

Advances in LS-DYNA[®] Metal Forming (II)

Li Zhang & Xinhai Zhu

Livermore Software Technology Corporation

Abstract

Some of the new features developed since the last conference will be discussed.

- 1) *Lancing – instant and progressive
Cutting of sheet metal during forming to alleviate thinning and splits.*
- 2) *Auto close of open trim curve loop
Improvement in trimming simulation by automatically closing an open trim curve.*
- 3) *Tailor-rolled blank thickness specification
Specification of thickness field of a tailor-rolled blank for any ensuing simulation.*
- 4) *Springback compensation referencing original tool mesh
Compensation using the original tool mesh for iterations to improve tool surface geometry.*
- 5) *Springback compensation – for small part shape change
Compensation made easier for those parts with small shape changes that do not affect springback results.*
- 6) *Simulation-based blank size optimization
A significant development in blank size and trim line optimization of stamping dies.*

Lancing

In severe metal forming conditions, lancing operation in strategic locations and in an engineered fashion can alleviate thinning/necking of sheet metal parts/panels. Lancing is often done at the last few millimeters before punch reaches home. Although not favored by all stampers, this operation is sometimes critical and makes a difference between ‘making’ or ‘breaking’ the panels. Applications of lancing are often used in the window corners and cutout areas of liftgate inner/outer, door inner/outer, and along the door belt line, etc. As shown in Figure 1, the upper and lower corner of a door inner C-pillar are instantly lanced in a closed-loop circular shape, and formability at those two corners are improved (right) as compared to the case without lancing (left). Sometimes, lancing is done gradually, much like a scissor’s shearing action (progressive lancing). The new keyword (*ELEMENT_LANCING) supports both types of lancing operations. Meshes are first rearranged along the lancing route with appropriate adaptive constraints added; instant lancing is done by releasing all the constraints at a time specified by the variable AT; progressive lancing is a done by gradually and evenly releasing the constraints along the defined curve NTIMES (number of releases) between AT (starting releasing time) and ENDT (end releasing time), as shown in Figure 2.

The inputs to the keyword are:

- 1) IDPT – PID of the sheet blank to be lanced, as in *PART.
- 2) IDCV – Curve ID (the variable TCID in *DEFINE_CURVE_TRIM_3D).
- 3) IREFINE – Mesh refinement level around the lancing route, to be supported in the future. Currently, no refinement will be made.

- 4) SMIN - Minimum element characteristic length to be refined along the lancing route, to be supported in the future. Currently, no refinement will be made.
- 5) AT – Activation time for lancing operation. This variable needs to be defined for both instant and progressive lancing types.
- 6) ENDT – End time (for progressive lancing only).
- 7) NTIMES – Average number of times to be cut, between AT and ENDT, for progressive lancing only.

Both close and open looped lancing curves are supported, see Figures 3 and 4. Since progressive lancing starts from the beginning of the curve, the direction of the curve needs to be defined accordingly based on the cut direction (Figure 2). This can be done in LS-PrePost®; the menu option *GeoTol/Measure/with Edge* checked can be used to show the direction of the curve; if the direction is wrong, *GeoTol/Rever* can be used to reverse the direction. The effect of NTIMES can be seen in Figure 5. Setting NTIMES to a value of 20 results in a smoother lancing boundary and less stress concentration along the final lanced route. For the lancing curve input, currently there is no direct support for IGES format in the keyword *DEFINE_CURVE_TRIM_3D, meaning only XYZ format (TCTYPE = 1 or 0) is admissible. To convert IGES file to the XYZ format required, procedures outlined in the keyword manual pages in *INTERFACE_BLANKSIZE_DEVELOPMENT can be followed. Currently, lancing can be done only in Z-direction, therefore, no lancing is to be defined on draw wall. Tailor-welded blanks are supported, however, lancing route should not cross the laser line, as only one part can be defined with one lancing curve. Keywords *PARAMETER, *PARAMETER_EXPRESSION are not supported for ENDT and AT.

A partial keyword example is listed below for a multiple progressive lancing starting at the same point. A sheet blank with part ID of 9 is progressively lanced along a curve defined by IDCV of 1116 with *DEFINE_CURVE_TRIM_3D. Lancing commences at 0.0505 seconds, finishing at 0.0535 seconds, with average cuts of 21 times along the route. A second lancing curve starts at the same coordinates and the same time, defined by IDCV of 122 in the opposite direction, and also finished up at the same time. The lancing results are shown in Figure 6.

```
*ELEMENT_LANCING
$      IDPT      IDCV      IREFINE      SMIN      AT      ENDT      NTIMES
      9      1116
      9      122
      0.0505      0.0535      21
      0.0505      0.0535      21
*DEFINE_CURVE_TRIM_3D
$#      tcid      tctype      tflg      tdir      tctol      tolcn      nseed
      1116      1      1      0.100      1
$#      cx      cy      cz
      172.99310      42.632320      43.736160
      175.69769      -163.08299      46.547531
      177.46982      -278.03793      49.138161
...
*DEFINE_CURVE_TRIM_3D
$#      tcid      tctype      tflg      tdir      tctol      tolcn      nseed1      nseed2
      122      1      1      0.100      1
$#      cx      cy      cz
      172.99310      42.632320      43.736160
      171.33121      47.22141      42.513367
      171.28690      128.84601      43.032799
...
```

The output is not much different from the regular forming simulation output; namely, D3PLOT files from which lancing progression can be observed, along with the usual stress/strain and thickness distribution. These forming results can be analyzed so lancing route may be modified to optimize the final forming results.

Future improvement to the lancing includes, but is not limited to, making IGES format available to define the lancing route, activating *PARAMETER to work with the keyword, defining onset of lancing using distance from punch home position, and enabling lancing in any direction with a vector. The lancing feature is available starting in Revision 83562, in SMP and with explicit dynamic calculation only. Latest revisions offer various improvements.

Auto close of open trim curve loop

Both 2-D and 3-D trimming of stamping panels require all trim curves to be fully closed, otherwise unexpected results may occur, or the trimming may fail. Sometimes an unintended small gap exists in a trimming curve in an otherwise large drawn panel, and the gap is very difficult for engineers to notice. In this situation, a new keyword, *CONTROL_FORMING_TRIM_MERGE can be used to automatically close the trim curve to form a fully closed-loop. Users are required to input the parameter GAPM, which is the threshold value under which the gap existed in the trim curve will be closed before trimming is to proceed. In Figure 7, a gap of 2.38mm is found in an open trim curve. With the value of GAPM set at 2.39, the 2-D trimming is successful (top); if the GAPM is set at a value slightly smaller than the gap, the trimming fails. It is noted for multiple open trim loop curves in one trimming simulation, GAPM should be set to a value larger than any of the gap distances of any trim curves in the trim model. This keyword can be added to the usual trimming simulation input deck to make the trimming more robust, even if there is no gap in a trim curve.

This new feature is available starting in Revision 84098.

Tailor-rolled blank thickness specification

In the case where a blank's thickness varies across the sheet surface, such as those in a tailor-rolled blank, a new keyword, *CONTROL_FORMING_INITIAL_THICKNESS, can be used to specify the blank thickness variation for use in a simulation, such as draw forming. The tailor-rolled blank offers distinctive advantage in reducing part counts, increased structural integrity of the component, but may be more expensive to produce thus limiting its use in some high-end vehicle application and in hot stamped parts. The blank thickness variation is limited in one direction of the sheet surface. Users need to supply blank PID, starting position coordinates, a vector on the sheet surface along which the thickness is to be varied, and finally a load curve where the thickness information along the vector vs. the distance to the starting position is listed. For thickness values beyond specification, the last value is used and maintained as a constant. If this card is specified, *SECTION_SHELL for the blank PID is ignored.

In Figure 8, a sheet blank is defined with a varying thickness across its surface in a vector direction pointed from the start to end point. The thickness variation vs. the distance from starting point in section A-A is shown in Figure 9.

This new feature is available starting in Revision 82990.

Springback compensation referencing original tool mesh

For some tool mesh, compensated die surfaces become somewhat distorted. The keyword option `*INCLUDE_COMPENSATION_ORIGINAL_TOOL` is created to allow the compensation to use the original tool mesh (starting in the second compensation) to extrapolate the addendum and binder in the compensated tooling surfaces. This minimizes the accumulative error, as compared with using the last compensated tooling mesh, and therefore is a preferred method. A complete keyword example is listed below, as part ID 3 (included in part set ID 1) is being compensated after ITERATION #3 (ITER3), using method #8, with a scale factor of 0.5. The ‘dynain’ files of ITER3 trimming and springback are taken as ‘before’ and ‘after’ sheet blank shapes, respectively. ‘Desired’ blank shape is from ITER0 trimmed ‘dynain’ file, which never changes. ‘Compensated shape’ is taken from the ‘disp.tmp’ file of the last compensation run. ‘Current tool’ is also from last compensation. The ‘original tool’, is taken from the tool mesh in ITER0. Updated trim curves ‘geotrm.new’ are taken from mapped trim lines of last compensation. It is noted that, in an automatic compensation-loop runs, as shown in the path of the input files, input files ‘disp.tmp’, ‘rigid.new’, and ‘geotrm.new’, taken from the default file names of the previous compensation, should not be in the same directory as the current compensation run, as these files will be overwritten. In Figure 9, the application of this new feature is shown on a stamping panel. Compared with tool surface shape (Figure 9 middle) using the previous iteration tool, the tool surfaces compensated using the original tool are much smoother (Figure 9 right).

```
*KEYWORD
*INTERFACE_COMPENSATION_NEW
$---+---1---+---2---+---3---+---4---+---5---+---6---+---7---+---8
$ METHOD      SL      SF      ELREF      PSID      UNDRCT      ANGLE      NLINEAR
      8      10.000      0.500      2      1      1      0.0      1
*INCLUDE_COMPENSATION_BLANK_BEFORE_SPRINGBACK
../7_iter3.dir/2_trim.dir/dynain
*INCLUDE_COMPENSATION_BLANK_AFTER_SPRINGBACK
../7_iter3.dir/3_spbk.dir/dynain
*INCLUDE_COMPENSATION_DESIRED_BLANK_SHAPE
../1_iter0.dir/2_trim.dir/dynain
*INCLUDE_COMPENSATION_COMPENSATED_SHAPE
../6_compensation.dir/disp.tmp
*INCLUDE_COMPENSATION_CURRENT_TOOLS
../6_compensation.dir/rigid.new
*INCLUDE_COMPENSATION_ORIGINAL_TOOLS
../1_iter0.dir/sim_forming_mesh.k
*INCLUDE_COMPENSATION_TRIM_CURVE
../6_compensation.dir/geotrm.new
*SET_PART_LIST
$ PSID
1
$ PID
3
*END
```

This new feature is available starting in Revision 82701.

Springback compensation – for small part shape change

Often times a part will have some small amount of shape change as a result of a product change. If the amount of shape change does not significantly alter the springback results, the compensated tools can be updated with the part mesh (inside the trim lines) or formed blank shape without going through another iterative compensation loop. This is accomplished using a new keyword `*INTERFACE_COMPENSATION_NEW_PART_CHANGE`. Within the specified `MAXGAP` – the maximum part dimensional change input by the user, compensated tool shape can be updated. It should be noted that geometry features such as sharp corners and transition with no fillet are not permissible. A complete keyword example is provided below, where a maximum gap of 5 mm is specified between the original shape and modified product shape. The updated part file name is ‘updatepart.tmp’ under the keyword `*INCLUDE_COMPENSATION_UPDATED_BLANK_SHAPE`, and the output file for the new rigid tool is ‘newrigid.k’ under the keyword `*INCLUDE_COMPENSATION_UPDATED_RIGID_TOOL`. In Figure 10, a part change is seen on the top section of a simple hat-shaped channel (left); the updated compensated tool is shown at the upper right, along with the original compensated tool (lower right).

```
*KEYWORD
*INTERFACE_COMPENSATION_NEW_PART_CHANGE
$ MAXGAP
5.0
*INCLUDE_COMPENSATION_DESIRED_BLANK_SHAPE
../1_iter0.dir/2_trim.dir/dynain
*INCLUDE_COMPENSATION_COMPENSATED_SHAPE
../6_compensation.dir/disp.tmp
*INCLUDE_COMPENSATION_CURRENT_TOOLS
../6_compensation.dir/rigid.new
*INCLUDE_COMPENSATION_UPDATED_BLANK_SHAPE
./updatedpart.tmp
*INCLUDE_COMPENSATION_UPDATED_RIGID_TOOL
$ file name to output the new rigid tools
./newrigid.k
*END
```

This new feature is available starting in Revision 82698.

Simulation-based blank size optimization

This keyword (`*INTERFACE_BLANKSIZE_[OPTION]`) activates a blank size development program for sheet metal forming. This feature requires for input (1) a final shape from a completed simulation, (2) the shape of the initial blank, and (3) a desired target boundary (final) or mesh. This algorithm compares the final shape from the completed simulation against the target shape and then adjusts the initial shape. The adjusted initial blank shape can be run through a second simulation again to see if the final shape is close enough to the target blank; if it is not close enough, then the results from the second simulation can be used as inputs to this keyword again for a new estimate of the initial blank, until the final shape is within the range of the target shape. The corrected initial blank can be used to precisely determine the material cost,

the optimal blank nesting configuration, the gaging pins/blocks for the stamping tools, and the trim lines need for the trim die.

The iterative loop is illustrated in Figure 10. A more detailed example of this iterative method is given in Figures 25-9 through 25-13 in Volume I of the User Manual, under the keyword *INTERFACE_BLANKSIZE_[OPTION], where more examples can be found.

In cases where the target curves go beyond the initial blank mesh in a specific designed shape, the parameter REFERENC and FILENAME4 can be used to define the shape with a reference surface. In a keyword example below, REFERENC is set to '1' and the reference file name is given as "ref3.k". The maximum change between the initial and final blank size per iteration is set as 20.0 mm. Point spacing distance (SPACE) of calculated trim curve on the reference surface is set at 2.0 mm. Note that with IOPTION set to '2', the inner holes and outer boundary curves only need to be defined in "target.xyz"; they do not necessarily need to exist in the initial or final blank mesh. The input details and output results are shown in Figure 11.

```
*KEYWORD
*INTERFACE_BLANKSIZE_DEVELOPMENT
$ IOPTION          IADAPT  MAXSIZE REFERENCE      SPACE
   -2              1      20.000      1          2.0
$ input file for target mesh
target.xyz
$ input file for simulated mesh
final.k
$ input file for initial blank mesh
initial.k
$ reference file for extended initial shape
ref3.k
*END
```

Summary

Various features related to metal forming have been developed to meet the requirements of our stamping users. LSTC has benefited from working with the best and brightest researchers and engineers, and will continue to improve to stay ahead.

References

- 1) LS-DYNA User's Manual R7.0 (Volume I), <ftp://user:computer@ftp.lstc.com/manuals>.

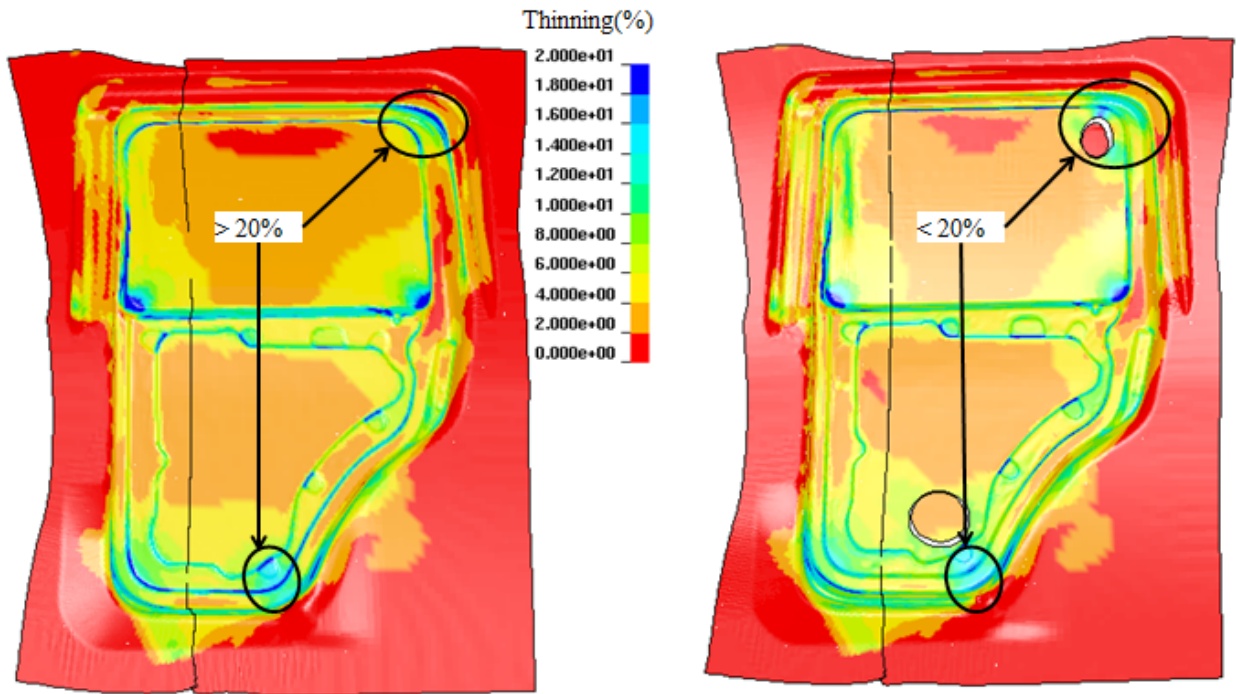


Figure 1. Effect of lancing – no lancing (left); with lancing (right).

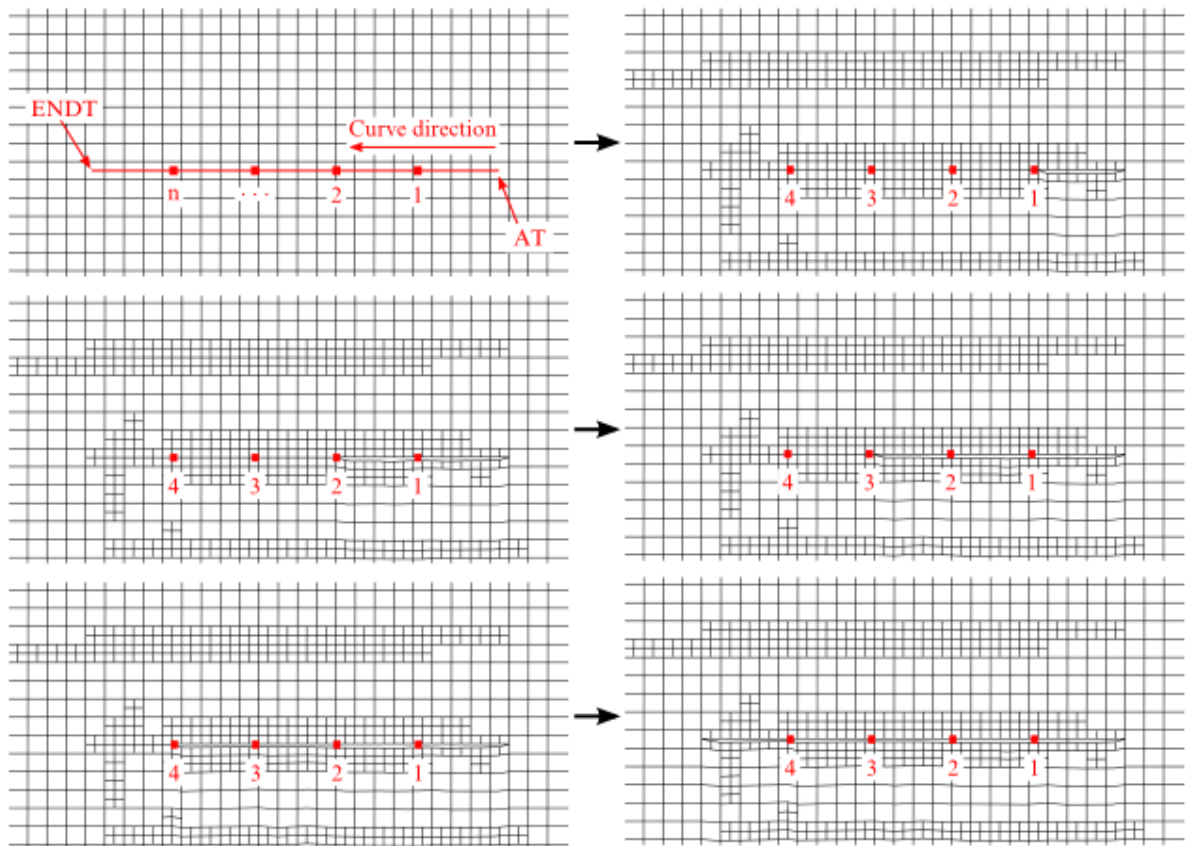


Figure 2. Progressive lancing and parameters definition.

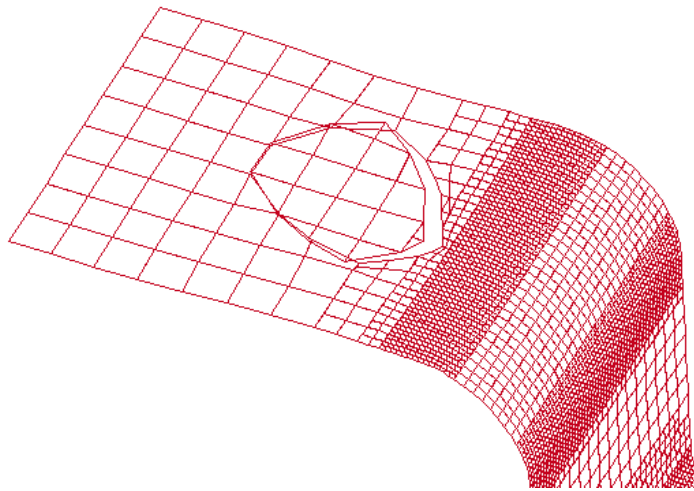


Figure 3. Closed loop lancing.

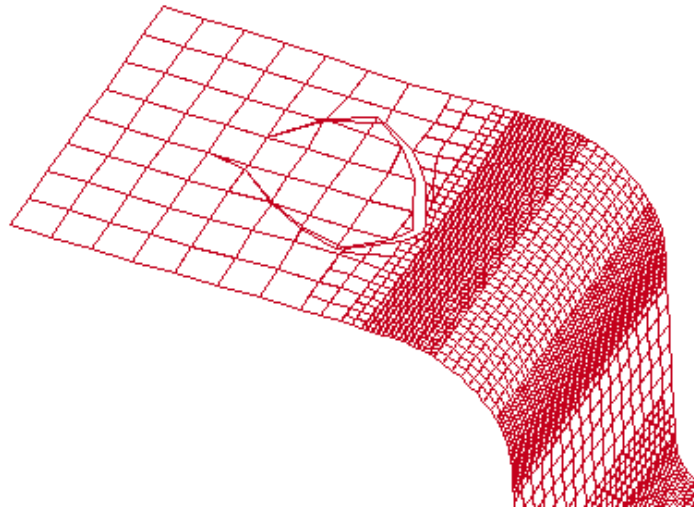


Figure 4. Open loop lancing.

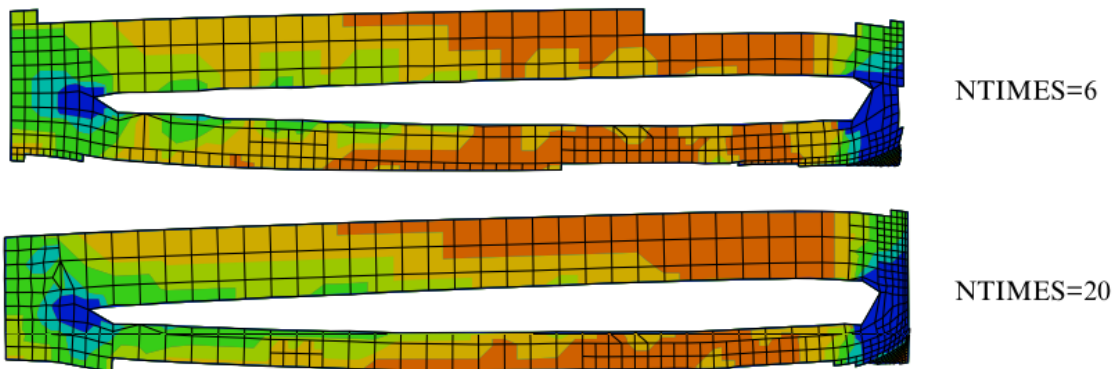


Figure 5. The effect of NTIMES.

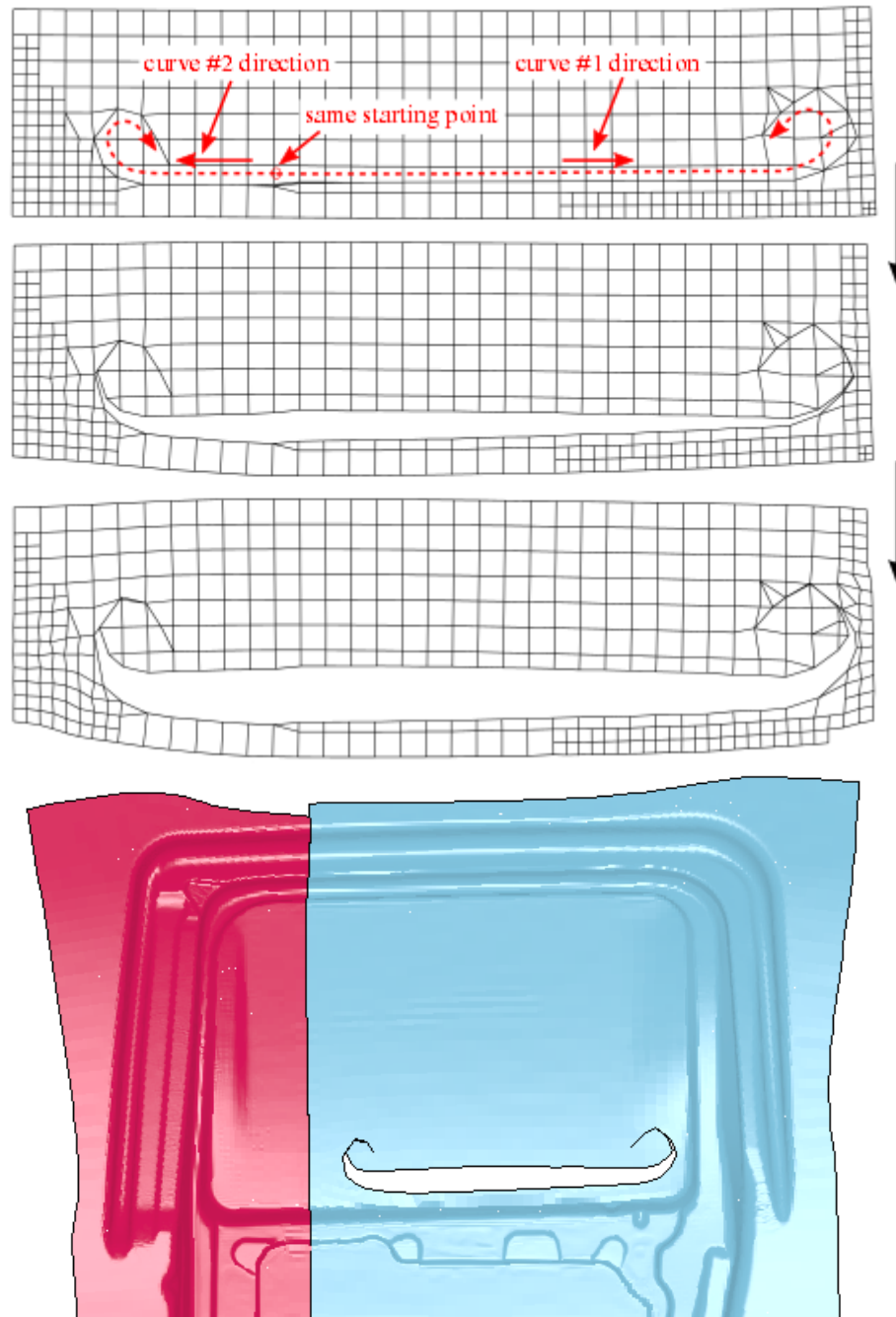


Figure 6. Multiple lancing starting at the same point.

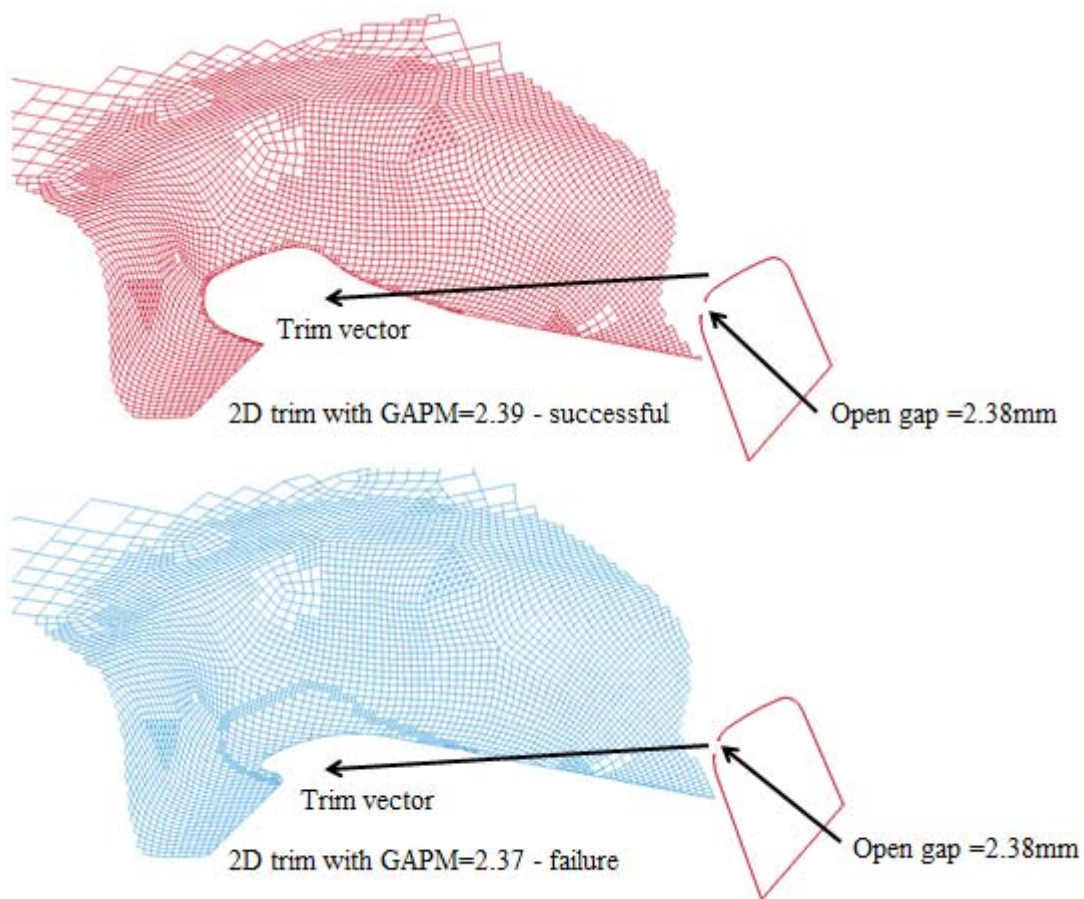


Figure 7. Open curve trimming without auto-close (top), and with auto-close (lower).

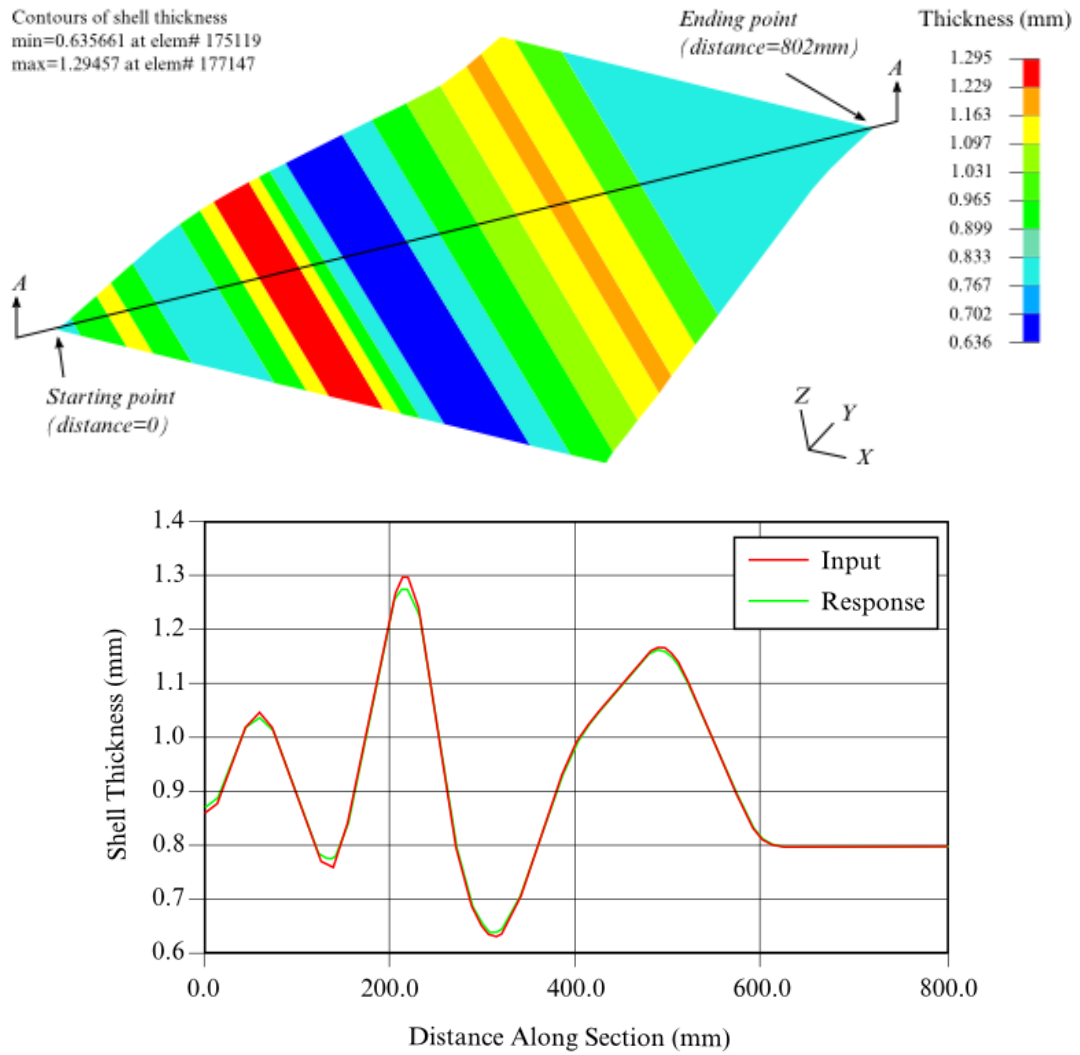


Figure 8. Specify a thickness field in the beginning of a simulation.

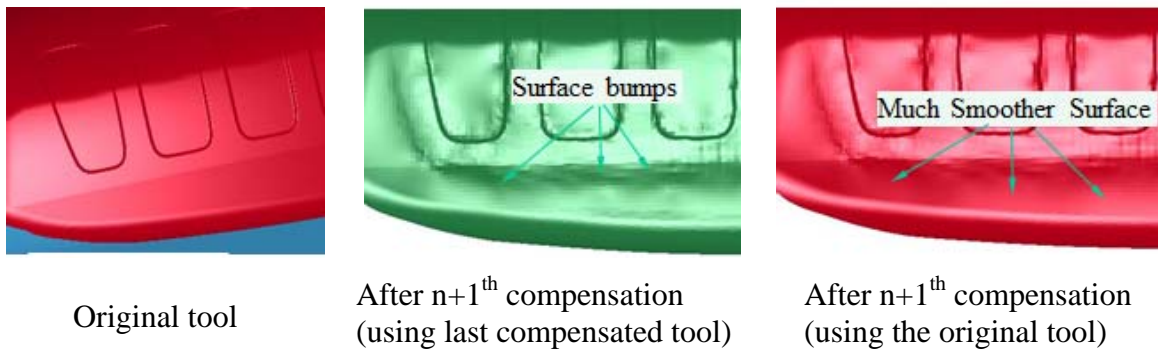


Figure 9. Springback compensation using the original tool as the reference.

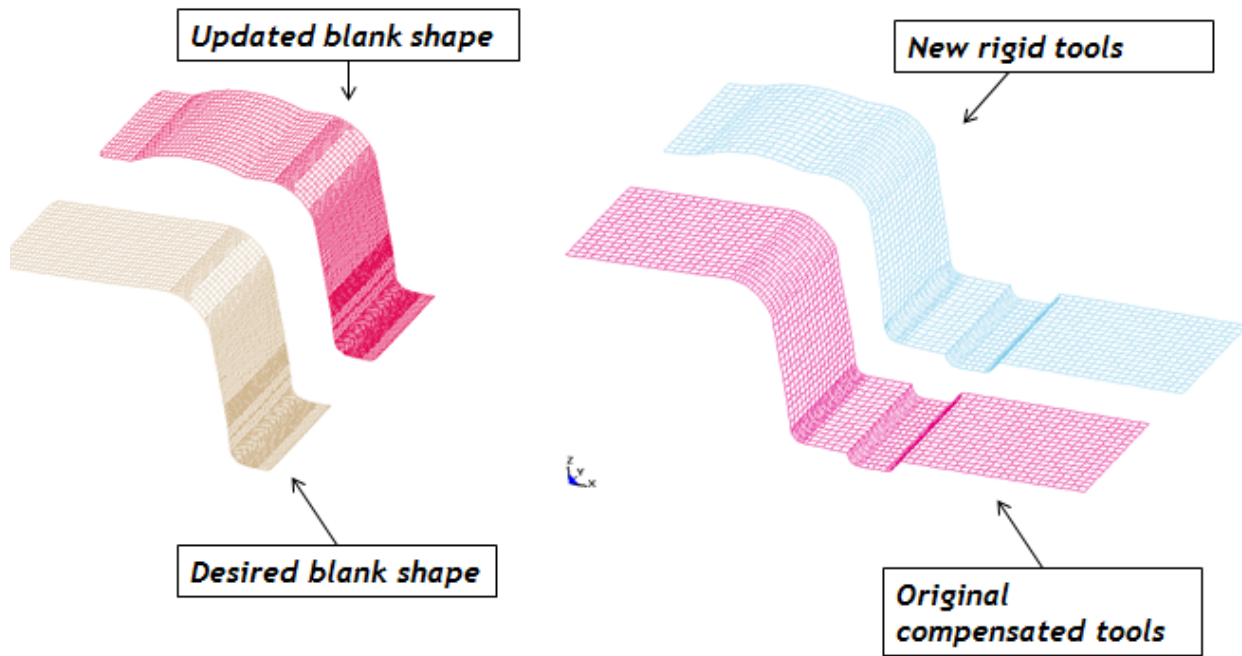


Figure 10. Springback compensation of parts with small shape change.

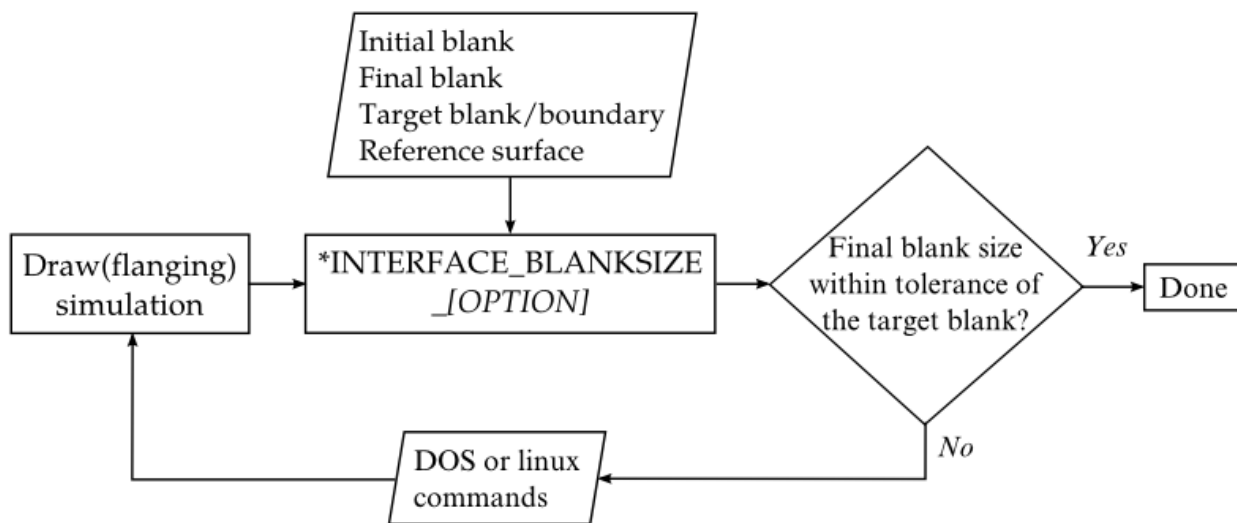


Figure 11. Iterative blank size optimization.

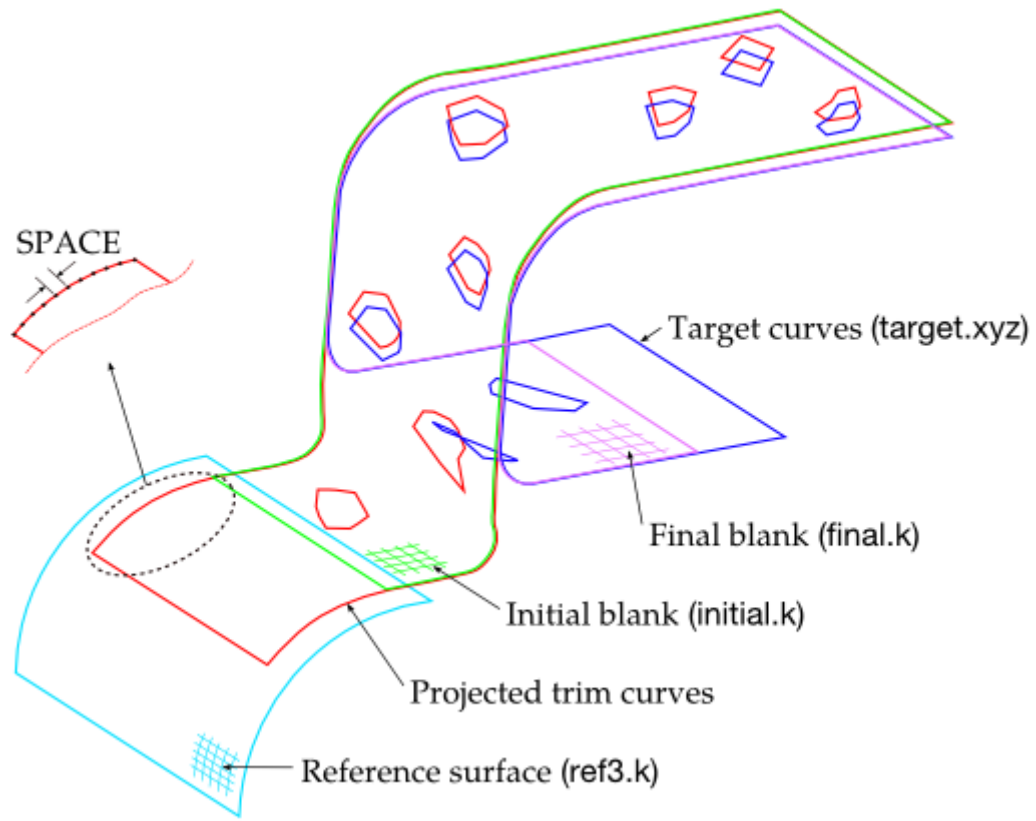


Figure 11. Springback compensation of parts with small shape change.