Simulation of plastic forming process by variation of geometric parameters

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Abstract. In this paper the complex research method was used, which includes theoretical analysis and verification of the results using numerical simulation in Pam-Stamp 2G solution. During determination of stress-strain condition of the workpiece the functional was solved, which allows minimal thickness fluctuations of the thin-walled parts during the forming. The radius of the punch was chosen as variable parameter. Its calculated values served as input parameters for the simulation.

Keywords: Functional, Minimal thickness fluctuation, Forming, Modeling.

1. Introduction

Development of the sheet metal deformation theory, considering minimization of the functional between the set uniform thickness value and the technologically possible thickness, allows more possibilities and different approaches to the analysis of such cases. The methods of obtaining accurate geometric dimensions of the complex shaped parts with minimal thickness fluctuations can raise productivity and reduce defects [1,2]. The stable operation flow is achieved by maximization the usage of the internal deformational reserves of the metal and by deep analysis of the stress-strain condition of the workpiece. Availability of the developed mathematical apparatus allows creation of the model, but usually the difficulties are in the application of the simplifications and assumptions which are required by that apparatus. Adequate mathematical model, however, allows predicting and evaluating the performance of the process in the set conditions and testing the hypothesis about the reasons of the observed effects and undesirable changes.

2. The object of the study

Fulfillment of requirements to aviation parts, including thin-walled shells, is possible by analytically representing the condition as the functional and solving it [3]:

$$\iint_F \left(S_T - S_{set}\right)^2 dF \to \min , \tag{1}$$

where S_{set} - set thickness of the part;

S_T - technologically possible thickness, which emerges after the forming of the blank;

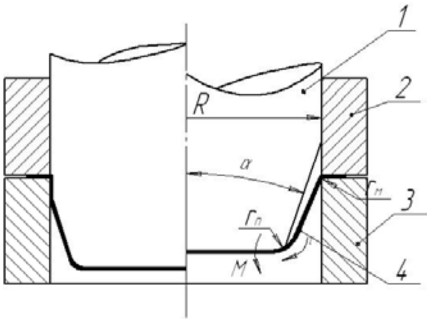
F - area of the median surface of the part.

Using the dependence (1), the condition for the axisymmetric part can be presented as:

$$\int_l \left(S_T - S_{set}\right)^2 dl \to \min \quad , \qquad (2)$$

where l - length of generatrix of the part.

The functional requires the approach of the technologically possible thickness S_T to the set thickness of the part S_{set} with the condition of the minimal deviation to the positive or the negative difference between the two functions of the thicknesses. For the thin-walled shells ($\frac{S_{blank}}{2R} \leq 0.008$) in order to prevent the corrugations on the free portion of the workpiece two processes is used – flanging and forming, since tensile stresses are in action in meridional and tangential directions during the deformation of the flat blank. Between this two process the forming process is preferable for the obtaining the minimal thickness fluctuations. It can be separated onto two stages: the first one takes place until the moment then the free portion of the workpiece touches the tapering part of the punch, the second one – then the cylindrical portion is formed. The second stage is characterized by the presence of the active friction forces, leading to the reduce of the thickness fluctuations of the part. During the forming, stresses and strains have more uniform values across the deformation area.



1 - punch; 2 - holder; 3 - die; 4 - part

Figure 1. Cheme of the forming using the conical punch.

3. Methods and theoretical foundations

Considering the mechanism of the forming process, it should be noted, that on the free portion the meridional stresses are larger of the two kinds. So, from the Laplace equation [4] we get:

$$\frac{\sigma_\theta}{\sigma_\rho} = -\frac{R_\theta}{R_\rho} \quad , \qquad (3)$$

where $\left|R_\rho\right| \geq\geq \left|R_\theta\right|$, $\sigma_\rho > \sigma_\theta$;

σ_ρ - meridional stresses;

σ_θ - tangential stresses;

R_ρ - radius of the part in the meridional direction;

R_θ - radius of the part in the tangential direction.

Forming of the part takes place due to the thinning of the blank. The forces on the radial surfaces of the punch and the die are directed in the opposite sides, thus compensating each other. Friction forces in the bottom portion of the workpiece are almost neglectable due to the action of the bending momentum in the radial portion of the workpiece [4]. We consider that the stresses picture, due to the relatively small extend of the free portion, is influenced by the additional stresses from the bending and the friction $\Delta\sigma_\rho$ on the radiuses of the punch and the die (figure 2).

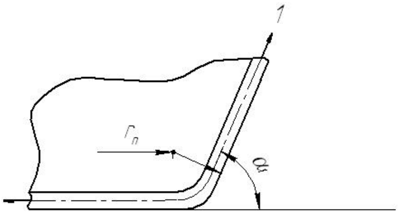


Figure 2. Cheme of the influence of the bending radius on the stresses

$$\Delta\sigma_\rho = (1+\frac{1}{2\frac{r_n}{S_{blank}}+1})e^{f_1\alpha_1} \quad (4)$$

where f_1 - friction coefficient on the radiuses of the punch and the die;

α_1 - bending angle of the workpiece;

$\frac{r_n}{S_{blank}} = \bar{r}_n$ - relative radius of the punch;

S_{blank} - thickness of the blank.

Let us write the equilibrium equation for the conical portion of the shell:

$$\rho\frac{d\sigma_\rho}{d\rho} + \sigma_\rho - \sigma_\theta - \sigma_\theta fctg\alpha = 0 \quad (5)$$

where α - conical angle at $\rho = \rho_c$;

ρ - the independent variable representing the current radius.

The ratio of the stresses $\frac{\sigma_\theta}{\sigma_\rho}$ we estimate by the limits of the forming, accepting the assumption about the linear nature of changes of the ratio, due to the small extend of the conical portion.

If $r_n = r_m = 0$, then the movement of the workpiece in the tangential direction is absent, and from the linking equation:

$$\frac{\sigma_\theta}{\sigma_\rho} = \mu;\ e_\theta \approx 0, \quad (6)$$

where μ - the coefficient of the anisotropy of the transversely isotropic body.

If $r_n \to \infty$, then we consider the element of the part, corresponding to the element on the axis of the symmetry, where $\frac{\sigma_\theta}{\sigma_\rho} = 1;\ e_\theta \approx e_\rho$.

Considering the above mentioned, we get:

$$\frac{\sigma_\theta}{\sigma_\rho} = 1+\frac{\mu-1}{2\bar{r}_n}. \quad (7)$$

Expression (7) demonstrates which ratio of the stresses will take place on the free portion of the workpiece, when the radiuses of the punch and the die are equal. Stresses themselves are changing proportional to one parameter, but their ratio remains constant.

Minimization of the expression (2) as the functional can be performed using the technological parameters, which remains constant during forming. Among them are: the initial thickness of the blank, forming coefficients, geometrical parameters of the tooling, friction coefficient, some mechanical properties, including the transversely isotropic body parameters, which is determined due to the nature of the material. For the simplification of the solution sake, in the boundaries of the considered error margin it is enough to identify the conditions and parameters, which are most relevant for the alteration of thickness and can be regulated. For further use in the engineering solution method as the variable parameter we choose the relative radius of the punch [3]. After some transformations we get the following expression:

$$\bar{r}_n = \frac{1-\mu}{1-\dfrac{1}{1+f ctg\alpha}} - \frac{1}{2} \quad . \qquad (8)$$

4. Simulation results

For the labor-intensive tasks the application of the modern means of automatization allows to avoid the significant volume of the routine work and represent the results of the simulation in the graphical form [7,8]. The simulation of the investigated process was implemented using theoretical dependencies, assumptions and limitations. The adequate mathematical allows to predict the development and degradation of the system, as well as to estimate its performance and survivability under specified conditions and to evaluate hypothesis about the reasons to the effects observed and possible unwanted changes in the state of the system. So as the result, the technological parameters (tools geometry, shape and size of the blank, friction coefficient, transversely isotropic body coefficient), which influence the distribution of the thickness in the part obtained was established. Special attention was paid to the geometry of the punch, in particular its relative radius, since by variating this parameter we aim to get the desired minimal thickness fluctuations (figure 3).

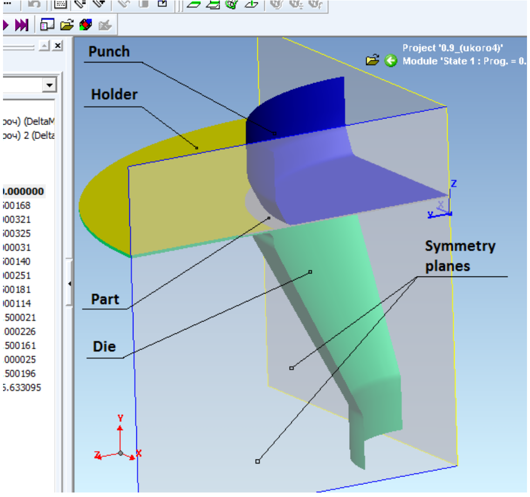
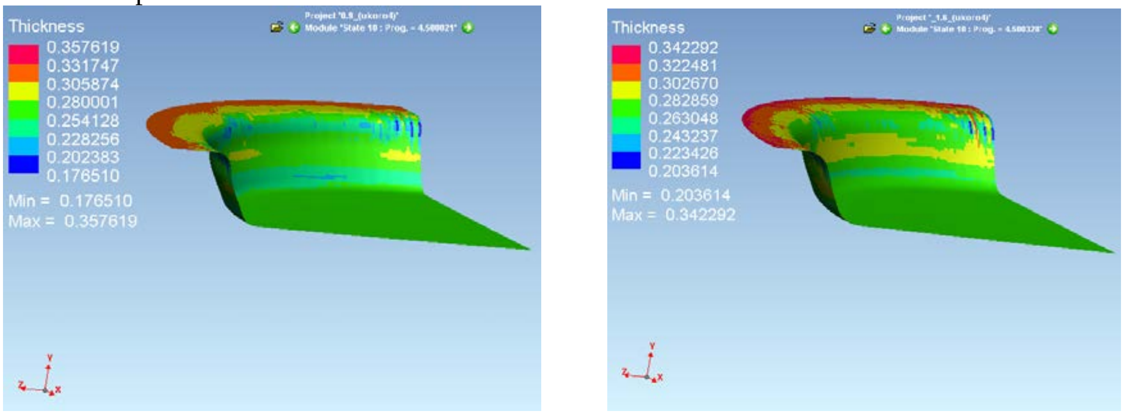


Figure 3. Kinematic scheme of the process in Pam-Stamp 2G (ESI Group).

5. Conclusions

It was discovered, that using the punch with the radius of the curvature of 0.9 mm the thickness fluctuations on the conical portion is 10.7%, but using the punch with curvature radius of 1.6 mm – the thickness unevenness is 8.5% (figure 4). So we get the decrease of the thickness fluctuations at the increase of the punch curvature radius.



а $r = 0{,}9mm$

б $r = 1{,}6mm$

Figure 4. Thickness distribution on the conical portion.

Modern technologies of obtaining thin-walled shells are based on the methods, which are labor-intensive, since one of the mandatory conditions of the manufacturing is the presence of heat setting and mechanical treatment steps, in order to obtain the set geometrical dimensions (including thickness) of the part. Manufacturing of the thin-walled shells is economical (lower labor-intensity, higher coefficient of useful usage of metal) to perform, basing on the forming process of the flat blank, which allows to minify thickness fluctuations.

6. References

[1] Demyanenko, E.G. Directional thickness alteration of a thin-walled ring blank using flanging and forming for the purpose of receiving conical part / E.G. Demyanenko, I.P. Popov // Key Engineering Materials, Trans Tech Publications, Switzerland. – 2016. – Vol. 684. – P. 253-262.

[2] Khaimovich, I.N. Computer-aided design of blank forging production facilities for aircraft engine compressor blades / I.N. Khaimovich // Russian Aeronautics. – 2014. – 57(2). – P. 169-174.

[3] Demyanenko, E.G. Research of the process of axisymmetric forming of thin-walled flat blanks into the conical parts with minimal thickness variation / E.G. Demyanenko, I.P. Popov, V.S. Menshikov // IOP Conference Series: Materials Science and Engineering. – 2017. – Vol. 177.

[4] Storozhev, M.V. Theory of pressure working of metals / M.V. Storozhev, E.A. Popov // Mashinostroenie. – Moscow, 1971. (in Russian).

[5] Erisov, Y.A. Development of the criterion of plasticity for calculation of the formation of highly textured anisotropic workpieces / Y.A. Erisov, F.V. Grechnikov // Samara: Vestnik SSAU. – 2012. – №1. – P. 94-99. (in Russian).