Forecasting of the Holes Shape Accuracy of Thin-Walled Body Parts Through the Application of Artificial Neural Networks

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Forecasting of the Holes Shape Accuracy of Thin-Walled Body Parts Through the Application of Artificial Neural Networks

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Abstract. In this paper is proposed a method to predict deviations of accuracy of a basic shape of holes due to a thermal deformation (TD) at the design stage of the technological process. Proposed method of control of technological process consists of two stages: the first stage (auxiliary) is based on the finite element method (FEM), the second (main) - on the modeling of artificial neural network (Ann). In this paper is developed an algorithm of calculation of input and output parameters of the network using LS-DYNA. A structure of the Ann to predict and to adjust a trajectory of a movement of a tool at the preparation stage of the technological process for work pieces included in group process is invented in this article.

1. Introduction

During the competition any business should focus on release of quality products, which must meet the requirements of a customer and a consumer. Application of modern technologies in a field of computer simulation contributes to achieve these goals. The use of artificial neural networks in combination with the method of finite elements will allow to improve indicators such as the manufacturing accuracy and surface quality.

In modern conditions of production mechanical treatment by cutting still does not meet the requirements, resulting in an inclusion in the process of costly finishing operations. Therefore, improving of blade processing through the use of information technologies, which allow to increase performance and to provide high quality of products, is an urgent task.

As objects of study were selected base holes of thin-walled body parts, because they imposed high demands on dimensional accuracy (6-8 degree), deviation (4-5 grade), surface roughness (RA=1.6 to 0.08 μm) (figure 1) [1].

Thin-walled housing parts in order to facilitate the mass are manufactured by casting from aluminum alloys. Through cooling of castings due to a different thickness of walls is forming a heterogeneous structure, non-uniform hardness, which results in a formation of unstable mechanical properties of a surface, different roughness and a deviation of a size and a shape of a surface during processing. Accuracy of the shape is one of the important requirements in the treatment of underlying holes of body parts, because they imposed increased demands for durability.

Significantly on accuracy of processing also affects a non-uniform hardness, which leads to a change of cutting forces and different elastic deformations of elements of technological system. This results in a scattering of size and a deviation of the shape of the hole.
During the measurement of hardness the Converter type USDT-100N was used. The surface of the cylinder is divided into 6 equal parts at intervals of 11 mm. Over the length of a border of each piece in different places were made 5 measurements, average values were recorded in table (table 1).

### Table 1. The study of hardness.

| The number of the workpiece | Hardness, MPa |
|-----------------------------|---------------|
| 1                           | 1.1 327 302 361 364 322 320 |
| 2                           | 1.2 289 337 313 373 410 405 |
| 3                           | 2.1 299 329 305 364 337 315 |
| 4                           | 2.2 272 296 317 299 337 342 |

For hardness values of workpieces mean values were calculated, which resulted in the graphs (figure 2).

Variable hardness leads to a change of cutting forces and different elastic deformations of elements of technological system. This results in a scattering of size and a deviation of the shape of the hole. It can be assumed that variable hardness occurs during a crystallization of a metal due to varying wall thickness of the workpiece and it is one of the negative factors that affect the expected accuracy.

The expected machining accuracy is a cumulative result of many elementary inaccuracies. Each of them contributes its share to the total inaccuracy and at the same time indirectly or directly affects the other elementary inaccuracies [2].

Share of elementary inaccuracies in the total inaccuracy for the most common cases is approximately [2]:

- setting inaccuracy during the processing of holes of these body parts: 2...40%;
- inaccuracies due to elastic deformations of the technological system: 0...80%;
- inaccuracies from the settings and tool wear: 5...40%;
- inaccuracies due to thermal deformations of elements of TS: 15...70%;
- form inaccuracies of the machined surface due to the geometric inaccuracies of the machine: 1...15%.
For thin-walled parts with variable wall thickness errors, involved with thermal deformation, can account for up to 70% [3]. Consequently a reduction of heat generation during cutting and, accordingly, a decrement in TD of a workpiece are possible mainly by reduction of processing modes, that leads to reduction of performance. Thus, it is necessary to predict the magnitude of thermal deformation at the design stage of a technological process using an integrated approach, that consists of two stages: the first stage (auxiliary) based on the method of finite element analysis (LS-DYNA), the second (prediction) stage based on a learning and building of neural networks (Statistica Neural Networks).

2. Theory

Analysis in LS-DYNA simplifies and automates only a calculation of required parameters, but has several disadvantages: greatly increases a duration of preparation of a technological process, even on modern computers calculations are carried out a considerable time; complex preparatory phase; it is required a high qualification of specialists. Thus, the phase of calculation using the finite element method is complement and necessary for a calculation of input and output parameters of the artificial neural network used to predict deviations of a precision of a hole shape. For this purpose one detail is selected on which simplified models are built (training set), that include the following specifications: hole diameter (D), long hole (L), difference between minimum and maximum wall thickness (a), a workpiece material, a cutting tool material. To improve a performance of calculation, instead of the cutting tool cutting wedge is used, because TD is calculated only for harvesting (figure 3).

One of the most important stages of finite element analysis is building a finite element mesh, in this case accuracy of calculations depends on the correct choice of types and sizes of elements. In LS-DYNA there are two main methods: constructing the arbitrary grid and building the ordered mesh. Practice of calculations using the finite element method demonstrates that the most preferred is the ordered grid; furthermore a rectangular grid is more favorable than a triangular mesh element. A fine mesh is required where it is expected a large gradient of deformations or tension, for example, due to the presence of hubs, cracks or ruptures of cell references. A large mesh can be used in areas with little
varying relative deformations and tension, as well as in areas not of particular interest for the calculation.

In the study of fluidity any field there are two ways of splitting it into elements –elements are fixed in space and provide for the flow of material through them (the Euler equation), or elements are fixed on the flowing material, so as to move together with it (the Lagrange equation) [4]. On one hand the advantage of analysis by the method of Lagrange is easy to monitor changes of material properties, on the other hand is a computational complexity. Simplicity of computation by the Euler method does not allow implementing the modeling of the chip formation fully in conditions of large displacements of free surfaces.

The element type must conform to the task from the point of view of physics of process and have the appropriate mathematical description and degrees of freedom. So, to perform finite element analysis of cutting process, it is necessary to use several elements and models focused on their task.

To determine the temperature and its distribution in the cutting zone choose the element SOLID70 used for temperature analysis, and which allows calculating of heat transfer and computation the value of the temperature in the nodal points. This element supports heating by the friction, nonlinearity of the material and allows specifying a core set of its properties: density, thermal conductivity, heat capacity, thermal expansion coefficient, etc. As the load is possible to use different heat sources. Calculation results shape the temperature field and heat fluxes.

![Image](image.png)

Figure 3. The finite element method with specified conditions.

Thus the algorithm is constructed as follows:

**Auxiliary stage [5-7].**
1) Construction of the 3D model and the cutting tool (insert).
2) Generation of a grid
3) Export to LS-DYNA and assignment of material properties and contact conditions.
4) The task of coordinates of the tool path and a frequency of rotation of the workpiece (cutting data).
5) Perform of elastic-plastic analysis (the tool movement and rotation of the workpiece).
6) Calculation of a temperature of the workpiece in a cutting zone. Determining of the significance of thermal strains.
7) Analysis of deformations and deflections shape of basic hole of thin-walled housing part.
8) If the deviation is above acceptable, then back to item 4.
If the deviation is within the valid value, then a file with data is created and exported to a database, and from there is populated the artificial neural network model and training.

**The main phase [8].**

According to results of the auxiliary stage the artificial neural network is constructed and it consists of 12 independent parameters, which are given per input: submission (s), cutting speed (V), depth (t), the material of the cutting, the workpiece material, hole diameter (D), difference between minimum and maximum wall thickness (a), hole length (L), the ratio of stutter (CRC), hardness of parts, thermal conductivity of the workpiece material, the temperature in the cutting zone (T). Cutting fluid is applied during whole treatment.

The output will have four adjusted parameters: feed rate (dS), cutting depth (dt), cutting speed (dV), allowable thermal distortion (dT) (figure 4).

![Artificial Neural Network Diagram](image)

Figure 4. A structure of the artificial neural network for forecasting of deviations of hole shape.

In further the network is tested with input values of input parameters not involved in training sample, and results of the response of the artificial neural network with test values of output data are compares. The actual value of the thermal deformation and the value of the thermal deformation, calculated by using the artificial neural network, are analyzed. If the error is within the acceptable range, a program code of this network prints on one of the programming languages (e.g. C++). It is developed the program, the core of which consists of code of the neural network, and the interface is used to enter calculation parameters and obtain corrected cutting data.

### 3. Results and discussion

When predicting values of TD the method based on the artificial neural network is able to consider not only a large number of factors and their mutual influence on each other. It, theoretically, has a possibility of approximating of arbitrarily complex dependencies that enables to predict accuracy of machining directly depending on values of input parameters of the process. Disadvantages of this method are: the use of the same type of tool materials and workpiece materials (in our case solid alloys...
of various grades and aluminum alloys of varying hardness and density). So, forecasting of the technological process of processing of base holes of thin-walled body parts using this neural network will work within boundaries of the group of parts close by design features.

4. Conclusion

The proposed method allows at the design stage of technological process to adjust the trajectory of the cutting tool on the basis of temperature deformations of the workpiece, when there is not stock of technological precision, i.e. there is a possibility of a manufacturing defect due to excess of the error processing over the permissible value. Application of the artificial neural network method will reduce time of technological preparation when designing the group process.

Main factors from the point of view of economic efficiency from implementation of the proposed method in the production are: reduction of time and costs of development of new technology, reduction of costs related technological processes of manufacturing parts and product assembly, increase reliability, durability and serviceability of products. Reduction of terms of development of new technology has important economic value. Long time of design and development of new products reduce efficiency of social production.

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