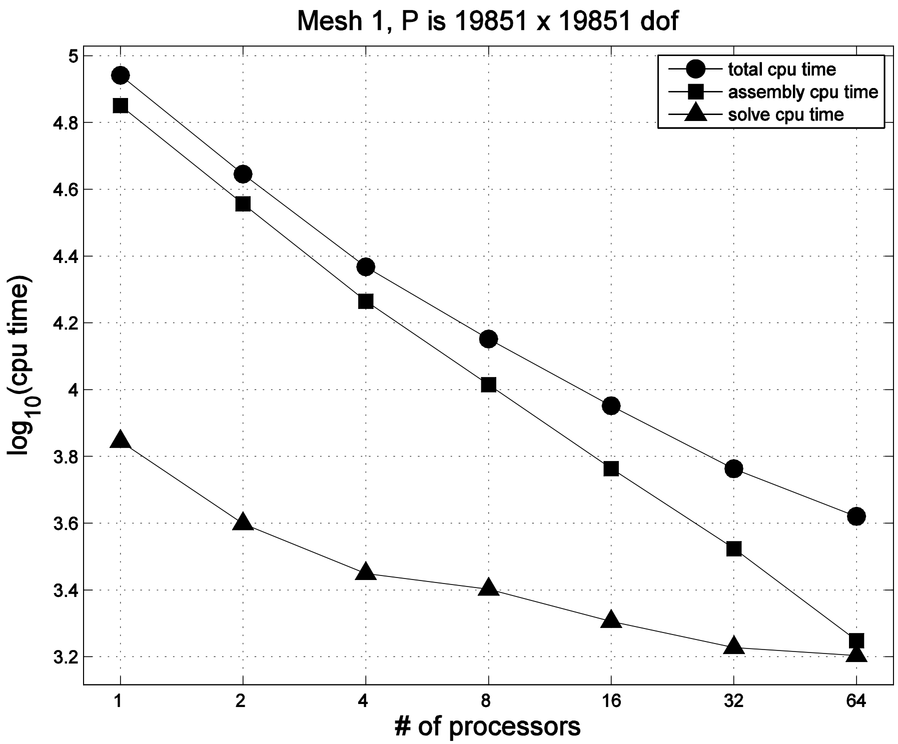
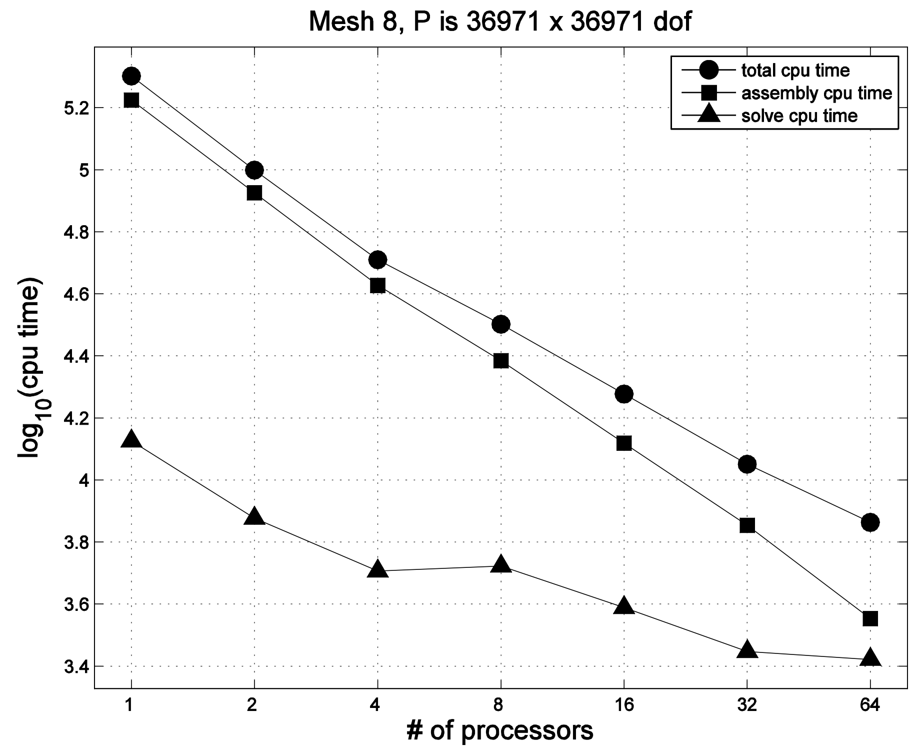
Mesh1



Mesh8



Total time

BEM matrices assembly time

BEM systems solve time

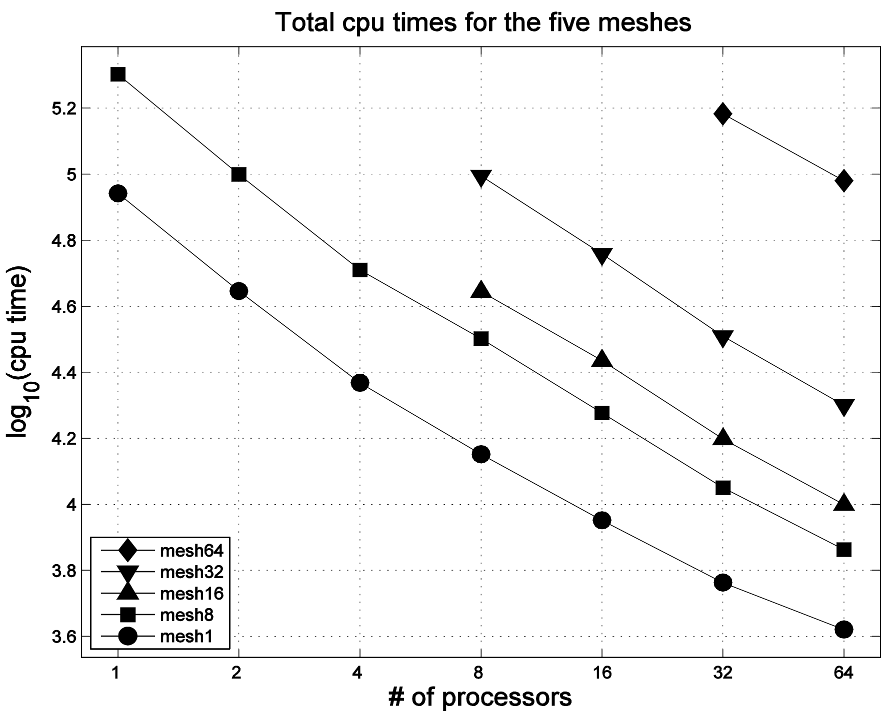
Total time/efficiency vs # of processors for the different meshes

Efficiency defined as:

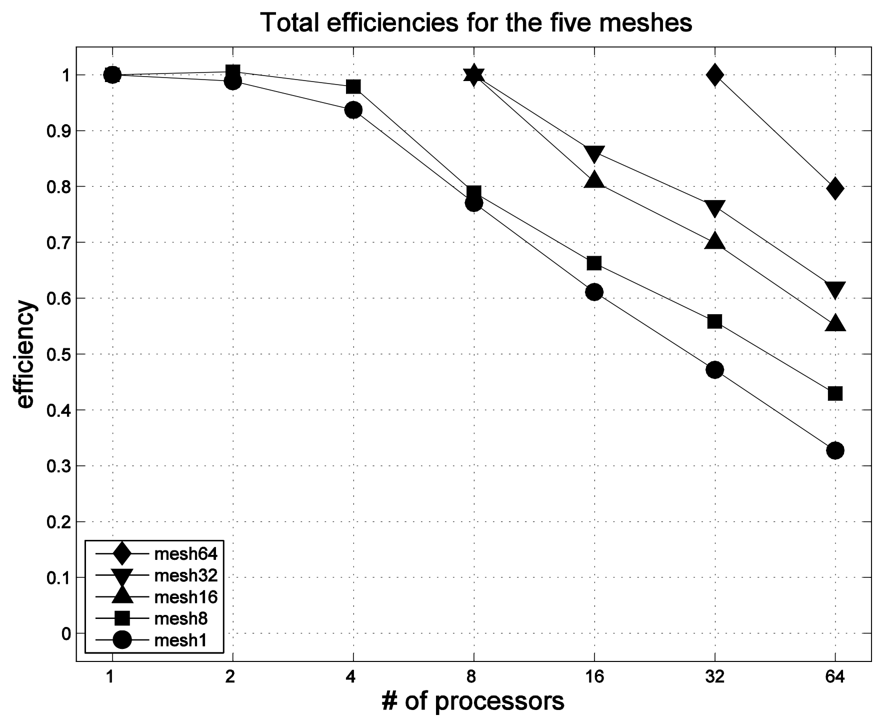
$$E_p = \frac{p_0 T_{p_0}}{p T_p}$$

P : number of processor
T_p: run time for p processors
T_{p0}: run time for p0 processors (reference)

We would like Ep to be as close to 1 as possible

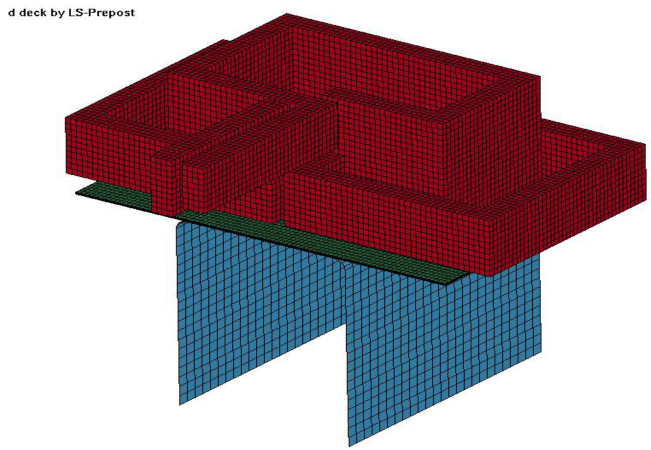


Total CPU time

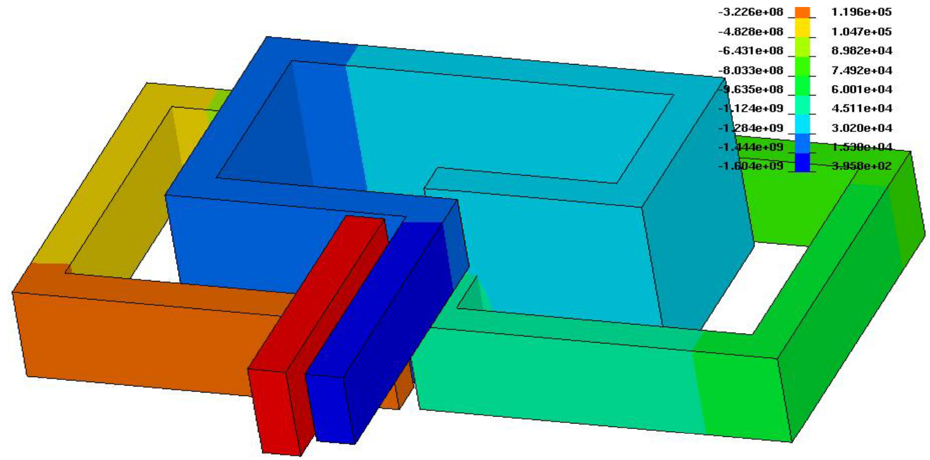


Total efficiency

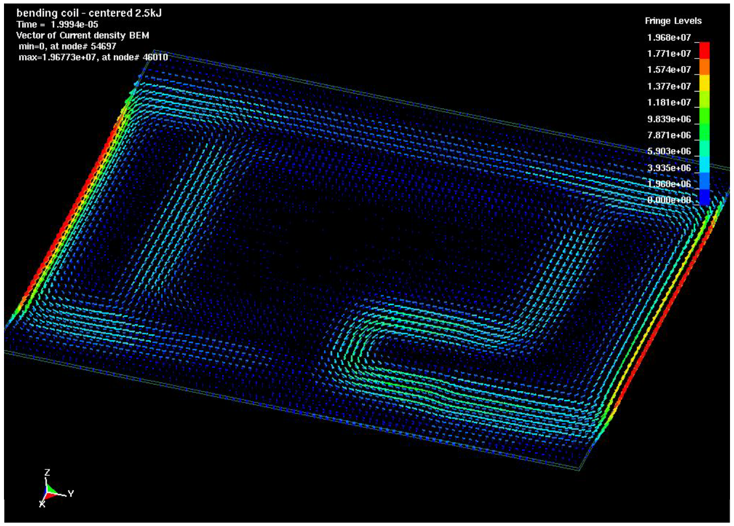
Electromagnetic bending case (1)



Mesh (general view)

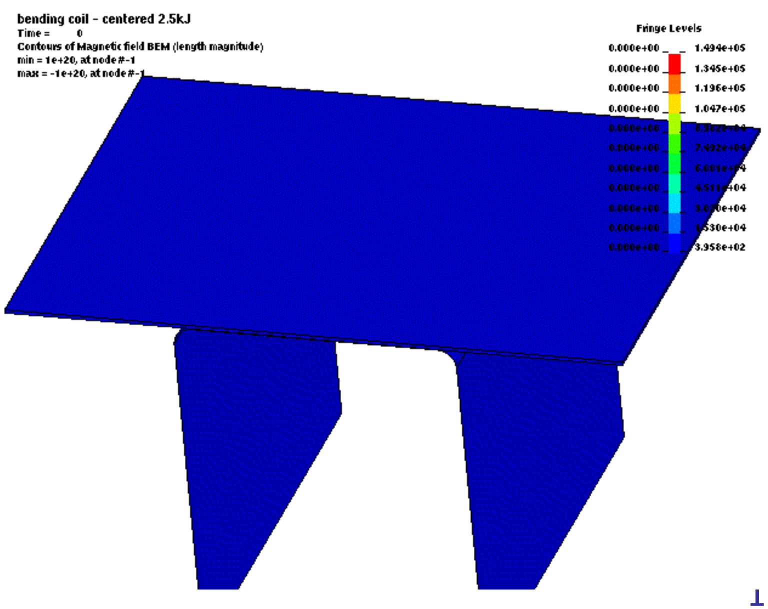


Scalar potential on coil



Sheet current density

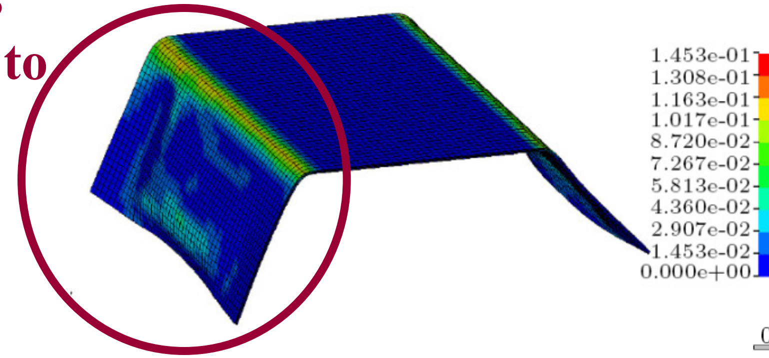
B field

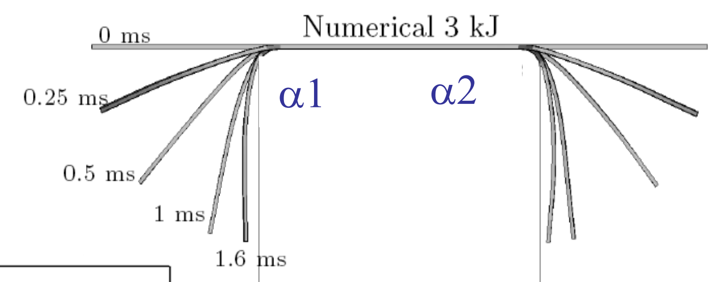


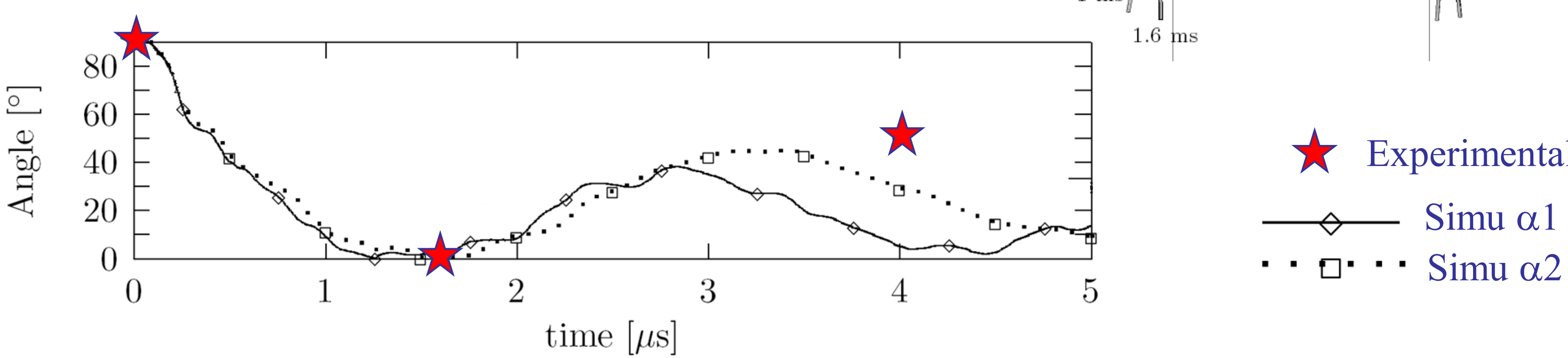
Electromagnetic bending case (2)

Experimental vs numerical comparisons

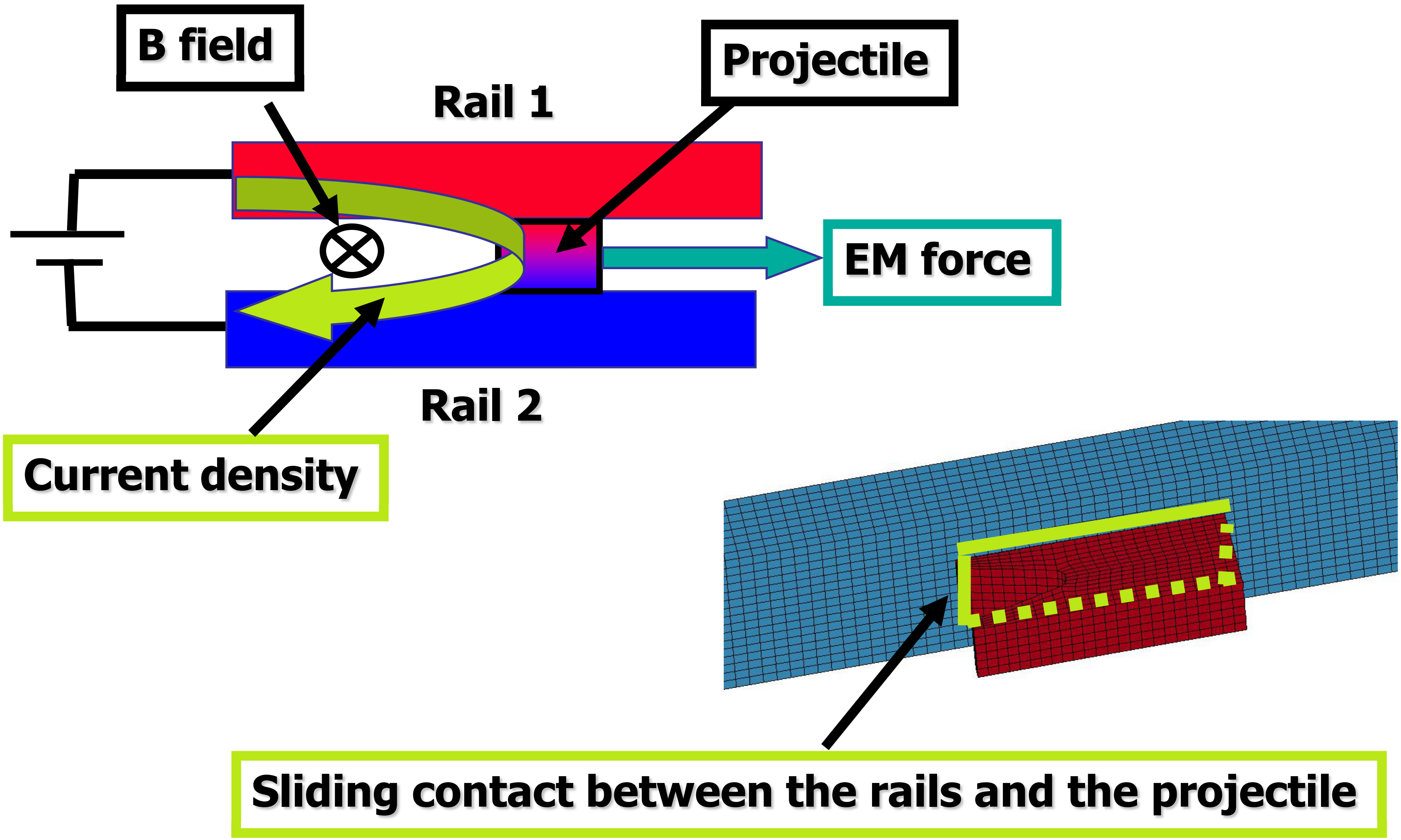
Non homogeneus deformation due to induced currents



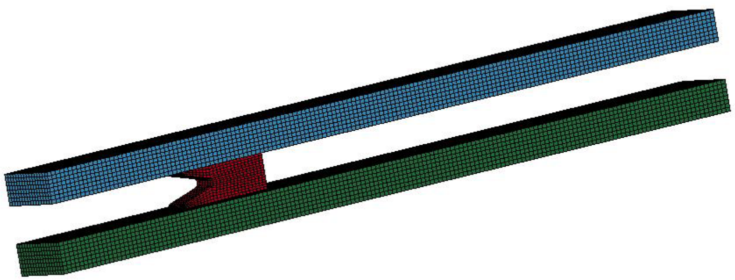




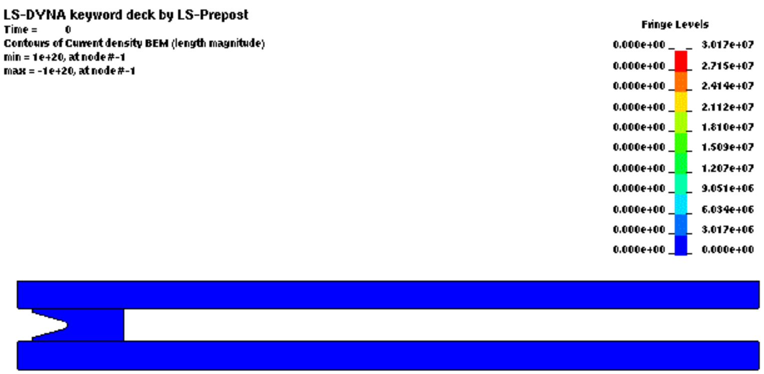
Sliding contact for rail gun applications

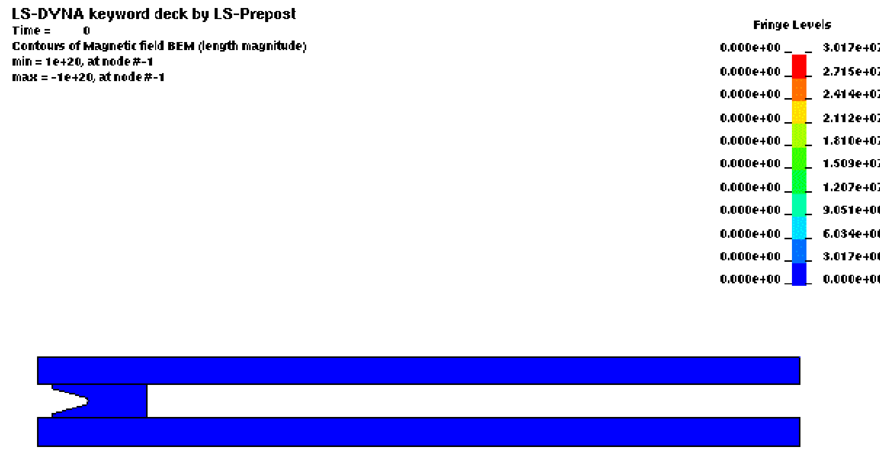


Typical rail gun simulation (3D)



52,000 nodes
43,000 solid elements





Current density **B field**

Conclusions

- MPP version of the EM module allows sharing memory and CPU between processors, hence faster computations on larger cases.
- Future developments (pre-conditioners,…) should allow even better scaling.
- Recent EM contact capability allows rail gun like applications.
- LS-DYNA with EM module available as a "beta" version called "ls980".

Please contact Pierre L'Eplattenier

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