Developments in LS-DYNA for Metal Forming Simulation

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Improvements to *ELEMENT_LANCING
**Keywords:** *ELEMENT_LANCING, *DEFINE_CURVE_TRIM_3D

- Specify instant or progressive lancing
- Define lancing curves

**Drawbacks**

- Only 1 part (PID) is allowed
- Only X, Y, Z data pairs are allowed to define lancing curves
- No adaptive refinement along lancing route
- Lanced scraps cannot be removed
- Lancing start point cannot be defined directly using distance from punch bottom.

**Enhancements**

- A part set is now allowed, which enables lancing across tailor-welded blanks.
- IGES format curves can now be used as input to define the lancing route.
- Meshes along the lanced boundary is now automatically adapted to provide a smooth edge.
- Trimming now can be defined after lancing to remove the scrap. This is done with the new keyword *DEFINE_LANCE_SEED_POINT_COORDINATES.
- Lancing activation distance can now be defined using a new variable CIVD.
negative IDPT: part set ID

IREFINE activated, =1

AT, ENDT=distance from punch bottom if CIVD is used.

CIVD: load curve ID under *BOUNDARY_PRESCRIBED_MOTION_RIGID

<table>
<thead>
<tr>
<th>Card 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>IDPT</td>
<td>IDCV</td>
<td>IREFINE</td>
<td>SMIN</td>
<td>AT</td>
<td>ENDT</td>
<td>NTIMES</td>
</tr>
<tr>
<td>Type</td>
<td></td>
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<td>1</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
</tbody>
</table>
- Automatic mesh refinement along the lancing curves
- To improve the mesh quality

Lanced mesh prior to Revision 107708

Improved lanced boundary mesh with IREFINE=1 after Revision 107708
- Lancing across laser welded line using negative IDPT.
- Lancing scrap removal.
- Automatic mesh refinement along lancing route.
Lancing in Hot Forming
Checking Fixture Clamp Definition and Simplification of FORMING Contact Definition
Clamping Simulation

• Example of clamping simulation
Keywords:

*DEFINE_FORMING_CLAMP
*DEFINE_FORMING_CONTACT

Advantages:

● eliminate the need to use auto-position cards between the formed panel and clamps;
● do away with prescribed rigid body motion (*BOUNDARY... and *DEFINE_CURVE);
● simplify the contact definition between the panel and the clamps.
# DEFINE_FORMING_CLAMP

<table>
<thead>
<tr>
<th>CLP1</th>
<th>CLP2</th>
<th>VID</th>
<th>GAP</th>
<th>AT</th>
<th>DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>-46980</td>
<td>1.02</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>-46980</td>
<td>1.02</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

# DEFINE_FORMING_CONTACT

<table>
<thead>
<tr>
<th>IPS</th>
<th>IPM</th>
<th>FS</th>
<th>ONEWAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.125</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.125</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>0.125</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>0.125</td>
<td>1</td>
</tr>
</tbody>
</table>

**Clamping direction:**
- G.T.0: vector
- L.T.0: nodal normal

**Moving clamp PID**
**Corresponding fixed clamp PID**

**Final clamps gap**
**Activation time**
**Duration**

**Slave PID**
**Master PID**
**Contact friction**
**Contact way**
New Options in *INTERFACE_BLANKSIZE
Keywords:

*INTERFACE_BLANKSIZE_SCALE_FACTOR
*INTERFACE_BLANKSIZE_SYMMETRIC_PLANE

Advantage:

● The option SCALE_FACTOR allows user to include or exclude a target curve in the calculation of the initial curve. It also allows user to scale up or down in size of a target curve involved in the calculation.
● The option SYMMETRIC_PLANE allows user to define a symmetric plane by specifying a point on the symmetric plane with X, Y, Z coordinates, and vector components for the normal of the plane.
Target curve #

Scale factor:
0.0 = not to optimize
1.0 = to optimize

A point coordinates on the sym. plane

Vector components of the symmetric plane normal
A channel in deep draw, one-half model with symmetric boundary condition.

Optimization loop:
Draw baseline → Opt1 → Draw #1 → Opt2 → Draw #2

Symmetric plane YOZ.

Initial blank

Target blank outline

Final drawn blank
Baseline results.

Baseline final drawn blank

Target blank outline (scale factor=1.0, to optimize)

Target inner hole #1 size and shape outline (scale factor =1.0, to optimize)

Impose Sym. BC along this edge with *INTERFACE_BLANKSIZE_SYMMETRIC_PLANE

Target inner hole #2 size and shape outline (scale factor =0.0, not to optimize)
Iteration 1 based on blank optimization: final drawn blank is much closer to the target.
Iteration 2 based on blank optimization: final drawn blank and holes exactly overlap the target.
Optimized initial blank evolution.
2D and 3D trimming of solids and laminates

(*CONTROL_FORMING_TRIMMING, *INCLUDE_TRIM,
 *DEFINE_CURVE_TRIM)
### Solid, laminate, TSHELL trimming capability summary:

<table>
<thead>
<tr>
<th></th>
<th>2D (along one direction)</th>
<th>3D (element normal)</th>
<th>2D &amp; 3D Double Trim</th>
<th>Adaptive mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Solids</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Laminates</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>One layer of solids only*; Multiple layers of solids okay for non-adaptive mesh*.</td>
</tr>
<tr>
<td>TSHELL</td>
<td>Yes*</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note: items designated * are new capabilities.
Trimming of Solids

- Inputs to trim of solids are like that for trimming of shells, use:

  *ELEMENT_TRIM       (or, *CONTROL_FORMING_TRIMING)
  *DEFINE_TRIM_CURVE_NEW, (or 3D)
  *DEFINE_TRIM_SEED_POINT_COORDINATES

- Additional input to indicate solid normals:

  *DEFINE_CURVE_TRIM_3D
  $\#$ tcid tctype tflg tdir tctol toln nseed1 nseed2
  
<table>
<thead>
<tr>
<th>tcid</th>
<th>tctype</th>
<th>tflg</th>
<th>tdir</th>
<th>tctol</th>
<th>toln</th>
<th>nseed1</th>
<th>nseed2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0.1</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

  Set TDIR=1: If trim curve is close to the positive normal side. Set TDIR=-1: otherwise

- Must use *INCLUDE_TRIM
Usage - Laminates Trimming

- Trimming of laminates (solid layers sandwiched by top and bottom layers of shells):

  *ELEMENT_TRIM (or, *CONTROL_FORMING_TRIMING)
  $ PSID,,$ITYP
  (set ITYP=1 to activate a laminate trim)

- Must use *INCLUDE_TRIM
LS-PrePost® 4.3 GUI

-Developed by Q.Yan.
Double Trim of Solids

- 2D trimming:

- 3D trimming:

```
*DEFINE_TRIM_SEED_POINT_COORDINATES
$ NSEED X1 Y1 Z1 X2 Y2 Z2
  2 20.7 -153 84.5 -42.9 -410 -42.990
$-+---1-+---2---3---4---5---6---7
```
Double Trim of Laminates

- 2D trimming:

- 3D trimming:
Trim of TSHELL

- 2D trimming only:

Drawn panel

Trimmed panel
- Laminate trim - adaptive mesh trimming capable:

- Solid trim - automatic adaptive refinement along trim curve:
Enhancements in One-step Simulation

(*CONTROL_FORMING_ONESTEP)
1. Re-positioning of unfolded blank in one-step simulation:
   - The position of the blank can be undesirable after unfolding
   - Not easy to be aligned in the forming tools

   ```
   *CONTROL_FORMING_ONESTEP_AUTO_CONSTRAINT
   1,NID1,NID2,NID3
   ```

   - The option “AUTO_CONSTRAINT” is extended:
   - NID1, NID2 and NID3 are the ID of the nodes on the folded part for repositioning after unfolding.
Example 1

Select 3 nodes for reposition after unfolding

*CONTROL_FORMING_ONESTEP

```
7,

The reference nodes are defined

*CONTROL_FORMING_ONESTEP_AUTO_CONSTRAINT
1, 1921, 1935, 1947
```
Example 2

Undesirable position after unfolding

Reposition after unfolding, with the keyword invoked and 3 nodes defined
2. Damage inclusion in one-step simulation:

- Damage accumulation $D$ is calculated based on (refer to *MAT_ADD_EROSION):

$$D = \left( \frac{\varepsilon_p}{\varepsilon_f} \right)^{\text{DMGEXP}}$$

- A load curve can be defined for plastic failure strain vs. stress triaxiality relationship and DMGEXP can be input. The calculated damage accumulation is written into a file called “onestepresult” as history variable #6, and can be plotted in LS-PrePost.

```
*CONTROL_FORMING_ONESTEP
$-+-++-+---2-----+---3-+---4-++-5---+---6-++-7-++-8
$# option autobd thinmin epsmax
  7

*DEFINE_CURVE
500
-0.3,0.6
-0.2,0.3
0.0,0.2
0.2,0.25
0.4,0.46
0.65,0.28
0.9,0.18

LCID 500
DMGEXP 1.254
```
Input load curve ID 500

LS-DYNA keyword deck by LS-PrePost

Contour of History6
reference shell surface
min=0, at elem# 3008924
max=1.06, at elem# 3217736

History variable #6 fringe plot from file
“onestepresult”
Automatic Offset of Tool Element & Node IDs

(*INCLUDE_AUTO_OFFSET)
Adaptive trimming results in additional nodes and elements whose ID may overlap those of the tools of the following operations, resulting in error termination.

- Include `drawn.dynain`
- Include `DEFINE_CURVE_TRIM_3D`
- Include `CONTROL_ADAPTIVE_CURVE`

Automatically offset mesh ID of any tools included.

- Include `trimmed.dynain`
- Include `AUTO_OFFSET` `upperdie.k`
- Include `AUTO_OFFSET` `lowerpunch.k`
- Include `AUTO_OFFSET` `binder.k`
- Include `AUTO_OFFSET` `pins.k`

Default in LSPP eZ-Setup for metal forming.
New features in state output with *
*CONTROL_FORMING_OUTPUT
A new variable CIDT is added to allow definition of state outputs according to simulation time specified. The new state outputs will be in addition to the state outputs according to punch distance from home (bottom), specified by the existing variable LCID.

```plaintext
*CONTROL_FORMING_OUTPUT
$ 0 1 2 3 4 5 6 7 8
$ CID NOUT TBEG TEND Y1/LCID Y2/CIDT Y3 Y4
1116 0 &clstime &endtime -980 -999
1117 0 &clstime &endtime -980 -999
1118 0 &clstime &endtime -980 -999
1119 0 &clstime &endtime -980 -999
*DEFINE_CURVE
999
1.0e-03
2.0e-03
3.0e-03
4.0e-03
*DEFINE_CURVE
980
13.5,0.0
13.0,0.0
5.0,0.0
3.0,0.0
2.5,0.0
2.0,0.0
1.0,0.0
```

- Output time
- Curve ID defining output distance from punch bottom
- Curve ID defining output time
- Output distance from punch bottom
Extra state plots based on simulation time (load curve ID 999)

State plots based on Distance from punch bottom (load curve ID 980)
Strain Ratio Smoothing for Failure Prediction under Nonlinear Strain Paths
Effect of Non-linear strain path

• Effect of non-linear strain path and FI

\[ \beta = \frac{d\varepsilon_2}{d\varepsilon_1} \]

\[ FI = \frac{Y}{Y_L} \]
Real Strain Ratio is Noisy
Issue:

● Choppy strain ratio affects Formability Index (F.I.) calculation

New keyword:

● *CONTROL_FORMING_TOLERANCE  (developed jointly with the Ford Motor Company)

● Applicable to *MAT_037 and *MAT_036 nonlinear strain path option (NLP).

● Smoothed history variables:
  ○ #1 - F.I.
  ○ #2 - β (strain ratio)
  ○ #3 - effective plastic strain

● Additional outputs to “.o” file (batch queue scratch file)

Advantage:

Much less noisy strain ratio output, better terminal strain ratio correlation.
DT/CYCLE.LT.0: The absolute value is the time interval between outputs.
DT/CYCLE.GT.0: Cycle numbers between outputs.

Coefficient α in equation:
\[
\Delta \varepsilon_{1(n-1)} (1 - \alpha) + \Delta \varepsilon_{2(n-1)} \alpha \\
\Delta \varepsilon_{2(n-1)} (1 - \alpha) + \Delta \varepsilon_{2(n)} \alpha \\
\beta = \frac{\Delta \varepsilon_{2(n-1)} (1 - \alpha) + \Delta \varepsilon_{2(n)} \alpha}{\Delta \varepsilon_{1(n-1)} (1 - \alpha) + \Delta \varepsilon_{1(n)} \alpha} \\
- \frac{\bar{r}}{1 + \bar{r}} < \beta < 1
\]

Output flag. When OUTPUT is set to 1, information such as integration point, element ID, time, strain ratio β, major and minor strains will be output to the “.o” file.

<table>
<thead>
<tr>
<th>Card 1</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>DT/CYCLE</td>
<td>WEIGHT</td>
<td>OUTPUT</td>
</tr>
<tr>
<td>Type</td>
<td>F</td>
<td>F</td>
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</tr>
<tr>
<td>Default</td>
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<td>none</td>
<td>0</td>
</tr>
</tbody>
</table>

Output items

<table>
<thead>
<tr>
<th>IP #</th>
<th>Element ID</th>
<th>Time</th>
<th>β</th>
<th>( \epsilon_1 )</th>
<th>( \epsilon_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
<td>1st to 8th</td>
<td>9th to 18th</td>
<td>19th to 29th</td>
<td>30th to 40th</td>
<td>41th to 51th</td>
</tr>
</tbody>
</table>

Table 0-1. “.o” file output information and positions. Note only the mid-IP information are output.
Summary

- Many new features are developed and in production use.
- LSTC continue to work with our users to meet their future requirements.