Pressing tubes with conical-stepped needles computer simulating

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Abstract. There are the results of computer simulating using DEFORM-2D specialized software and experimental researches during the pressing of aluminium alloys tubes with conical-stepped needles. On the basis of the experiment mathematical planning and dividing coordinate grid the influence of the taper angle and needle position to the pressing stress and the intensity of deformation relative to the die parallel land was established. The optimal parameters determining methods of conical-stepped needles geometry were proposed.

1. Introduction
Pressed tubes are widely used for making various machine parts as directly after the pressing (pipelines, parts of drilling rigs columns, hollow shafts, elements of power machines), as well as economical blanks for making hollow details of various configuration by stamping or mechanical processing [1].

Two types of needles are used during tubes pressing: cylindrical and conical-stepped needles. The use of the latter is constantly expanding, as it allows to produce tubes with different inner diameter form the ingot with special internal diameter, which is impossible during the pressing with a cylindrical needle. In addition, a conical-stepped needle is almost indispensable during the pressing of tubes with a large outer and small inner diameter, because in this case, the use of cylindrical needles inevitably leads to their breakage, especially under conditions of pressing at high temperatures [1-7]. Despite the high efficiency of tubes pressing with conical-stepped needle, the information about the optimal needle geometry in literature [1-6] is absent.

2. Methodology
The technological tool design was based on the experience and intuition of experts. Figure 1 shows the conical-stepped needle geometry containing the body of the needle 1 and the cylindrical part of a smaller diameter 2, called gauge, connected by a conical transition 3.

Sections 2 and 3 constitute forming part of the needle. During the tubes pressing with the stationary conical-stepped needle, it should be strictly regulated in the die channel 4, in order to fix the parallel land of the needle and of the die precisely relative to each other. The valid value of the needle position \( h = h_{\text{min}} + k \) is found from the inequality \( h/(R_{\text{out}} - R_{\text{in}}) \geq 1 \) where \( R_{\text{out}} \) and \( R_{\text{in}} \) are the outer and inner radii of the ready-made tube, \( h_{\text{min}} \) – minimum value, \( k \) – average value equal to the positive tolerance for the installation of the needle, \( k \approx 3\text{mm} \ (0.12'') \). \( h_{\text{min}} \) is the shortest distance from the upper edge of the die parallel land to conical transition and a gauge section of the needle.
Figure 2 contains AB=AC \( h_{min} = CE \). The height of the circle segment CE is calculated by the well-known formula. Then:

\[
h_{min} = 2(R_{out} - R_{in}) \sin \frac{\alpha}{2}.
\]

Thus, \( h_{min} \) depends on the wall thickness of the ready-maid tube and the angle of the needle cone \( \alpha \). When \( \alpha \) decreases, \( h_{min} \) diminishes.

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**Figure 1.** Basic parameters of the conical-stepped needle geometry.

**Figure 2.** Calculation of \( h_{min} \).

The gauge section length in the pic. 1 forming the tube inner surface

\[
L = h + l_{pl} + \Delta,
\]

where \( l_{pl} \) is the height of the die parallel land;

\( \Delta \) - value of the needle front end lip outside the die gauge section, ensuring the tube straightness at the outlet of the die channel; \( \Delta = (0,1 \div 0,5)(R_{out} - R_{in}) \).

For calculations of the conical-stepped needle geometry optimal parameters there were used methods of the experiment mathematical planning \[8\] which allow the joint variation of two parameters: \( \tilde{x}_1 \) - the slope angle of the conical needle part \( \alpha \) and \( \tilde{x}_2 \) - the conical part position relative to the gauge parallel land of the die \( h \). Parameters variation intervals are: \( \tilde{x}_1 = 30^\circ - 60^\circ \), \( \tilde{x}_2 = 10 - 30 \).
mm (0.39'' – 1.18''). The criteria for the assessment of the main needle parameters are: $P$ – the pressing strengthening at the beginning of the process primary stage, $\varepsilon_i$ – deformation intensity reaching extreme values on the gauge die part.

3. Experimental work
The plan of the complete factorial experiment $2^2$ and its results are presented in the table 1.

| Experiment № | Parameters |
|---------------|------------|
|               | $x_1$ (°)  | $h(x_2)$ mm (°) | $x_2$ | $P$ MN | $\varepsilon_i$ |
| 1             | 30         | 10 (0.39)        | -1    | 11.2   | 4.84         |
| 2             | 60         | 10 (0.39)        | -1    | 11.9   | 6.16         |
| 3             | 30         | 30 (1.18)        | +1    | 10.8   | 4.63         |
| 4             | 60         | 30 (1.18)        | +1    | 11.3   | 5.07         |

The numerical experiments were conducted on the computer model of the pressing tube direct method $\varnothing 60 \times 20$ mm (2.36''×0.79'') made of aluminum alloy AD31 in the conical die with the angle $\beta = 75^\circ$ from the container with inner sleeve diameter 150mm (5.91'') and stationary conical-stepped needle with the parameters given in table 1. The heating temperature of the container, press-washer and the die 350°C, of the ingot with the dimensions $\varnothing 145 \times 63 \times 300$ mm (11.81'') is 400°C. The pressing is conducted with the grease of the needle surface. Pressing velocity $16 \text{ mm/sec}$ (0.63''/sec).

For the process simulating the software DEFORM-2D was chosen designed for the analysis of the metal processing by pressure using the finite elements method [9]. The regression equation were derived as a result of the computer simulating

$$P = 11.3 + 0.30x_1 - 0.25x_2,$$
$$\varepsilon_i = 5.17 + 0.44x_1 - 0.32x_2,$$

where

$$x_1 = \frac{\bar{x}_1 - 45}{15}, \quad x_2 = \frac{\bar{x}_2 - 20}{10}.$$

Equations analysis proves that, if the needle cone angle increases relative to the pressing axis and the approaching of the needle cone to the die, the pressing stress and, consequently, deformation intensity increase. The most favorable conditions for the tubes pressing were obtained in the third experiment.

In order to check the accuracy of the computer model, the experiment on the pressing of the tube $\varnothing 60 \times 40$ MM (2.36''×1.57'') made of AD31 alloy on a horizontal hydraulic press 15 MN. For obtaining the picture of the metal flow there was used an ingot in the form of two identical hollow semi-cylinders. In the semi-cylinder meridian section the reference grid with the step of $3 \pm 0.2$ mm (0.12'' ± 0.0079'') is traced. Figure 3a shows the deformed reference grid in a real process, Figure 3b shows this one on the computer model. In Figure 3 it is evident that the simulated process with required accuracy predicts the process of pressing tubes with conical-stepped needle.

As the computer simulation has shown, the needle setting violation relative to the die leads to the tube wall thinning, Figure 4. In this case, you can get a tube with a variable length cross-section by moving the needle relative to the die.

Analysis of the deformed condition in the distorted reference grid shows the metal flow complicated character when tube pressing with a conical-stepped needle [6]. In order to decrease uneven deformations there should be determined the needle optimal position relative to the die. A taper angle in the zone of a needle form sudden change should ensure minimum resistance to the metal outflow. For the purpose of reducing the resistance to the metal outflow and reduction of uneven
deformation the transition zone from the cylinder to the cone needs to have a curved surface coinciding with the fluid tube.

![Figure 3](image)

**Figure 3.** Deformed reference grid during the pressing of the tube ∅ 60-40мм (2.36''×1.57'').

a) physical experiment; b) numerical experiment in DEFORM-2D.

![Figure 4](image)

**Figure 4.** Needle setting violation relative to the die

Due to the difficult production of such needles there the simplified needle design is proposed, the taper angle of which is determined form the condition of the metal radial flow in the zone of deformation (**Figure 1**):

\[
\alpha = \arctg \frac{R_{inner}}{h+R_{c}ctg\beta}
\]

where \(\beta\) – taper angle of the deformation zone border.

As it follows from the physical experiment on fig. 5, the needle geometry with the design values of the needle position relative to the die \(h\) and the taper angle \(\alpha\), reduces uneven metal outflow by a smooth transition in the coupling zone of a cone ledge and a calibrating section.
Figure 5. Deformed reference grid during the tube pressing made of AD31 alloy with dimensions Ø 60-20 мм (2.36”×0.79”) with the needle geometry optimal calculation parameters.

4. Conclusion

The proposed tool for pressing tubes containing the matrix with the gauge belt and a stationary cylindrical needle of variable section having an annular recess and the rim, characterized in that on the front end of a cylindrical needle in the plane of the output pipe of the gauge belt is made successively in the course of pressing the annular recess with a diameter of 0.9 D and a collar with a spherical surface of diameter D equal to the diameter of the inner surface of the pipe.

The influence of the taper angle and the needle gauge section position relative to the die on energy-power and deformation parameters of tubes pressing is shown.

1. The calculation methods of conical-stepped needles optimal geometry parameters during tubes pressing were proposed.

2. The usage of needles with optimal geometry reduces the process power intensity and uneven metal outflow.

References

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