

Movable-clamp undercutting of sheet metal parts

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Abstract—The paper analyzes a regulatory document that specifies undercut forming and parameters. We herein show where, according to that document, it is recommended to form such undercuts, and hence dwell upon problems the document fails to tackle. Discussing a standard-undercut part, we demonstrate how and why underforming occurs and propose solving this problem by using movable clamps. We exemplify two model parts to show how movable-clamp forming can produce parts with non-standard undercuts. The paper presents the results of simulation and field experimentation for such model parts. The scheme and the technology of forming with a movable clamp are illuminated. The theoretical component of the shaping of the undercuts and the conditions necessary for eliminating defects during their shaping are described.

Keywords— hydroforming, sheet stamping, undercuts.

I. INTRODUCTION

Modern-day aircraft engineering is facing serious problems relating to forming undercuts on sheet metal parts. There are multiple options of joining sheet metal parts in an assembly, including overlap joints and butt joints. Overlap joints are simpler in design, lighter, and more rigid compared to butt joints. The main drawback of overlap joints is the need for so-called undercuts. The overlapping length depends on how many fixtures have to be placed to ensure the desired strength. When forming an undercut on the board of a part using the existing equipment, the elastic medium does not provide sufficient pressure resulting in such defects as underforming or corrugation, which is exactly the problem. A butt joint is more convenient to produce, but it is heavier and requires an additional part (lining) [12].

Highly complex manual correction of parts is necessary to eliminate such defects and underforming or corrugation. Local manual correction disrupts the entire part outline, necessitating total manual correction. Manual correction also means one can ignore tooling springing, as manual correction completely alters the shape of the part in its undercut section.

Underforming and corrugation occur due to the excessive apical rigidity of the undercut, which is the case when hydroformed. This is due to the geometric shape of the undercut. To overcome such excessive apical rigidity, the pressure of the elastic medium should be applied to an additional tooling component, which will transfer such increased force locally to the undercut apex to create a stress-strain condition similar to uniform compression. The effect of

such additional tooling can be maximized by moving it during the forming process. It is the ratio of undercut parameters that gives rise to or excludes the emergence of, a defect. OST 1.52468-80 contains a nomogram (see Fig. 1) that shows the recommendable undercut parameter ratio areas. These graphs show the defect-free undercutting areas for such materials as AMr2M - AMr6M, Д16М, Д19М, В95М, 1201, 1420 with a tool radius $r = 2S$.

The nomogram shows that the forming of an undercut may give rise to three defects: corrugation (C); underforming (H); and breakage (P). This nomogram also presents areas of increased defect probability. The probability of underforming is greater at greater workpiece thicknesses (i.e. lower h/S ratios). The probability of corrugation is greater at smaller workpiece thicknesses (i.e. higher h/S ratios). The probability of breakages is higher at greater undercut steepness, i.e. greater h/l ratios.

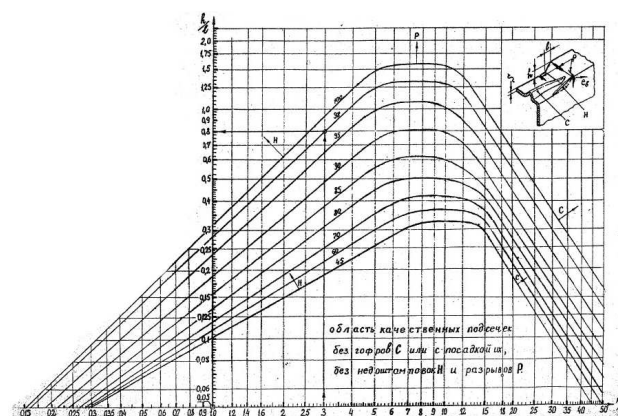


Fig. 1. Maximum steepness of median undercuts for rubber pad forming.

However, when using this nomogram and regulatory documentation, the following problems may rise:

- geometric parameters of the undercut are not within recommendable levels;
- the part material is not on the list in these recommendations;
- correctable defects such as corrugation and underforming might occur under recommended parameters due to a number of non-controllable factors,

e.g. if the supplied material has different properties. This will necessitate manual correction;

- the machinery does not generate enough pressure to form high-quality undercuts with recommended forming parameters.

II. PROBLEMS WITH SHEET METAL PARTS UNDERCUT IN ACCORDANCE WITH REGULATORY DOCUMENTATION

However, even if the undercut parameters are within GOST thresholds, i.e. within the extreme graphs of the nomogram in Fig. 1, it alone does not warrant defect-free production. To prove this statement, we chose a 1163AM sheet part, see Fig. 2. As can be seen from Fig. 2, the undercut parameters are within the defect-free range.

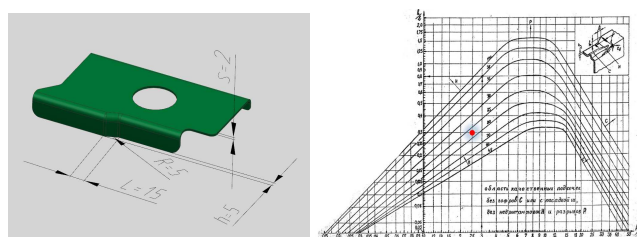


Fig. 2. Standard-undercut part.

To simulate the forming process, we used PAM-STAMP software suit by ESI Group, France.

The 1163AM workpiece material had the following parameters for simulation [4], [21], [22], [23]:

- Young's modulus equaled 70 GPa;
- Poisson's ratio equaled 0.33;
- density equaled 2.6 kg/mm³;
- anisotropy r_0° , r_{45° , r_{90° equaled 0.5089, 1.2808, 0.6654, respectively [13];
- the plastic part of the flow curve was described by the Krupkowsky law. Functional constants for 1163AM were as follows: $K= 0.32417$ GPA, $n= 0.2183$, 0.0011 .

The hydroforming process was simulated for a pressure of 100 MPa, which is the maximum hydroforming pressure with the today's machinery; computing showed a 0.704 mm undeforming at the undercut apex, see Fig. 3.

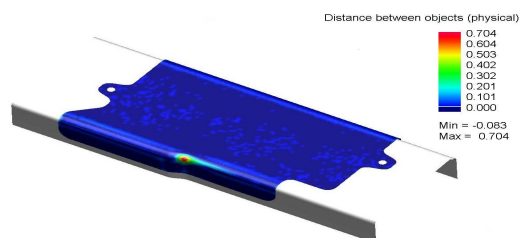
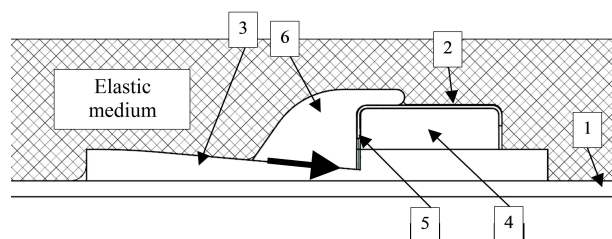


Fig. 3. Modeling a standard-undercut part.

To correct such defects, we propose using an additional tooling component, which is movable clamp. Defects are corrected by pre-hydroforming and movable-clamp post-forming. Prior to forming, tooling is mounted upon the press table and is fixed to the sow block with a slot for movable components; the workpiece is mounted onto the tooling studs and is pre-formed; then the movable clamp is mounted in the sow-block slots and is used for post-forming, which is how high-quality undercut parts are produced [11].

The elastic medium affects the sloped surfaced of the clamp and moves it along the inclined surface of sow-block slots, see Fig. 4. Moving the clamp during the post-forming process creates the necessary stress-strain state and generates enough force to be applied to the deformable part of the workpiece, which excludes underforming.



1 is the press table; 2 - the positioning pins;

3 is the sow block; 4 is the forming tooling;

5 is the workpiece (developed); 6 is the movable clamp;

Fig. 4. Places where the elastic medium affects the movable clamp; the basic forming-force vector.

Modeling the process in accordance with this technology resulted in a less-than-0.1 mm underforming, hence the defect was successfully corrected, see Fig. 5. See Fig. 6 for the movable-clamp and sow-block model. Fig. 6 also shows how the movable clamp moves in the sow block during the forming process.

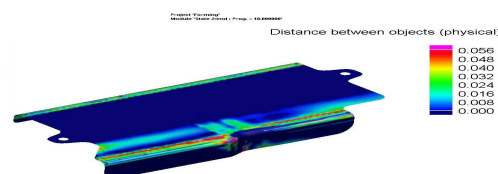


Fig. 5. Results of modeling a standard-undercut part, using a movable clamp.

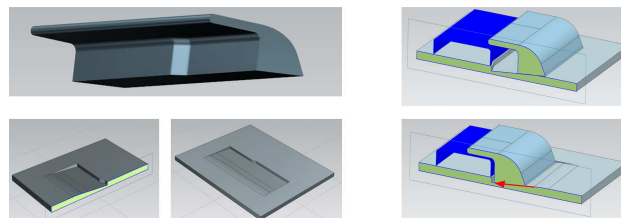


Fig. 6. Movable clamp, sow block, and movable-clamp motion vector.

Based on the modeling results, we carried out a field experiment which produced three defect-free parts, see Fig. 7.



Fig. 7. Produced standard-undercut parts.

Measuring the underforging [28], [29] with a CMM probe where the inclined undercut becomes flat showed that the deviations of real parts from their respective digital models were within acceptable levels, see TABLE I.

TABLE I. PART MEASUREMENTS

Part No. (Pressure , MPa)	Simulation for 100 MPa with the given tooling		Experimental test
	no clamp	movable clamp	
1 (60)	0.704	0.056	0.092
2 (80)			0.071
3 (80)			0.065

Therefore, this technology can produce quality defect-free parts.

III. FORMING MODEL PARTS

The proposed movable-clamp forming technology proved feasible for standard undercuts. However, it has a much higher potential. Its applications go far beyond the nomogram shown in Figure 1. To prove this hypothesis, we generated undercut part models that went beyond the regulatory nomogram values, see Fig. 8, Fig. 9.

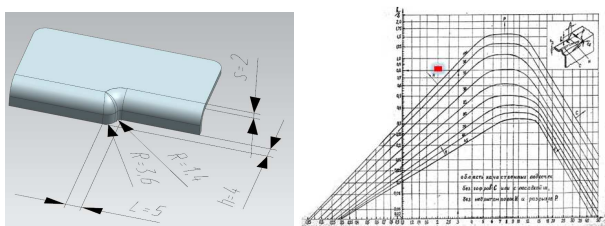


Fig. 8. Part 1, thick, low undercut runoff.

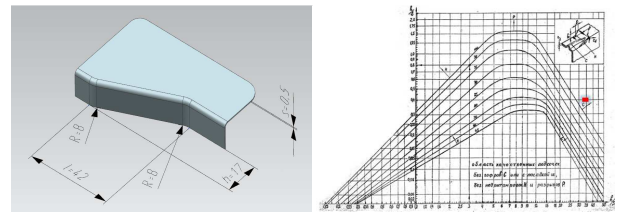


Fig. 9. Part 2, thin, high undercut runoff.

For Part 1, we produced tooling, a movable clamp, and a sow block, see Fig. 10. We also simulated the process by means of the ESI Group PAM-STAMP 2G software suit, using the same material parameters as for the standard-undercut part, i.e. material 1163 AM, see Fig. 11. Simulation was done for various pressures corresponding to that of a laboratory machine and that of the QFC 1.2x3 -1000 industrial press.

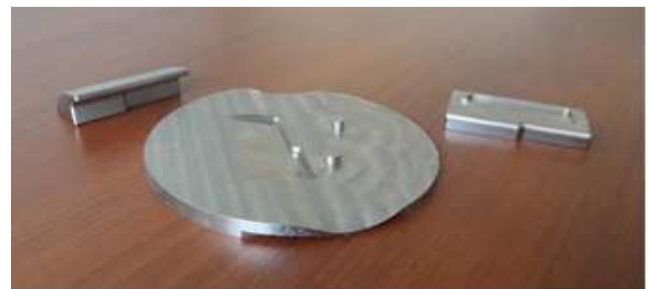


Fig. 10. Sow block, movable clamp, and tooling for Part 1.

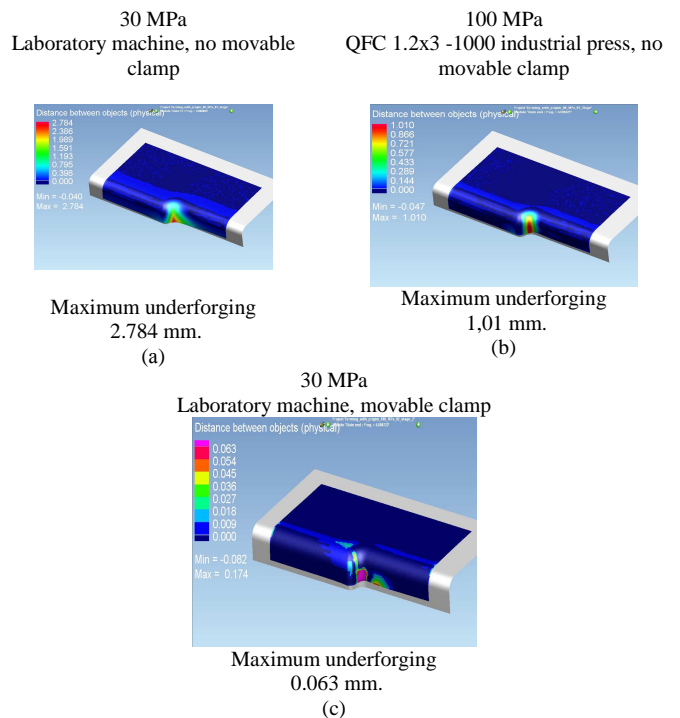


Fig. 11. Part 1 simulation results.

As shown in Fig. 11, a and Fig. 11, b, the underforming of the model Part 1 occurred when using no movable clamps; greater pressure reduced underforming but didn't solve the problem. However, as can be seen in Fig. 11, c, using a movable clamp completely eliminates underforming even at low pressure.

For Part 2, we produced tooling, a movable clamp, and a sow block, see Figure 12. We also simulated the process by means of the ESI Group PAM-STAMP 2G software suit, using the same material parameters as for the standard-undercut part, i.e. material 1163 AM, see Figure 13.



Fig. 12. Sow block, movable clamp, and tooling for Part 2.

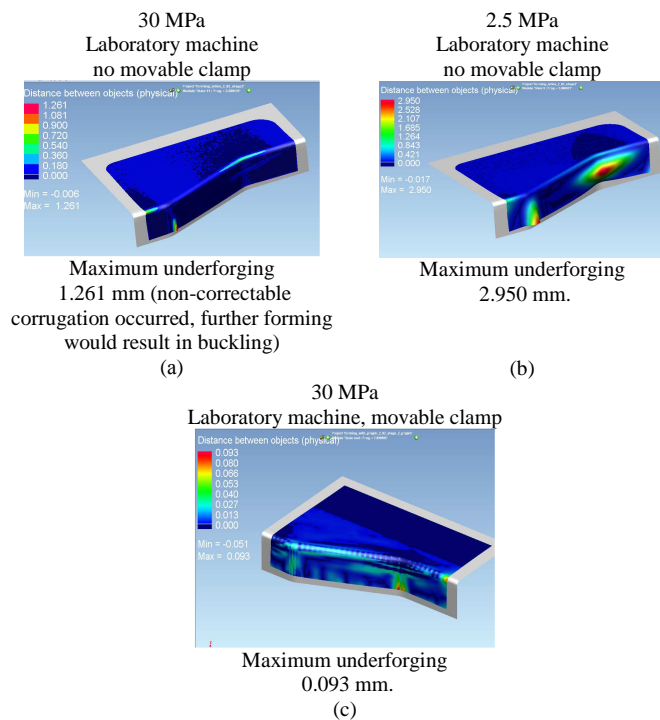








Fig. 13. Part 2 simulation results .

As can be seen from Fig. 13, a, corrugation is not a problem soluble by greater pressures. On the contrary, greater pressures may cause a high corrugation, which may become unstable and result in buckling. Using a movable clamp in this high-corrugation situation destabilizes the process as all the force is applied to a small-area apex, which again may result in buckling. To avoid this situation, first-stage pressure has to be minimized for undercuts with such parameters, see Fig. 13, b. At lower pressures, corrugation is of a more consistent

shape for shrinking. Further movable-clamp forming can correct this defect, see Fig. 13, c.

We carried out field experiments using the tooling we had produced as well as the results of our finite-element analysis. The results were fully repeatable, see TABLE II. This again proves the movable-clamp technology feasible.

TABLE II. RESULTS OF FIELD EXPERIMENTS

Part 1	Part 2
<p>30 MPa Laboratory machine, no movable clamp</p>  <p>Maximum underforming 2.784 mm.</p>	<p>30 MPa Laboratory machine no movable clamp</p>  <p>Maximum underforming 1.261 mm (non-correctable corrugation occurred, further forming would result in buckling)</p>
<p>80 MPa QFC 1.2x3 -1000 industrial press, no movable clamp</p>  <p>Maximum underforming 1,01 mm.</p>	<p>2.5 MPa Laboratory machine no movable clamp</p>  <p>Maximum underforming 2.950 mm.</p>
<p>30 MPa Laboratory machine, movable clamp</p>  <p>Maximum underforming 0.063 mm.</p>	<p>30 MPa Laboratory machine, movable clamp</p>  <p>Maximum underforming 0.093 mm.</p>

IV. CONCLUSIONS

We have therefore discovered a movable-clamp undercutting technology that can consistently produce defect-free parts with standard or sub-/super-standard undercuts. We have applied to patent this technology, see app. no. 2017142652.

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