

# Investigation of forming method based on flanging process

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**Abstract.** In this paper the new method of forming based on flanging is investigated using computer simulation. The obtained results supported the theoretical conclusions and allowed us to create a mathematical model, to define geometric dimensions of a blank for forming of the thin axisymmetric parts with minimal thickness variation. This analysis serves as a foundation for further design of the technological process.

## 1. Introduction

Application of thin-walled axisymmetric parts ( $\frac{S_{blank}}{D} < 0.008$ , where  $S_{blank}$  - thickness of a blank;  $D$  - larger diameter of a part) is limited by capabilities of known methods of sheet stamping [1,2,3,4]. Another limiting factor is time-consuming theoretical and experimental studies, requiring expensive equipment. At the initial stage of research, the viable option is usage of computer simulations in various software solutions, allowing obtaining the stress-strain picture and estimating the features of the process.

## 2. Investigation of the forming mechanism

In current state of machine and aircraft building industry, the relevant tasks are developing new and improving the existing technological processes, providing increased quality of manufactured parts and lowering expenses on their manufacturing. The proposed earlier method [5] requires development of technological process for its implementation in manufacturing. The method is based on the flanging process, during which forming is performed on the edge of the smaller diameter of the blank, and then on the elements of the larger diameter. The proposed deformation sequence provides almost equal degree of deformation of the elements through the thickness of the workpiece and allows to obtain thin-walled parts of different shape (conical, convex, concave) with uniform enough thickness of the walls.

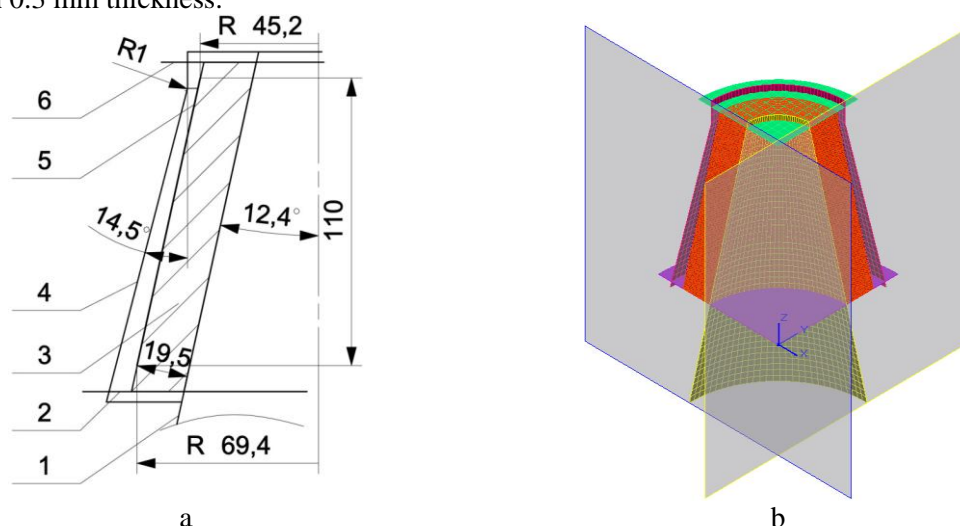
During deformation, at the same expansion of diameter of the blank, the degree of deformation of elements will be different: the greatest – at the elements in the zone of smaller diameter, and the lowest – at the elements in the zone of larger diameter. The equal displacement of the elements in radial direction is observed due to the action of the device with expanding sectors: by moving downwards they drag the elastic medium, which expands in diameter. In order to obtain the part with uniform wall thickness, the conic angle of the blank must be lower than the conic angle of the part with  $tg\alpha \leq f$  condition, where  $f$  - the friction coefficient. Herewith elements of the larger diameter get the larger absolute displacement, which allows bringing closer their degree of deformations to those of elements of the zone of smaller diameter.



### 3. Computer simulation of the process and its results

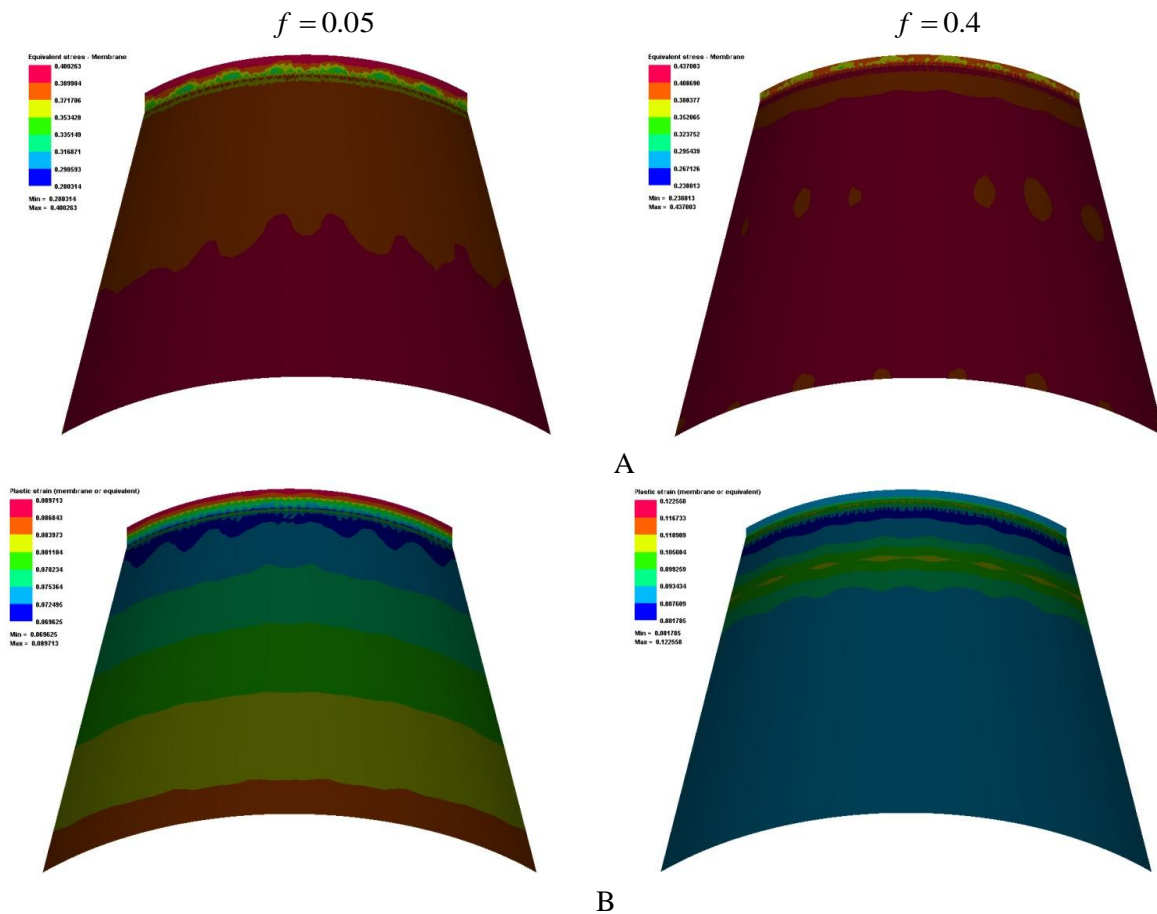
During development of better forming methods, using approximate solution methods such as computer simulation in finite-element program complexes [6,7,8,9] allows to expand the approaches to process analysis. Theoretically found assumptions and limitations can be applied to analyze the data, obtained by simulation in specialized software such as PAM-STAMP (ESI Group), which is universal for optimizing technological modes of sheet stamping.

The computer model of the process (see Figure 1) consists of the elastic medium 3, the finite-element mesh of which was generated using the volumetric 8-nodes elements; the punch 1, the die 4, the lower 2 and the upper 6 pads (to limit the axial movement of the elastic medium), and the blank 5, finite element meshes of which were generated using the shell 4-nodes elements. To lower the number of elements during solution of axisymmetric case,  $\frac{1}{4}$  of the total volume was used, concluded between ZOY and ZOX coordinate planes (the OZ axis was aligned with the symmetry axis), appropriate boundary conditions were also applied (such as movement limitations for the nodes on the planes of the symmetry). The speed of the punch was set to 5.0 m/s, and its movement to complete flanging of the blank to 40 mm. In order to investigate the influence of the friction between the blank and the elastic medium on the distribution of thickness of the finished part, the appropriate friction coefficient was set to 0.05 and 0.4. The corrosive resistant steel 12C18N10T was set as material for the conical blank with 0.3 mm thickness.



**Figure 1.** Physical (a) and finite-element (b) models of the flanging process of the conical shell by the pressure of elastic medium: 1 – the punch; 2 – the lower pad; 3 – the elastic medium; 4 – the die; 5 – the blank; 6 – the upper pad

The obtained pictures of the stress-strain condition (see Figure 2) of the blank during forming allow one to make a conclusion that the largest stress is being created in the area of transition from the conical portion of the part to the cylindrical portion, herewith larger friction coefficient leads to increase of the friction (437 MPa against 408 MPa) and unevenness of strain distribution along the generatrix (Figure 2, b). But the difference in absolute values is not that large, less than 7%, meanwhile elastic medium actively acts on the workpiece, causing tensile stress, and larger friction coefficient causing the need to apply larger force (160 kN against 136 kN). In general the influence of the friction coefficient on the thickness variation is insignificant, since difference in the stress-strain condition is less than 1.5%. Thus, the friction coefficient in the range of 0.05-0.4 in the theoretical solution can be neglected.



**Figure 2.** Stress (a) and strain (b) distribution pictures during flanging

#### 4. Theoretical investigation of the process basing on the simulation results

For making the mathematical model and estimating minimal thickness variation let us use axisymmetric functional [10]. Its solution requires approximation of technologically possible thickness  $S_T$  to the set thickness of the final part  $S_{set}$  under the condition of the minimal inclination to the positive and negative difference between the two thickness functions:

$$\int_l (S_T - S_{set})^2 dl \rightarrow \min, \quad (1)$$

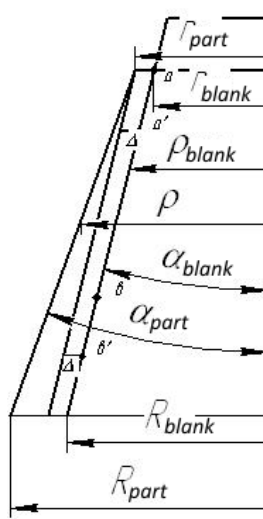
where  $l$  - length of the part generatrix.

Deliberate alteration of the thickness of the workpiece, approximating it to the set one, is possible by altering the technological parameters of the process: the dimensions of the initial blank, the geometry of the tools, the anisotropy of the transversely anisotropic body, boundary conditions and etc. Since the geometry of the part is among the initial parameters, the blank dimensions definition is mandatory for further development of the technological process and calculation of its parameters.

Let us consider that the process consists of two stages:

- When all the elements of the workpiece are expanding on the same radius value  $\Delta$  (see Fig 3) until the elements of the smaller diameter touch the die. The stresses on the edges of the workpiece equal zero. An increase of the stresses in the middle portion is considered negligible, also let us take stresses ratio  $\sigma_p / \sigma_\theta$  as nearing zero in the whole area of deformation. On the surface of the workpiece the friction forces act in the mutually opposite directions: on the inner surface of the workpiece and the punch contact – active forces, on the outer surface of the workpiece an the elastic medium contact – reactive forces.

- When the elements of the smaller diameter is pinched, the deformation only occurs for the elements in the area of the larger diameter. In this case meridional stresses take place, which should be increasing from the the free egde of larger diameter to the elements of the smaller diameter area.



**Figure 3** – The scheme of the process:  $r_{part}$  - smaller radius of the part;  $R_{part}$  - larger radius of the part;  $\rho$  - current radius of the part;  $\rho_{blank}$  - radius of the blank;  $r_{blank}$  - smaller radius of the blank;  $R_{blank}$  - larger radius of the blank;  $\Delta$  - horizontal displacement of the elements of the blank due deformation in the area of the smaller diameter;  $\alpha_{blank}$  - conic angle of the blank;  $\alpha_{part}$  - conic angle of the part

The coupling equation for the both stages can be written as:

$$S_T = S_{blank} \left[ 1 - (1 - \mu) \cdot \frac{\sigma_\rho / \sigma_\theta + 1}{1 - \mu \cdot \sigma_\rho / \sigma_\theta} \left( \frac{\bar{\rho}}{\bar{\rho}_{blank}} - 1 \right) \right], \quad (2)$$

where  $\bar{\rho} = \frac{\rho}{r_{part}}$ ,  $\bar{\rho}_{blank} = \frac{\rho_{blank}}{r_{part}}$  - relative radii of the part and the blank, respectively.

In equation (2) the  $\frac{\bar{\rho}}{\bar{\rho}_{blank}}$  ratio determines the dimensions of the blank needed in order to achieve uniform thickness of the part. Let us present it in the form of linear relationship:

$$\frac{\bar{\rho}}{\bar{\rho}_{blank}} = c + m\bar{\rho} \quad (3)$$

From the two unknown coefficients,  $c$  can be found from the condition that at  $\rho = r_{part}$  (see Figure 3) the following relation takes place:

$$\rho_{blank} = r_{part} - \Delta. \quad (4)$$

And in relative units at  $\bar{\rho} = 1$  it is possible to get:

$$\bar{\rho}_{blank} = 1 - \bar{\Delta}, \quad (5)$$

where  $\bar{\Delta} = \frac{\Delta}{r_{part}}$ . Thus,  $\frac{1}{1 - \bar{\Delta}} = c + m$  is obtained, from which:

$$c = \frac{1}{1 - \bar{\Delta}} - m. \quad (6)$$

By substituting (6) in (3), the following happens:

$$\frac{\bar{\rho}}{\bar{\rho}_{blank}} = \frac{1}{1 - \bar{\Delta}} + m(\bar{\rho} - 1). \quad (7)$$

After finding  $m$  and  $c$ , larger and smaller radii of the blank can be found using (7):

$$\bar{\rho}_{blank} = \frac{\bar{\rho}}{\frac{1}{1-\Delta} + m(\bar{\rho}-1)}. \quad (8)$$

By substituting (2) in (1), it is possible to obtain the minimal thickness variation condition considering ratios  $\bar{S}_{part} = \frac{S_{part}}{S_{blank}}$ ,  $\frac{r_{part}}{r_{part}} = \bar{r}_{part}$ ,  $\frac{R_{part}}{r_{part}} = \bar{R}_{part}$ , from 1 to  $\bar{R}_{part}$ :

$$\int_1^{\bar{R}_{part}} \left\{ \bar{S}_{part} - \left[ 1 - (1-\mu) \cdot \frac{\sigma_\rho / \sigma_\theta + 1}{1 - \mu \cdot \sigma_\rho / \sigma_\theta} \left( \frac{1}{1-\Delta} + m(\bar{\rho}-1) - 1 \right) \right] \right\}^2 d\bar{\rho} \rightarrow \min. \quad (9)$$

The minimization of expression (9) is conducted by varying coefficient  $m$ , which determines the dimensions of the blank:

$$\frac{\partial}{\partial m} = \int_1^{\bar{R}_{part}} \left\{ \bar{S}_{part} - 1 - (1-\mu)b + \frac{(1-\mu)b}{(1-\Delta)} + (1-\mu)b \cdot m(\bar{\rho}-1) \right\} (\bar{\rho}-1) d\bar{\rho} = 0. \quad (10)$$

or  $\left[ \bar{S}_{part} - 1 - b(1-\mu) + \frac{b(1-\mu)}{(1-\Delta)} \right] \frac{(\bar{R}_{part}-1)^2}{2} + \frac{(1-\mu)m}{3} (\bar{R}_{part}-1)^3 = 0$ , which leads to:

$$m = 3 \frac{1 + (1-\mu)b - \bar{S}_{part} - \frac{(1-\mu)b}{(1-\Delta)}}{2(\bar{R}_{part}-1)(1-\mu)b}, \quad (11)$$

where:

$$b = \frac{\sigma_\rho / \sigma_\theta + 1}{1 - \mu \cdot \sigma_\rho / \sigma_\theta}. \quad (12)$$

For the 1-st stage  $b = 1$ , since  $\sigma_\rho / \sigma_\theta = 0$ ; for the 2-nd stage it can be found using the equilibrium equation [11] and the plasticity condition for the transversely isotropic body:

$$\sigma_\theta = k\sigma_s = \sigma_s^*, \quad (13)$$

where  $\sigma_s$  - yield stress;  $k$  - coefficient, which equals  $k = \sqrt{2}\sqrt{1-\mu}$  [12,13];  $\mu$  - coefficient of anisotropy of transversely isotropic body.

$$\rho \frac{d\sigma_\rho}{d\rho} + \sigma_\rho - \sigma_\theta (1 + f \cdot \text{ctg} \alpha_{part}) = 0, \quad (14)$$

where  $\alpha_{part}$  - the inclination angle along the generatrix tangent drawn to the current element with coordinate  $\rho$  and the axis of symmetry.

The solution of (13) and (14) considering conclusions, acquired by simulation, without taking into account the thickness coefficient, takes the following form:

$$\sigma_\rho = k\sigma_s \left( 1 - \frac{\bar{\rho}}{\bar{R}_{part}} \right) \geq 0, \quad (15)$$

where  $\bar{\rho} = \frac{\rho}{r_{part}}$ ;  $\bar{R}_{part} = \frac{R_{part}}{r_{part}}$ .

In order to calculate  $m$ , the ratio between  $\bar{\Delta}$  and  $\bar{S}_{part}$  must be found for  $\bar{\rho} = r_{part}$  or  $\bar{\rho} = 1$ . From

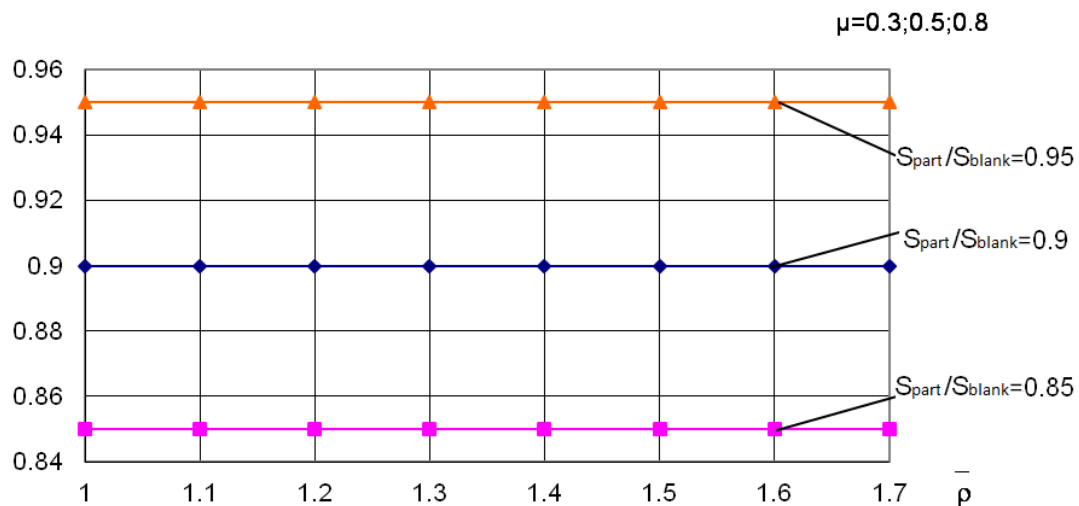
(2), after taking  $\bar{S}_{part} = \bar{S}_T$  and accepting the following ratios:  $r_{part} - r_{blank} = \Delta$  or  $1 - \bar{r}_{blank} = \bar{\Delta}$  or  $\bar{r}_{blank} = 1 - \bar{\Delta}$ , it is possible to get the expression:  $\bar{S}_{part} - 1 = -(1 - \mu) \frac{(1 - \bar{r}_{blank})}{\bar{r}_{blank}} = -(1 - \mu) \frac{\bar{\Delta}}{1 - \bar{\Delta}}$ , and from it the following is obtained:

$$\bar{\Delta} = \frac{1 - \bar{S}_{part}}{2 - \bar{S}_{part} - \mu}. \quad (16)$$

## 5. Conclusion

Using the obtained equations the geometric dimensions of the blank for the considered improved method of manufacturing thin-walled axisymmetric parts with minimal thickness variations can be calculated.

Taking into account the  $S_{part}/S_{blank}$  ratio and different values of coefficient of anisotropy, using the expressions (2,8,12,13,15), the chart of  $S_T/S_{blank}$  can be built.



**Figure 4.** The  $S_T/S_{blank}$  ratio dependency by the  $S_{part}/S_{blank}$  ratio for different anisotropy coefficient values  $\mu = 0.3$ ;  $\mu = 0.5$ ;  $\mu = 0.8$

The obtained dependences allow one to make the conclusion that coefficient of anisotropy has an impact on the ratio between the part and the blank thickness, without altering the shape of the dependency. For the conical part, the obtained thickness is uniform along the generatrix.

## References

- [1] Popov V G and Yaroslavcev N L 2001 *Liquid rocket engines* (Moscow: "MATT" Publishing and typographical center – Tsiolkovsky KTU) p 171
- [2] Khaimovich I N 2014 *Rus. Aeronaut.* **57(2)** 169-174
- [3] Demyanenko E G and Popov I P 2016 *Key Eng. Materials* **684** 253-262
- [4] Nesterenko E 2016 *Key Eng. Materials* **684** 234-241
- [5] Demyanenko E G and Popov I P, RU Patent No. 2532581 (28 December 2012)
- [6] Zvonov S and Shlyapugin A 2016 *Key Eng. Materials* **684** 468-472

- [7] Mikheev V A and Surudin S V 2016 *Key Eng. Materials* **684** 21-28
- [8] Mikheev V A, Smol'nikov S D, Surudin S V, Savin D V 2016 *Rus. Aeronaut* **59(1)** 145-150
- [9] Epifanov A N, Demyanenko E G and Popov I P 2016 *Proc. of the Samara Scien. Center of the Rus. Ac. of Scien.* **18 (1)** 59-65
- [10] Demyanenko E G and Popov I P 2013 *Sheet stamping technology, pt.1, Forming methods based on molding, flanging and drawing processes for the thin-walled axisymmetric parts* (Samara: Samara State Aerospace University) p 112
- [11] Storozhev M V and Popov E A 1971 *Theory of pressure working of metals* (Moscow: Mashinostroenie) p 424
- [12] Grechnikov F V 1998 *Deformation of anisotropic materials* (Moscow: Mashinostroenie) p 448
- [13] Dmitriev A M and Vorontsov A L 2004 Approximation of hardening curves of metals *KSP OMD* **1** 23–26