Formation of “undercuts” on titanium case parts

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Abstract. The paper presents a variant of the formation of a part from a hard-to-form case. The calculation of the required area of the movable clamp depending on the stresses arising during the formation of the “undercut” is performed. The results of real and virtual experiments are presented. The conclusions about the applicability of the technology and the advantages that the use of a movable clamp gives are made.

1. Introduction
In sheet forging, there is an acute issue of the formation of sheet parts of their hard-to-form cases. These cases have physical and mechanical characteristics that allow them to work in very difficult conditions (such as high temperatures and loads). The problem is that these cases are either poorly processed in the cold state (realizable deformation in the cold state is from 5 to 7%), or require large formation actions to obtain the desired form. The most common solution is the formation of parts from heated cases. However, the introduction of heating during formation complicates the process and makes it necessary to ensure that a case does not absorb harmful impurities from the air during heating. In particular, titanium cases should not be heated in an uncontrolled environment, since there is a high risk of an alpha case and cracking of the part during operation.

The aircraft construction industry is an industry that widely uses sheet metal forging. It is believed that the parts for aircraft are the most complex in geometry and have the most stringent requirements. The industry also often uses sheet metal parts made of hard-to-form cases. In particular, they often try to use titanium case parts in loaded parts because they combine the best strength-to-weight ratio. However, most of the sheet metal parts are connected with other parts by means of such a complex element for formation as “undercut”.

2. Results
According to the articles [2–4], the main problem in the formation “undercut” is the appearance of two defects such as “underforging” and “fold”. This paper will show the use of technology with a movable clamp for the formation of a part from a hard-to-deform case OT-4 (Figure 1).

Figure 1 shows the characteristics of the “undercut” which allows determining the place of this part on the nomogram of the normative document regulating the formation of “undercuts”.
This regulation document shows that a part with these characteristics must be produced without defects. For verification, finite element modeling was carried out in PAM-STAMP-2G software package of French company ESI-Group. The process of elasto-formation in the cold state at a pressure of 100 MPa was simulated. As a result of modeling, a defect of the “underforging” type was found (Figure 3).

This simulation shows that this part, due to the hard-to-deform case has a defect appeared in the upper part of the nomogram. It is recommended to apply to this part the technology of the formation of a movable clamp described in the article [3].
In order to calculate the characteristics of the movable clamp, first it is necessary to determine the total deformation according to the method from the paper [3] (Formula (1), Figure 4):

$\varepsilon_{\text{tot}} = \frac{S_3 - S_4}{S_3} \cdot 100\% = \frac{1710,334 \text{ mm}^2 - 1511,767 \text{ mm}^2}{1710,334 \text{ mm}^2} \cdot 100\% = 11.61\%$  \hspace{1cm} (1)

As it can be seen from the stresses during undercut formation, this part can be produced only with the use of additional accessories such as a movable clamp [4]. Using the stresses in the sub-section, we calculate the required formation force on the basis of fact that all the effort is directed to the “undercut” area and at different moments of formation it is different and increases from the top to the full area (formula (3)).
This value allows determining the required surface for the distribution of pressure on the movable clamp in order to create this force (Formula (4)). Forming pressure is 20.5 MPa.

\[
S_{rec} = \frac{F_{rec}}{q_{rec}} = \frac{687021.769}{20.5 \text{MPa}} = 33633 \text{ mm}^2
\]  

The following curve is set as the profile for the reference curve of the movable clamp (Figure 5)

![Figure 5. Reference curve of the movable clamp](image)

Using the method of least squares, we interpolate the profile of the curve by a polynomial of the 4th order and compose the equation of the surface for the movable clamp (formula (5):

\[
z(x, y) = -0.076615 + 0.812644 \cdot x + 0.013748 \cdot x^2 - 0.00104381 \cdot x^3 \\
+0.0000188464 \cdot x^4
\]  

As a result, according to these data, a set of equipment for the formation of the studied part with a movable clamp was designed (Figure 6).

Using CAD system and the built-in system of integral calculus of the surface, the surface of the movable clamp was calculated (it was 33363.3009 mm$^2$, which minimally diverged from the calculated one) (Figure 7).

Using this geometry of the tool, finite element modeling was carried out using a movable clamp with a pressure of 20 MPa. As a result, “underforging” was 0.111 mm. in fact, it was absent (Figure 8).
Figure 6. Formation tool kit

Figure 7. Contact surface of the movable clamp

Figure 8. Distribution of the “underforging” defect over the part (maximum value was 0.054 mm.)
According to the analytical calculation and created geometric models, a set of equipment was produced (Figure 9).

![Tool kit for the formation of a titanium part](image)

**Figure 9.** Tool kit for the formation of a titanium part

As a result of the formation using QFC 1.2x3-1000 press at a pressure of 20.5 MPa, the part was molded using a movable clamp (Figure 10).

In order to confirm the efficiency of the method and to prove the impossibility of the production of this part without a movable clamp, a real experiment was carried out on a QFC 1.2x3-1000 production unit at a pressure of 100 MPa (Figure 11).

Visually we can estimate that the undercut zone is not formed even at maximum pressure (Figure 10), while with the proposed technology the pressure is 5 times less and the part is produced (Figure 11).

![Titanium formed part with a movable clamp](image)

**Figure 10.** Titanium formed part with a movable clamp
3. Conclusion

As a result, it is shown that the proposed technology can form undercuts on parts made of hard-to-deform cases without temperature exposure.

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