Simulation of the combined flanging and forming process taking into account the springback effect

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Abstract. In this paper, the simulation of the method, which combines the deformation and the investigation of the elastic comeback effect during the forming of the thin-walled shells are presented. The springback value on the edge of the part after removing the deforming force is also evaluated.

1. Introduction
In the rockets and aircraft manufacturing the thin-walled axisymmetric shells, such as nozzles, fairings, deflectors, etc., take a special place. Identification of the forming mechanism and its major parameters, including elastic comeback, which influences the quality of the part and the applicability of improved methods to thin-walled axisymmetric shells, allows intensification of manufacturing, since lowering the volume of mechanical treatment also improves the part quality due to the preservation of the deformed metal structure [1, 2, 3].

2. The object of the study
Modern investigations of the elastic comeback and springback effects are conducted in several directions [4], which depend on the method and the way of applying force and obtaining empirical dependencies or comparing empirical data to the calculated numbers. We conduct the investigation of elastic comeback mechanism [5, 6] during forming the thin-walled shells, by the new method, combining processes of flanging and forming. We compare several numerical models during the finite-element analysis, which allows us to estimate the influence of parameters of the simulated processes and predict the elastic comeback for the experimental studies.

3. Methods
Let us analyze the possible springback of the edge in the processes of flanging and forming. [7]. We estimate the springback of the edge after flanging by the known formulas (figure 1) when the stress-strain conditions are close to the linear scheme: \( \sigma_s = \sigma_p = 0 \), \( \sigma_y \neq 0 \), \( e_s = e_y = 0 \), \( e_p = e_y = -2e_s = -2e_y \).

It is known that the value of the elastic strain is:

\[
e_{\text{elast}} = \frac{\sigma_{\text{edge}}}{E},
\]

(1)
where \( \sigma_{\text{edge}} = \sigma_{TO} + \Pi e_{\theta_{\text{edge}}} = \sigma_{TO} + \Pi \ln \left( \frac{r_{\text{edge}}}{r_{\text{blank}}} \right) \); \( \sigma_{\text{edge}} \) - stress intensity on the edge of the part; \( e_{\theta_{\text{edge}}} \) - the elastic deformation of unloading; \( E \) - the elasticity modulus; \( r_{\text{edge}} \) - radius of the edge; \( r_{\text{blank}} \) - radius of the blank.

**Figure 1.** Scheme of the springback calculation in the flanging process.

On the other side of the elastic unloading leads to a decrease in the radius of the edge, since:

\[
\epsilon_{\text{elast}} = \ln \left( \frac{r_{\text{part}}}{r_{\text{edge}}} \right),
\]

where \( r_{\text{part}} \) - radius of the part.

Hence, the radius of the part from the equations (1) and (2) is:

\[
r_{\text{part}} = r_{\text{edge}} \cdot \exp \left( -\frac{\sigma_{\text{edge}}}{E} \right).
\]

Then the difference in the radii is:

\[
\Delta r_{\text{flang}} = r_{\text{edge}} - r_{\text{part}} = r_{\text{edge}} \left[ 1 - \exp \left( -\frac{\sigma_{\text{edge}}}{E} \right) \right].
\]

It should be considered, that \( \sigma_{\text{edge}} = \sigma_{\theta_{\text{edge}}} \) for the edge during flanging.

Let us examine the process of forming (figure 2).

**Figure 2.** The springback effect estimation scheme during the forming.

At the similar stress intensities in the separately considered processes of flanging and forming, tangential stresses in the flanging process are 2 times larger, than they are during the forming (and reduce of edge radii respectively). During the forming for the isotropic body:
\[ \sigma_{\text{edge}} = 2\sigma_{\text{edger}} \]  

(5)

As \( \sigma_{\text{edger}} = \frac{\sqrt{3}}{2}\sigma_{\text{edger}} \), that:

\[ \sigma_{\text{edger}} = \frac{2}{\sqrt{3}}\sigma_{\text{edger}} = 2\sigma_{\text{edger}} \]  

(6)

\[ \sigma_{\text{edger}} = \frac{1}{\sqrt{3}}\sigma_{\text{edger}} = 0.5\sigma_{\text{edger}} \]  

(7)

Even if we suppose that the springback depends only from tangential stresses, then the difference in the radii is:

\[ \Delta r_{\text{form}} = r_{\text{edger}} \left[ 1 - \exp \left( -\frac{\sigma_{\text{edger}}}{2E} \right) \right]. \]  

(8)

By analyzing the expressions (4) and (8) we see, that the springback value during the forming is lower than that during the flanging:

\[ \Delta r_{\text{form}} \leq \Delta r_{\text{flang}} \]  

(9)

Using the preliminary conclusions, we propose to study a method realize with the help of the device (figure 3), in which the conical blank is set in the die with the same cone angle as in the blank [8]. The blank then is clamped with the conical holder in the area of its larger edge. In this portion, during the downward movement of the punch, the flanging takes place at first. The blank is intensively thinning in the area of the larger diameter until the moment then in the side of the smaller edge, it touches the surface of the punch and the surface of the elastic element. As the punch continues its downward movement, the lower portion of the blank is squeezed between the punch and the elastic element, whose inner surface corresponds to the surface of the punch. The process evolves to forming in the situation close to plane-strain-conditions when tangential deformation tends to zero. It is important to know the dimensions of the elastic element and the pressure with which the workpiece is pressed against the bottom of the punch:

\[ q_y = \frac{S_y \cdot E \varepsilon_y}{R_{\text{ring av}}}, \]  

(10)

where \( \varepsilon_y \) - the deformation of the elastic element around the circumference of the average diameter \( 2R \); \( E \) - modulus of elasticity of the elastic rolling element; \( S_y \) - the thickness of the elastic rolling element; \( R_{\text{ring av}} \) - the average radius of the elastic ring on the middle surface.

The force \( F_{f_e} \) with which the elastic movable element of the lower clamp, holds the small end of the workpiece, will be:

\[ F_{f_e} = F_{\text{con}} f_y \cdot q_y, \]  

(11)

where \( F_{\text{con}} \) - the surface area of the workpiece under the elastic movable ring; \( f_y \) - total coefficient of friction between the workpiece and the punch and the elastic movable element of the lower clamp.

The force \( F_{f_e} \) must not be less than the effort \( P_{\text{down}} \) with which the workpiece can slip out of the clamp. In terms of molding, this effort is equal to:

\[ P_{\text{down}} = \pi \cdot D_y S_w \sigma_a, \]  

(12)

where \( D_y \) - the largest diameter of the elastic rolling element; \( S_w \) - the thickness of the workpiece; \( \sigma_a \) - tensile strength of the workpiece (material).
Equating expressions (11) and (12) we have:

\[ F_w = \pi \frac{D_y S_w}{f_y q_y} \sigma_w, \]  

(13)

The area of the elastic moving element in the form close to the conical shell is equal to:

\[ F_{con} = 2\pi \frac{h_y}{\cos \alpha_y} R_{ing} av, \]  

(14)

where \( \alpha_y \) - the angle of taper of the inner working surface of the elastic rolling element; \( h_y \) - the height of the elastic movable element.

We assume that the surface area of the workpiece under the elastic ring and the area of the elastic moving element is equal, then from expressions (10, 12, 14) we find:

\[ S_y \geq \frac{D_{el} S_w \cos \alpha_y \sigma_w}{2E \cdot f_y \cdot h_y}. \]  

(15)

Given the height \( h_y \), the thickness of the elastic moving element is determined. The force of the lower pressure of the press must be constant during the molding process and not less:

\[ P_{pr} = P_n \frac{F_{fr}}{\cos \alpha_y f_y} = P_n \frac{F_{fr}}{\cos \alpha_y f_y}. \]  

(16)

where \( P_n \) - the normal force acting from the elastic moving element.

Given the expression (10-15) we find:

\[ P_{pr} \geq \frac{\pi \cdot D_y S_w \sigma_w}{f_y} \cos \alpha_y. \]  

(17)

In order to avoid plastic deformation of the elastic moving element, it has limitations during distribution. In this case, the gap, i.e. the difference between the outer diameter of the elastic movable element and the diameters of the working surface of the lower clamp, which limits the movement of the elastic movable element, is constant in height and must be determined:

\[ \frac{\Delta}{2R_{ing} av} \leq \left[ \varepsilon_{el} \right], \]  

(18)

where \( \Delta \) - the gap between the outer diameters of the elastic movable element and the working surface of the lower clamp; \( \left[ \varepsilon_{el} \right] \) - the value of the limit value of elastic deformation.

**Figure 3.** Scheme of the action of the friction forces on the barrel-shaped part 1 - Upper conical holder; 2 - Conical die; 3 - The punch; 4 - Elastic element; 5 - Lower holder; 6 - The blank; 7 - Support ring; 8 - The casing; 9 - Stamp plate.
Using modeling techniques in different kinds of program complexes allow getting the idea of the stress-stain condition and technological features of the processes. Our choice of Pam-Stamp 2G (ESI Group) is justified by its ability to simulate thin shells and to analyze deformation processes of sheet metal stamping.

4. Simulation results
By replacing the real process scheme by the simplified one we could achieve an adequate and precise model for the numerical simulation [9, 10]. We expand our search for the influence of the elastic comeback during the two processes by using the punch of conical and spherical shape, since its shape could also influence the springback.

Let we examine the results of the simulation (figure 4).

![Figure 4. The area of the springback during flanging using conical punch.](image)

For more accurate estimation of the springback let us compare the corresponding points on the average diameter of the parts before and after the release of the deforming force (figure 5).

![Figure 5. The coordinates of the investigated point (on the left the part before springback effect, on the right- the part after springback).](image)

According to the achieved data, the value of the springback was estimated $Z=Z_1-Z_2=12.676-12.645=0.031$ [mm]. This value was calculated for the flanging process using the conical punch and it is 10.33% of the workpiece thickness (0.3 mm).

By the analogy, the values of the springback for the flanging using the spherical punch (figure 6), the flanging-forming with the conical (figure 7) and spherical (figure 8) punches were estimated.

5. Conclusions
The analysis of the achieved data demonstrated, that the value of the springback effect for the flanging process using the spherical and conical punches is 0.031 mm (10.33% of the wall thickness) and 0.034 mm (11.33% of the wall thickness) accordingly. On the other hand, for the flanging-forming process...
using the conical and spherical punches this value is 0.004 mm (1.33% of the wall thickness) and 0.003 mm (1.0% of the wall thickness) accordingly. Thus the simulation of the process approved the fact of almost complete compensation of the unwanted springback effect of the flanging process using the combined method of deforming the part by the flanging and forming processes.

Figure 6. The springback of the part after the flanging with the spherical punch.

Figure 7. The springback of the part after the flanging-forming with the conical punch.

Figure 8. The springback of the part after the flanging-forming with the spherical punch.

6. References

[1] Miranda S S, Barbosa M R, Santos A D, Pacheco J B and Amaral R L 2018 Forming and springback prediction in press brake air bending combining finite element analysis and neural networks Journal of Strain Analysis for Engineering Design 53(8) 584-601

[2] Barros P D, Neto D M, Alves J L, Oliveira M C and Menezes L F 2018 Study on the influence of orthotropy and tension-compression asymmetry of metal sheets in springback and formability predictions Journal of Physics: Conference Series 1063(1) 12053

[3] Hafsa A, Chahbouni M, Said B and Driss A 2018 An analysis of springback of compliant assemblies by contact modeling and welding distortion International Journal of Engineering and Technology (UAE) 7(1) 85-89

[4] Yilamu K, Hino R, Hamasaki H and Yoshida F 2010 Air bending and springback of stainless steel clad aluminum sheet Journal of Materials Proc. Technology 210 272-278

[5] Tekaslan O and Nedim G B 2008 Determination of spring-back of stainless steel sheet metal in "V" bending dies Materials and Design 29 1043-1050

[6] Parsa M H, Nasher Al, Ahkami S and Ettehad M 2010 Experimental and finite element study on the spring back of double curved aluminum/polypropylene/aluminum sandwich sheet Materials and Design 31 4174-4183

[7] Zvonov S, Popov I and Shlyapugin A 2010 Peculiarities of the process of hollow conical parts shaping from a ring blank Russian Aeronautics 3 358-361
[8] Demyanenko E and Popov I 2014 Ru Patent 2580269-2014140637
[9] Khaimovich I and Klentak L 2013 Improvement of smoothing methods of complex surfaces using interpolation splines Fundamental studies 10-12 2634-2638
[10] Grechnikov F V, Ersov Ya A and Alexandrov S E 2016 Effect of anisotropic yield criterion on the springback in plane strain pure bending CEUR Workshop Proc. 1638 569-577