The stress-strain state simulation of the aircraft fuselage stretch forming in the ANSYS

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Abstract. The work is devoted to the study of the stress-strain state of a thin-walled blank in the stretch forming process. The reasons for the occurrence of defects in the process of shaping, in particular ruptures, were investigated in this work. The task of the research was to assess the behavior of the blank in the process of loading, identify areas of unstable forming, zones of non-passing into the plasticity stage, as well as areas in which the strains reach the limit value. The analysis of the current state of the issue of scientific elaboration of the problem of defect-free coating is carried out. A finite element model of the stitching process is constructed, including models of the rigid surface of the punch and the sheet being molded. The loads were simulated using displacements in the longitudinal direction and rotations in the transverse plane of the workpiece sheet. As part of the study, the reasons for the breakdown of the stocking process in the process of stitching in the places where the sheet was clamped with sponges were determined.

1. Introduction
Shell structures made of sheet materials are used in aircraft as skins. The skins have a double or single curvature and are manufactured by stretch forming methods on the curtain presses. The breaks in the blank sheet in the clamping area of the jaws and the corrugation of the blank sheet in the longitudinal direction are one of the most common problems during stretch forming. Modern problems of modeling of stitching processes are reflected in the works [1-3,5,7]. The formatter will need to create these components, incorporating the applicable criteria that follow.

2. Relevance
The relevance of the study is due to the use in aircraft construction of thin-walled parts of complex shape, especially with combined curvature. The use of methods of cold stamping for forming a workpiece allows you to maintain the integrity of the entire product while minimizing the number of joints in the case of connecting different parts of the part, obtained separately. Methods and features of the calculation of the formation processes of are presented in the writings [4,6].

The use of the stamping modeling tool by the authors is discussed in the paper [3]. The stretch forming is the main technological operation for the production of shell-type parts with combined curvature. The edges of the sheet are rigidly clamped into the grips of the stretching device and move relative to the tool with the specified speeds when fitting. This method of forming is widely used in the manufacture of thin-walled aircraft elements. Stretch forming is of two types: longitudinal and transverse [1]. These questions investigated in the works [8-10].
Irregularity of plastic deformations, elasticity of the workpiece in the zones of minimal plastic deformation, ruptures in the zones of greatest tension, thickness variation of the blank are the main problems of the blank stretch forming. The problem of distortion of the cross section in the process of loading the workpiece often occurs in the operations of forming shaped blanks by the method of coating. An algorithm that allows modeling the shaping of shaped blanks by bending with stretching and predicting distortion of the billet sections depending on the loading program and the conditions of contact of the billet with the clamping punch, was proposed in [1].

The technique of designing punches for coating processes in order to reduce friction was proposed in [2]. The development makes it possible to increase the uniformity of deformations during the shaping of perforated linings, to eliminate the probability of their rupture, to reduce the number of transitions and to reduce the laboriousness of making linings 1.5 - 2 times.

3. Formulation of the problem

It is necessary to understand the picture of the stress-strain state of the workpiece during the stitching process in order to take measures to eliminate these defects. In this regard, the analysis of stresses and strains of the sheet blank at various sheet elongations was required in the work. The clamping of the sheet by the press jaws was not modeled in the task, thereby excluding from consideration the possible contact stresses due to the clamping, since the compressive stresses across the sheet thickness do not have a significant effect on the stress-strain state of the blank. The process of longitudinal stretch forming was considered in this study. The task of the study was to assess the stress-strain state of the workpiece, the kinematics of its shaping, determine the zones of minimal plastic deformation, assess the transition of the workpiece to the stage of plasticity based on the constructed model in works [14].

4. Theoretical part

The SSJ100 aircraft fuselage, which has a cylindrical surface and a pronounced section of double curvature (fig.1) was examined for the research. Initially, the blank is a sheet of rectangular shape. The sections AD and BC of the sheet are fixed with clips. Then the straight AD and BC sections take the form of an arc in the process of shaping. In this case, the points of the curves AD and BC remain in the same plane during the stitching process. Planes can rotate and move in all directions. This is due to the clamping of the edges of the workpiece jaws, which, distorting, form an arc of the sheet that determines the shape of the blank. Zones with the expected maximum stress gradient: 1, 2, 3 are shown in fig.1 with a dotted line.

The stretch forming process includes the following steps: the clamping of the blank sheet with sponges occurs first, after which the sponges are rotated to set the required curvature of the blank. The central sponge remains stationary. The formation of the top occurs as a result of the contact of the workpiece and the punch. The tensile force in the longitudinal direction is pre-applied to the workpiece in order to bring the state of the workpiece beyond the yield point. After that, the blank is wrapped around the punch. The final step is calibration.

![Figure 1. Sheet blank regions.](image-url)
5. Practical significance

The modeling of the stitching process consisted in the plastic deformation of the workpiece by stretching in the longitudinal direction, the formation of the tip of the contact of the workpiece and the punch, the wrapping of the workpiece around the punch, calibration. In the ANSYS software package, this loading scheme was simulated by specifying an array of displacements of nodal points using data on the kinematics of the shaping machine. The sampling of the working surface of the punch and the workpiece was carried out using shell elements SHELL 163 wording Hughes-Liu and with five points of integration in thickness. The finite element model of the blank includes 2568 elements, and the punch model has 2275 elements. Models of working surfaces of a tightening punch and preparation are presented in fig. 2, fig.3 AMG2M alloy was used as a blank material.

The process of the stitching blank forming is temporarily shown in fig.4

![Figure 2. Finite element model of the punch working surface](image1)

![Figure 3. Finite element model of the blank working surface](image2)

![Figure 4. The blank stretch forming at times: 1 - t = 0 sec., 2 - t = 5 sec., 3 - t = 10 sec., 4 - t = 15 sec.](image3)
The assessment of the stress state was carried out according to the distribution of Lode parameters in Fig. 5, which allow determining the prevailing stress state of the blank. In the main part of the workpiece surface, tensile stresses prevail, with the exception of the gripping section along both contours, where compressive stresses are more active. In addition, we can note areas 1 and 2 in Fig. 5, which are also characterized by compression in the process of deformation, which causes the appearance of folds in the areas. The stress and strain state in these zones is minimal, which can also determine the unstable behavior of the workpiece in this area.

Figure 5. The Lode parameters distribution on the blank surface

Most of the workpiece remains outside the yield zone after wrapping the workpiece along the punch according to the stress state. The process of transition to the stage of plasticity is noted after the application of tensile forces in the longitudinal direction. The largest tensile stresses are noted according to the stressed state of the edge of the workpiece at the places of application of loads. The tensile load was applied in such a way as to increase the length of the sheet by 0.4, 0.42, 0.44, 0.46, 0.48 m. The picture of the stress-strain state of the workpiece in the process of forming is uneven. The main zones, in which the stresses and strains vary insignificantly, are separated by a dotted line in Fig 6, Fig. 7. Evaluation of equivalent strains and stresses, reflecting the total effect of stresses and strains in all directions, does not provide an objective picture in the process of stretching the workpiece with a bend. The longitudinal along the X axis normal stresses and strains make the greatest contribution to the development of the stress-strain state of the sheet.
Figure 6. The relative longitudinal strain along the X-axis at the blank stretch forming with a tension of 0.4 m, 0.42 m, 0.44 m, 0.46 m, 0.48 m.

Figure 7. The distribution of normal stresses along the X-axis at the blank stretch forming with a tension of 0.4 m, 0.42 m, 0.44 m, 0.46 m, 0.48 m.
Tensile stresses in the longitudinal direction are maximum in the process of stretching the sheet by bending around the punch according to fig. 7. The appearance of the most problematic areas, in particular: the edges of the workpiece in the places of fixation of the extreme sponges, as well as the middle part of the workpiece is traced as the tensile load increases.

As the load increases with an increase in the length of the sheet by 0.4, 0.42, 0.44, 0.46, 0.48 m, non-uniform stress distribution is observed.

6. Conclusion
The dependence of the elongations on the maximum stresses and longitudinal deformations is nonlinear. The rapid growth of stresses and strains with an extreme increase in the length of the workpiece is noted. The edges of the workpiece in the places of fixation with sponges are the most loaded, which causes possible ruptures of the workpiece in the process of forming. The conclusion about the uneven distribution of stresses and plastic deformations in the plane of the sheet can be made according to the analysis of the stress-strain state.

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