A method of technological identification of metal-cutting machine

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Abstract. The paper demonstrates the disadvantages of formulations of the purposes of metal-cutting machine. The authors suggest to use the modules of the parts surfaces as the subject of machine tool production. The paper presents the method of determination the process capabilities of the machine tool and identifies the process capabilities of a milling machine.

1. Introduction

To form the manufacturing program of an enterprise, determine the possibilities of performance of individual orders for output of products, acquisition of machine tools as well as to develop the processes of parts manufacture, it is necessary to know the process capabilities of the enterprise machinery. The process capabilities of machinery consist of the process capabilities of each machine tool, which means the list of the subjects of production of particular range of sizes, accuracy and roughness with particular parts dimensions. The process capabilities of the machine tool should be reflected in the formulation of its purpose. The analysis of formulations of purposes of various types of machine tools has shown that they contain no information about process capabilities of the machine tools. As an example, the table 1 shows the formulations of purposes of three different types of machine tools which do not clearly set out, what kind of surfaces can be manufactured at these machine tools and what their characteristics will be.

| Machine tool                  | Formulation of purpose                                                                                                                                                                                                 |
|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Screw-cutting lathe CDE6250A  | Designed for performance of various turning works, including cutting of metric thread, British standard Whitworth thread, modular and pitch thread. It provides the use of the advanced high-speed processing modules with coolant supply, with the use of progressive tools and devices. |
| Vertical milling machine 6P12 | Designed for milling, drilling and boring of parts of any shape of steel, pig-iron, non-ferrous metals, their alloys and other materials. The high-performance drives and improved rigidity of the structure of this reliable tool provides efficient utilization of the mills of high-speed steel as well as supplementary equipment provided with plates of rare and super-hard synthetic materials. |
| IS horizontal boring mill 2A636 | Intended for complex mechanical processing of box-type parts weighing below 12 t.                                                                                                                                                                                                  |
This problem is especially important for multi-purpose machine tools, and, to a lesser degree, for specialized and operational tools.

The ambiguity in the description of process capabilities of the machine tools complicates the choice of machine tools during the designing of parts manufacturing processes, the acquisition of new machine tools, complicates the process audit of the company’s machinery, assessment the possibility of adherence to manufacturing programs and orders.

In view of this fact, the purpose of determining the process capabilities is quite important. To reach the set purpose, the authors have formulated the task to elaborate a method of determining the process capabilities of the machine tool.

2. Methods
The problem of determining the process capabilities of the tool lies in the determination of the subject of production. In the specifications of the purpose of machine tools the subject of predication means a surface, an integrity of surfaces or a part. A part is characterized by almost unlimited diversity of possible structures and their characteristics which are impossible to cover. The integrity of surfaces is characterized by a greater diversity of the surfaces it consists of and their characteristics. The surfaces also feature with unlimited diversity both in geometrical shape and in size and dimension characteristics.

The above-mentioned disadvantages are possible to eliminate using the principle of modular technology, which means that any part can be presented by the integrity of functional surface modules (SM). SM means the combination of surfaces united by joint performance of the service function of the part [1]. The SMs’ main advantage is their limited variety. As per the classification, all SMs fall under three classes: basic, working and connecting ones. Each SM has its own number of standard designs, and each design has its own classification by size, accuracy and roughness.

Taking an SM as a subject of machine tool production, the formulation of process capabilities of the machine should contain the list of the produced SM designs with the ranges of size, accuracy and roughness of surfaces and overall dimensions of the parts manufactured.

3. Results
As a result of the work performed, the authors developed a method for determining the process capabilities of machine tools at the modular level. The initial data are the processing methods implemented using the machine tool, the machining tool used and the technical characteristics of the machine tool. The method consists of the following stages:

- determination of the surfaces manufactured using the machine;
- determination of SMs by the structure of the surfaces manufactured using the machine;
- determination of conformity of positions of surfaces in SM designs with their positions in working space of the machine in the process of production;
- determination of the ranges of SM sizes obtained using the machine;
- determination of achievable accuracy of SM production using the machine.

To test the presented method, the authors chose a vertical milling machine 6P12, widely used in machine-building enterprises.

First, a list of surfaces manufactured on the machine was established. They are determined by the machining methods, the diagrams of shaping movements (DSM) of the tool, and in some cases by the geometry of the machining tools used.

The working bodies of the vertical milling machine 6P12 perform the following shaping movements (figure 1): rotation of the spindle with the tool around Z-axis ($R_{Z}^{T}$); vertical movement of the spindle sleeve ($M_{Z}^{T}$); longitudinal ($M_{X}^{T}$), transverse ($M_{Y}^{T}$) and vertical ($M_{Z}^{T}$) movement of the table with the workpiece.
Table 2 presents the processing methods implemented at the vertical milling machine 6P12, machine DSM for every processing method, processing tool used and the manufactured surfaces.

From the list of surfaces produced at the machine tool (table 2), the authors determined SMs containing these surfaces: B11, B12, B311, B321, B51, B52, R111, R112, R121, R21, P22, C111, C112, C121, C21 и C22.

Table 2. Surfaces manufactured at the machine 6P12.

| Processing method | DSM | Machining tool | Surface manufactured          |
|-------------------|-----|----------------|------------------------------|
| 1. Milling        | $R_Z^S, M_X^T$ | face mill, end mill | Flat outer surface |
|                   |      | mills: end mill, angle mill, T-slot cutters | Flat inner surface |
| 2. Drilling       | $R_Z^S, M_Y^T$ | face mill, end mill | Flat outer surface |
|                   |      | mills: end mill, angle mill, T-slot cutters | Flat inner surface |
|                   | $R_Z^S, M_X^T, M_Y^T$ | end mill | Shaped closed-contour surface |
| 3. Boring         | $R_Z^S, M_Z^S$ | twist drill, countersink | Cylindrical inner surface |
|                   |      | boring head | Cylindrical inner surface |

At the next stage, the conformity of the surfaces in the SM structure to the surfaces they occupy in the machine tool workspace during the manufacture was determined.

To check the structure, the SM is conditionally placed on the diagram of the machine tool workspace so that one of the SM surfaces to occupy the position providing its manufacture. After that, the other SM surfaces are checked for compliance with the position necessary for its manufacture. If the position of at least one of the SM structure surfaces does not correspond to the necessary position, such SM structure cannot be manufactured at the machine tool.

The ranges of SM sizes obtained at the machine tool are determined from the diagram of the machine tool workspace diagram. The diagram specifies the boundaries of the machine tool workspace, the ranges of it working bodies displacement and, in some cases, the sizes of the working part of the machining tool. Figure 2 presents the diagram with the boundaries of the machine tool.
workspace (WS) and the ranges of displacement of the working bodies of the vertical milling machine 6Р12.

For example, the ranges of dimensions of SP B12, that consists of flat outer surface, are determined by the values of the characteristics of the vertical milling machine 6Р12, presented in the table 3.

| Dimensions | Machine tool characteristics | Value (mm) |
|------------|------------------------------|------------|
| $l$        | Maximal longitudinal displacement of table; Length of the table workspace. | 800 1250 |
| $b$        | Maximal table transverse displacement; Width of the table workspace. | 320 320 |

The next stage in the determination of the process capabilities of the machine tool is the establishment of achievable accuracy of SM production, which depends on geometrical precision of the machine tool, because at the finishing processing modes, when maximal accuracy is obtained, the effect of other factors is negligible. In turn, the geometrical accuracy of the machine tool is characterized by accuracy parameters governed by the corresponding standards for each machine tool type.

As per GOST 17734-88 [2], the accuracy of console milling machines is governed by eighteen accuracy parameters, including, but not limited to, the straightness of the table workspace, the straightness of guiding slot, axial runout of milling spindle, radial runout of conical hole of the milling spindle, etc.

SM accuracy is described by the accuracy of dimensions, the accuracy of surface shapes, the accuracy of relative position and the roughness of the surfaces. For example, B12 SM (figure 3) is described by:
- the accuracy of length ($l$) and width ($b$) of the flat outer surface;
- the shape accuracy: the deviation of flatness and the straightness of the flat outer surface;
- the roughness of flat outer surface ($Ra$).
Figure 3. B12 SM draft with accuracy parameters.

It is necessary to establish the indicators of geometrical accuracy of the machine tool affecting the indicators of SM accuracy and to determine the value of their effect.

Table 4 shows the accuracy indicators of the machine 6P12, affecting each accuracy indicator of B12 SM.

Table 4. Machine tool and SM accuracy indicators.

| B12 SM accuracy indicators                      | Machine tool accuracy indicators                                      |
|------------------------------------------------|-----------------------------------------------------------------------|
| 1. Accuracy of dimensions                       | Accuracy of size adjustment of the tool.                              |
| 2. Deviation from flatness of flat outer surface | Straightness of the table working surface in longitudinal and transversal sections. |
| 3. Deviation from straightness of flat outer surface | Straightness and parallel alignment of trajectory of parallel displacement of the table against its working surface; Straightness and parallel alignment of trajectory of transversal displacement of the table against its working surface. |
| 4. Roughness of flat outer surface, Ra           | Axial runout of milling spindle; Radial runout of bearing end of the spindle. |

The values of SM errors arising from the effect of geometric errors of the machine tool are determined by geometric constructions on the diagrams showing the effect of geometric errors of the machine tool on the accuracy indicators of the SM.

As a result, the wording of formulation of the purpose of the vertical milling machine 6P12 will sound as follows: “The machine tool is designed for milling, drilling and boring of the following SMs: B11, B12, B311, B321, B51, B52, R111, R112, R121, R21, R22, S111, S112, S121, S21, S22 on the parts of any shape, made of steel, cast iron, non-ferrous metals, their alloys and other materials”. Process capabilities of the machine should be executed as an appendix to the certificate of the machine tool, which provides a list of SMs manufactured at the machine tool with the ranges of characteristics obtained (dimensions, accuracy and roughness). For example, table 5 presents the characteristics of the B12 SM obtained at a vertical milling machine 6P12.
Table 5. B12 SM parameters.

| SM parameters          | Value   |
|------------------------|---------|
| $l$ (mm)               | 0-800   |
| $b$ (mm)               | 0-320   |
| $IT(l)$                | 6-8     |
| $IT(b)$                | 6-8     |
| $Ra$ (μm)              | 12.5-0.63 |
| Deviation from flatness (μm) | 25-60 |
| Deviation from straightness (μm) | 25-60 |

4. Conclusions
The considered example has shown that the methods suggest can be used for assessment of process capabilities of metal-cutting tools at modular level, reduce the labor intensity of solution of production tasks, related to process capabilities of the machine tools.

References
[1] Bazrov B 2001 *Modular technology in mechanical engineering* (Moscow: Mashinostroenie) p 368
[2] GOST 17734-88 Console milling machines. Standards of accuracy and rigidity (Moscow: Izdatel'stvo standartov)