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	ISI (Dubai, UAE) = **0.829**	**РИНЦ** (Russia) = **0.126**	**PIF** (India) = **1.940**
	GIF (Australia) = **0.564**	**ESJI** (KZ) = **8.716**	**IBI** (India) = **4.260**
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INTERNAL FORCE FACTORS IN A SHEET BLANK MATERIAL WHEN DRAWING BY THE DIRECT METHOD

Abstract: *Calculated dependencies of changing of internal force factors in a steel sheet blank from time of a drawing process by the direct method are presented in the article. The conclusion about influence of wrinkles formation on a flange of the sheet blank to changing of a value and a direction of forces and moments arising in material was given.*

Key words: *a sheet blank, drawing, force, moment, wrinkles, time.*

Language: *English*

Citation: Chemezov, D., et al. (2019). Internal force factors in a sheet blank material when drawing by the direct method. *ISJ Theoretical & Applied Science, 09 (77),* 241-251.

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Introduction

Stamping of a sheet blank is characterized by various types of plastic deformation of material: bending, tension, compression and etc. Observation of the sheet blank drawing is difficult, because a deformation process is hidden by parts of a drawing die. Intensity of stress-strain state of the sheet blank material from all sides can be considered by a computer simulation. The various methods of shallow and deep drawing of the sheet blanks of round and square shapes made of various metal alloys in conditions of finite element modeling were considered in the works [1 – 19].

Wrinkles formation on a flange of the deformable round blank is due to excess material and a small thickness of a sheet. Deformation force of the blank increases in conditions of overcoming of material resistance by smoothing of wrinkles on side walls of the part in the die hole of the drawing die. Action of external active forces (pressure and movement of a punch) leads to an emergence of internal force factors in material of the deformable sheet blank. These factors determine the value and the type of stresses (strains) in the sheet blank material. A calculated range of changes of the internal force factors will allows to select required force of drawing for performing of the process.

Materials and methods

The calculation of the internal force factors have been implemented in the LS-DYNA software environment. The round sheet blank model with the thickness of 2 mm had the volume of 2.5736×10^{-5} m^3 and the surface area of 0.026532 m^2. The sheet blank drawing was performed by the direct method without a blank holder. Implementation conditions of the drawing process are presented in the special text format.

```
*TITLE

$         Created with ANSYS Workbench v14.5.7
$
$         Units: mm, mg, ms, mN, K
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                      SECTION DEFINITIONS                    $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*SECTION_SOLID
$  1SECID  2ELFORM    3AET
      1       1
*SECTION_SOLID
$  1SECID  2ELFORM    3AET
      2       1
*SECTION_SOLID
$  1SECID  2ELFORM    3AET
      3       1
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                      MATERIAL DEFINITIONS                    $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY
$    1MID      2RO       3E      4PR     5SIGY     6ETAN     7FAIL     8TDEL
$#    mid       ro        e       pr      sigy      etan      fail      tdel
        1  7.850000  2.0000E+8  0.300000  7.8500E+5  7.9300E+7
$     1C       2P     3LCSS    4LCSR      5VP  6EPSTHIN  7EPSMAJ  8NUMINT
$#      c        p     lcss     lcsr       vp   epsthin   epsmaj    numint
    0.000    0.000        0        0    0.000    0.000    0.000    0.000
$  1EPS1    2EPS2    3EPS3    4EPS4    5EPS5    6EPS6    7EPS7    8EPS8
$#   eps1     eps2     eps3     eps4     eps5     eps6     eps7     eps8
    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
$    1ES1     2ES2     3ES3     4ES4     5ES5     6ES6     7ES7     8ES8
$#    es1      es2      es3      es4      es5      es6      es7      es8
    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
*MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY
$    1MID      2RO       3E      4PR     5SIGY     6ETAN     7FAIL     8TDEL
$#    mid       ro        e       pr      sigy      etan      fail      tdel
```

```
        3  7.850000  2.0000E+8  0.300000  7.8500E+5  7.9300E+7
$       1C        2P     3LCSS     4LCSR       5VP  6EPSTHIN   7EPSMAJ   8NUMINT
$#       c         p      lcss      lcsr        vp   epsthin    epsmaj    numint
     0.000     0.000         0         0     0.000     0.000     0.000     0.000
$    1EPS1     2EPS2     3EPS3     4EPS4     5EPS5     6EPS6     7EPS7     8EPS8
$#    eps1      eps2      eps3      eps4      eps5      eps6      eps7      eps8
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
$     1ES1      2ES2      3ES3      4ES4      5ES5      6ES6      7ES7      8ES8
$#     es1       es2       es3       es4       es5       es6       es7       es8
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
*MAT_PLASTIC_KINEMATIC
$     1MID       2RO        3E       4PR     5SIGY     6ETAN     7BETA
$#     mid        ro         e        pr      sigy      etan      beta
        2  2.770000  7.1000E+7  0.330000  1.2000E+5  2.5500E+7
$#     src       srp        fs        vp
     0.000     0.000     0.000     0.000
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                           PARTS DEFINITIONS                                  $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*PART
$  HEADING
Part 1
$     1PID    2SECID      3MID    4EOSID     5HGID     6GRAV   7ADPORT     8TMID
        1         1         1         0         0
*PART
$  HEADING
Part 2
$     1PID    2SECID      3MID    4EOSID     5HGID     6GRAV   7ADPORT     8TMID
        2         2         1         0         0
*PART
$  HEADING
Part 3
$     1PID    2SECID      3MID    4EOSID     5HGID     6GRAV   7ADPORT     8TMID
        3         3         1         0         0
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                            LOAD DEFINITIONS                                  $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*DEFINE_CURVE
$    1LCID     2SIDR      3SFA      4SFO     5OFFA     6OFFO   7DATTYP
        1
$                 1A                  2O
                   0              1e+011
                5000              1e+011
               50000              1e+011
*DEFINE_CURVE
$    1LCID     2SIDR      3SFA      4SFO     5OFFA     6OFFO   7DATTYP
        2
$                 1A                  2O
                   0       -3.40909e+006
                5000       -3.40909e+006
               50000       -3.40909e+006
*DEFINE_CURVE
$    1LCID     2SIDR      3SFA      4SFO     5OFFA     6OFFO   7DATTYP
        3
$                 1A                  2O
                   0                   0
                5000                   0
```

```
        50000          0
*DEFINE_CURVE
$  1LCID   2SIDR   3SFA   4SFO   5OFFA   6OFFO  7DATTYP
     4
$         1A           2O
          0           0
         5000          0
        50000          0
*DEFINE_CURVE
$  1LCID   2SIDR   3SFA   4SFO   5OFFA   6OFFO  7DATTYP
     5
$         1A           2O
          0           0
         5000          0
        50000          0
*DEFINE_CURVE
$  1LCID   2SIDR   3SFA   4SFO   5OFFA   6OFFO  7DATTYP
     6
$         1A           2O
          0           0
         5000          0
        50000          0
*DEFINE_CURVE
$  1LCID   2SIDR   3SFA   4SFO   5OFFA   6OFFO  7DATTYP
     7
$         1A           2O
          0           0
         5000          0
        50000          0
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                    CONTACT DEFINITIONS                    $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*CONTACT_AUTOMATIC_SINGLE_SURFACE
$  1SSID   2MSID   3SSTYP   4MSTYP  5SBOXID  6MBOXID    7SPR     8MPR
     0      0      5      0                  1      1
$    1FS     2FD     3DC     4VC     5VDC   6PENCHK     7BT     8DT
     0      0      0      0     10
$   1SFS    2SFM    3SST    4MST    5SFST    6SFMT     7FSF    8VSF

$  1SOFT  2SOFSCL  3LCIDAB  4MAXPAR   5SBOPT   6DEPTH   7BSORT  8FRCFRQ
     2                         3      5
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                      CONTROL OPTIONS                      $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*CONTROL_TERMINATION
$ 1ENDTIM  2ENDCYC   3DTMIN  4ENDENG   5ENDMAS
     1   300000     0.01      10       0
*CONTROL_TIMESTEP
$ 1DTINIT  2TSSFAC   3ISDO  4TSLIMT   5DT2MS   6LCTM   7ERODE   8MS1ST
     0     0.9      0      0      0      1      1      0
*CONTROL_HOURGLASS
$   1IHQ     2QH
     1    0.1
*CONTROL_BULK_VISCOSITY
$    1Q1     2Q2    3TYPE
    1.5    0.06     -2
*CONTROL_CONTACT
```

```
$ 1SLSFAC  2RWPNAL  3ISLCHK  4SHLTHK  5PENOPT  6THKCHG   7ORIEN  8ENMASS
      0       0       1       1       1       0       2       0
$ 1USRSTRC  2USRFRC   3NSBCS  4INTERM   5XPENE   6SSTHK    7ECDT  8TIEDPRJ

$  1SFRIC   2DFRIC    3EDC    4VFC     5TH    6TH_SF   7PEN_SF

$  1IGNORE  2FRCENG  3SKIPRWG  4OUTSEG  5SPOTSTP  6SPOTDEL 7SPOTTHIN
      2       0       0       1       0       1     0.5
*CONTROL_SOLID
$  1ESORT   2FMATRX  3NIPTETS   4SWLOCL
      1
*DAMPING_GLOBAL
$   1LCID  2VALDMP    3STX     4STY     5STZ     6SRX     7SRY     8SRZ
      0       0
*CONTROL_ENERGY
$   1HGEN    2RWEN   3SLNTEN   4RYLEN
      2       1       2       2
*CONTROL_ACCURACY
$    1OSU     2INN   3PIDOSU
      1       4
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                      TIME HISTORY                            $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*DATABASE_GLSTAT
$     1DT  2BINARY    3LCUR   4IOOPT   5DTHFF   6BINHF
     500
*DATABASE_MATSUM
$     1DT  2BINARY    3LCUR   4IOOPT   5DTHFF   6BINHF
     500
*DATABASE_NODOUT
$     1DT  2BINARY    3LCUR   4IOOPT   5DTHFF   6BINHF
     500
*DATABASE_ELOUT
$     1DT  2BINARY    3LCUR   4IOOPT   5DTHFF   6BINHF
     500
*DATABASE_BINARY_D3PLOT
$     1DT    2LCDT    3BEAM   4NPLTC
    0.005
*DATABASE_BINARY_RUNRSF
$     1DT      2NR
    5000
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                    BOUNDARY CONDITIONS                            $
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
*LOAD_NODE_SET
$     1ID     2DOF    3LCID      4SF     5CID      6M1      7M2      8M3
      2       3       2   1.000       0
*BOUNDARY_PRESCRIBED_MOTION_SET_ID
$  1KeyID  2HEADING
      1Displacement
$     1ID     2DOF     3VAD    4LCID      5SF     6VID   7DEATH   8BIRTH
      3       1       2       3   1.000       0       0       0
*BOUNDARY_PRESCRIBED_MOTION_SET_ID
$  1KeyID  2HEADING
      2Displacement
$     1ID     2DOF     3VAD    4LCID      5SF     6VID   7DEATH   8BIRTH
      3       2       2       4   1.000       0       0       0
```

```
*BOUNDARY_PRESCRIBED_MOTION_SET_ID
$  1KeyID  2HEADING
       1Displacement 2
$     1ID     2DOF     3VAD     4LCID      5SF     6VID   7DEATH   8BIRTH
       4        1        2        5    1.000        0        0        0
*BOUNDARY_PRESCRIBED_MOTION_SET_ID
$  1KeyID  2HEADING
       2Displacement 2
$     1ID     2DOF     3VAD     4LCID      5SF     6VID   7DEATH   8BIRTH
       4        2        2        6    1.000        0        0        0
*BOUNDARY_PRESCRIBED_MOTION_SET_ID
$  1KeyID  2HEADING
       3Displacement 2
$     1ID     2DOF     3VAD     4LCID      5SF     6VID   7DEATH   8BIRTH
       4        3        2        7    1.000        0        0        0
*BOUNDARY_SPC_SET
$  1NSID     2CID    3DOFX    4DOFY    5DOFZ   6DOFRX   7DOFRY   8DOFRZ
       1        0        1        1        1        1        1        1
```

where **1**, **2** and **3** – the models identifiers of the punch, the sheet blank and the die; ***TITLE** – heading to appear on output and in output files; ***SECTION_SOLID** – the section properties for solid continuum and fluid elements; **1SECID** – the section ID; **2ELFORM** – the element formulation options; **3AET** – the ambient element type; ***MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY** – elasto-plastic material supporting the arbitrary stress versus strain curve as well as the arbitrary strain rate dependency; **1MID** – the material identification; **2RO** – mass density; **3E** – the Young's modulus; **4PR** – the Poisson's ratio; **5SIGY** – yield stress; **6ETAN** – the tangent modulus; **7FAIL** – the failure flag; **8TDEL** – the minimum time step size for the automatic element deletion; **1C**, **2P** – the strain rate parameters; **3LCSS** – the load curve ID or the table ID; **4LCSR** – the load curve ID defining strain rate scaling effect on yield stress; **5VP** – the formulation for rate effects; **6EPSTHIN** – thinning strain at failure; **7EPSMAJ** – major in plane strain at failure; **8NUMINT** – the number of the integration points which must fail before the element is deleted; **1EPS1** – **8EPS8** – the effective plastic strain values; **1ES1** – **8ES8** – the yield stress values; ***MAT_PLASTIC_KINEMATIC** – the model of isotropic and kinematic hardening plasticity with the option of including rate effects; **7BETA** – the hardening parameter; **src** – the strain rate parameter, *C*, for the Cowper Symonds strain rate model; **srp** – the strain rate parameter, *P*, for the Cowper Symonds strain rate model; **fs** – effective plastic strain for the eroding elements; **vp** – the formulation for rate effects; ***PART** – the define parts, i.e., the combine material information, the section properties, the hourglass type, the thermal properties, and the flag for the part adaptivity; **HEADING** – heading for the part; **1PID** – the part identification; **2SECID** – the section identification; **3MID** – the material identification; **4EOSID** – the equation of the state identification; **5HGID** – the hourglass/bulk viscosity identification; **6GRAV** – the flag to turn on gravity initialization; **7ADPORT** – indicate if this part is adapted or not; **8TMID** – the thermal material property identification; ***DEFINE_CURVE** – define the curve, for example, load versus time, often loosely referred to as the load curve; **1LCID** – the load curve ID; **2SIDR** – the flag controlling use of the curve during dynamic relaxation; **3SFA** – the scale factor for the abscissa value; **4SFO** – the scale factor for the ordinate value; **5OFFA** – offset for the abscissa values; **6OFFO** – offset for the ordinate values; **7DATTYP** – the data type; **1A** – the abscissa values; **2O** – the ordinate values;

***CONTACT_AUTOMATIC_SINGLE_SURFACE** – the contact interface in the 3D model; **1SSID** – the slave segment, the node set ID, the part set ID, the part ID, or the shell element set ID; **2MSID** – the master segment set ID, the part set ID, the part ID, or the shell element set ID; **3SSTYP** – the ID type of SSID; **4MSTYP** – the ID type of MSID; **5SBOXID** – include in contact definition only those slave nodes/segments within box; **6MBOXID** – include in contact definition only those master segments within box; **7SPR** – the slave side forces included; **8MPR** – the master side forces included; **1FS** – the static coefficient of friction; **2FD** – the dynamic coefficient of friction; **3DC** – the exponential decay coefficient; **4VC** – the coefficient for viscous friction; **5VDC** – the viscous damping coefficient in percent of critical or the coefficient of restitution expressed as percentage; **6PENCHK** – small penetration in the contact search option; **7BT** – birth time (the contact surface becomes active at this time); **8DT** – death time (the contact surface is deactivated at this time); **1SFS** – the scale factor on default slave penalty stiffness; **2SFM** – the scale factor on default master penalty stiffness; **3SST** – the optional contact thickness for the slave surface; **4MST** – the optional contact thickness for the master surface; **5SFST** – the scale factor applied to the

contact thickness of the slave surface; **6SFMT** – the scale factor applied to the contact thickness of the master surface; **7FSF** – the Coulomb friction scale factor; **8VSF** – the viscous friction scale factor; **1SOFT** – the soft constraint option; **2SOFSCL** – the scale factor for constraint forces of the soft constraint option; **3LCIDAB** – the load curve ID defining the airbag thickness as the function of time; **4MAXPAR** – the maximum parametric coordinate in the segment search; **5SBOPT** – the segment-based contact options; **6DEPTH** – the search depth in automatic contact; **7BSORT** – the number of cycles between bucket sorts; **8FRCFRQ** – the number of cycles between contact force updates for the penalty contact formulations; ***CONTROL_TERMINATION** – stop the job; **1ENDTIM** – termination time; **2ENDCYC** – termination cycle; **3DTMIN** – the reduction factor to determine the minimum time step; **4ENDENG** – percent change in the energy ratio for termination of the calculation; **5ENDMAS** – percent change in the total mass for termination of the calculation; ***CONTROL_TIMESTEP** – the set structural time step size control using the different options; **1DTINIT** – the initial time step size; **2TSSFAC** – the scale factor for the computed time step; **3ISDO** – basis of the time size calculation for 4-node shell elements; **4TSLIMT** – the shell element minimum time step assignment; **5DT2MS** – the time step size for the mass scaled solutions; **6LCTM** – the load curve ID that limits the maximum time step size (optional); **7ERODE** – the erosion flag for the solids and thick shells; **8MS1ST** – the option for the mass scaling; ***CONTROL_HOURGLASS** – redefine the default values of the hourglass control type and the coefficient; **1IHQ** – the default hourglass control type; **2QH** – the default hourglass coefficient; ***CONTROL_BULK_VISCOSITY** – reset the default values of the bulk viscosity coefficients globally; **1Q1** – the default quadratic viscosity coefficient; **2Q2** – the default linear viscosity coefficient; **3TYPE** – the default bulk viscosity type; ***CONTROL_CONTACT** – change defaults for computation with the contact surfaces; **1SLSFAC** – the scale factor for the sliding interface penalties; **2RWPNAL** – the scale factor for the rigid wall penalties, which the treat nodal points interacting with the rigid walls; **3ISLCHK** – initial penetration check in the contact surfaces with indication of initial penetration in the output files; **4SHLTHK** – the flag for consideration of the shell thickness offsets in the non-automatic surface-to-surface and non-automatic nodes-to-surface type contacts; **5PENOPT** – the penalty stiffness value option; **6THKCHG** – the shell thickness changes considered in the single surface contact; **7ORIEN** – optional automatic reorientation of the contact interface segments during initialization; **8ENMASS** – treatment of the mass of the eroded nodes in contact; **1USRSTRC** – storage per the contact interface for the user supplied interface control subroutine; **2USRFRC** – storage per the contact interface for the user supplied interface friction subroutine; **3NSBCS** – the number of cycles between contact searching using three dimensional bucket searches; **4INTERM** – the flag for intermittent searching in the old surface-to-surface contact using the interval; **5XPENE** – the contact surface maximum penetration check multiplier; **6SSTHK** – the flag for using the actual shell thickness in the single surface contact; **7ECDT** – the time step size override for eroding contact; **8TIEDPRJ** – bypass projection of the slave nodes to the master surface in the types; **1SFRIC** – the default static coefficient of friction; **2DFRIC** – the default dynamic coefficient of friction; **3EDC** – the default exponential decay coefficient; **4VFC** – the default viscous friction coefficient; **5TH** – the default contact thickness; **6TH_SF** – the default thickness scale factor; **7PEN_SF** – the default local penalty scale factor; **1IGNORE** – ignore initial penetrations; **2FRCENG** – the flag to activate the calculation of frictional sliding energy; **3SKIPRWG** – the flag not to display the stationary rigid wall by default; **4OUTSEG** – the flag to output each beam spot weld slave node and its master segment; **5SPOTSTP** – the spot weld node or the face; **6SPOTDEL** – this option controls the behavior of spotwelds when the parent element erodes; **7SPOTTHIN** – the optional thickness scale factor; ***CONTROL_SOLID** – provide controls for the solid element response; **1ESORT** – automatic sorting of the tetrahedral and pentahedral elements to avoid use of the degenerate formulations for these shapes; **2FMATRX** – the default method used in the calculation of the deformation gradient matrix; **3NIPTETS** – the number of the integration points used in the quadratic tetrahedron elements; **4SWLOCL** – the output option for stresses in the solid elements used as spot welds; ***DAMPING_GLOBAL** – define the mass weighted nodal damping that applies globally to the nodes of deformable bodies and to the mass center of the rigid bodies; **1LCID** – the load curve ID which specifies the system damping constant vs. time; **2VALDMP** – the system damping constant, *Ds*; **3STX** – the scale factor on the global *X* translational damping forces; **4STY** – the scale factor on the global *Y* translational damping forces; **5STZ** – the scale factor on the global *Z* translational damping forces; **6SRX** – the scale factor on the global *X* rotational damping moments; **7SRY** – the scale factor on the global *Y* rotational damping moments; **8SRZ** – the scale factor on the global *Z* rotational damping moments; ***CONTROL_ENERGY** – provide controls for the energy dissipation options; **1HGEN** – the hourglass energy calculation option; **2RWEN** – the rigidwall energy (a.k.a. stonewall energy) dissipation option; **3SLNTEN** – the sliding interface energy dissipation option; **4RYLEN** – the Rayleigh energy dissipation option; ***CONTROL_ACCURACY** – the define

control parameters that can improve the accuracy of the calculation; **1OSU** – the global flag for the 2nd order objective stress updates; **2INN** – the invariant node numbering for the shell and solid elements; **3PIDOSU** – the part set ID for objective stress updates; ***DATABASE_GLSTAT** – the global data; **1DT** – the time interval between outputs; **2BINARY** – the flag for binary output; **3LCUR** – the optional curve ID specifying the time interval between dumps; **4IOOPT** – the flag to govern behavior of the plot frequency load curve; **5DTHFF**, **6BINHF** – no data; ***DATABASE_MATSUM** – material energies; ***DATABASE_NODOUT** – the nodal point data; ***DATABASE_ELOUT** – the element data; ***DATABASE_BINARY_D3PLOT** – the database for the entire model; **2LCDT** – the optional load curve ID specifying the time interval between dumps; **3BEAM** – the discrete element option flag; **4NPLTC** – this overrides the DT specified in the first field; ***DATABASE_BINARY_RUNRSF** – the database for restarts; **2NR** – the number of the RUNning ReStart Files, runrsf, written in the cyclical fashion; ***LOAD_NODE_SET** – apply concentrated nodal force to the node or each node in the set of the nodes; **1ID** – the node ID or the nodal set ID; **2DOF** – applicable degrees-of-freedom; **3LCID** – the load curve ID; **4SF** – the load curve scale factor; **5CID** – the coordinate system ID; **6M1** – the node 1 ID; **7M2** – the node 2 ID; **8M3** – the node 3 ID; ***BOUNDARY_PRESCRIBED_MOTION_SET_ID** – define the imposed nodal motion (velocity, acceleration or displacement) on the node or the set of the nodes; **3VAD** – the velocity/acceleration/displacement flag; **6VID** – the vector ID; **7DEATH** – time the imposed motion/constraint is removed; **8BIRTH** – time that the imposed motion/constraint is activated; ***BOUNDARY_SPC_SET** – the option is required since it specifies whether the SPC applies to the single node or to the set; **3DOFX** – the insert 1 for the translational constraint in the local *X*-direction; **4DOFY** – the insert 1 for the translational constraint in the local *Y*-direction; **5DOFZ** – the insert 1 for the translational constraint in the local *Z*-direction; **6DOFRX** – the insert 1 for the rotational constraint about the local *X*-axis; **7DOFRY** – the insert 1 for the rotational constraint about the local *Y*-axis; **8DOFRZ** – the insert 1 for the rotational constraint about the local *Z*-axis.

Results and discussion

The calculated dependencies of changing of the internal force factors when drawing of the round steel sheet blank with the thickness of 2 mm from performing time of the plastic deformation process are presented in the Fig. 1.

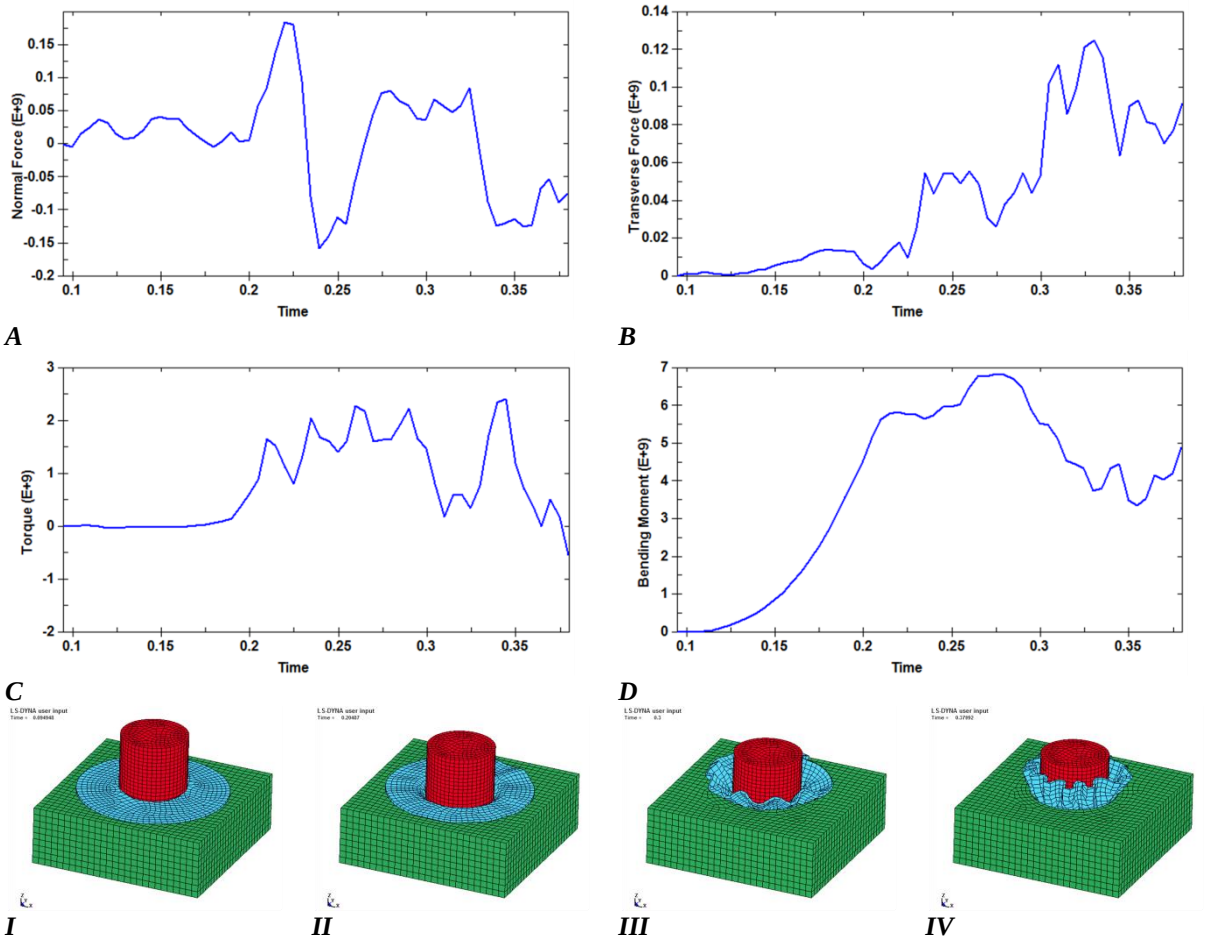

Figure 1 – The internal force factors in material of the sheet blank when drawing: *A* – changing of normal force from time drawing; *B* – changing of transverse force from time drawing; *C* – changing of torque from time drawing; *D* – changing of bending moment from time drawing; *I* – deformation of the sheet blank at 0.095 s of the drawing process; *II* – deformation of the sheet blank at 0.2 s of the drawing process; *III* – deformation of the sheet blank at 0.3 s of the drawing process; *IV* – deformation of the sheet blank at 0.38 s of the drawing process.

The drawing process of the sheet blank was depicted in the three-dimensional statement: 0.095 s – the end surface of the punch touches the flange of the sheet blank; 0.2 s – beginning of wrinkles formation on the flange; 0.3 s – increasing of wrinkles radii on the flange; 0.38 s – finishing of the drawing process. The values of normal force characterize a deformation degree of compression and tension of the sheet blank material. The sheet blank is subjected to alternating deformations of tension and compression over the entire time range of the drawing process. The maximum values of compression and tension of material are observed on the small time range of the deformation process at the stage of active formation of wrinkles. Gradual punching of the sheet blank into the die hole leads to increasing of transverse force by 6 times. Changes of transverse force are associated with the smoothing process of wrinkles on the sheet blank in the die hole. Transverse force is less than normal force. The calculation results show that torque acts clockwise and counterclockwise in the blank material. The negative values of torque were determined only in the end of the drawing process. Bending moment acts only in one direction when drawing. The maximum value of bending moment reaches at the stage of active formation of wrinkles. Bending moment is more than torque.

The dependence of changing of the deformation area of the steel sheet blank from time of the drawing process is presented in the Fig. 2.

The deformation area of the sheet blank in beginning of the drawing process is equal to the area of the end surface of the punch. The deformation area increases by 20% of the initial area of material deformation at the stage of wrinkles formation.

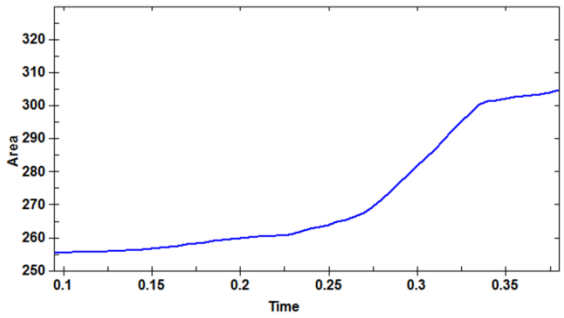

Figure 2 – Changing of the deformation area of the sheet blank from time of the drawing process.

Conclusion

In the direction of the axial line of the round sheet blank there is more plastic deformation of material than in the transverse direction. The drawing process occurs intermittently due to uneven of distribution and the different sizes of wrinkles on the sheet blank. Rational force of drawing of the round steel sheet blanks of the small thickness without using of the blank holder can be determined by the calculated maximum values of the internal force factors.

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