Numerical simulation of multi-point stretch forming for hyperbolicity workpiece and it's process analysis

Chuan Min Zhang[1,a], Wei Liu[2,b] and Wen zhi Fu[3,c]

[1]Department of electromechanical engineering, Zhuhai school, Jilin University, China, Guangdong, Zhuhai

[2]School of electromechanical engineering, Henan University of Technology, China, Henan, Zhengzhou

[3]Roll forging institute, Jilin University, China, Jilin, Changchun

[a]chuanminzhang@163.com, [b] lww1975@yahoo.com.cn, [c] fuwenzhi8005@163.com

Keywords: multi-point stretch forming, numerical simulation, hyperbolicity, amendment.

Abstract. A finite element model was built for the sheet metal multi-point stretch forming (MPSF), and the numerical simulation of the MPSF for the saddle and spherical surface workpiece were performed. The simulation results show that， to hyperbolicity workpiece, the influence on precision is different in dissimilar direction, and the reason was analysed. Besides， In MPSF, the contact between sheet and punches group is discontinuous, so it is very important to structure the enveloping surface of punch group. In this paper, four boundary line method was used to describe it to obtain smooth curved face, and B-spline curve was adopted to approach curves in four boundary line method. Finally, the experiment was done to approve the validity of method.

Introduction

Multi-point forming (MPF) [1-3] is a flexible manufacturing technique for the forming of three-dimensional surfaces of sheet metals. MPF is dividing the curved surface of the die into many discrete pins, using many punches instead of the traditional dies, and each punch can be controlled by computer so that the enveloping surface of punch group can be changed at any time. Stretch forming is a main method for skin parts. Therefore, through the application of MPF technique to stretch forming, namely, multi-point stretch-forming (MPSF), the flexible manufacturing of skin parts can be realized [4-6].

Dimple is a particular defect in MPF, thus, dimples will also generate in MPSF for skin parts. Elastic cushion technology can be used to suppress dimples commendably [7, 8], but it also influences precision of formed workpiece. Especially for hyperbolicity workpiece, the influence of elastic cushion and spring back upon precision is not identic in X and Y direction. Therefore, the amendment of enveloping surface of punch group should be taken into account attentively.

In this paper, the process of MPSF is introduced briefly, and finite element model is built for the sheet metal MPSF. Then simulation result is given on saddle part, and the cause is analyzed. In addition, the four boundary line method is used to obtain smooth curved face in amendment of MPSF die. Finally, an experiment is done to approve the validity of compensation method.

Process of MPSF

MPSF takes full advantage of the MPF's feature that MPD can vary easily during forming process.Generally, process of MPSF can be divided into three steps, they are, adjusting shape of enveloping surface of punch group to gain MPSF die, sheet metal is pre-drawed to yield limit of material, and matched mould is generated between sheet metal and punch group by rising of working table (see Fig.1). Operation of MPSF consists of longitudinal pulling force applied by clamp and normal force by punch group. In MPSF, the action of clamp mechanism is very complex, and it is difficult to gain precise kinematic trace of clamp. Thus, the clamp model is established to simplified study, as shown in Fig.1.

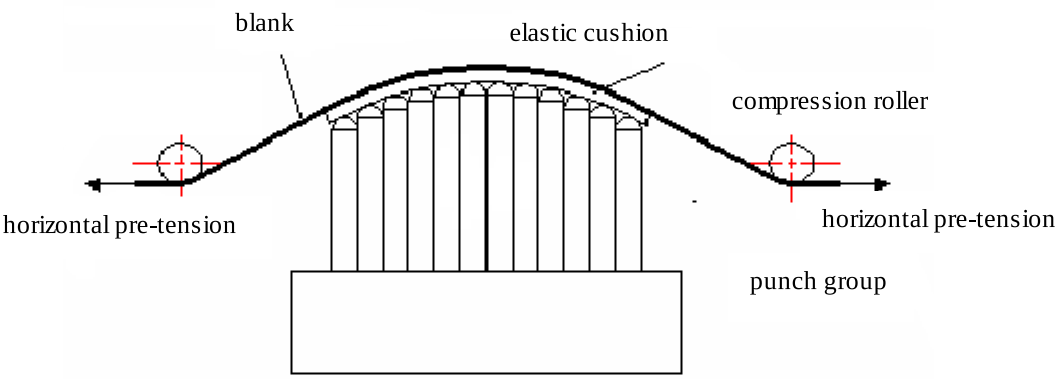
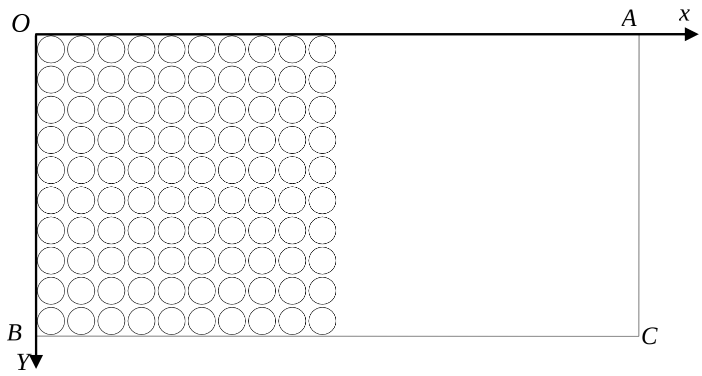


Fig.1 Process of MPSF

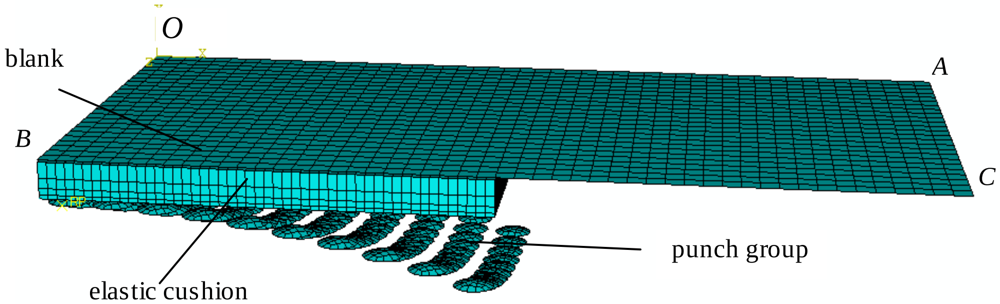
Establishing finite element model

The election of element type has a very great effect on the final result of simulation. Sheet bending effect is primary in MPSF, and the shell element could simulate in-plane bending efficiently, so shell element is used to divide sheet. In this paper, the shell element BWC is selected, which belongs to the finite strain element, and the element adopts reduced integral which has a superior efficiency than complete integral. Its counting equation can reflect perfectly thickness variation in in-plane deformation, and there isn't unconfined hourglass node in it. Punches and press roll are assumed not to be curved during modeling, and a rigid body model BT is adopted. The elastic cushion is regarded as a linear-elastic model with the thickness of 8mm, Young's modulus of 100MPa, Poisson ratio of 0.49, and solid element C3D8R is adopted to divide it.

Finite element model is shown in Fig.2. In this model, the blank has the rectangular shape 400 mm×200 mm., with the thickness of 1mm, material of LY12 aluminium alloy, and material parameter is as follows: Density 2.71g/Cm3, Young's modulus 69GPa, Poisson ratio 0.33, Yield strength 25MPa. The matrix of punches used in the MPSF contains 20×20 punches. Besides, thickness of the elastic cushion is 8mm, and the area 210mm×200mm. In order to economize the computational time of CPU, just adopt the half-spherical surface of elements as the model; due to rigid body, the bulb portion of punches which contact with part is reserved. Furthermore, the $5\pi/9$ cylindrical surface in compression roller is kept which comes into contact with the blank.



a) plane diagrammatic sketch (1/4)



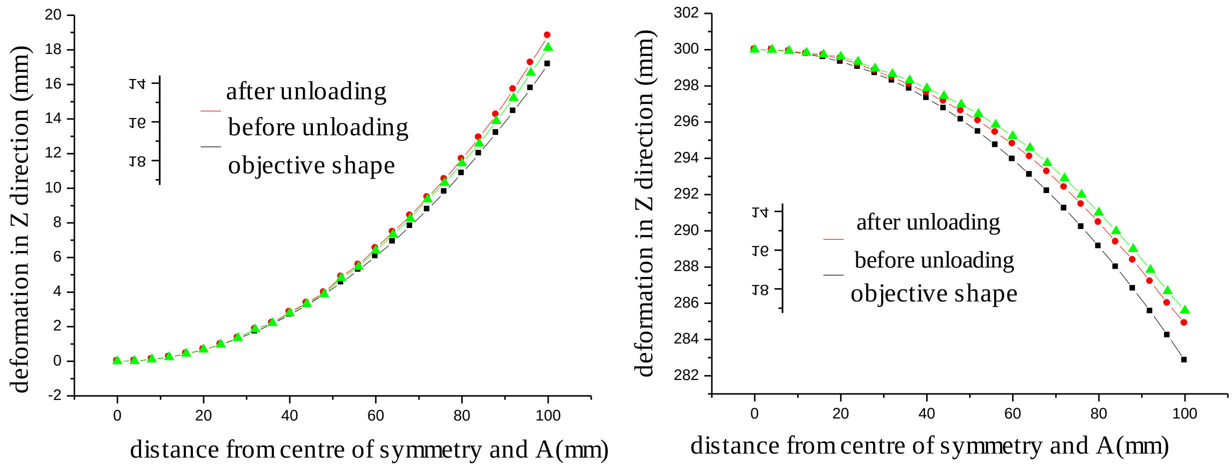
b) finite element diagrammatic sketch (1/4)

Fig.2 Finite element model for MPSF (1/4)

Analysis affecting forming accuracy

In MPSF, the spring-back is an unavoidable phenomenon. Besides, elastic cushion can suppress effectively generation of dimples, but the non-uniform deformation of elastic cushion has an effect on formed accuracy of workpiece.

The saddle workpiece is a typical two-way hyperbolicity wokpiece. Fig.3 shows the deformation curves before and after unloading in X and Y direction obtained by numerical simulation method. The objective shape is saddle surface with curvature radius of 300mm, and the forming area of blank is 200mm×200mm. It can be seen that the amount of deformation exceeds objective shape in x direction, whereas the opposite effect happens in Y direction.



a）Deformation curves in X direction

b）Deformation curves in Y direction

Fig.3 Deformation curves before and after unloading in different direction

Owe to the concave deformation in X direction and convex in Y direction, elastic cushion makes curvature decrease and increase respectively. As shown in Fig.4, after using elastic cushion, for the convex region, the radius of curvature on any point in sheet (point A) is:

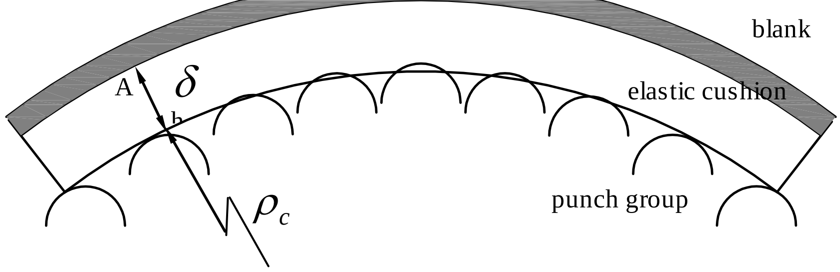
$$\rho = \rho_c + \delta \quad (1)$$

where, ρ_c is the radius of curvature of arbitrary point in enveloping surface of punch group, and δ is the thickness of elastic cushion.

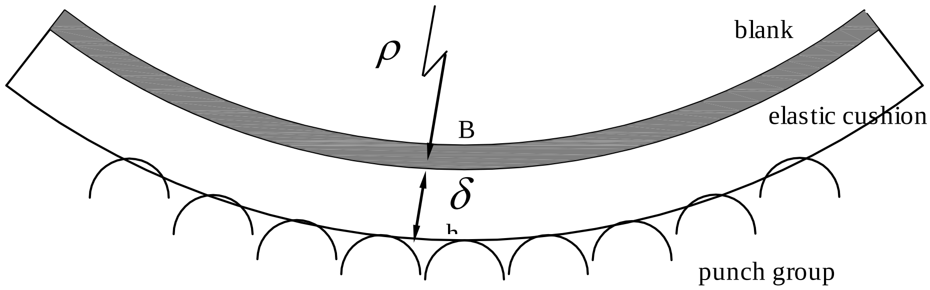
For the concave region, the radius of curvature on any point in sheet (point B) is:

$$\rho = \rho_c - \delta \quad (2)$$

In addition, the thickness of sheet can be neglected, as the thickness of sheet is much less than elastic cushion. For the convex hood face (Fig.4-a), middle punches have been pressed in the elastic cushion, when bilateral punches come into contact with sheet in MPSF. So, the stress of sheet is larger in middle position than bilateral one. Thus, forming error of workpiece is caused by non-uniform deformation of elastic cushion.



a）the convex enveloping surface of punch group



b）the concave enveloping surface of punch group

Fig.4 Error analysis on MPSF with elastic cushion

Accuracy of formed workpiece decreases because of the non-uniform deformation of the elastic-cushion and the spring back after unloading. To increase forming accuracy, the enveloping surface of punch group can be corrected according to the numerical simulation results as shown in Fig.5. The specific process for Correction can see reference [6].

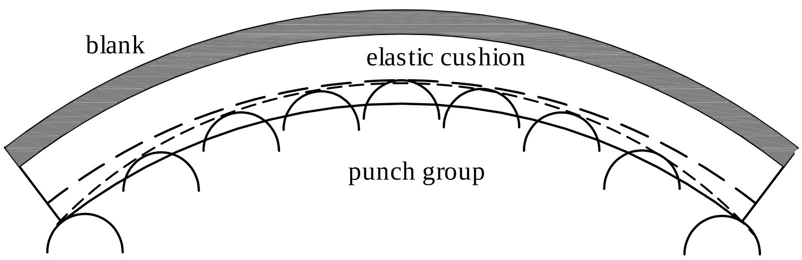


Fig.5 the convex enveloping surface of punch group modified

In MPSF, the contact between sheet and punches group is discontinuous, then it is very important to structure the enveloping surface of punch group. Supposing offset of displacement is added directly to nodal point, then curved face is generated by space nodal point interpolation, but the curved face generated is not smooth, which will lead to wrinkling in the process of MPSF. For curved face with hyperbolicity, four boundary line method can be used to describe it to obtain smooth curved face. In addition, B-spline curve is adopted to approach curves in four boundary line method.

Constitution on smooth curved face

Digital point $\boldsymbol{q}_i(i=0,1,\cdots,m)$ is given, and parameter value $\tilde{u}$ and node complexor $\boldsymbol{U}$ are calculated in advance to find a k th - B spline curve:

$$\boldsymbol{p}(u)=\sum_{j=0}^{n}\boldsymbol{d}_j N_{j,k}(u), u\in[0,1] \qquad (3)$$

here, $\boldsymbol{q}_0=\boldsymbol{p}(0)$, $\boldsymbol{q}_m=\boldsymbol{p}(1)$; other digital point $\boldsymbol{q}_i(i=1,2,\cdots,m-1)$ is approached in least-squares procedure, object function is:

$$f=\sum_{i=1}^{m-1}[\boldsymbol{q}_i-\boldsymbol{p}(\tilde{u}_i)]^2 \qquad (4)$$

it is a minimum value on $n-1$ control vertex $\boldsymbol{d}_j(j=1,2,\cdots,n-1)$.
Generally, approximate curve isn't precisely pass through the data points $\boldsymbol{q}_i(i=1,2,\cdots,m-1)$, and on the curve, $\boldsymbol{p}(\tilde{u}_i)$ isn't the nearest point to $\boldsymbol{q}_i$. Supposing:

$$\boldsymbol{r}_i=\boldsymbol{q}_i-\boldsymbol{q}_0 N_{0,k}(\tilde{u}_i)-\boldsymbol{q}_m N_{n,k}(\tilde{u}_i),\quad i=1,2,\cdots,m-1$$

parameter value $\tilde{u}$ and formula above are substituted in formula (4), so:

$$f-\sum_{i=1}^{m-1}[\boldsymbol{q}_i-\boldsymbol{p}(\tilde{u}_i)]^2=\sum_{i=1}^{m-1}[\boldsymbol{r}_i-\sum_{j=1}^{n-1}\boldsymbol{d}_j N_{j,k}(\tilde{u}_i)]^2 \qquad (5)$$

for minimal object function f, standard linear least square fitting technic is applied to make derivative on $\boldsymbol{d}_j(j=1,2,\cdots,n-1)$ equal zero, so

$$\sum_{j=1}^{n-1}\left[\sum_{i=1}^{m-1}N_{l,k}(\tilde{u}_i)N_{j,k}(\tilde{u}_i)\right]\boldsymbol{d}_j=\sum_{i=1}^{m-1}\boldsymbol{r}_i N_{l,k}(\tilde{u}_i) \qquad (6)$$

equation (6) is a linear equation, in which control apex $\boldsymbol{d}_1$、$\boldsymbol{d}_2$、$\cdots$、$\boldsymbol{d}_{n-1}$ are unknown quantity.
As $l=1,2,\cdots,m-1$, $n-1$ equations are obtained with $n-1$ the unkown quantities:

$$(\boldsymbol{N}^T\boldsymbol{N})\boldsymbol{D}=\boldsymbol{R} \qquad (7)$$

here, $\boldsymbol{N}$ is $(m-1)\times(n-1)$ scalar matrix:

$$\boldsymbol{N}=\begin{bmatrix} N_{1,k}(\tilde{u}_i) & \cdots & N_{n-1,k}(\tilde{u}_i) \\ \vdots & \ddots & \vdots \\ N_{1,k}(\tilde{u}_{m-1}) & \cdots & N_{n-1,k}(\tilde{u}_{m-1}) \end{bmatrix}$$

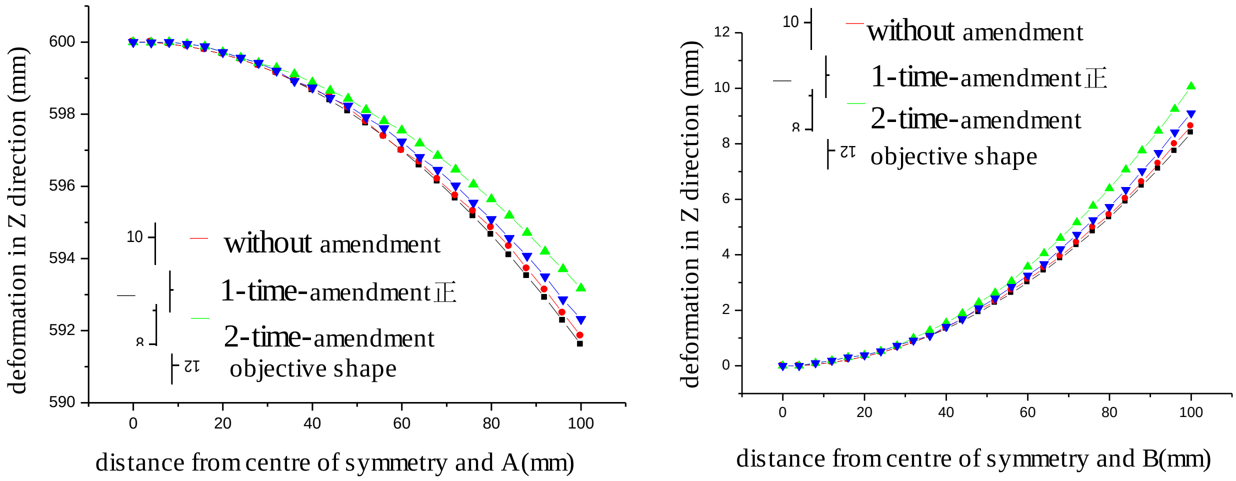
$\boldsymbol{N}^T$ is transposed matrix of $\boldsymbol{N}$. And $\boldsymbol{R}$ and $\boldsymbol{D}$ are arrays with $n-1$ vector element:

$$\boldsymbol{R}=\begin{bmatrix} N_{1,k}(\tilde{u}_i)\boldsymbol{r}_1+ & \cdots & +N_{1,k}(\tilde{u}_{m-1})\boldsymbol{r}_{m-1} \\ \vdots & & \vdots \\ N_{n-1,k}(\tilde{u}_1)\boldsymbol{r}_1 & \cdots & N_{n-1,k}(\tilde{u}_{m-1})\boldsymbol{r}_{m-1} \end{bmatrix},\quad \boldsymbol{D}=\begin{bmatrix} \boldsymbol{d}_1 \\ \vdots \\ \boldsymbol{d}_{n-1} \end{bmatrix}$$

thus, smooth curve required can be gained by substituting control point to equation (3).
Control points received are substituted in equation (3) by solution of equation (7), and the smooth curves required can be obtained.

Results

The spherical part was selected in SMPF, and the method mentioned above was used to compensate deformation of elastic cushion in the forming and spring back after unloading. In stretch forming simulation, thickness of elastic cushion is 10mm, radius of curvature 600mm.



(a) the compensation result of OA (b) the compensation result of OB

Fig.6 The compensation result of OA and OB

The enveloping surface of punch group amended is approximately ellipsoid according to analysis and method above. In this paper, the formative accuracy of work is investigated respectively in X orientation and Y. As seen from Fig.6, cross-section curve of workpiece is close to objective shape after 2-time-amendment, maximum deviation are 0.29mm(X direction) and 0.23mm (Y direction). So, it is very effectively to use this method to enhance forming accuracy of MPSF part.

Experimental verification

The MPSF experiment is carried out to check the validity of the compensation method presented. The final product shape of this example is a spherical surface, whose size is 600mm×400mm, whose bidirectional curvature radiuses are both 600mm. It was formed by a MPF press with the forming area of 800mm×1200mm and the punches of 32×48. In the experiment, the elastic cushion is adopted with the thickness of 10mm, and 2-time-compensation result is utilized to amend enveloping surface of punch group and final multi-point stretch die is obtained (see Fig.7), it takes 50 minutes to adjust punch group. The formed workpiece is shown in Fig.8.

Fig.7 The multi-point stretch die

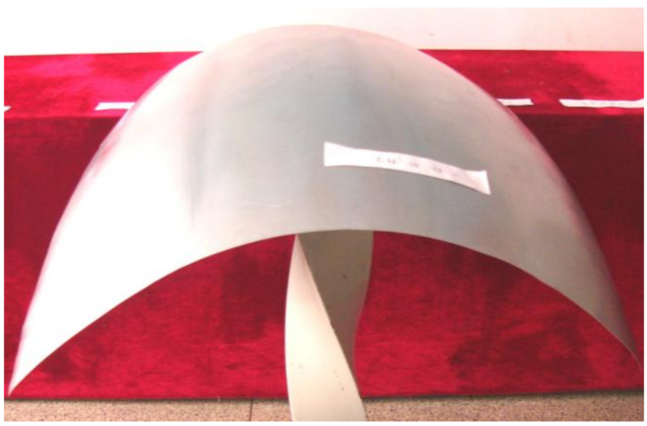


Fig.8 Spherical workpiece made by MPSF

CLY-0505 laser three-coordinates measuring machine was used to measure the precision of workpiece, and the measurement accuracy of apparatus is 0.01mm. The method of measurement is shown in Fig.9, that is, one point is selected every 5mm at center line in spherical workpiece. Besides, tab.1 shows the result of measurement, and compared with shape of objective part, maximum error of formed region is approximately 0.3mm, which is also anastomotic with the numerical simulation result.

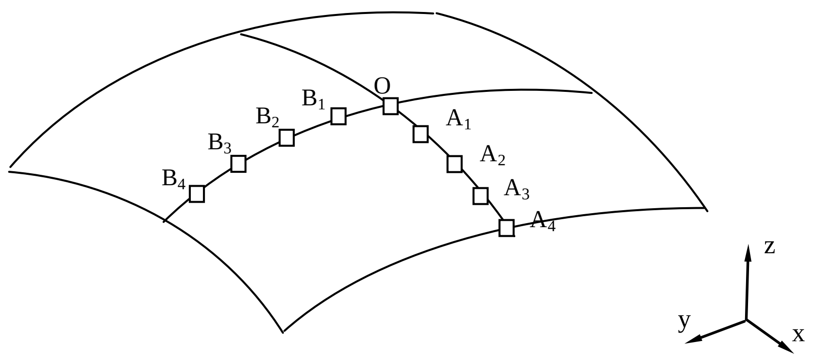


Fig.9 the sketch of measuring precision of workpiece

Tab.1 the forming error on point selected（mm）

measuring point	O	A_1	A_2	A_3	A_4
without amendment	0	0.33	0.79	1.25	2.82
1-time-amendment	0	0.14	0.33	0.42	0.89
2-time-amendment	0	0.09	0.15	0.21	0.30
measuring point	O	B_1	B_2	B_3	B_4
without amendment	0	0.29	0.62	1.11	2.41
1-time-amendment	0	0.11	0.28	0.37	0.83
2-time-amendment	0	0.06	0.10	0.19	0.26

Conclusions

(1) Non-uniform deformation of elastic cushion and spring back of formed workpiece after unloading lead to error of part shape compared with objective shape, besides, to hyperbolicity workpiece, the influence on precision is different in dissimilar direction.

(2) The four boundary line method is used to obtain smooth curved face with hyperbolicity, and the experiment approved that this method is effective.

References

[1] Li M, Nakamura K, Watanable S, Akutsu Y (1992) Study of the basic principles (1st report: Research on Multi-point forming for sheet metal). Proc. of the Japanese Spring conf. for Technology of Plasticity 519-522 (in Japanese)

[2] Liu C, Li M, Fu W (2008) Principles and apparatus of multi-point forming for sheet metal. Int J Adv

Manuf Technol 35: 1227-1233 DOI 10.1007/s00170-006-0802-1
[3] Peng H, Li M, Liu C, Cao J (2013) Study of multi-point forming for polycarbonate sheet. Int J Adv Manuf Technol 67: 2811-2817 DOI 10.1007/s00170-012-4694-y
[4] Cai Z, Wang S, Xu X, Li M (2009) Numerical simulation for the multi-point stretch forming process of sheet metal. J Mater Process Technol 209: 396-407
[5] Wang S, Cai Z, Li M (2010) Numerical investigation of the influence of punch elemenht in multi-point stretch forming process. Int J Adv Manuf Technol 49: 475-483 DOI 10.1007/s00170-009-2420-1
[6] Liu W, Yang Y, Li M (2010) Numerical simulation of multi-point stretch forming and controlling on accuracy of formed workpiece. Int J Adv Manuf Technol 50: 61-66 DOI 10.1007/s00170-009-2501-1
[7] Song X, Cai Z, Li M (2004) Numerical simulation on dimples and analysis on limited forming force in multi-point forming. Material science and technology, 8: 368-371 (in Chinese)
[8] Cai Z, Wang S, Li M (2007) Numerical investigation of multi-point forming process for sheet metal: wrinkling, dimpling and springback. Int J Adv Manuf Technol 37: 927-936 DOI 10.1007/s00170-007-1045-5