Computer modelling of the conical springs stamping with using of elastic medium

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Abstract. The technology improvement of conical springs manufacturing is considered in the work. It is proposed to change of the standard die scheme for the production of conical springs. As an improvement of the stamp, an elastic medium is used in the forming space of the stamping tool. Such a change in the die tool lead to improvement of the conical springs operational features and a reduction in their costs. The technique for estimating of a conical spring operational properties has been proposed. The technique was developed on the basis of mathematical modeling of the compression process in the operation of a spring. It was revealed that the existing technology of making conical springs promotes the formation of sharp edges. Improving of the spring section shape and form it with a curvilinear generatrix is proposed to eliminate the additional manufacturing stage of their dulling and for the increase in the endurance of the conical spring. To study the stamping process with using an elastic medium, a mathematical simulation of the conical springs stamping with an elastic medium was conducted. The dependences of the stamping force on the punch displacement are obtained. The experimental design of the tool for the conical springs stamping with the use of an elastic medium is designed. Experimental stamping of blanks with optimal parameters was carried out.

1. Introduction
A large number of works deals with the process of sheet punching of conical springs. The usual methods of sheet punching, widely used in large-scale and mass production, can be insufficient and irrational in small-scale and quickly-retooled production. It takes a long time to produce structurally complex and expensive stamps. In some cases, the costs incurred do not pay off. The need for rapid development of new products requires the use in the specified conditions of new technological processes: cheap and universal or partially universal equipment. Improving the technology of manufacturing conical springs, eliminating of the mechanical edge treatment, will reduce production costs and improve the performance characteristics of the spring.

Reduction of stresses is possible by optimizing the design parameters of the spring, based on the results of the strain-stress state analysis, during compression. Conical spring folding will increase the area of its contact surface. To produce an improved spring with optimal design parameters, it is necessary to change the design of the die tool. Most systems based on FEM use the methods of calculating the stress-strain state on the basis of variational methods created by the works of many scientists, such as J. L. Bassani [1], G. San-Vicente and I. Aguinaga [2], J. Wang and J. Sun [3], R. Hill [4], D.Banabic [5], F. Barlat [6-10], et al [11-21]. However, the use of FEM codes for complex shape parts requires considerable machine resources. One possible solution is the preliminary study in the 2D model, and then on the problem areas more accurate 3D modeling [24-25].
Thus, the manufacture of an improved spring by conventional stamping requires a die design changing. Therefore, to cancel the edge folding stage and to reduce the manufacturing costs, it is proposed to press the spring using an elastic medium.

Estimation technique of disk spring operational properties is developed by mathematical modeling of the compression process during the operation of a spring [30-32]. A technique for optimizing the design parameters of a conical spring is developed, which ensures a minimum stress value when operated in the edge of the spring hole.

2. Materials and methods
A new design of a die is proposed for the production of a conical spring preform using an elastic medium (Figure 1). The punch 1 is made with a steplike end face corresponding to the shape of the produced conical spring taking into account its springing during stamping [28, 29].

![Figure 1. The longitudinal section of the die, where 1 is the punch, 2 – container, 3 – blank, 4 – elastomer:](image)

- a) Scheme of the longitudinal section of the stamp,
- b) Longitudinal section of the 3D model of the stamp.

The punch consists of two elements. The first element: the central slugger punch is destined to form a spring hole and is equal to hole diameter. The second element: a punch with a diameter equal to the spring diameter, is designed to form a conical surface of the spring and its cutting along the contour. The central slugger punch protrudes by a relative value of \( h \) over the middle punch (Figure 1a). In the proposed die design a container 2 filled with an elastic medium is matrix (Figure 1b). When the punch 1, the blank 3 and the elastic medium 4 are interacting, at first the cone surface is formed and then the hole is pierced, and with further movement of the punch 1, it cutting along the outside diameter of the conical spring [32].

The finite element method (FEM) is a typical deformation method focusing on physical accuracy. This method uses continuum mechanics to govern the elastic behaviours of soft tissues. To confirm the
effectiveness of the proposed design of the stamping tool, a computer experiment was conducted. Computer modeling was carried out in the CAE system "Deform 3D".

Modelling was carried out with the following assumptions: friction on the entire contact surface of the blank with the tool obeys the Coulomb dry friction law with a constant friction coefficient; we consider the deformation process as an isothermal process; mechanical characteristics of materials is independent of temperature. Conditions for modeling the technological process of stamping the elastic medium: material of the billet - steel 65G; elastomer material (elastomer material characteristics corresponded to rubber); the friction coefficients (since dry friction was considered) of the rubber/steel was set at 0.4, and the steel/ steel was set at 0.3; constructive parameters of the die tool (STL-model of the stamp); the punch speed was equal to 0.2 mm.

For clarity, the stamping process was divided into four characteristic stages. The first stage was moving the punch before punching holes. At this stage it is necessary to choose gaps and cavities filled with air. The second stage was punching the hole, preliminary forming the taper of the spring. The third stage was the displacement of the punch before cutting down the outer contour, forming the taper of the spring. The fourth was cutting along the outer contour.

The first stage shows the distribution of stresses in the blank at the beginning of the stamping process (Figure 2a). Analysis of the Figure shows that at this stage of stamping the maximum stresses are uniformly distributed in the center of the blank and equal to 686 MPa. At this stage, the flange of the spring opening flanges. At the first stage of modeling the process of stamping the Belleville spring with an elastic medium at different ratios of the height of the punch \( h \) and the thickness of the blank \( S \), the formation of defects was not revealed.

![Image](image1.png)

**Figure 2.** Stress distribution in the blank; a) first stage; b) second stage.

The source of the crack appearance along the hole of the conical spring edge was the low value of the plastic properties of the material and the incorrect ratio of the punch height \( h \) and the thickness of the blank \( S \) (Figure. 2a). The maximum stresses (663 MPa) were observed only at the inner edge of the blank, and on the remaining part of the stress blank are insignificant (3.7 MPa). It can be seen from Figure. 2b that, after punching of the blank hole, a rounding of the edge was formed, that is, the flanging process occurred. As a result, a conical spring is formed with a curvilinear generatrix. Further movement of the punch after cutting the hole (third stage) evenly distributes stresses on the entire billet approximately was equal to 350 MPa. At the third stage of modeling the process of stamping the blank of the conical spring with an elastic medium, there were no defects in the various design parameters of the punch. Figure 3 shows the distribution of stresses in the blank in the fourth stage of the stamping process.
In the area of the spring hole cutting, the stress reached their maximum value of 679 MPa. At this stage, can be seen drawing of the conical spring (Figure 3). At the fourth stage of computer simulation of the stamping process with various design parameters of the punch of defects, cracks or burrs, it was not revealed on the blank.

3. Results and discussion

The dependences of the stamping force on the displacement of the punch for the blank thickness $S = \text{const}$ and the varying values of $h$ are obtained (Figure 4, 5, 6). It is determined that the change in the height of the protuberance of the punch $h$ does not significantly influence the energy-force parameters of the process of stamping the disc blank preforms, one-pots on the quality of the spring being formed, which was determined by the absence of cracks and delaminations in accordance with State standard 3057-90.

It was noted that when the ratio of the height of the protruding punch protrusion over the penetration and $S$- blank thickness $h / S \neq 2$ during stamping, the blanks’ metal underwent considerable deformations and as a result, cracks were formed along the edge of the hole, but it did not occur for $h / S \approx 2$. Therefore, the ratio $h \approx 2S$ is rational from the point of view of the spring quality.

Figure 3. Stress distribution in the spring blank at the fourth stage.

Figure 4. Punching force dependence on the displacement of the punch $\Delta L$ for steel 65G: 1) $h=0.2 \text{ mm}$, 2) $h=1 \text{ mm}$, 3) $h=2 \text{ mm}$, 4) $h=3 \text{ mm}$. 
4. Conclusions
To confirm the effectiveness of the proposed design of the working tool for stamping, a simulation of the technological process of cold stamping of blanks of disk springs with dies with an elastic medium using the CAE system "Deform" was carried out. Simulation of the stamping process has shown the effectiveness of the application of the proposed die design (Figure 1) for the manufacture of disc springs. By the results of the experiment it is shown that the proposed die design forms a poppet spring with a flange along the edge of the hole. In the operation of designed new spring, the stress in the edge of the hole is less than that of a standard spring with a rectilinear generatrix, by redistributing the stresses and increasing the area of the contact surface.
As a result of modeling, a rational ratio of the height of the punch protrusion and the thickness of the blank when stamping the conical spring with an elastic medium has determined, it is equal to 2 ± 0.1. This ratio makes it possible to forming of the disk springs without defects. It has determined that the influence of the absolute values of the height of the protruding punch protrusion over the punched punch and the thickness of the blank on the punching force is insignificant.
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