ANALYSIS OF FORCE INTERACTION BETWEEN PUNCHEON'S WORKING TOOL AND METAL FITTINGS AT THE STAGE OF DEFORMATION OF PUNCHEON'S LAST CONIC PART

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***Abstract:** The article deals with force interaction between puncheon working tool and metal fittings at the stage of deformation of puncheon's last conic part. Eyelet's deformation stages have been studied, components of eyelet's stress-strain state have been analyzed, and eyelet's deformation effort with puncheon's conic surfaces has been calculated. A series of experiments to prove validity of the obtained mathematical model has been conducted. The obtained dependencies can be used to achieve approximate calculation of maximum efforts of metal eyelet's deformation with puncheon's conic surfaces.*

***Keywords:** eyelet, fitting, deformation effort, puncheon.*

1 INTRODUCTION

Calculation of deformation force parameters is rather useful when tackling a number of practical tasks. It allows to predict tool's solidity, equipment's capacity and wear resistance. Information about force parameters enables to define the final effort of eyelet's pressing to the base, which totally defines quality of the device. Analysis of previous research showed that calculation of stress-strain state of such constructions has been studied partially [1, 2]. Tackling of the task of metal fittings deformation with puncheon's shape-generating surfaces has not been previously studied. This is why it is rather urgent to define eyelet's deformation effort in the function of puncheon's motion. Tackling of this task is the content of further research. Obtaining of analytical correlations of this dependency will allow to study the influence of puncheon's geometrics and, as a result, to control deformation force mode.

2 THEORETICAL PART

2.1 Stages of eyelet's deformation

Analysis of geometrical forma of puncheon's shape-generating surface will allow to define three stages of deformation with various character of interaction between puncheon and eyelet, each of which requires respective calculation algorithm. Schematically, these stages are shown in Figure 1 [1, 3].

The first stage is deformation with puncheon's curvilinear surface, which is arch-shaped having the radius of r = 0.0022 m (Figure 1a). Eyelet deformation is done with a part of this surface from the section of initial contact with the eyelet, which has the radius of r_3 to upper point of the surface. Given the fact that the length of the surface, on which deformation takes place, is small, the surface can be construed as a cone.

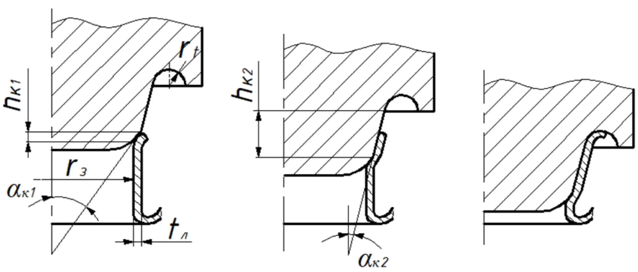


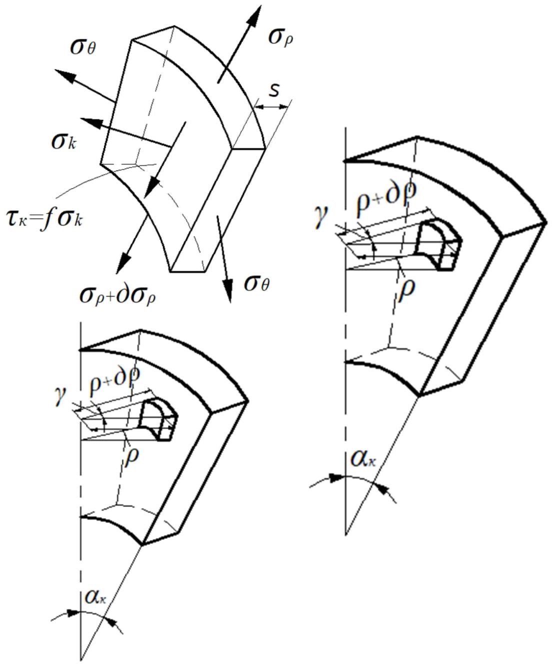
Figure 1 Diagram of characteristic stages of eyelet's deformation: a) first; b) second; c) third; r_3 - eyelet's internal radius; $t_л$ - eyelet's thickness; r_t - radius of puncheon's toroidal part

The height of this part of the puncheon is marked as $h_{к1}$, while angle of inclination towards the axis is $\alpha_{к1}$. The surface at the second stage of deformation is also conic having the length of $h_{к2}$ and angle of inclination towards the axis $\alpha_{к2}$ (Figure 1b). The third stage if eyelet deformation with toroidal part of puncheon's surface. The radius of this surface is marked as r_t (Figure 1c). The surface is continuation of the conic part; however, angles on inclination of adjacent surfaces differ.

This article deals with force interaction between working tool and metal fitting at the first two stages.

2.2 Analysis of components of eyelet's stress-strain state

Radius of internal surface of this element is marked as ρ, while external one as $\rho+\partial\rho$ (Figure 2b), on horizontal planes of which normal meridional tensions are in effect σ_ρ, $\sigma_\rho+\partial\sigma_\rho$, which are distributed over its upper and lower verges, are changeable in height, and are tangential or circumferential σ_θ, which do not change along the circle. The element receives meridional ξ_ρ and circumferential ξ_θ deformations. Thickness of the element that has been cut out is marked as $t_п$. We shall consider it as small. This means that movable and normal in regards to surface tension is unavailable, while areas, on which they are in effect σ_ρ, σ_θ, are primary.



a) b)

Figure 2 Components of stress-strain state: a) cut out element; b) elements geometrical dimensions; γ - angle between meridional planes turned to each other

For this case (small thickness of the element), contact load σ_k, which is in effect along the internal surface, is considered as pressed to element's middle plane. Tangent friction tensions τ_k will be in effect there, volume of which shall be defined by Coulomb's law:

$$\tau_k = f \cdot \sigma_k \tag{1}$$

in which f - friction coefficient.

Conic surface, from which the element has been cut out, is inclined towards the axis at an angle that is marked as $\alpha_к$. Based on these assumptions we will reveal distribution of tensions along eyelet's height depending on puncheon's motion, which will allow to solve the given task [1].

2.3 Calculation of eyelet's deformation effort with puncheon's conic surfaces

Solution will be obtained on the basis of differential equilibrium equation given in the paper [4]. It is as follows:

$$\rho \cdot \frac{d\sigma_\rho}{d\rho} + \sigma_\rho - \sigma_\theta \cdot (1 + f \cdot ctg\alpha_K) = 0 \tag{2}$$

Solution of this equitation along with plasticity condition:

$$\sigma_\theta - \sigma_\rho = \sigma_S \tag{3}$$

in which σ_s - fluctuation tension at a single-axis trained state, gives the following correlation

$$\rho \cdot \frac{d\sigma_\rho}{d\rho} - \sigma_\rho \cdot f \cdot ctg\alpha_K - \sigma_S \cdot (1 + f \cdot ctg\alpha_K) = 0 \tag{4}$$

After integration the equation is brought to the following:

$$\frac{\ln\left[\sigma_\rho \cdot f \cdot ctg\alpha_K + \sigma_S \cdot \left(1 + f \cdot ctg\alpha_K\right)\right]}{f \cdot ctg\alpha_K} = \ln\rho + c \tag{5}$$

Integration constant c can be defined if meridional tensions σ_ρ equal 0 on eyelet's upper edge, the radius of which is marked as R_k (Figure 3) [1]. Given this, integration constant will equal:

$$c = \frac{\ln\left[\sigma_S \cdot \left(1 + f \cdot ctg\alpha_K\right)\right]}{f \cdot ctg\alpha_K} - \ln R_k \tag{6}$$

After substitution of the obtained value into the previous equation, we receive the following:

$$\sigma_\rho = -\sigma_S \cdot \left(1 + \frac{tg\alpha_K}{f}\right) \cdot \left[1 - \left(\frac{\rho}{R_k}\right)^{\frac{f}{tg\alpha_K}}\right] \tag{7}$$

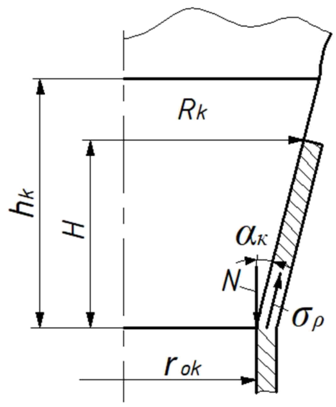


Figure 3 Generalized diagram of cylindrical workpiece deformation with puncheon's conic surface

Now, we will find value of radius R_k as puncheon's H motion function:

$$R_k = r_{0k} + H \cdot tg\alpha_K \tag{8}$$

in which r_{0k} is radius of conic surface in lower section.

Given this, (7) is as follows:

$$\sigma_\rho = -\sigma_S \cdot \left(1 + \frac{tg\alpha_K}{f}\right) \cdot \left[1 - \left(\frac{\rho}{r_{0k} + H \cdot tg\alpha_K}\right)^{\frac{f}{tg\alpha_K}}\right] \qquad (9)$$

Resultant of these tensions N_ρ will equal:

$$N_\rho = 6{,}28\sigma_\rho \cdot \rho \cdot t_Л \qquad (10)$$

Analyzing equation (9), it can be seen that the value of meridional tensions increases with decreasing radius ρ (Figure 3). In this case, they gain biggest values in cone's lower part at $\rho = r_{0k}$:

$$\sigma_{\rho_{k0}} = -\sigma_S \cdot \left(1 + \frac{tg\alpha_K}{f}\right) \cdot \left[1 - \left(\frac{r_{0k}}{r_{0k} + H \cdot tg\alpha_K}\right)^{\frac{f}{tg\alpha_K}}\right] \qquad (11)$$

Respective value of resultant of these tensions equals:

$$N_{k\rho} = -\sigma_S \cdot \left(1 + \frac{tg\alpha_K}{f}\right) \cdot \left[1 - \left(\frac{r_{0k}}{r_{0k} + H \cdot tg\alpha_K}\right)^{\frac{f}{tg\alpha}}\right] \cdot 6{,}28 \cdot r_{0k} \cdot t_Л \qquad (12)$$

Given the fact that the value of this resultant is a projection of cone's N_k deformation projection we see that deformation effort equals:

$$N_k = \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_K}{f}\right) \cdot \left[1 - \left(\frac{r_{0k}}{r_{0k} + H \cdot tg\alpha_K}\right)^{\frac{f}{tg\alpha_K}}\right] \cdot 6{,}28 \cdot r_{0k} \cdot t_Л}{\cos\alpha_K} \qquad (13)$$

The biggest deformation on the cone is gained at contact with the puncheon along the entire conic surface, i.e. at $H = h_k$ [1]:

$$N_{kH} = \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_K}{f}\right) \cdot \left[1 - \left(\frac{r_{0k}}{r_{0k} + h_k \cdot tg\alpha_K}\right)^{\frac{f}{tg\alpha_K}}\right] \cdot 6{,}28 \cdot r_{0k} \cdot t_Л}{\cos\alpha_K} \qquad (14)$$

In this case, puncheon's eyelet deformation has two conic surfaces with different angles of inclination and radiuses of lower butt (Figure 4).

These values will be marked the following way: angles of inclination of lower and upper cones as α_{k1}, α_{k2}, smallest radiuses as r_{0k1} and r_{0k2}. We will calculate these values in a specific case. For lower cone $r_{0k1} = r_3$, while the value of angle of inclination in radians will be defined according to puncheon's drawings α_{k1}*=arctg(0.0008/*h_{k1}*)=0.8 rad*. By analogy, for the second cone r_{0k2}*=0.003+0.0022=0.0052 m*, while angle α_{k2}*=26°=0.47 rad*.

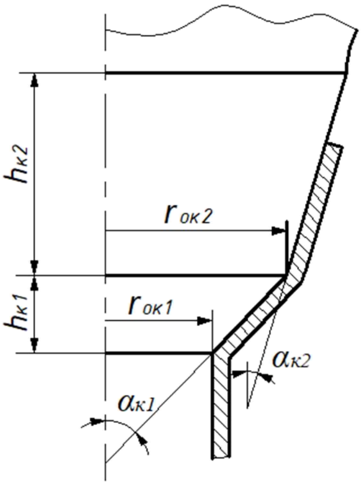


Figure 4 Diagram of eyelet deformation with puncheon's conic surfaces

Given the revealed parameters of correlation, (13, 14) for the first and second cone will be as follows.

For the first cone:

$$N_{k1} = \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_{K1}}{f}\right) \cdot \left[1 - \left(\frac{r_З}{r_З + H \cdot tg\alpha_{K1}}\right)^{\frac{f}{tg\alpha_{K1}}}\right] \cdot 6{,}28 \cdot r_З \cdot t_Л}{\cos\alpha_{K1}} \qquad (15)$$

while its biggest value at $H = h_{k1}$

$$N_{Hk1} = \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_{K1}}{f}\right) \cdot \left[1 - \left(\frac{r_З}{r_З + h_{k1} \cdot tg\alpha_{K1}}\right)^{\frac{f}{tg\alpha_{K1}}}\right] \cdot 6{,}28 \cdot r_З \cdot t_Л}{\cos\alpha_{K1}} \qquad (16)$$

For the second:

$$N_{k2} = \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_{K2}}{f}\right) \cdot \left[1 - \left(\frac{r_{0k2}}{r_{0k2} + (H - h_{k1}) \cdot tg\alpha_{K2}}\right)^{\frac{f}{tg\alpha_{K2}}}\right] \cdot 6{,}28 \cdot r_{0k2} \cdot t_Л}{\cos\alpha_{K2}} + \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_{K1}}{f}\right) \cdot \left[1 - \left(\frac{r_З}{r_З + h_{k1} \cdot tg\alpha_{K1}}\right)^{\frac{f}{tg\alpha_{K1}}}\right] \cdot 6{,}28 \cdot r_З \cdot t_Л}{\cos\alpha_{K1}} \qquad (17)$$

The biggest effort on the second conic area N_{Hk2} is gained at $H = h_{k2} + h_{k2}$, the value of which equals [1]:

$$N_{Hk2} = \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_{K2}}{f}\right) \cdot \left[1 - \left(\frac{r_{0k2}}{r_{0k2} + h_{k2} \cdot tg\alpha_{K2}}\right)^{\frac{f}{tg\alpha_{K2}}}\right] \cdot 6{,}28 r_{0k2} \cdot t_Л}{\cos\alpha_{K2}} + \frac{-\sigma_S \cdot \left(1 + \frac{tg\alpha_{K1}}{f}\right) \cdot \left[1 - \left(\frac{r_{0k1}}{r_З + h_{k1} \cdot tg\alpha_{K1}}\right)^{\frac{f}{tg\alpha_{K1}}}\right] \cdot 6{,}28 r_З \cdot t_Л}{\cos\alpha_{K1}} \qquad (18)$$

It should be noted that the obtained correlations can be applied in certain limits of puncheon's motion. Correlations (15, 16) within $0 \le H \le h_{k1}$, while (17, 18) - at $h_{k1} \le H \le h_{k1} + h_{k2}$.

3 RESULTS AND DISCUSSION

To prove validity of the obtained mathematical model (18) of eyelet's *N* deformation total effort dependency on puncheon's *H* motion, the process of eyelet's deformation with puncheon's conic surfaces has been experimentally studied. With the help of measuring system, diagrams of eyelet's N deformation technological effort dependency and puncheon's *N* motion have been taken.

Comparison of values deformation effort obtained in the same way as experimental results is given in Figure 5.

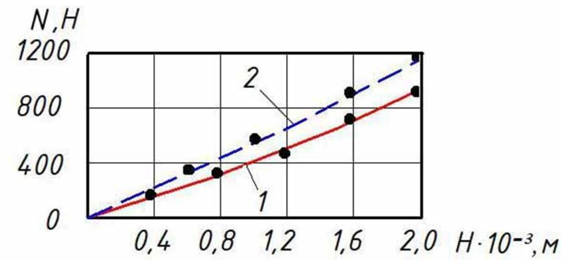


Figure 5 Eyelet's deformation total effort on both conic parts dependency on puncheon's motion: 1) calculation values; 2) experimental

4 CONCLUSION

Having analyzed the obtained results we may conclude that the shape of working surfaces and puncheon's geometrics have significant influence on technological effort *N*. The biggest influence have: conicity angels α_{k1}, α_{k2}, radiuses of conic parts r_{0k1} and r_{0k2} and height of conic part *H*.

The error between calculation and experimental values fastening *N* effort is around 20%, which is permissible. Thus, formula (18) can be used for approximate calculation of maximum effort of metal eyelets deformation with puncheon's *N* conic surfaces [5].

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