Problems of ensuring accuracy in the manufacture of large-sized thin-walled parts

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Abstract. The manufacture of large-sized thin-walled parts is a complex, time-consuming and high-tech process, as practice shows. The result of production does not always meet the requirements of the design documentation, which leads to the exclusion of parts from further production and the loss of time spent by a team of specialists and workers. The paper analyses the occurrence of defects leading to faults. It identifies the direct and indirect causes of their occurrence, suggests ways to eliminate them using the control parameters of the technological system: tool path in the control program, cutting conditions, cutting tool geometry. The proposed recommendations, tested in the production process, have significantly improved product quality and reduced production preparation time.

Specialists from all over the world working in the field of metalworking are faced with distorted parts. Products from various metals and alloys are subjected to deformations, with overall dimensions ranging from a few millimetres to tens of meters. Distortion is particularly critical for large-sized body parts, the deviation from the flatness of which reaches 30 mm per 1 m². And if some parts are subject to addressing and thermo-levelling, then for others, such methods are not acceptable and the resulting deviations are the basis for their exclusion from further production.

The works [1, 2] are devoted to the study of ensuring the accuracy of parts such as bodies of rotation, whereas there are fewer works devoted to processing of body parts. A particular feature of milling is the intermittent cutting process, which causes the tool and part to vibrate.

The need to fulfil the requirements of design documentation and the absence of materials-substitutes proposed by the product developer, analysis and subsequent optimization are carried out only according to technological parameters. In this regard, the task of analysing the manufacturing process and identifying ways to improve it to improve the quality of processing based on the operational management of technological parameters is particularly relevant.

The greatest need for thin-walled parts is traditionally observed in the aerospace industry, as well as in instrument-making, shipbuilding, radio electronics. Due to the absence of clear criteria for describing large-sized thin-walled parts, it is proposed to be guided by the parameters given in table 1. The amount of mechanical processing in the proportion of the total labour intensity of manufacturing this type of parts reaches 85%. So the cases of modern laptops are milled from solid aluminium blanks.
Table 1. Parameters of basic large-sized thin-walled parts.

| Parameter                                                                 | Value                          |
|--------------------------------------------------------------------------|--------------------------------|
| Overall dimensions of the part:                                          |                                |
| - length                                                                 | from 700 mm                    |
| - width                                                                  | from 400 mm                    |
| The surface area of the part feature                                    | from 200000 mm² (0.2 m²)        |
| The thickness of the minimum cross section of a structural element       | not more than 10 mm            |
| The tolerance of the form on the size of the structural element          | not more than 0.1 mm           |

As an example, let us consider the structural element of a large-sized thin-walled part, shown in figure 1.

![Figure 1. Design element of large-sized thin-walled part.](image)

Production of high-precision large-sized thin-walled parts is carried out over a long period, consisting of 4-6 cycles of removing the minimum allowance using the milling method followed by heat treatment. The machining of the presented part takes place in a special machine tool under the following processing modes: depth of cut \( t = 3 \) mm; minute feed \( S = 3000 \) mm/min; cutting speed \( v = 300 \) m/min. Deformation in the form of warping-surface deformation \( A \) is manifested at the stage of geometry control on measuring machines or portal machining centres with Renishaw sensors in a free state. When measuring, the excess of the flatness tolerance is recorded several times (figure 2).

![Figure 2. Deformation diagram of the part section.](image)

Studies and calculations carried out in [3] show that in the process of milling the residual tensions are formed as a result of the action of the cutting force components and heat generation in the cutting zone. The arising technological tensions in the course of machining lead to deformations of the surfaces, considerably exceeding the tolerances of the form laid down in the design documentation for the product.

At high tension in the products, cracking and brittle fracture can occur. The harmful effect of residual tension affects the overall chemical reactivity of the metal.
Comprehensive assessment of the manufacturing process of the considered type of parts and literature [4, 5, 6, 7] is presented in figure 3.

**Figure 3.** Analysis of ensuring accuracy in the manufacture of large-sized thin-walled parts.

The causes of the deformations in the structure under consideration are determined by the following phenomena:

- **Defect - deformation of details**
  - Controlled parameters
    1. Flatness tolerance - warping of surfaces
    2. Tolerance for linear dimensions

- **Forms of defects**
  1. Cracking
  2. Brittle and fatigue failure
  3. Increasing the chemical activity of the metal

- **Causes of defects**
  Phenomena and factors arising during machining
  1. Effect of residual process voltages
  2. Fluctuations and vibrations of the instrument
  3. The unevenness of the fastening force in the machine tool
  4. Deformation of the MTTD system
  5. Worn cutting tools

- **Defect repair methods**
  1. The use of an alternative method of processing parts - creating minimal power loads.
  2. Reducing power loads
  3. Reduction of heat generation during processing and intensification of heat removal from the cutting zone

- **Operationally controlled parameters**
  1. Cutting conditions
  2. Processing path

- **Parameters changed in the production preparation process**
  1. Geometry and material of the cutting tool
  2. Machine and tool equipment
  3. Cooling system
  4. Fixing scheme and clamping force
  5. Thermal stability of the environment (thermally insulated room)
1. The level and distribution of residual and thermal tensions arising and redistributing as a result of plastic deformation of the surface layer during blade processing of the part;
2. Forced vibrations and regenerative vibrations of the tool due to intermittent cutting process during milling;
3. The unevenness of the efforts of fixing the workpiece in the device and the uneven distribution of heat throughout the volume of the part;
4. Elastic deformations of the MTTD system;
5. Wear on the back surface of the tooth and chipping of the cutting edge.

Processing conditions determine the level and distribution of technological residual tensions and strains: cutting force, temperature in the cutting zone, vibration of the tool and the workpiece. These parameters are recorded using modern equipment and software, which allows you to manage them, knowing the degree of influence of input data on the force and temperature of cutting:

\[ P = f_1(v, s, t, \alpha, \gamma) \]
\[ T = f_2(v, s, t, \alpha, \gamma) \]
\[ \sigma = f_3(P, T) \]

where \( P \) – tool effort; \( T \) – temperature in the cutting zone; \( v, s, t \) – cutting speed, feed and depth of cut respectively; \( \alpha, \gamma \) - front and rear cutter angles; \( \sigma \) - technological residual tensions.

In the initial approximation, it is advisable to consider changing the parameters \( P \) and \( T \) only depending on the \( x, y \) coordinates.

In this case, you can use the plate bending equation in expanded form [8]:

\[ \frac{\partial^4 \omega}{\partial x^4} + 2 \frac{\partial^4 \omega}{\partial x^2 \partial y^2} + \frac{\partial^4 \omega}{\partial y^4} = \frac{q}{D(x)} \]

where \( D(x) \) is a cylindrical stiffness, which is variable in \( x \) and constant in the \( y \) coordinate, which allows to take into account longitudinal stiffening ribs, \( q \) is the external load acting on the surface of the part along the normal to the mid-plane.

Then the cutting force will be determined by the formula:

\[ P = \int q(x, y)dx \, dy \]

where \( S_u \) – contact area of the tool with the workpiece.

Deformations of structural elements are determined by the dependence:

\[ \Delta = \omega_{max} = f_4(\sigma) \]

where \( \omega_{max} \) - maximum surface deflection.

We will define the input process data that have a direct impact on the causes of the deformations as follows:

- Cutting conditions.
- Processing strategy: tool path and the amount of allowance removed.
- Geometrical parameters of the cutting tool, the material of the cutting tool and its durability.
- Scheme and efforts of basing and fixing the workpiece in a special tooling

The number of heat treatments and their modes:

- Tooling: mandrels with thermal clamp and hydraulic clamp.
The tools used coolant, coolant cooling.

Environmental parameters - thermally insulated room.

**Conclusion**

Analysis of the input data of the technological process shows that only cutting modes, the processing strategy, the number and modes of heat treatment, including the operation of natural aging, are subjected to operational control. It should be noted that an increase in the number of heat treatments leads to an increase in product manufacturing time.

The adjustment of the applied cooling systems, tools, accessories requires the revision of machine tools, the order of new cutting tools and tool mandrels, lubricating coolants with a transportation term of up to 4-6 months. Thus, mistakes made at the stage of technological production preparation lead either to a break in production time or to the need to level defects only due to parameters subject to operational control, such as cutting conditions, machining path and cutting tool geometry.

The research results of this work, to ensure accuracy in the manufacture of large-sized thin-walled parts, empirical dependencies established in [9, 10] and the need to ensure high processing performance make it possible to formulate recommendations to reduce the deformation of large-sized thin-walled parts during and after machining:

- increase in cutting speed to the range of 600-1100 m/min, at which the cutting forces decrease and the concentration of generated heat in the chips occurs;
- reduction of the cutting depth is proportional to the increase in cutting speed;
- increase the front angle of the cutter to 14-18 degrees to reduce the work of deformation and friction forces on the front surface;
- reduction of the radius of rounding of the cutting edges of 0.08-0.1 mm.

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