MATEC Web of Conferences **224**, 01021 (2018) https://doi.org/10.1051/matecconf/201822401021
ICMTMTE 2018

Reverse engineering as a way to optimize and design parts produced by elastic-medium drawing

Vladimir Mironenko[1,*], *Elena* Matsuro[1], and *Catherine* Ledovskikh[1]

[1]Irkutsk National Research Technical University, 664074, Irkutsk, the Russian Federation

Abstract. On the example of an aeronautical part of the classical form for a box-type part, optimization of the cavity elastic forming process using a cover with guaranteed clearance is considered, as well as classical optimization of a part based on modeling and optimization based on the technology of "technological reconstruction". Schemes of classical cavity elastic forming process and cavity elastic forming process with guaranteed clearance are presented. The main aspects of using NURBS technology for restoring the shape of a part from a finite element mesh are described. The problems arising in the case of classical optimization using simulation and the ways of their solution using "technological reconstruction" are shown. The results of calculation in the form of gradients are presented: plastic deformations; thickness and quality zones based on the Keller-Goodwin limit strain curve.

Modern blanking-and-stamping production is facing considerable issues relating to the optimization of deep-drawn parts and designing the same with due account of manufacturing options. When optimizing the shape of a part that cannot be produced defectlessly, the question is how to reshape the part to guarantee zero manufacturing defects while also preserving its full functionality. In this case, designers solve the complex problem of finding such a shape that can be generated defectlessly, eliminating the need for further optimizations.

This problem is partly soluble by process simulation. However, while simulation, or modeling helps find out whether this or that technology can actually produce this or that part, it doesn't help optimize the part to avoid any and all manufacturing defects. In this case, simulation could be used as the basis for using reverse engineering to solve the problem.

Using a box-type part (see Fig.1) as an example, we herein optimize the process of elastic-medium drawing while also dwelling upon conventional simulation-based optimization as well as optimization by reverse engineering.

* Corresponding author: mironenko_vv@istu.edu

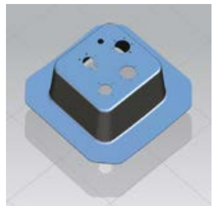


Fig. 1. Box-type part

This is a classical shape for a 1.2 mm box-type drawing. Its dimensions (350 x 360 x 65 mm) do not exceed the area of tabletops used in modern elastic-molding presses. The part is made of 12X18H10T stainless steel. Drawing performed by hydro-elastic molding using presses like QFC by Quintus Technologies. Minimum permissible thickness when shaped is 0.96 mm. Theoretical weight is 1.47 kg given a constant 1.2-mm thickness.

For simulation we used the PAM-STAMP software suit by ESI Group, France.

The 12X18H10T workpiece material has the following parameters for simulation:

- Young's modulus equals 184 GPa;
- Poisson's ratio equals 0.27;
- density equals 7.8 kg/mm3;
- anisotropy r0º, r45º, r90º equals 0.5089, 1.2808, 0.6654, respectively;
- the plastic part of the flow curve is described by the Krupkowsky law. Functional constants for 12X18H10T are as follows: K= 1.44504 MPa, n= 0.6138, ε_{ps0}= 0.0271.

A classical problem occurring in elastic-medium drawing of deep parts is the so-called "base tearing." This happens when:

- the flange of the workpiece is over-clamped by the tooling;
- too large a friction factor prevents the workpiece from being moved to the deformation zone;
- the workpiece is larger than the part itself in its developed view.

We simulated a box-type part using a workpiece 700 mm in diameter; simulation was based on the conventional elastic-medium drawing technology, see Fig.2.

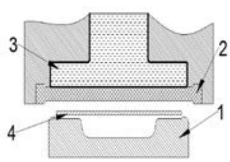
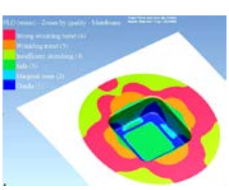
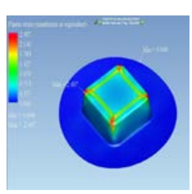


Fig. 2. Conventional elastic-medium drawing technology
1 is a rigid matrix; 2 is a protective elastic diaphragm;
3 is a liquid in an elastic container; 4 is a workpiece.

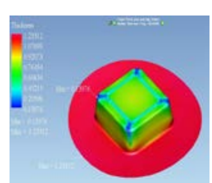
Simulating this process detected a base-tearing defect, see Fig.3:



Dangerous deformation areas are in blue



Plastic deformation (red) — 249%



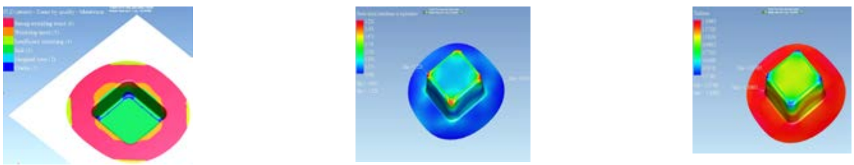
Minimum thickness (blue) — 0.139 mm, a 88% thinning

Fig. 3. Simulation results.

• by distributing the limit-state of the material, we identified the so-called dangerous de-formation areas where tearing is very likely;
• excessive thinning;
• deformations in excess of the deformation capacity of the material.

Reducing friction (the Amontons-Coulomb friction factor reduced from 0.12 to 0.05) resulted in:
• reducing the area of dangerous deformations in the limit-state distribution model;
• reduced thinning and deformations.

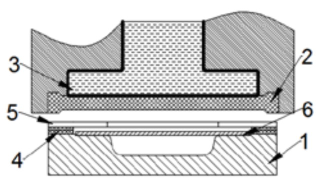
However, the base-tearing issue persisted.



Dangerous deformation areas are in blue | Plastic deformation (red) — 122% | Minimum thickness (blue) — 0.373 mm, a 68% thinning

Fig. 4. Reduced-friction simulation results.

As reduced friction did not eliminate the base-tearing defect, we had to ensure the movement of the flange. However, free movement of the flange might result in intensive corrugation, therefore slowing down or stopping the flange. For that purpose, we propose minimum-clearance drawing. Fig.5 shows the process.



1 is a rigid matrix; 2 is a protective elastic diaphragm;
3 is a liquid in an elastic container; 4 is a supporting stencil;
5 is a cover; 6 is a workpiece.

Fig. 5. Minimum-clearance drawing technology

The technology is essentially about using a supporting stencil and a cover to warrant a mini-mum clearance thrice the thickness of the workpiece, which enables the flange to move freely while shaping. Corrugations in the flange cannot be too high as they are restrained by the cover. To get rid of such corrugations, the process has to be divided into transitions consisting of molding and corrugation shrinking. Molding includes shaping the workpiece with a cover and a stencil to a specific pressure; corrugation shrinking consists in placing a stencil-less cover upon a corrugated workpiece and further shaping with the same pressure as in the molding phase. As a result, corrugation shrinking results in the removal of corrugations without the emergence of new ones thanks to low pressure.

We suggest the following transition division, see Fig.6. Corrugation shrinking is not done in the fifth transition, as the latter only consists in maximum-pressure (80 MPa) molding.

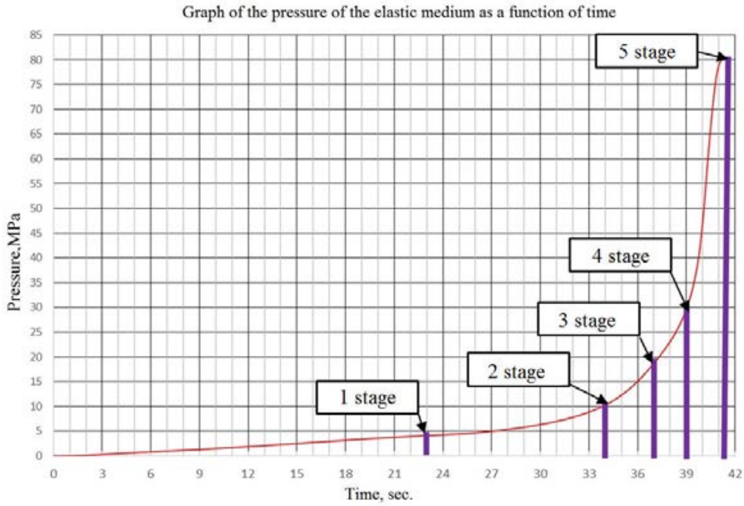
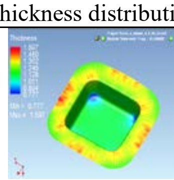
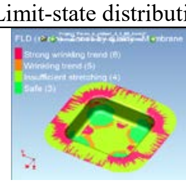
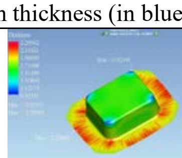
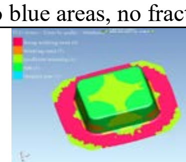


Fig. 6. Pressure graph

To improve the flange movement to the deformation zone, we calculated the shape of the workpiece based on the shape of the part, and applied a reduction thereafter. We simulated a 1.2 mm thick workpiece with these parameters. As a result, limit-state distribution did not detect any base-tearing detects, but the minimum distributed thickness was 25% less than the required 0.96 mm, This was not acceptable. The simplest logical way to increase minimum thickness was to increase the workpiece thickness to 1.8 mm. Simulating the process did not result in what we wanted either, as the minimum thickness would still be 5% less than required. Besides, the part would become 45% heavier (2.13 kg vs theoretical 1.47 kg). Simulation results shown in Table 1.

Table 1. Minimum-clearance shaping simulation results

Workpiece thickness	Thickness distribution	Limit-state distribution
1.2 mm.	 Minimum thickness (in blue) 0.77 mm	 No blue areas, no fractures
1.8 mm.	 Minimum thickness (in blue) 0.92 mm	 No blue areas, no fractures

We therefore conclude that to increase minimum thickness, we have to optimize the part in the radial transitions between its walls and base. The questions is how to do that. Today, one just increases the radius in such cases. We increased the radius from 7 mm to 16 mm, see Fig.7.

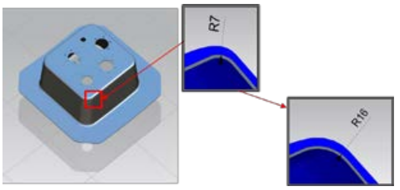
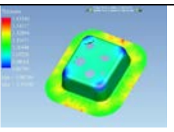
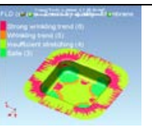
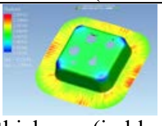
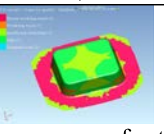


Fig. 7. Part shape optimization

Simulating the shaping of such an optimized part with an increased radial transition showed such optimization was inefficient. With a 1.2 mm thick workpiece, the minimum thickness would be 13% less than required; with a 1.8 mm workpiece, it would be 17% greater than required and at 2.21 kg 50% heavier than in theory. Results of simulating the optimized part are shown in Table 2.

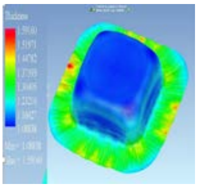
Table 2. Simulating the minimum-clearance shaping of the optimized part

Workpiece thickness	Thickness distribution	Limit-state distribution
1.2 mm.	 Minimum thickness (in blue) 0.86 mm	 No blue areas, no fractures
1.8 mm.	 Minimum thickness (in blue) 1.12 mm	 No blue areas, no fractures

Therefore, simulating the original and the optimized part showed that corrugation shrinking results in excessive flange thickness while thinning the radial transitions in the part base. Greater thickness means greater weight. Corrugations emerge due to the shaping of radial transitions in the base corners at the end of the shaping phase. After the tooling reaches the base, the shaping process goes from the center to the corners, which necessitates integral radii in the corners.

When specifying such radii, the only condition to stick to is that, the holed base should pre-serve its shape. The main problem is that just like in conventional optimization, it is difficult to predict defectless shaping with specific radii so that the part matches all the required parameters. In this case, reverse engineering is the recommended technology.

Reverse engineering is essentially about simulating such shaping in which the workpiece is altered from a flat structure to a tooling-specific shape. By taking the shape of the tooling, the workpiece uses a finite-element mesh to describe the best integral-radius shapes from the deformation perspective. Now we only have to specify a pitch, which will produce a desired minimum thickness and the necessary shape of the flat holed base. This is the shape shown in Fig.8. The shape was determined when simulating an unoptimized part made of a 1.2 mm thick workpiece.

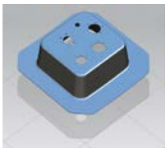


Minimum thickness (in blue) 1.088 mm (15% greater than required)

Fig. 8. Shape of a part with integral radii

To reverse-engineer the facet surface, we used NURBS (Non-uniform rational B-spline). NURBS consists in generating splines based on a facet body. Splines must make a specifically primitive (rectangular or triangular) closed loop. This technology is similar to generating second-order finite-element meshes, but surfaces are differently-sized here. NURBS is essentially about representing a facet in the set of basic surfaces. The primary advantage of this method is its high accuracy in reverse engineering integral surfaces. This technology produces the inner surfaces of a no-flange part; it is those surfaces that contain integral radii.

Based on this surface with integral radii, we obtained the optimized FEM of the part. Fig.9 shows the initial FEM of the part and the FEM of the RE-optimized part.



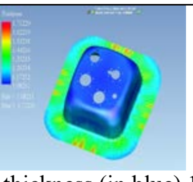
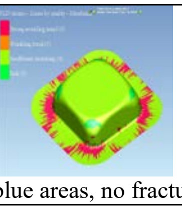
Initial FEM

FEM of the RE-optimized part

Fig. 9. Initial and optimized FEM compared

Further simulation of optimized shaping by minimum-clearance drawing with a 1.2 mm workpiece showed that the minimum thickness was no less the required (0.96 mm), whereas the weight matched its theoretical value of 1.47 kg, see Table 3.

Table 3. Simulation of minimum-clearance shaping with optimization by reverse engineering

Workpiece thickness	Thickness distribution	Limit-state distribution
1.2 mm.	 Minimum thickness (in blue) 1.082 mm	 No blue areas, no fractures

We have therefore demonstrated for a box-type part how reverse engineering could be used to optimize parts with due account of the shaping technology and the material deformation capacity. This technology can be used to reverse-engineer the shape of a workpiece at any stage of shaping. Using this technology helps reduce elastic-medium drawing costs when optimizing the shape while also enabling the development of higher-manufacturability shapes when designing.

References

1. S.G. SHAHRAI, N.A. SHARYPOV, P.V. POLYAKOV, V.V. KONDRATIEV, A.I. KARLINA, *Quality of anode. Overview of problems and some methods of their solution part 2. Improving the quality of the anode*, INTERNATIONAL JOURNAL OF APPLIED ENGINEERING RESEARCH, v.**21**, pp. 11268-11278 (2017)
2. A.S. Govorkov, *Technique of designing of the product of aviation technics with maintenance of the set criteria of adaptability to manufacture,* Journal of International Scientific Publications: Materials, Methods & Technologies, v.**5(3)**, pp. 156-161 (2017)
3. M.V. Lavrentyieva, A.S Govorkov, *Identifying the objects in the structure of an e-model by means of identified formal parameters in the design and engineering environment*, MATEC Web of Conferences, Volume **129**, pp. 03002 (2017)
4. M.V. Lavrentyieva, A.S Govorkov, *Using a discrete product model to determine the design element junctures,* MATEC Web of Conferences, Volume **129**, pp. 03003 (2017)