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Ways for determining the intermediate dimensions when designing the machining technology

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Abstract. Among other problems to be solved, the design of a technological process of machining by cutting a part involves establishing the dimensions that can be achieved in the pre-final machining of the same surface of the part. There are distinct ways to calculate the so-called intermediate dimensions and, in particular, to define the dimensions for adjusting the position of the cutting tool tip before starting the actual machining process. The paper analyzes some such ways of establishing the intermediate dimensions, highlighting the conditions under which they can be applied, their advantages and limitations of use. Subsequently, the double-entry matrix method was applied to identify one or more methods with wider possibilities of use. It was concluded that the method of tolerance chart and respectively a method that takes into account a statistical processing of the results accumulated over time are methods likely to lead to an efficient solving the problem of determining the intermediate dimensions.

1. Introduction

Over the last decades, it was considered that one of the main aspects specific to the general concept of *machine manufacturing technology* is the concept of *technological process*. Generally, *a process* defines the sequence of states through which a phenomenon or product passes.

There is the convention to use the concept of *production process* to define the assembly of all the technical-productive, interdependent and interconditioned activities, carried out using the means of work, as well as the totality of the natural processes related to the transformation, direct or indirect, of the objects of the work. The transformation is conceived, designed, organized, conducted and executed of people.

The concept of *industrial process* is the process able to generate changes of the materials and substances and such processes could be the cutting processes, the welding processes, the heat treatment, etc.

In an industrial company, there are *base processes* that supposes a direct transformation of the workpieces in finite products (obtaining the workpieces, machining, assembling, dispatching, etc.) and *auxiliary processes* that includes activities of preparing and helping the development of base processes (manufacturing of tools, jigs and fixture, and tools for quality control, repairing and maintenance of equipment, etc.)

The technological process is that component of the production process related only to the activities of direct, quantitative and/or qualitative transformation, of the object of work [1, 2]. This means, for example, the change of the shape, of the dimensions, of the state of the surfaces, of the chemical composition, of the structure, of the physical-mechanical properties, the location in space, etc.

When the problem of designing the technological process of mechanical machining of a workpiece, the main stages to be passed are generally the following: analysis of the initial information (technical drawing, available machine tools and technological equipment, the available staff and the level of qualification of the operators), selecting the type of workpiece, establishing the technological route, calculating the machining allowances and intermediate dimensions, establishing the machining parameters, calculation of the time norm, economical assessment of the technological process and selecting of the optimal version, etc.

The intermediate dimensions are those dimensions obtained by the successive application of different processing in the case of the same surface. The adequate establishing of the intermediate dimensions is important due to its influence on the machining accuracy and the processes productivity.

Over the years, different opinions were expressed about the way of establishing the intermediate dimensions.

Thus, Whybrew et al. they appreciated that the usual elaboration of tolerance charts takes a long time [3]. They proposed a graph-theoretic approach to developing a tolerance chart that could be used for microcomputer-aided design of those charts.

Pairel et al found that frequently the dimensions obtained by processing are related to the surface that locates the part in the workpiece holder [4]. They have developed a methodology that takes into account the identification of the machining groups that must be performed before extracting workpiece from the workpiece holder and the surfaces to be measured. They appreciated that in this way it becomes possible to use higher tolerances of intermediate dimensions.

Thilak considered that to reduce the machining time, an optimal design of the process plan is necessary [5]. He proposed and developed a model for the simultaneous selection of optimum machining datums and machining tolerance using an evolutionary algorithm.

Within the semestrial design activity at the matters of machine manufacturing technology, establishing the intermediate dimensions is usually a problem that can be solved in various ways. The objective of the research whose results were presented in this paper was to analyze and evaluate some of the known solutions of establishing the intermediate dimensions when approaching the design of the technology of a part mechanical machining. Initially, several methods for calculating intermediate dimensions were briefly analyzed. Subsequently, a way of ordering these methods was used (namely the double-entry matrix method), by taking into account a global analysis, but starting from the usual criteria for evaluating those methods.

2. The connections between the intermediate dimensions and the dimension that characterizes the positioning of the cutting tool tip before processing

The intermediate dimensions are dimensions obtained successively during the operations or machining phases of each surface, by removing the machining allowances (fig. 1). From a theoretical point of view, there is a minimal machining allowance that ultimately ensures the placement of the dimensions of the part inside the prescribed tolerance fields. In some cases, the machining allowance is higher than the minimum and it can be removed by several passes (tool strokes), but within the same machining phase.

The intermediate dimensions may be necessary both for the design of tools, devices and measuring tools required by the technological process of obtaining the part, as well as for the design of molds used to obtain the workpieces.

The calculation of the machining allowances and of the intermediate dimensions is made starting from the dimension b_{max} of the part inscribed in the mechanical drawing, in reverse order to the one applied for obtaining a certain surface. In essence, after calculating the nominal machining allowance A_{cnom} (usually equal to the maximum machining allowance), the maximum size is calculated before applying the last machining operation, for example by means of a valid relation in the case of a flat outer surface of the shape:

$$a_{max} = b_{max} + A_{cnom} \tag{1}$$

where b_{max} is the size obtained at the previous step. Next, the so-called nominal dimension must be determined, this being usually the dimension at which the position of the cutting tool tip is set.

It is obvious that the minimum dimension a_{min} will be determined starting from the maximum size a_{max} and from the tolerance T_p corresponding to the machining by which the analyzed surface is obtained:

$$a_{min}=a_{max}-T_p. \tag{2}$$

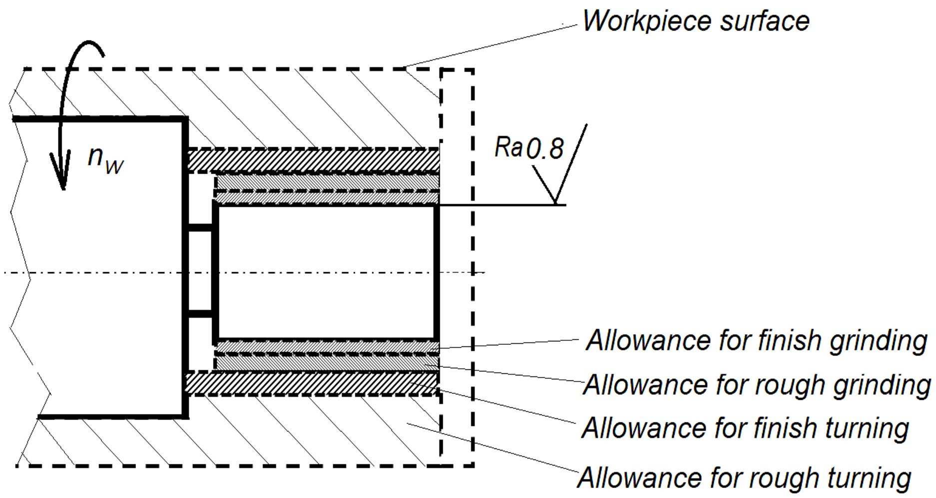

Figure 1. Machining allowances in the case of an external cylindrical surface.

3. Methods for determining intermediate dimensions

At this point, it is possible to consider different situations, mentioned below. It is necessary to mention that the version *A* is valid in the case of individual production, with the individual obtaining of each dimension of the analysed surface, while the other variants can be adopted in the case of automatic obtaining the dimensions, by using a certain adjustment method. of the tool tip to the work dimension [1, 6].

Method A. In the case of individual production, the nominal size can be taken equal to the maximum dimension; once the operator, using the test chip method, has obtained a dimension equal to the maximum allowed dimension, the accuracy requirement valid for the respective surface and for the analysed phase is considered fulfilled.

Method B. In the case of automatic obtaining of the dimensions, the nominal dimension (considered here equal to the positioning dimension of the cutting tool tip) can correspond to the dimension in the middle of the tolerance field (fig. 2):

$$a_{nom}=a_{max}-(1/2)T_p. \tag{3}$$

The argument of such an option considers a possible normal dispersion of the dimensions of the machined surface around this average dimension, which would mean the most convenient situation from the point of view of framing the dimensions of the machined parts in the tolerance field prescribed for the dimension in question.

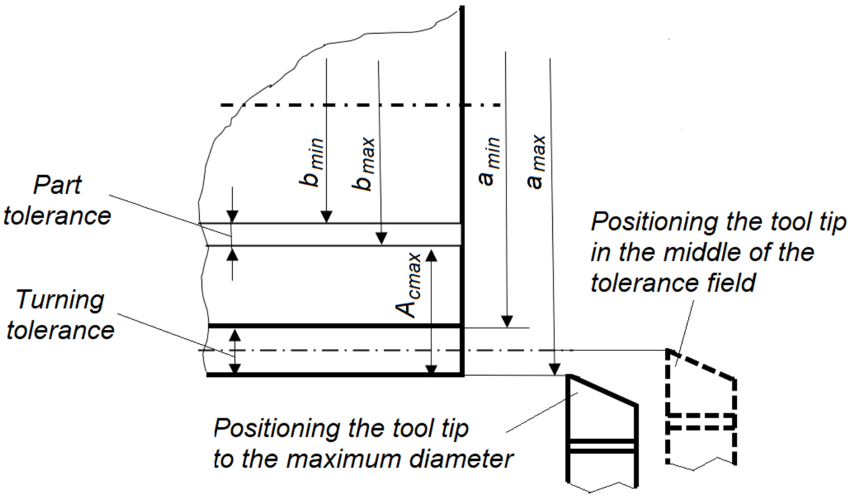

Figure 2. Positioning the turning tool tip when obtaining an intermediate dimension.

Method C. If in the case of automatic obtaining the dimension it is estimated that the wear of the cutting tool tip could have an important role, it is possible to recommend that the nominal dimension be located at 2/3 of the tolerance field T_p in relation to the maximum dimension a_{max}:

$$a_{nom}=a_{max}-(2/3)T_p. \tag{4}$$

It is appreciated that, in this way, even with the evolution of tool wear (cutting along the direction of the dimension to be obtained), it is possible to obtain a maximum number of dimensions of the machined parts within the prescribed tolerance field.

Method D. A fourth variant of calculation of the nominal size a_{nom} takes into account a possible initial expansion of the cutting tool, which would lead to a decrease in the dimension of the machined surface and only then to intervene decisively the wear of the cutting tool tip, which would determine a gradual increase and possibly in accordance with a certain law of evolution (in accordance with the law of wear of the cutting tool) of the dimension of the machined surface. It is now recommended that the nominal size be about one-third of the tolerance range relative to the maximum dimension a_{max}:

$$a_{nom}=a_{max}-(1/3)T_p. \tag{5}$$

Method E. A fifth variant is even more complex, taking into account aspects of statistical nature valid in the case of adjusting the position of the tool tip to the machining dimension by using the test method:

$$a_{pos}=a_{min}+ks \tag{6}$$

in which a_{pos} is the dimension of positioning the cutting tool tip, k is a coefficient determined statistically, as a result of research specific to different machining processes and s is an approximate value of the standard deviation that characterizes the instantaneous dispersion of the dimensions when developing the machining process on a certain machine tool [1, 7, 8].

Method F. Another option for establishing the intermediate dimensions and their related tolerances is applied in some of the economically advanced countries [9, 10]. This version corresponds to a design stage of the technological process called "tolerance charting". After *Part Design Analysis*, the following steps must be completed: *1. Processing*, in which the operations and their contents are described; *2. Strip Layout*, materialized by the elaboration of a set of machining schemes, with the tools tip at the end of the work stroke and with the highlighting of the quotas characteristic of the machined surfaces; *3. Tolerance Chart Form*, when a somewhat standardized form is prepared for further use; *4. Show Strip Layout Data on Tolerance Chart Form*, in which the form is partially completed using certain agreed

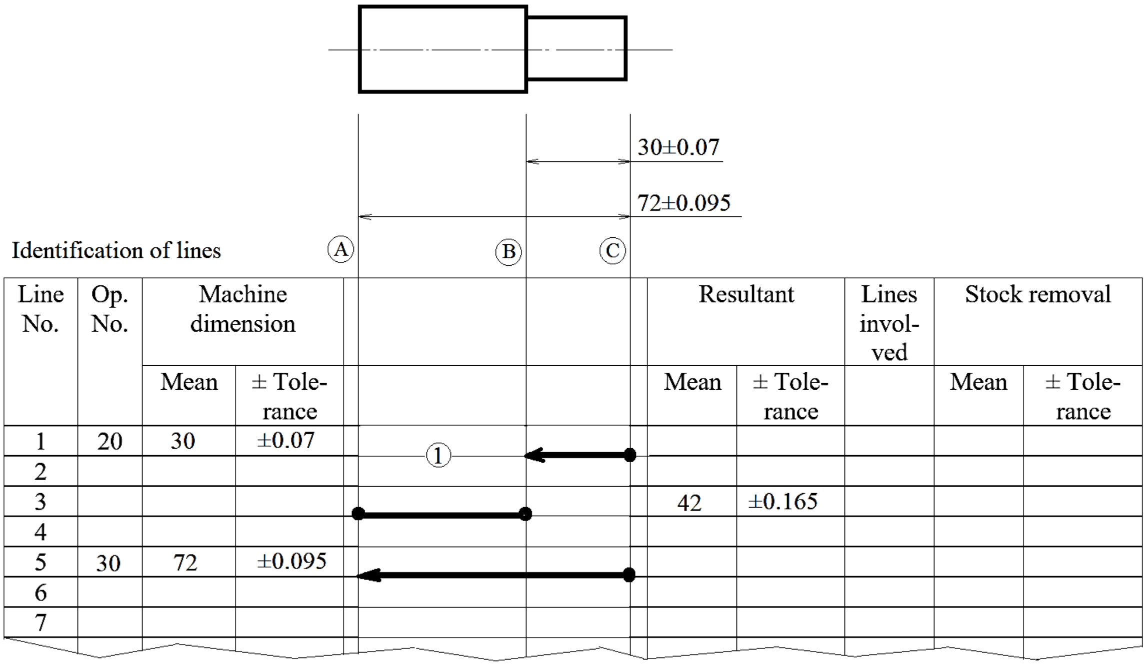

Figure 3. Fragment of the tolerance chart form valid for turning of a cylindrical shaft type part in two-stage (adapted from [9]).

symbols; *5. Calculation of the Resulting Dimensions*, when what we call intermediate dimensions are calculated; 6. *Calculation of the Stock Removal; 7. Indication of the conclusions of Tolerance Charting*, materialized by entering additional information in the standard form; *8. Adding Part Design Dimensions and Tolerances*; *9. Determination of Actual Dimensions and Tolerances and Comparison with the Part Design Specifications; 10. Making Any Required Changes and Corrections*. A fragment of a final form resulting from the application of the steps mentioned above is shown in Figure 3.

4. Comparison of different methods for determining intermediate dimensions

Most of the methods mentioned above are applicable in specific cases (individual or series production, taking into account thermal expansion and tool wear, etc.). An overall evaluation of these methods should take into account several distinct criteria (duration of necessary calculations, need to perform preliminary tests, need to use statistically determined tables, application limits, etc.).

Accepting the risk of a subjective evaluation of these methods for determining the intermediate dimensions, the double-entry matrix method was used to achieve an ordering of the respective methods (Table 1). In this sense, a comparison of the methods was used according to the principle of comparing each with each, granting and entering in Table 1 evaluation marks of type 1-0, when the first method is considered more advantageous, 0-1 then when the second method is appreciated as more convenient and 0.5-0.5, respectively, when the two compared methods are considered to be of equal importance. The entry of the results of the comparisons in Table 1 was made taking into account first of all the information along a column, so that in an additional line of the table it is possible to enter the sum of the marks given to each method. A relative value (a so-called importance coefficient) was used to order the methods, determined as a ratio between the sum of the marks given to each method and the total number of comparisons made. This number of comparisons N_c is determined using the relationship:

$$N_c = n\,(n-1)/2 \qquad (7)$$

where n corresponds in this case to the number of methods compared. For the 6 methods that were considered, the number of comparisons is equal to $6{\cdot}5/2 = 15$.

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In the penultimate line of Table 1, a relative value having the significance of a coefficient of importance was included. Based on this importance coefficient, the order of the methods considered was introduced in the last line of the table. It can be seen that the assessment leads to the finding that a greater applicability seems to correspond to methods *E* and *F*, of course with the consideration of a certain degree of subjectivism in the action of comparing the methods two by two.

Table 1. Use of the double entry matrix method to compare the ways of determining the intermediate dimensions.

Method	*A*	*B*	*C*	*D*	*E*	*F*
A	X	0.5	0.5	0.5	1	1
B	0.5	X	0	0	0.5	1
C	0.5	1	X	0.5	1	1
D	0.5	1	0.5	X	1	1
E	0	0.5	0	0	X	0.5
F	0	0	0	0	0.5	X
Sum of marks	1.5	2.5	1.0	1.0	4.0	4.5
Coeff. of importance	0.1	0.16	0.06	0.06	0.26	0.3
New order of methods	*F – E -B – A – C or D*					

5. Conclusions

In the context of the elaboration of the technology of mechanical machining by cutting of a part, one of the problems that must be solved is that of determining the so-called intermediate dimensions. The correct establishment of the intermediate dimensions is important given their use when adjusting the positions of the cutting tool tip, before starting the actual machining. Over the years, various methods of calculating the intermediate dimensions have been proposed and used, by taking into account certain proper conditions specific to the analyzed machining process. Several such methods have been briefly approached and characterized. Formulating the requirement for an ordering of these methods by applying a global evaluation method, the double-entry matrix method was used. Considering the possible application in the context of educational activities in the field of manufacturing engineering, it was appreciated as more convenient the method of tolerance chart and a method based on statistical processing of practical information accumulated up to a certain moment. In the future, there is the intention to identify and use optimal methods for determining the intermediate dimensions, so as to obtain a minimization of the process time and processing cost.

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