New Metal Forming Keywords in LS-DYNA®

Xinhai Zhu, Yuzhong Xiao and Jin Wu Livermore Software Technology, an ANSYS Company

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_CONTACT *CONTROL_ENERGY *CONTROL_ADAPSTEP *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	XM	IOV	YM	OV	ZM	OV	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.

Velocity



***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

16th International LS-DYNA® Users Conference

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	e forming duration. Default ((PHASE=0) for contact in all phases.
CDCID			

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----+---6----+----7----*INCLUDE Blank.k *INCLUDE_AUTO_OFFSET Tool mesh.k CONTROL SETTINGS ---1----+----2-+----4--------5----+----6----+----7----+ CONTROL FORMING DEFAULT UNIT DT2MS 1 -1.0e-06 ADPENE NEIPH NEIPS MAXINT SLSFAC 0.10 5.0 *DEFINE_FORMING_ADAPTIVE_PHASE ADPSIZE PHASE CYCLES MAXLVL 20 4.0 2.0 100 4 CONTROL_FORMING_OUTPUT_PHASE LCID PHASE PSID NOUT 15 MODEL POSITIONING --1-----2----6----+----7----5 BLANK *SET_PART_LIST 91 UPPER DIE SET_PART_LIST 92 \$ LOWER BINDER *SET PART LIST S LOWER POST SET_PART_LIST 94 SET_PART_LIST 111 4 5 *DADAMETED ----- blank move variable initialization R blankmy 0.0 upper die move variable initialization

ş				upper di	e move van	riable init	ialization	L
R S	updiemv	0.0		lower bi	nder move	variable i	nitializat	ion
R	bindmv	0.0						
÷.	CONTROL FOR	DMING AUTO	DOSTITION D	ADAMETED S	+5- FT	6-	/-	8
s	+1	+2-	+3-	+4-		6-		8
ş	SID	CID	DIR	MSID	POSITION	PREMOVE	THICK	PARORDER
ş	plank move 91	2	3	111	1		3.0	blankmv
ş	upper die 92	move	3	91	1		3.0	updiemv
Ş	lower bind	der move						
	93		3	91	-1		3.0	bindmv
\$	+1	+2-	+3-	+4-	+5	6-		8
*	PART_MOVE							
ş	SID	X	MOV	YMOV		ZMOV	CID IFSE	T
ş	blank move	e -						
	91		0.0	0.0	ab:	Lankmv		1
ş	upper die 92	move	0.0	0.0	6 Li	pdiemv		1
Ş	lower bind	der move						
s	93		0.0	0.0	۵b: 	indmv		1
ŝ				TOOL	MOTION	l		
ŝ	+1	+2-	+3-	+4-	+5	6-		8
*	PARAMETER P	TYPEFSSTON						
R	clsdisp	abs ((abs (updiemv)-a	bs(bindmv)))			
R R	clsdisp drwdisp	abs((abs() abs(bindm	updiemv)-a v)	bs(bindmv)))			
R R Ş	clsdisp drwdisp +1-	abs((abs() abs(bindm	updiemv)-a v) +3-	bs(bindmv))) +5	6-		+8
R R \$	clsdisp drwdisp +1- DEFINE_FORM	abs((abs() abs(bindm +2- MING_MOVE_	updiemv)-a v) +3- PROFILE	bs(bindmv))) +5·	6-	7-	+8
R R \$ \$	clsdisp drwdisp +1 DEFINE_FORM PROFILE	abs((abs() abs(bindm +2- MING_MOVE_ UMAX	updiemv)-a v) +3- PROFILE RAMP1	bs(bindmv) +4- RAMP2)) +5- DELAY	6-	7-	+8
R R \$ \$	clsdisp drwdisp +1- DEFINE_FORM PROFILE 1	abs((abs)) abs(bindm +2- MING_MOVE_ UMAX 2000.0	updiemv)-a v) +3- PROFILE RAMP1 2.0	bs(bindmv) +4- RAMP2 2.0)) +5 DELAY	6-	7-	+8
R R \$ *	clsdisp drwdisp DEFINE_FORM PROFILE 1 2	abs((abs() abs(bindm +2- MING_MOVE_ UMAX 2000.0 5000.0	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0	bs(bindmv) +4- RAMP2 2.0)) +5 DELAY	6-	7-	+8
R R \$ *	clsdisp drwdisp +1 DEFINE_FORM PROFILE 1 2 DEFINE_FORM	abs() (abs) abs()bindm +2- MING_MOVE_ UMAX 2000.0 5000.0 MING_TRAVE	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L	bs(bindmv) +4- RAMP2 2.0)) +5 DELAY	6-	7-	+8
RR\$*\$	clsdisp drwdisp +1 DEFINE_FORM PROFILE 1 2 DEFINE_FORM PSID	abs() (abs) abs()bindm +2- MING_MOVE UMAX 2000.0 5000.0 MING_TRAVE PHASE	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV	bs(bindmv) +4- RAMP2 2.0 PROFILE)) +5- DELAY DIST	6-	7-	+8
RR\$*\$	clsdisp drwdisp +1- DEFINE_FORD PROFILE 1 2 DEFINE_FORD PSID 92	abs((abs() abs(bindm +2- MING_MOVE_ UNAX 2000.0 5000.0 MING_TRAVE PHASE 1	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0	bs(bindmv) +4- RAMP2 2.0 PROFILE)) +5. DELAY DIST &clsdisp	6-	7-	+8
R R \$ * \$ * \$	clsdisp drwdisp +1 DEFINE_FORD PROFILE 1 2 DEFINE_FORD PSID 92 92	abs((abs() abs(bindm 2- MING_MOVE_ UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0 0	bs(bindmv) +4- RAMP2 2.0 PROFILE 1 2)) +5 DELAY DIST &clsdisp &drwdisp	6-	7-	+8
RR\$*\$ *\$ *	clsdisp drwdisp DEFINE_FOR PROFILE 1 2 DEFINE_FOR 92 92 DEFINE_FOR 92	abs((abs() abs(bindm +2- MING_MOVE UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASST	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE 0 VE_MOVE	bs(bindmv) +4- RAMP2 2.0 PROFILE 1 2 PROFILE)) +5 DELAY DIST &clsdisp &drwdisp	6-	7-	+8
RR\$*\$ *\$	clsdisp drwdisp DEFINE FOR PROFILE 1 2 DEFINE_FOR PSID 92 92 DEFINE_FOR PSID 92 0 DEFINE_FOR PSID	abs((abs) abs(bindm +2- MING_MOVE UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASST MPSID 2000	updiemv)-a v) PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE MXDIST	bs(bindmv) +4- RAMP2 2.0 PROFILE 1 2 BDIST)) DELAY DIST &clsdisp &drwdisp	6-	7-	8
RR\$*\$ *\$	clsdisp drwdisp DEFINE FOR PROFILE 1 2 DEFINE FOR 92 92 92 DEFINE FOR FOR FOR 93	abs ((abs) abs (bindm +2- UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASST MPSID 92	updiemv)-a v) PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE MXDIST &updiemv	bs(bindmv) +4- RAMP2 2.0 PROFILE 1 2 BDIST &clsdisp)) +5- DELAY DIST &clsdisp &drwdisp	6-	7-	+8
RR\$*\$ *\$ \$	clsdisp drwdisp +1- DEFINE_FORM PROFILE 1 2 DEFINE_FORM 92 92 92 DEFINE_FORM PSID 93	abs((abs() abs(bindm -+2) TING_MOVE TUMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASST MPSID 92	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE &UPDIST &updiemv	bs(bindmv) +4- RAMP2 2.0 PROFILE 1 2 BDIST &clsdisp)) DELAY DIST &clsdisp &drwdisp	6-	7-	+8
RR\$*\$ *\$ *\$ \$	clsdisp drwdisp 	abs((abs() abs(bindm +2- UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASST MPSID 92	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE &UPDIST &updiemv CO	bs (bindmv) +4- RAMP2 2.0 PROFILE 1 2 BDIST \$clsdisp NTACT E)) DELAY DIST &clsdisp &drwdisp DEFINITI	6- ON	7-	+8
RR\$*\$ *\$ *\$ \$	clsdisp drwdisp +1- DEFINE_FORJ PROFILE 2 DEFINE_FORJ 92 92 92 DEFINE_FORJ 93 1-	abs((abs() abs(bindm -+2 MING_MOVE UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASST MPSID 92	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE &UXDIST &updiemv CO	bs (bindmv) +4- RAMP2 2.0 PROFILE 1 2 BDIST \$clsdisp NTACTE +4-)) DELAY DIST &clsdisp &drwdisp DEFINITI	ON	7-	
RR\$*\$ *\$ *\$ \$ \$	clsdisp drwdisp +1 DEFINE FOR PROFILE 2 DEFINE FOR 92 92 92 DEFINE FOR 93 93	abs((abs() abs(bindm +2- MING_MOVE_ UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASSI MPSID 92 2- MING_CONTA	updiemv)-a v) +3- PROFILE RAMP1 2.0 5.0 L IDV 0 VE_MOVE MXDIST &updiemv CO +3- CT	bs (bindmv) +4- RAMP2 2.0 PROFILE 1 2 BDIST \$clsdisp NTACT [] 4-)) DELAY DIST &cladisp &drwdisp DEFINITI DEFINITI	6- ON 6-	7-	+8
RR\$*\$ *\$ \$ \$ \$ \$	clsdisp drwdisp +1 DEFINE FORD PROFILE 2 DEFINE FORD 92 92 DEFINE FORD 93 +1- DEFINE FORD PHASE	abs ((abs (abs (bindm +2 MING_MOVE_ UMAX 2000.0 5000.0 MING_TRAVE PHAS 4ING_PASSI MPSID 92 2 	updiemv)-a v) 3- PROFILE RAMP1 2.00 5.0 L IDV MCDIST \$updiemv CO CC MPSID	bs(bindmv) 4- RMMP2 2.0 PROFILE 1 2 BDIST 6clsdisp NTACT [4- FS 0.055)) DELAY DIST \$cledisp \$drwdisp DEFINITI DEFINITI S MST	6- ON ONE	7-	+8
RR\$*\$ *\$ \$\$\$\$	clsdisp drwdisp 	abs ((abs (abs (bindm +2- MING MOVE_ UMAX 2000.0 5000.0 MING TRAVE PHASE 1 1 MING PASST MPSID 92 +2- IIIN <u>C</u> CONTA SPSID 91	updiemv)-a v) 	bs(bindmv) 4- RAMP2 2.0 PROFILE 1 2 BDIST 6clsdisp 4- FS 0.125 0.125)) DELAY DIST &clsdisp &drwdisp DEFINITI DEFINITI MST	6- ON ON ONEWAY	7-	+8
RR\$*\$ *\$ \$\$\$\$	clsdisp drwdisp DEFINE_FOR PROFILE 2 DEFINE_FOR PSID 32 2 2 DEFINE_FOR PSID 33 3 	abs ((abs (abs (bindm +2- MING_MOVE_ UMAX 2000.0 5000.0 MING_TRAVE PHASE 1 2 MING_PASSI PHASE 1 2 4ING_PASSI 92 2- MING_CONTA SPSID 91 91	updiemv)-a v) 	bs(bindmv) 4- RAMP2 2.0 PROFILE 1 2 BDIST 6clsdisp 4- FS 0.125 0.125 0.125)) DELAY DIST &clsdisp &drwdisp DEFINITI DEFINITI S. MST	ON ON	7-	+8 8
RR\$*\$ *\$ *\$ \$ \$ \$ \$ \$	clsdisp drwdisp + DEFINE_FORN PROFILE 2 DEFINE_FORN PSID 92 DEFINE_FORN 93 DEFINE_FORN PHASE	abs ((abs (abs (bindm -+2 MINE_MOVE_ MINE_MOVE_ MINE_TRAVE PHASE PHASE PHASE 92 2 AIING_CONTA SPSID 91 91 91	updiemv)-a v) 3- PROFILE RAMP1 2.0 L 5.0 L MXDIST &updiemv CC CT MPSID 92 93 34	bs(bindmv))) DELAY DIST ¢clediep ¢drwdisp DEFINITI 5. MST	6- ОN олемач	7-	
RR\$*\$ *\$ *\$ \$\$\$*\$	clsdisp drwdisp 	abs ((abs (abs (bindm +2- MING MOVE UMAX 2000.0 5000.0 MING TRAVE PHASE 1 1 2 MING PASST MPSID 92 2- MING CONTA SPSID 91 91 91	updiemv)-a v) 3- PROFILE RAMP1 2.00 5.0 L IDV 0 0 VE_MOVE MXDIST & updiemv MXDIST & updiemv MXDIST CT MPSID 92 93 94	bs(bindmv) RAMP2 2.0 PROFILE 2 BDIST Sclsdisp TACCT FS 0.125 0.125 0.125)) DELAY DIST &clsdisp &drwdisp DEFINITI DEFINITI MST	6- ON ON6- ONEWAY	7-	

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