On the issue of compensation of spring fittings for parts made by longitudinal stretching

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Abstract. The paper considers the problem related to the compensation of springing in the fitting of parts produced by longitudinal stretching. The imitating modeling of shaping by longitudinal stretching using elasto-plastic model of material taking into account anisotropy was carried out on the example of one element. The adequacy of modeling was checked according to the following criteria: deformation ratio; thinning; Keller-Godwin’s chart and required shaping force. Conclusions were drawn on the adequacy of modeling. Implicit calculation of springing gradients in an element was carried out and thus the iterative calculation of compensation of springing in the fitting. The negative effect of springing compensation at such scheme of shaping is shown. Change of the springing size in the course of iterative calculation of springing compensation in the fitting is also shown.

1. Introduction
One of the most difficult tasks in the production of aircraft sheet parts is the manufacture of aircraft outline parts. The specifics of such manufacturing is that the deformation of the formation in the conventional manufacturing process of such parts is sufficiently small and there is a high probability that the springs will be very large after the formation. This, in turn, leads to an increase in manual refinement so much that in fact it turns out that the part is made manually. In order to avoid this, a forming process was proposed – stretching. By adding tension at the end of the process, additional deformations are applied to an element that prevent its large elastic response. However, in most cases it is not possible to completely avoid springing, and compensating for the springing in the tooling remains an urgent task.

2. Problems arising in the compensation of springing of sheet parts produced by longitudinal stretching
Stretching of sheet metal parts may be of two types – transverse and longitudinal. The typical representatives of parts for transverse and longitudinal stretching are shown in Figure. 1.
It is known that the loading scheme in parts made by transverse and longitudinal stretching is different [10]. Hence, the nature of springing will be different. Based on this, it can be concluded that the compensation algorithms that exist at the moment cannot effectively compensate for the tooling for longitudinal stretching. Let us prove this with an example of one element.

3. An element made by longitudinal stretching and compensation of its springing in tooling
Let us consider an element made by longitudinal stretching from aluminum alloy 1163AM (Figure. 2).

Let us simulate the forming process. The software product PAM-STAMP 2G by the French company ESI Group will be used as a program for finite element analysis. The material model in the software product was set by the following parameters:
• Young modulus – 72.05 GPa;
• Poisson coefficient – 0.323;
• density – 2.6 kg/mm³;
• anisotropy coefficients r₀, r₄5, r₉₀ – 0.534, 0.834, 0.59;
• plastic part of the flow curve is set by the Krupkowsky law function, which looks as follows (Formula 1):

\[ \sigma = K \left( \varepsilon_0 + \varepsilon_p \right)^n \]  

(1)

Function constants for the material: K=0.65204 GPa, n=0.2949, \( \varepsilon_p = 0.0045 \).
A fitting model was built for element forming (Figure. 3).
Figure 3. Fitting model for longitudinal stretching

As in real life, the formation process was divided into stages:
• first stage – lengthwise curvature (most often more than the necessary shape of an element);
• second stage – fitting from the bottom of an element upwards and its shaping by “unbending”.

The simulation results are shown in Figure 4.

Figure 4. Distribution of plastic deformations during shaping

To verify the adequacy of simulation, deformation and thinning were checked in the element area on a workpiece. As a result, it can be seen that deformation and thinning do not exceed 20% (Figure. 5) [12]. The deformation capacity of the material on a workpiece in the contour of the element was also checked according to the Keller-Goodwin limit deformation diagram [9] in the material model. Hence, no dangerous areas of deformation were found. Based on the above results it is possible to conclude that the element can be made with longitudinal stretching according to the above flow chart.
a – distribution of plastic deformations in the element contour on a workpiece, maximum deformation – up to 5.5%, < 20%

b – thickness distribution in the element contour on a workpiece, minimum thickness (blue) – 1.410 mm, thinning – up to 6%, less than 20%

Figure 5. Results in the element contour on a workpiece

Figure 6. Results of the Keller-Goodwin diagram on a workpiece and in element contour on a workpiece

To check convergence, the tensile force was calculated elementwise according to formula 2:

\[ F = \sigma \cdot s \cdot a \]  \hspace{1cm} (2)

where \( \sigma \) – equivalent tension in an element, MPa; \( s \) – thickness in the element, mm; \( a \) – length of the edge of the element, mm.

The total force at the ends of the workpiece is calculated by elementwise addition. Thus, the following results were obtained (Figure. 7).

The total forming force is equal to 575 kN + 547 kN = 1122 kN = 112.2 tons. Besides, the dimensions of the workpiece for stretching are 5700 mm x 1800 mm. The PO-3M press [13] has a force of 2700 kN = 270 t and the largest dimensions of the workpiece: 8000 mm x 1800 mm x 10 mm, i.e. it is possible to manufacture this element using this press. All of the above indicates the adequacy of simulation.

A springing gradient was also calculated for the area of the workpiece in contact with fitting (Figure. 8 a). The thesis from the section of this paper was confirmed (section “Problems of springing compensation of sheet parts formed with longitudinal stretching”) (Figure. 8 b). With such a sequential loading scheme, as with longitudinal stretching, the element will spring inward due to the fact that in the second forming step it is formed to reduce curvature. As a consequence, the elastic components of deformation will tend to return it to its original state i.e. bending.
Figure 7. Results of shaping force

a – spring distribution for the area of the workpiece in contact with fitting, the maximum distance of the workpiece from the fitting surface is 26.2 mm.

b – area of the workpiece in contact with fitting before and after the springing effect, white surface – workpiece after elastic response (springing caused the edges of the workpiece to deflect inward).

Figure 8. Distribution of longitudinal stretching springing

The springing compensation was carried out, which showed that this calculation does not make it possible to fight springing because it compensates for the springing to the side opposite the springing, i.e. reduces the curvature of the element (Figure 9).
6

Figure 9. Results of fitting compensation for longitudinal stretching

Reduced curvature results in reduced deformation during workpiece deformation. As a result, we have springing increase, which makes the springing compensation inefficient (Figure. 10).

Figure 10. Results of longitudinal stretching compensation

4. Conclusion

Thus, on the example of one element, a finite element analysis of forming the element by longitudinal stretching was carried out. The simulation results of the shaping process were estimated by the degree of deformation, thinning, Keller-Goodwin diagram and the required shaping force. The results showed that the element is formed without defects and can be made on the PO-3M press. The springing
distribution gradient in the element was also calculated, which showed that the element springs inward when springing. In the future, the results of the iterative calculation of springing compensation in the fitting showed that spring compensation with such a loading scheme is not effective.

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