Recent developments in the Commercial Software LS-DYNA for electromagnetic pulse forming and joining simulations

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Outlook

• The electromagnetic (EM) solver in LS-DYNA
• Applications (3D solver)
  • Magnetic Pulse Forming
  • Magnetic Pulse Welding
  • Induction heating
  • Induction welding
  • Battery crash modeling
  • Contact: rail gun, short circuits
  • Magnetic flux compression
  • Resistive heating
  • Electromagnetic spot welding
  • Coil design and optimization
• 2D axisymmetric solver
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)
- ... and ... electromagnetics
EM 3D Solver

Electromagnetic Forming/Crimping/Bending/Welding process

Source fields (currents) introduced in Coils

Induced magnetic and Electric fields in nearby conductors

Lorentz forces generated

Consequence

Motion, deformation of conductors which in turn changes EM properties

Joule Heating generated

Consequence

Heating which in turn changes EM related materials properties (conductivity)

Inductive heating process
Thermal
Implicit
Double precision

EM
BEM (Air)
FEM (Conductors)
Implicit
Double precision

Plastic Work

Mechanical
Implicit / Explicit
Double precision / Single precision

Fluids
ALE
ICFD
CESE
CPM

Heat Flux
Temperature

Joule Heating
Temperature

Force
Node Positions

Node motion
EM 3D Solver

- FEM (conductors) coupled with BEM (surrounding air)
- Automatically coupled with Mechanical and Thermal
- Possible to couple it with fluid solver
- Available in MPP
- EM contact capability
- EM fields can be visualized in LS-PREPOST (same environment as Mechanical, Thermal, ...)
Magnetic Pulse Forming (MPF)

- Achieve higher formability than traditional methods
- Can produce sharp corners and fine details
- Greatly reduced springback and good stress distribution
- Use one sided die (Optional - none metallic die)
- Can be combined with any other forming technology

Sheet forming on conical die

In collaboration with:
M. Worswick and J. Imbert
University of Waterloo, Ontario, Canada
Magnetic Pulse Forming (2)

In collaboration with G. Mazars, G. Avrillaud, Bmax, France
Magnetic Pulse Forming (3)

Combined deep drawing + MMF

Courtesy of Y. Kiliclar, IUL, TU Dortmund
Magnetic Pulse Welding (MPW)

MPW is a solid state cold welding generated by high speed collision between two metals at room temperature.

- Millisecond
- Dissimilar
- No heat affected one
- High performance joining, thinner parts
- Different shapes

Simulations are used to determine the collision parameters (3D) to insure a good weld:
- Impact velocity
- Impact angle
Magnetic Pulse Welding

Weld of an outer tube onto an inner one

Courtesy of G. Mazars, Bmax, France
Induction heating

Current induced by a coil -> Joule heating

- Conducting plaque moving though Coils,
- Coils generate Joule heating in the plaque,
- Induced heating problem coupled with the Thermal solver of LS-DYNA.
Continuous induction welding

Induction heating
Mechanical pressure applied for consolidation and maintained during cooling.

BMW M-series composite front bumper
(source: Jacob Composite GmbH)

In collaboration with:
M. Duhovic,
Institut für Verbundwerkstoffe, Kaiserslautern, Germany
Cooling of a coil by a flow of fluid (ICFD + thermal + EM)

The electric current heats up the coil so water is injected and circulated to avoid melting of the coil.

Experimental/numerical comparisons

In collaboration with: M. Duhovic,
Institut für Verbundwerkstoffe, Kaiserslautern, Germany
Many EM models are (quasi) axisymmetric

- Many geometries have (or nearly have) a cylindrical invariance (coils, field shapers, ...)
- The pitch of a coil is generally small to limit the inductance
- => Introduction of EM 2D axisymmetric solver
EM 2D: basics

- EM 2D coupled with mechanics and thermal 3D
- User needs to provide a 3D mesh with rotational invariance
- All the mechanical and thermal 3D capabilities available

- EM solved in a plane
- EM fields from 2D to 3D by rotation around the axis
- This process includes EM force and Joule Heating
- EM properties in the plane ($\sigma$, ...) = average over 360°
EM 2D : numerical method

- EM solved by combined FEM + BEM (as in 3D)
- In the BEM, change in the kernel to take into account integration over full circle.
- The simulation can be done on a slice of the full 360 °, with suitable mechanical and thermal boundary conditions
Capabilities

• Coupled with 3D mechanics and thermal, hence all the 3D features of LS-DYNA are available

• Allows coupling with all circuits (including RLC).

• Allows connecting different circuits together (e.g. for helix, spiral)

• EM contact available

• Available in MPP
How to set up a 2D axi case

Slice of the full 360° mesh

Define mechanical/thermal boundary conditions (e.g.)
*BOUNDARY_SPC_SET

Define EM 2D:
- 2D plane
- SSID in
- SSID out
Circuit connection

- 2D axi can be connected to any kind of circuit
- Circuits can be connected
- It is hence possible to model a helix/spiral coil, even connected to a RLC circuit

**EM_CIRCUIT_CONNECT**

\[ c_1 \cdot i_1 + C_2 \cdot i_2 = 0 \]

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Imposes: \( c_1 \cdot i_1 + C_2 \cdot i_2 = 0 \)
Contact

- The 2D contact works the same way as the 3D one:
  - Constraints on the FEM system
  - Local re-meshing if the BEM mesh
Comparison 3D – 2D axi (2)

- Forming of a plate with a spiral coil
- Coil connected to RLC circuit

3D vs 2D – z vs time at 2 nodes
Comparison 3D – 2D axi (3)

3D : 30 mn on 12 CPU

2D : 5 mn on 1 CPU
Comparison 3D – 2D axi (1)

- Forming of a tube with a helix coil

3D vs 2D – central radius vs time
Comparison 3D – 2D axi (1)

3D: 2 hours on 24 CPU

2D: 5 mn on 1 CPU
Plans: coupling EM-3D and EM-2D

- All in 3D
- Coil in 2D
- Plate in 3D
- Die in 3D
Plans for the Future

- Add 2D + 3D coupling
- Add erosion (element deletion) to EM
- Add magnetic materials
- Add piezoelectric materials
Thank You