New Metal Forming Keywords in LS-DYNA®

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Abstract

Newly developed forming keywords have been optimized to be easy for users. Besides the unification of all the control cards, the tool motion definition has been simplified dramatically and time-related tooling motion curve definition is no longer needed. Various contact algorithm parameters are also treated internally by the LS-DYNA solver. More realistic contact features are available to simulate draw beads and pins. New metal forming keywords therefore achieve an input deck with well-organized input formats which directly describe actual forming processes.

Introduction

A conventional LS-DYNA metal forming input deck consists of many keyword definitions including bunches of control cards, time-related tooling motion curves and various contact algorithm parameters. The text tediousness and bundled keyword utilization raise the technical threshold for new LS-DYNA metal forming users. A straightforward input format becomes always desirable for its efficient readability. New keywords have thus been developed for this purpose in metal forming applications, with five focused aspects as follows: Control Settings, Model Positioning, Tool Motion, Contact Definition, and Solution Algorithm.

Control Settings

A conventional forming input deck needs many control settings [1] such as:

*CONTROL_TIMESTEP
*CONTROL_ACCURACY
*CONTROL_ADAPTIVE
*CONTROL_HOURGLASS
*CONTROL_BULK_VISCOSITY
*CONTROL_SHELL
*CONTROL_CONTACT
*CONTROL_ENERGY
*CONTROL_ADAPSTEP
*CONTROL_RIGID
*CONTROL_OUTPUT
*DATABASE_BINARY_D3PLOT
*DATABASE_EXTENT_BINARY

In general, it is very difficult for a new user to understand technical usage of all control parameters. Most of them thus have to be left blank as default which may not be suited to a forming simulation. The unification of all the control cards becomes crucial and has been conducted with three following new keywords. The LS-DYNA solver presets the rest of control parameters especially for forming applications. It should be mentioned that all new forming keywords can be activated if and only if *CONTROL_FORMING_DEFAULT is defined.

***CONTROL_FORMING_DEFAULT**

Card 1	1	2	3	4	5	6	7	8
Variable	UNIT	DT2MS	ADPENE	SLSFAC	NEIPH	NEIPS	MAXINT	

UNIT: The system type of units
EQ.1: millimeter for length unit, second for time unit, and ton for mass unit.
DT2MS: Time step size, see *CONTROL_TIMESTEP.
ADPENE: The threshold of the distance measured from tooling surface for adaptive refinement, see *CONTROL_ADAPTIVE.
SLSFAC: Scale factor for sliding interface penalties, see *CONTROL_CONTACT.
NEIPH, NEIPS and MAXINT:
Control parameters for binary database output, see *DATABASE_EXTENT_BINARY.

***DEFINE_FORMING_ADAPTIVE_PHASE**

Card 1	1	2	3	4	5	6	7	8
Variable	PHASE	CYCLES	MAXLVL	ADPSIZE				

PHASE: Current phase ID in entire forming duration
CYCLES: Adaptive cycle parameter for mesh refinement
GE.0: Total adaptive cycle number in current phase
LT.0: |CYCLES| specifies the distance interval per adaptive cycle.
MAXLVL: Maximum adaptive refinement level in current phase
ADPSIZE: Minimum element size for mesh refinement in current phase

***CONTROL_FORMING_OUTPUT_PHASE**

Card 1	1	2	3	4	5	6	7	8
Variable	PHASE	PSID	NOUT	LCID				

PHASE: Current phase ID in entire forming duration
PSID: Part Set ID of the tool specified for d3plot output
The default PSID is the part set which has a maximum travel distance in current phase.
NOUT: Number of states written to d3plot between the first and last state in current phase
LCID: Load curve ID specifying the tool distances for the states of d3plot output

Model Positioning

For more efficient readability and representation of actual process parameters, the existing forming keywords have been implemented with new input options for model positioning.

***CONTROL_FORMING_TIPPING_COORDINATE_SYSTEM**

Card 1	1	2	3	4	5	6	7	8
Variable	PID/SID	ITYPE	IFSTRN	IFSTRS				
Card 2	1	2	3	4	5	6	7	8
Variable	*CID1*	*CID2*						

Card 2 is added to transfer a stamped part between two stamping operation coordinate systems:
CID1: Coordinate system ID as an initial position reference
CID2: Coordinate system ID as a destination position reference

***CONTROL_FORMING_AUTOPOSITION_PARAMETER**

Card 1	1	2	3	4	5	6	7	8
Variable	PID	*CID*	DIR	MPID	POSITION	PREMOVE	THICK	PORDER

Positioning along a vector is implemented:
CID: LT.0: |CID| specifies a vector ID used by *DEFINE_VECTOR.

***PART_MOVE**

Card 1	1	2	3	4	5	6	7	8
Variable	PID	XMOV		YMOV		ZMOV		*CID*

Positioning along a vector is implemented:
CID: LT.0: |CID| specifies a vector ID used by *DEFINE_VECTOR.

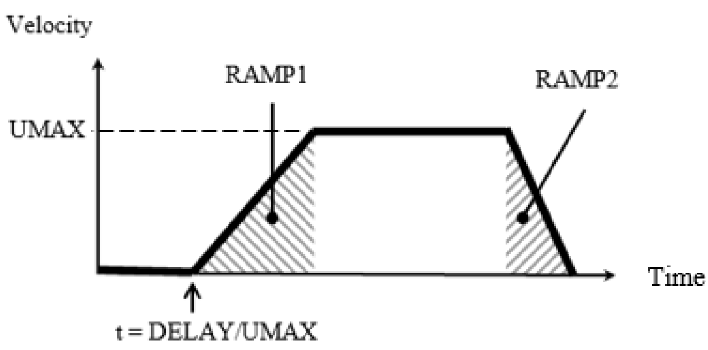
Tool Motion

Conventionally, a tooling motion is defined by time-related motion curves. Users' imagination is being challenged by those text tediousness and bundled keywords. Straightforward motion definition is thus expected in new forming keywords to describe actual forming processes which may consist of different motion phases.

***DEFINE_FORMING_MOVE_PROFILE**

Card 1	1	2	3	4	5	6	7	8
Variable	PROFILE	UMAX	RAMP1	RAMP2	DELAY			

PROFILE: ID of a velocity profile
UMAX: Maximum velocity value
RAMP1: Ramp-up distance
RAMP2: Ramp-down distance
DELAY: Delayed travel distance before the motion starts.



***DEFINE_FORMING_TRAVEL**

Card 1	1	2	3	4	5	6	7	8
Variable	PSID	PHASE	IDV	PROFILE	DIST			

PSID: Part Set ID of traveling tools
PHASE: Current phase ID in entire forming duration
IDV: ID of Vector defining a travel direction, see *DEFINE_VECTOR.
PROFILE: ID of current velocity profile, see *DEFINE_FORMING_MOVE_PROFILE

DIST: Total travel distance in current phase. A positive value is required.

***DEFINE_FORMING_PASSIVE_MOVE**

Card 1	1	2	3	4	5	6	7	8
Variable	PSID	MPSID	MXDIST	BDIST				

PSID: Part Set ID of the tools driven to move
MPSID: Part Set ID of a driving tool
MXDIST: The instantaneous travel distance of the driving tool to deactivate the driving
BDIST: The instantaneous travel distance of the driving tool to activate the driving

Contact Definition

A conventional contact definition involves too many control parameters and various contact algorithm options which definitely raise the technical threshold for new LS-DYNA metal forming users to figure out a set of experience-based inputs shortly. The contact definition has been simplified dramatically by new forming keywords. Various contact algorithm parameters are treated internally by the LS-DYNA solver.

***DEFINE_FORMING_CONTACT**

Card 1	1	2	3	4	5	6	7	8
Variable	PHASE	SPSID	MPSID	FS	OFSMS	ONEWAY		

PHASE: Current phase ID in entire forming duration. Default (PHASE=0) for contact in all phases.
SPSID: Slave Part Set ID in contact, typically a deformable sheet metal blank.
MPSID: Master Part Set ID in contact, typically a tool defined as a rigid body.
FS: Friction coefficient
OFSMS: Contact offset amount for the surfaces of the master part set
ONEWAY: EQ.0: The contact is FORMING_ONE_WAY_SURFACE_TO_SURFACE;
EQ.1: The contact is FORMING_SURFACE_TO_SURFACE.

***DEFINE_FORMING_CONTACT_PIN**

Card 1	1	2	3	4	5	6	7	8
Variable	PHASE	SPSID	MPSID	FS				

PHASE: Current phase ID in entire forming duration. Default (PHASE=0) for contact in all phases.
SPSID: Slave Part Set ID in contact, typically a deformable sheet metal blank.
MPSID: Master Part Set ID in contact, typically a guide pin defined as a rigid body.
FS: Friction coefficient

***DEFINE_FORMING_CONTACT__DRAWBEAD**

Card 1	1	2	3	4	5	6	7	8
Variable	SPSID	DBPID1	DBPID2	ACTGAP	LCIDRF	DFSCL		

SPSID: Slave Part Set ID in contact, typically a deformable sheet metal blank.
DBPID1 & DBPID2:
A pair of Part IDs for draw bead, typically male bead & female bead modeled by beam elements.
ACTGAP: The maximum gap between male bead and female bead to activate the draw bead restraining force
LCIDRF: Load curve ID specifying the restraining force per unit draw bead length as a function of displacement, see the description of 'LCIDRF' in *CONTACT_DRAWBEAD.
DFSCL: Scale factor of the restraining force values in the load curve specified by LCIDRF.

Solution Algorithm

The following new features have been implemented for implicit forming solution.

***CONTROL_IMPLICIT_FORMING_{*OPTION*}**

Card 1	1	2	3	4	5	6	7	8
Variable	*IOPTION*	NSMIN	NSMAX	BIRTH	DEATH	PENCHK	DT0	

New solution type is implemented:
IOPTION EQ.3: Fast convergent solution for gravity loading simulation

New option is available:
The new keyword of *CONTROL_IMPLICIT_FORMING_AUTO_CONSTRAINT allows users to perform springback simulation without input of any boundary constraints to eliminate rigid body motion. These constraints are determined by the solver automatically.

Input Example of New Metal Forming Keywords

New forming keywords achieve an input deck with well-organized input formats which directly describe actual forming processes. A complete input example with new forming keywords is shown below.

```
*KEYWORD
*TITLE
                 Input Example of New Metal Forming Keywords
$                          ( 3-Piece Air Draw )
$===============================================================================
$                          INCLUDED MODEL FILES
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*INCLUDE
Blank.k
*INCLUDE_AUTO_OFFSET
Tool_mesh.k
$===============================================================================
$                          CONTROL SETTINGS
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTROL_FORMING_DEFAULT
$     UNIT     DT2MS    ADPENE    SLSFAC     NEIPH     NEIPS    MAXINT
         1  -1.0e-06       5.0      0.10
*DEFINE_FORMING_ADAPTIVE_PHASE
$    PHASE    CYCLES    MAXLVL   ADPSIZE
         1        20         3       4.0
         2       100         4       2.0
*CONTROL_FORMING_OUTPUT_PHASE
$    PHASE      PSID      NOUT      LCID
         1                   5
         2                  15
$===============================================================================
$                          MODEL POSITIONING
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$ BLANK
*SET_PART_LIST
        91
         1
$ UPPER DIE
*SET_PART_LIST
        92
         3
$ LOWER BINDER
*SET_PART_LIST
        93
         4
$ LOWER POST
*SET_PART_LIST
        94
         5
*SET_PART_LIST
       111
         4         5
*PARAMETER
$-----------------------------   blank move variable initialization
R blankmv        0.0
$-----------------------------   upper die move variable initialization
R updiemv        0.0
$-----------------------------   lower binder move variable initialization
R bindmv         0.0
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*CONTROL_FORMING_AUTOPOSITION_PARAMETER_SET
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$      SID       CID       DIR      MSID  POSITION   PREMOVE     THICK  PARORDER
$ blank move
        91                   3       111         1                 3.0   blankmv
$ upper die move
        92                   3        91         1                 3.0   updiemv
$ lower binder move
        93                   3        91        -1                 3.0    bindmv
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*PART_MOVE
$    SID            XMOV            YMOV            ZMOV     CID   IFSET
$ blank move
      91             0.0             0.0        &blankmv               1
$ upper die move
      92             0.0             0.0        &updiemv               1
$ lower binder move
      93             0.0             0.0        &bindmv                1
$===============================================================================
$                          TOOL MOTION
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*PARAMETER_EXPRESSION
R clsdisp   abs((abs(updiemv)-abs(bindmv)))
R drwdisp   abs(bindmv)
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_FORMING_MOVE_PROFILE
$  PROFILE      UMAX     RAMP1     RAMP2     DELAY
         1    2000.0       2.0       2.0
         2    5000.0       5.0
*DEFINE_FORMING_TRAVEL
$     PSID     PHASE       IDV   PROFILE      DIST
        92         1         0         1  &clsdisp
        92         2         0         2  &drwdisp
*DEFINE_FORMING_PASSIVE_MOVE
$     PSID     MPSID    MXDIST     BDIST
        93        92  &updiemv  &clsdisp
$===============================================================================
$                          CONTACT DEFINITION
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_FORMING_CONTACT
$    PHASE     SPSID     MPSID        FS       MST    ONEWAY
                  91        92     0.125
                  91        93     0.125
                  91        94     0.125
$===============================================================================
*END
```

Summary

Newly developed forming keywords have been optimized to be easy for users:

- Unification of all control setting cards
- Simplified definition of tooling motion
- No need for time-related motion curves
- Straightforward contact definition
- Fast implicit solution for gravity loading

New forming keywords have been used in LS-FORM which is being developed as a dedicated forming package for LS-DYNA. Further implementation of more new keywords is in progress.

References

[1] LS-DYNA KEYWORD USER'S MANUAL, LS-DYNA R11, VOLUME I, LSTC