Experience in applying digital modeling to improve component manufacturing

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Abstract. A review of the application of digital modeling in the design of technological processes of aircraft parts manufacturing is presented. The examples of parts manufacturing by casting, volumetric and sheet forming methods, including the use in the mode of superplasticity are given. Technical solutions obtained on the basis of modeling results of manufacturing processes are applied in parts manufacturing. Digital models are compared with real parts. The possibility of detection of undesirable effects (corrugation, springing, porosity) on digital models is proved, which allows to correct the parameters of the technological process before the stage of real production.

1. Introduction
Rapid development of software and hardware systems for engineering analysis of various purposes is typical for the present time. Hardware is being rapidly improved. It becomes possible to use complex and time-consuming calculation algorithms to solve nonlinear problems in dynamic formulation. Such tasks include modeling of the processes occurring in the workpieces during the implementation of various methods of metal and alloy processing.

To date, the world has accumulated experience in the use of digital technologies for virtual modeling of manufacturing processes of parts in the preparation of their production. For this purpose different software is used - both universal: ANSYS, Marc, and specialized - PamStamp, QForm, ProCast and others.

Employees of the Irkutsk National Research Technical University have been working for more than ten years on the application of virtual technological modeling technology to improve the preparation of machine-building production of parts for various purposes.

All works were carried out by order and in close contact with the industrial partners of the university - engineering enterprises of our country: Irkutsk and Ulan-Ude aviation plants, Irkutsk Heavy Engineering Plant.

The main directions of work are modeling of casting processes, volume and sheet forming, both in cold and hot condition, including the use of superplasticity and diffusion welding.

Below are some examples of the application of virtual simulation of metal and alloy processing [1].

2. Modeling of casting processes
With the help of ProCast program the technological analysis of the process of casting the steel wheel of mining equipment with a diameter of two meters was performed (Fig. 1).
Результаты моделирования показали, что при применении типовых схем литья в песчаные формы могут образовываться многочисленные раковины в зонах пересечения обода и спиц (рис. 2).

After analyzing more than a dozen variants of the casting process, a solution was found that helped to ensure that the wheel was cast without defects.

One more example of the development of the sand casting process of the "front knot" part made of aluminum alloy (Fig. 3) [2, 3, 4].

According to the results of modeling, a variant of casting model and casting system design was found, which provided defect-free casting of the part (Fig. 4) [2, 3, 4].
Modeling of a more complex casting process - casting into shell molds produced by melting models can be illustrated by the example of casting a "lever" type part (Fig. 5, 6) [5, 6]. By means of changes in the initial design of the stearic melted-out model (the rotation of the part model by 180 degrees in the vertical plane relative to the casting system is proposed) it was possible to exclude the formation of porosity in the knee of the lever. The study of the finished part confirmed the correctness of such a technical solution - casting defects remained only in the casting system. (Fig. 6).
3. Modeling of three-dimensional forging processes
For virtual modeling of the manufacturing process of parts by methods of volume forging was used QForm program of the Russian developer. The drawbacks of the existing process of production of steel "angle" type parts were modeled and revealed [5]. On the basis of the results of modeling (Fig. 7) in the technological process for the purpose of manufacturing a workpiece close to spherical shape it was proposed to introduce an additional forging operation. Thus it was possible to reduce the material consumption on 32 % and to raise quality of stamping (fig. 8).
Figure 7. Results of die forging simulation

Figure 8. Ready forging

Figure 9. Voltage fields
In addition, QForm simulated the state of the deformation tools (Fig. 9), which showed that the lower tool at the end of the second stress transitions reach the limit values and the risk of stamp failure is high. The further search for tool configuration led to the decision to change the shape of the tool engraving to a smoother shape in the area of the forging flange by increasing the radii of transitions to and within the flange, increasing the thickness of the flange, as well as increasing the slope at the ends of the flange. The picture of stresses in the changed design is shown in Fig. 10.

![Figure 10. Voltage fields in the modified design](image)

4. Modeling of sheet-forming processes
In the production of many mechanical engineering products, various types of sheetmetal forging are used.

The production of titanium alloy parts is particularly difficult. An example of manufacturing of such a part are fairings (Fig. 11, 12) made of 0.5 mm thick sheet [6, 7].

![Figure 11. Electronic component workpiece of the "fairing" part (version of 1)](image)
Figure 12. Electronic component workpiece "fairing" (version 2)

Such a part was made by a molding-out in rigid stamps on a sheet-forming hammer from the sheet blanks heated up to the temperature of 550 - 700 °C, for 5 - 7 blows with manual landing of the formed corrugations after each blow. This forming process was simulated in the specialized PamStamp program. The results showed the following. For single part #1, 6 strokes are required. Residual corrugations are observed (Fig. 13) [8, 9, 10]. Virtual geometric trimming of the allowances showed that the corrugations remain on the parts, and there is a significant springing (residual deformation) and distortion of the part shape, requiring additional finishing works (fig. 14).

Figure 13. Corrugation of the workpiece after the 6th stroke
Figure 14. Part after cutting the workpiece

Similar results have been received and at modelling of process of stamping of a detail No. 2 (fig. 15, 16).

Figure 15. Corrugation of the workpiece after the 6th stroke (version 2)
Thus, virtual modeling of the process of forming the workpiece showed that forging in hard dies can be made fairings, but it is a rather labor-intensive process, complicated by a number of negative factors: the formation of hard-to-remove corrugations on parts, a large number of transitions with intermediate annealing, a high level of springing, the need for additional heat treatment in cramped conditions - thermal fixation.

In the manufacture of parts from the sheet is spread stamping elastic medium. This is due to lower tooling costs: one of the tools replaces rubber, liquid or gas. The production of complex shaped sheet parts by this method is also a difficult task. This is due to the corrugation and springing. To develop a rational process of manufacturing such parts in a traditional way will require a large amount of experimental work.

PamStamp, a specialized program for modeling die casting processes, allows you to define the contour of a rational workpiece, determine the nature and location of corrugations, evaluate the levels of springing, adjust the working surface of the tool by the size of this spring.

Thus, for the part "Diaphragm" (Figs. 17, 18) was simulated forming with the subsequent piercing of the window in the zone of location of the folding [9-11]. Based on the results of modeling, a real part was made and a good convergence of the virtual process of forming with the real forging was confirmed.
Figure 18. Finished component (top and bottom views)

Figure 19. Results of the "Bottom" part modeling

Figure 20. Ready component “Bottom”
Good results have been received at virtual and full-scale development of the process of elastoforming of a detail "Bottom" (fig. 19, 20). The manufactured part is considered suitable.

Particularly challenging are the processes of hot stamping in special material states of the parts, such as superplastic ones.

Thus, as an alternative option for the manufacture of fairings (Figs. 21, 22) it was proposed to use group pneumatic-thermal forming in the mode of superplasticity [12-15]. It is proposed to form 4 parts at once for one forming transition - 2 of each type in one tooling. The number of parts manufactured simultaneously in this case was determined by the size of the working area of the equipment at the disposal of the university staff.

Modeling of the group pneumatic-thermal forming in the mode of superplasticity was carried out in the program PAM-STAMP. The optimal law of forming pressure change from process time was calculated by its means.

![Figure 21. Workpiece model "Cowl"](image1)

![Figure 22. Molded component "fairing"](image2)

Virtual pneumatic thermoforming has shown that parts can be manufactured without corrugations and residual springs in superplasticity mode. In addition, it is established that the deformation capacity of the metal, despite the small thickness of the workpiece, is sufficient for forming without destruction. Both on the models and on the cut parts the corrugation formation did not appear (fig. 23, 24).
As a result of experimental works it is established that at formation of details in a mode of superplasticity there was no corrugation formation that excludes finishing works on their elimination, besides, the effect of a springing is not shown. The group moulding has provided manufacture of four details at once for one operation that allows to raise productivity of technological process. With large machine footprints and the use of an additional die for upward forming, a much larger number of parts can be produced at the same time. However, the expected reduction in labor intensity of the new technology can achieve more than 30%.

Thus, the offered variant of technological process of manufacture of fairings provides manufacture of low-tech details from hard-to-cut alloys.

Good results have been achieved in modeling and real development of the process of pneumatic thermoforming of complex pipeline elements (semi-pipes) made of titanium alloy (fig. 25, 26, 27, 28).
Figure 25. Molding simulation results

Figure 26. Ready components

Figure 27. Finished semi-pipes (bottom view)

Figure 28. Finished semi-pipes (top view)
The capabilities of IRNITU allowed to test the production technology of the wedge-shaped panel with different orientation of the inner set of titanium alloy.

Thickness of external sheets is 2 mm. The thickness of the inner sheet is 1 mm.

5. Conclusion

With the help of the universal program of engineering analysis of MSC.Mark virtual modeling of the process of pneumothermal formation of three-layer panel with transverse (Fig. 29, 31) and longitudinal set (Fig. 30, 32) was performed [8, 9], control programs for pneumothermal formation equipment were calculated. The panels were manufactured without defects.

Figure 29. Wedge-shaped panel model with transversal set

Figure 30. Wedge-shaped panel model with longitudinal set

Figure 31. Ready-made panel with transversal set

Figure 32. Ready panel with longitudinal set
Thus, with the help of virtual modeling of various machining processes it was possible to find rational schemes of technological processes, constructions of blanks and technological equipment quickly and at the minimum, in comparison with traditional empirical approaches, expenses. Besides, thanks to virtual modeling of machining processes it was possible to reduce labor input of manufacture of details not less than on 30...70% depending on a method of processing and complexity of a design of a detail.

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