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# Defining boundaries of CNC turning efficiency

**A A Abrazhenin and N N Trushin**

Tula State University, 92 Lenin ave., Tula, Russia

E-mail: winelless@gmail.com

**Abstract.** The study considers the problem of defining the quantitative value of design complexity of a general mechanical engineering workpiece through the analysis of its three-dimensional electronic model in the absence of statistical data on similar workpieces. During machine-building preproduction there is a need for quick assessment of design complexity of the developed product. Such assessment allows defining the design cost, determining the performance level of a designed workpiece, creating complexity priorities to split the processing operations between manual and NC machines.

## 1. Introduction

The design performance is one of the basic scientific concepts of mechanical engineering technology ensuring the use of design-technology reserves of a preproduction process to solve the tasks aimed at the increase of technical and economic indicators of production.

Besides, in the era of rapidly developing technologies, supply and demand for various products, the key elements include the following: time minimization of production, rational management of production processes.

## 2. Materials and methods

The electronic model of a workpiece corresponding to GOST 2.052-2006 served the source data for the solution of a task to assess the design complexity.

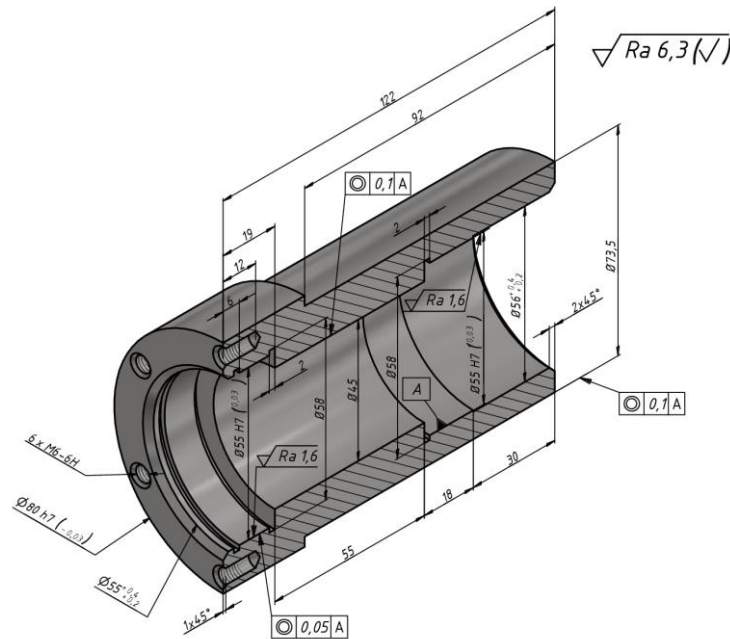
According to the standard, the electronic model of a workpiece contains the following data (attributes):

- description of a 3D geometric configuration;
- material properties;
- dimensional and geometric tolerance;
- surface roughness.

Modern CAD systems allow setting the specified data directly applying it on a 3D model of a workpiece (Figure 1).

Within the given study the geometrical model is designed using a complexity tree of an object realized in such CAD systems as COMPASS 3D, ADEM CAD, SolidWorks, Autodesk Inventor, Solid Edge.





**Figure 1.** Electronic model of a workpiece corresponding to GOST 2.052-2006.

It is especially important for CAM systems when at the early design stage it is possible to solve the issue of applicability of particular equipment and later to desing the technological process taking into account the corresponding equipment.

### 3. Defining the design complexity parameters

The design complexity is defined for workpieces as geometric objects regardless of construction material and processing method, and is expressed by the following ratio:

$$C_k = a \cdot n, \quad (1)$$

where  $a$  – geometrical complexity of some imaginary workpiece having one basic element;  $n$  – number of basic elements of a contour of workpiece geometrics.

According to a known mathematical model of assessing the design complexity [4], it is implied that each separate surface has its own design complexity  $C_i$  and represents a funtion of the following variables:

$$C_i = f(cur, A, N), \quad (2)$$

where  $cur$  – curvature of a separate surface;  $A$  – auxiliary attributive information;  $N$  – number of adjacent surfaces.

Hence, it may be presented as follows:

$$C_i = 2^{cur} + N^2 + T_{dim} + T_{geom}^3 + R, \quad (3)$$

where  $T_{dim}$  – number of dimension limits of a surface;  $T_{geom}$  – number of geometric limits of a surface;  $R$  – coefficient of surface roughness for the considered example  $R=1.2$ .

The complexity of a design element  $F_j$  is defined by the following expression:

$$F_j = \frac{\sum_{i=1}^n C_i}{Ar_j \cdot Mrr_j} + N_a \cdot G_a, \quad (4)$$

where  $Ar_j$  – number of elements in a massif containing  $i$  element;  $Mrr_j$  – number of created mirror reflections with  $i$  element;  $G_a$  – coefficient considering the applicability of construction geometry. It is suggested to accept  $G_a = 1.05$ ;  $n$  – total number of surfaces.

It is obvious that the final complexity of a workpiece consisting of  $m$  elements is defined in the form of a specified sum of difficulties of each design element:

$$C = \frac{\sum_{j=1}^m C_j}{m}, \quad (5)$$

The thread requires particular attention. As a rule, threads of accurate geometry are not designed in CAD but are marked by a symbol with texture. In this regard the thread is considered a special case of a single curvature surface with the coefficient of additional complexity, for instance 1.2.

Applying formulas (3-5), we get the following assessment result of design complexity presented in Table 1.

**Table 1.** Assessment of model complexity

Value	$\sum cur$	$\sum N$	$\sum R$	$\sum T_{din}$	$\sum T_{geom}$	$\sum C$
Outer surface	5	6	0	1	1	19
Inner surface	23	30	2	4	2	91
Facet	2	4	0	0	0	10
Threaded hole	24	36	0	6	0	102
End face	2	4	0	0	0	10
Total	56	80	2	11	3	232

The total design complexity of electronic model of a workpiece equals  $\sum C = 232$ . According to [2], considering such design complexity of the electronic model, the workpiece belongs to the medium complexity group.

#### 4. Defining the performance parameter

According to the regression analysis, it is possible to present the correlation dependence between the output value of machining intensity and the input parameters of a design model. The multiple regression equation may be presented as follows [1]:

$$T = f \left( M, \sum_{i=1}^n F(S_i, Ra_i, t_i) \right) \cdot k_{mam} \quad (6)$$

where  $M$  – weight of a machined workpiece;  $S_i$  – area of  $i$  surface;  $Ra_i$  – required roughness of  $i$  surface;  $t_i$  – accuracy for machining of  $i$  surface;  $k_{mam}$  – coefficient of machinability;  $n$  – number of surfaces of a model subject to machining.

Having solved the equation (1) using the regression analysis it is possible to present the labor input  $T$  as follows:

$$K = a_0 \cdot S^{x_1} \cdot Ra^{x_2} \cdot t^{x_3} \quad (7)$$

$$T = b_0 \cdot M^{y_1} \cdot K^{y_2} \quad (8)$$

where  $a_0$ ,  $b_0$ ,  $x_1$ ,  $x_2$ ,  $x_3$ ,  $y_1$ ,  $y_2$  – coefficients of the regression equation defined experimentally.

The above equations (7) and (8) can be shown as the regression equations for turning of design elements  $T_i$  in Table 2.

**Table 2.** Regression equations to define the turning labor input of basic design elements

Design element	Regression equation
Plane	$T = 10^{3.07} \cdot S^{-0.6} \cdot Ra^{-0.25} \cdot t^{-1.07}$
Cylindric surface	$T = 10^{3.03} \cdot S^{-0.68} \cdot Ra^{-0.34} \cdot t^{-0.72}$
Facet	$T = 10^3 \cdot S^{-0.77} \cdot Ra^{-0.31} \cdot t^{-0.14}$
Through-hole	$T = 10^{3.03} \cdot S^{-0.68} \cdot Ra^{-0.34} \cdot t^{-0.72}$
Curvature	$T = 10^{3.03} \cdot S^{-0.68} \cdot Ra^{-0.34} \cdot t^{-1.07}$
Thread	$T = 10^{3.03} \cdot S^{-0.68} \cdot Ra^{-0.34} \cdot t^{-0.72}$

Thus, using the given formulas in Table 2 it is possible to calculate the total labor input of workpiece machining following the known machining parameters.

$$Y = \sum_{i=1}^n T_i \quad (9)$$

$$T_d = 10^{-1.27} \cdot M^{-0.46} \cdot Y^{2.32} \cdot k_{mat} \quad (10)$$

where  $Y$  – cumulative labor input for separate design elements, min.;  $T_d$  – total labor input of workpiece manufacturing, min.

Then, let us analyze surfaces and parameters of machining. For this purpose, the design model of a workpiece presented in Figure 1 shall be split into elementary surfaces and design elements subject to machining. Let us bring the design elements in compliance with Table 1 to define the labor input.

Let us put the results of surface analyses in Table 3. Surface machining was performed following the 12<sup>th</sup> accuracy degree depending on a surface. Workpiece material: AK12 (AL2), GOST 1583-93. The workpiece weight and machinability coefficient equal to  $M = 0.81$  kg and  $k_{mat} = 0.5$  respectively.

**Table 3.** Characteristics of workpiece design elements

Design element	$S, \text{mm}^2$	$Ra$	$t_i$	Labor input, $T_i$ , min
Outer surface	29566.8	6,3	12	3.17
Inner surface	19128.3	1.6; 3.2	12	5.34
Facets	1021.9	6,3	12	0.55
Threaded holes	1290	6,3	12	2.03
End faces	3450	6,3	12	0.51

According to Table 3 let us define the cumulative labor input for machining of design elements  $Y$  by the formula (9).

$$Y = \sum_{i=1}^n T_i = 3.17 + 5.34 + 0.55 + 2.03 + 0.51 = 11.6 \text{ min}.$$

Then the total labor input of workpiece machining will be defined by the formula (10):

$$T_d = 10^{-1.27} \cdot 0.81^{-0.46} \cdot 11.6^{2.32} \cdot 0.5 = 8.72 \text{ min}.$$

The design labor input counted according to standard time tables equals 9.7 min. Thus, the divergence of results made 11.2%, which is a permissible deviation in calculating the design labor input. Hence, the study shows the adequacy and suitability of the considered technique to define the design labor input of turning for all types of productions, except for bulk production.

## 5. Conclusions

It is accepted to split machining between manual and NC machines on the basis of the developed priorities of machining complexity representing approximate values of some technological criteria. The priority of machining complexity of workpieces is assessed without detailed process design. A similar technique of defining the performance boundaries of CNC machines is described in work [3]. Here each workpiece is assigned with the parameters of constructive  $C_k$ .

Then, the dependence of production labor input  $T$  on complexity of a workpiece  $\sum C$  – for turning of rotation body on CNC machines can be approximately considered linear. The regression equation  $T = f(C)$  serves the boundary line of effective machining. Workpieces machined on CNC machines are defined according to condition  $T \leq f(C)$ .

The disadvantage of this technique is that for each particular case of a machine-building enterprise or in case of major changes of nomenclature of machined workpieces, the equation  $T \leq f(C)$  shall be obtained experimentally over again.

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