Journal of
MECHANICAL and ENERGY
ENGINEERING

ISSN: 2544-0780 | e-ISSN: 2544-1671
Vol. 1(41) | No. 2 | November 2017
pp. 135-140

ESTABLISHING THE OPTIMUM STRUCTURES OF TECHNOLOGICAL PROCESSING OF MACHINE TOOLS FOR THE MACHINING CENTER

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(Received 10 June 2017, Accepted 8 July 2017)

Abstract: The following paper presents the processing of the piece on the machining centre. When the technological dimensional structures are optimal, they are similar to the dimensional structure of the piece. This similarity is ensured by using a marker of the machining centre – the axle of the revolving table. However, the piece has to be resized. It can be done in several variants with different machining accuracy required.

Keywords: machining, technological dimensional structures, design dimensional structure

1. INTRODUCTION

A method of graphs [1] is commonly used as a tool for the process analysis. In the classic version, the method involves drawing the graphs of technological dimensional links for the already designed operations and compares them with the graph of constructive dimensional links. The analysis aims to solve the dimensional chain that consist of the closing element (constructive size) and components (technological sizes). If the result of analysis is unsatisfactory, the technological operation is not validated and the next iteration is proposed.

In the contemporary version, this method provides the design of processing operations with similar technological and constructive graphs. The graphs similarity is ensured also by constructive resizing. Thus, the dimensional analysis (verification) is replaced by dimensional synthesis (design).

2. PROCESSING TECHNOLOGY WITH OPTIMAL DIMENSIONAL STRUCTURES

It is known that the manufacturing process is considered optimum, if for all technological dimensional chains, the number of the technological sizes is minimum [2]. This condition is fulfilled, if, within the technological dimensional chain, for each constructive size there is a unique technological size; and for dimensional chains, each machining allowance is determined by two technological sizes or one technological size and one blank size. The last one has two technological sizes developed at the other phase of a manufacturing process. The minimum possible number of the technological sizes $N_{T_{MIN}}$ is determined from the relation:

$$N_{T_{MIN}} = N_C + 2 \cdot N_{Ad}, \qquad (1)$$

where:
N_C – number of constructive sizes,
N_{Ad} – number of machining allowances.
The optimum manufacturing process becomes ideal, if each surface is processed only once, thus providing the final constructive size [2].

One of directions to create the optimum technological processes is the observance of a similarity principle of the technological and constructive dimensional links graphs. Let's consider this approach using an example of a construction and of a technology of a detail machining (Fig. 1).

The graph of linear constructive dimensional links (Fig. 2a) has two poles (important constructive bases which should be used as technological bases). On the lathe processing technological contact base (*TCB*) the surface of the part (blank) is contacting with the front surface of the chuck. Technological contact base is also the base of dimensional reference by which the relationship between the dimensional systems of the workpiece and machine tools is developed.

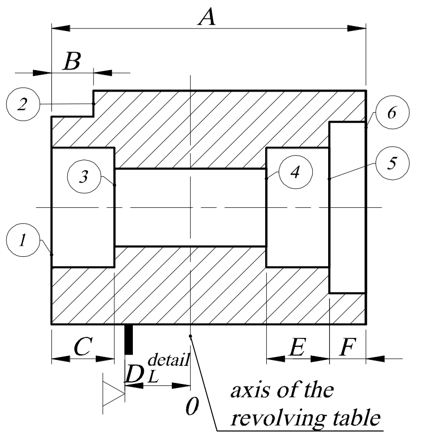

Fig. 1. Location of detail body at axis of revolving table

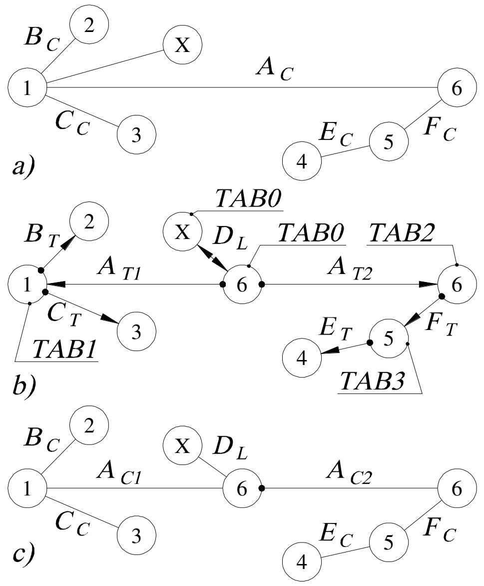

Fig. 2. Graphs of linear dimensional links: a) graph of linear constructive dimensional links; b) graph of linear technological dimensional links, c) graph of linear constructive dimensional links after resizing

In the processing of parts on machining centres, the technological contact base is a surface of the part (blank) coming in contact with a support surface of the device structure (Fig. 1). The difference (on the lathe processing) is that the axis of revolving table is the baseline to make the link between the dimensional systems of machine tools and workpiece. Thus, between the dimensional systems of machine tools and of workpiece there is an intermediate element, a dimension D_L^{detail} developed in the structure of the device by the size D_L^{device}.

In the process (Fig. 2), the centre of rotation of the revolving table 0 serves as initial technological adjusting base (*TAB*0), at which the technological size A_T is developed in two stages by rotating the table by 180°. The size A_T consists of two parts A_{T1} and A_{T2} (Fig. 2b). From the initial technological adjusting base *TAB*0 the technological size A_{T1} is developed (surface 1 is processed), then surface 1 becomes the technological adjusting base *TAB*1, from which the sizes B_T and C_T are successively developed (surfaces 2 and 3 are processed). After another rotating the table by 180° at the initial technological adjusting base *TAB*0 the technological size A_{T2} is developed (surface 6 is processed); surface 6 becomes the technological adjusting base *TAB*2, from which the size F_T is developed (surface 5 is processed); surface 5 becomes the technological adjusting base *TAB*3, from which the size E_T is developed (surface 4 is processed). Thus, it can be concluded that the processing of body parts on machining centres requires the resized piece right from the start, as shown in Figure 2c.

Analyzing Figure 2, it can also be concluded that the need for resizing the piece supplementary for surface *X*, which initially is spotted on the surface 1 to be spotted from the axis 0. The role of the surface X can be played by any surface, including 1 and 2.

2.1. The constructive resizing for technological reasons

The constructive resizing of the part aims to replace one size with another so that dimensional systems of the initial part are equivalent again (Fig. 3).

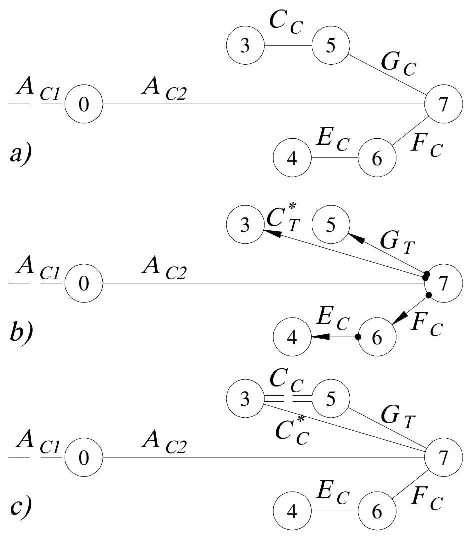

Fig. 3. Graphs of linear dimensional links: a) graph of linear constructive dimensional links; b) graph of linear technological dimensional links, c) graph of linear constructive dimensional links after resizing

Equivalence provides that the technical requirements on dimensional accuracy in accordance with the initial drawing of the part are totally realized. However, in certain cases, more accurate replacing sizes are insignificant.

During the resizing, the replaced size becomes the closing of dimensional chain, that consist of the replacing size (technologically favourable) and other constructive size that makes the connection between the first two.

This condition must be respected $\omega_{C_C} \geq \omega_{C_C^*} \cdot \omega_{G_C}$, in other words, the tolerance of the replaced element must be equal or more the sum of tolerances of the new elements. Otherwise, the replacement does not constitute an equivalent dimensional systems with the replaced.

During the resizing two special situations may manifest:

– the tolerance of the replaced size is sufficiently large and allows to fulfil the condition $\omega_{C_C} \geq \omega_{C_C^*} \cdot \omega_{G_C}$ without changing (increasing) the accuracy of the size ω_G (ω_{G_C} remains the same), and the accuracy of the replacing size ω_{C^*} ($\omega_{C_C^*}$) is acceptable in the context of the accuracy developed for other sizes. Then it is acceptable that $\omega_{C_C^*} = \omega_{C_C} - \omega_{G_C}$;
– the tolerance of the replaced size C_C is not sufficiently small and allows to fulfil the condition $\omega_{C_C} \geq \omega_{C_C^*} + \omega_{G_C}$ only if the accuracy of the size G_C increases (ω_{G_C} decreases), thus the accuracy of the replacing size C_C^* ($\omega_{C_C^*}$) becomes unacceptably large in the context of the accuracy developed for other sizes. In this case the rule of development becomes valid for both sizes ("replacing" C_C^* and "connection" G_C) to the same level of accuracy. As it can be seen, increasing of the processing accuracy is the case.

If the situation described in point 1 is achieved on each of the lines (7-5-3, the sizes G_C, C_C and 7-6-4, the sizes F_C, E_C, Fig. 3), then resizing can be made on one line or another (whatever). If the situation described in point 1 is achieved only on one line – it becomes a priority for resizing. If the situation described in point 2 is achieved on both lines, then it becomes the priority to resize the line that requiring a smaller increase of accuracy of machining.

The dimensional structures are very diverse and there may be more resize lines. Some lines may require a double, triple or multiple resizing.

2.2. Developing the "replacing" and "connection" technological sizes at the same level of accuracy

It is known that the level of accuracy (tolerance) is characterized by the number of tolerance units a and IT6 level with the geometric progression ratio $q = 1.6$. Unit of tolerance i (for the range of nominal sizes up to 500) is calculated from relationship $i = 0.45\sqrt[3]{N} + 0.001 \cdot N, \mu m$.

The tolerances of the sizes "replaced", "replacing" and "connection" (Fig. 4) will be respectively: $\omega_{C_C} = a_{C_C} \cdot i_{C_C}$, $\omega_{C_C^*} = a_{C_C^*} \cdot i_{C_C^*}$, $\omega_{G_C} = a_{G_C} \cdot i_{G_C}$.

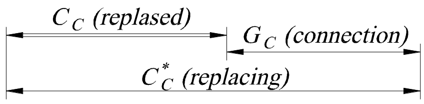

Fig. 4. Dimensional chain for resizing

$a_{G_C} = a_{C_C^*} = a^*$ reflects the equality of the level of accuracy for the sizes C_C^* and G_C. Units of tolerance values are different $i_{C_C^*} \neq i_{G_C}$ due to different nominal sizes. $\omega_{C_C} = \omega_{C_C^*} + \omega_{G_C}$, thus $a_{C_C} \cdot i_{C_C} = a_{C_C^*} \cdot i_{C_C^*} + a_{G_C} \cdot i_{G_C} = a^* \cdot \left(i_{C_C^*} + i_{G_C}\right)$. Then, the number of units of tolerance for "replacing" and "connection" sizes will be:

$$a^* = a_{C_C} \cdot \frac{i_{C_C}}{i_{C_C^*} + i_{G_C}}, \tag{2}$$

$$\omega_{C_C^*} = a^* \cdot i_{C_C^*}, \tag{3}$$

$$\omega_{G_C} = a^* \cdot i_{G_C}. \tag{4}$$

2.3. Constructive resizing of the detail according to its relative position to the axis of the revolving table

While working on machining centre (Fig. 1), the resizing is made to obtain the two replacing components (Fig. 5). If in the resizing discussed above the nominal of the replacing size was determined from the relation $C_C^* = C_C + G_C$ (Fig. 4), then, in this case, there is a certain liberty in determining the nominal values of the replacing sizes.

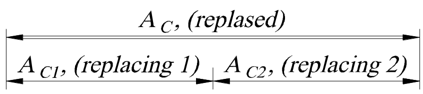

Fig. 5. Dimensional chain for resizing in case of machining a part on revolving table

Any variant of size replacing ratios is possible, including an option when one is null. It would mean that the rotary table axis plane belongs to one of the processed surface. The position of the part with respect to the rotary table axis depends on measure of increasing the processing accuracy after resizing (Fig. 6). If the axis of rotary table belongs to a processed surface ($A_{C1} = 0$ or$A_{C2} = 0$), it does not increase the processing accuracy. If $A_{C1} = A_{C2} = 0{,}5 \cdot A_C$, then the processing accuracy increases by almost one level.

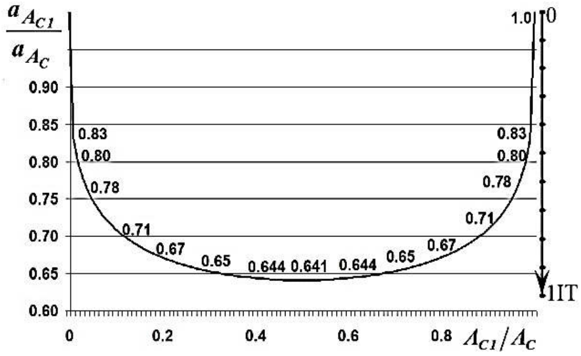

Fig. 6. Reducing number of units of tolerance depending on position of axis (A_{C1}) of revolving table within size A_C

There may be cases when the revolving table axis is located outside the boundaries of constructive size (Fig. 7).

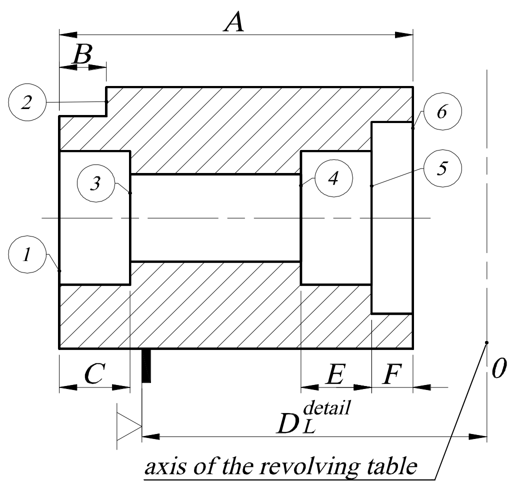

Fig. 7. External location of detail-body at axis of revolving table

The resizing dimensional chain is given in Figure 8. The replacing sizes can be quite great and the resizing requires a higher accuracy of processing (Fig. 9).

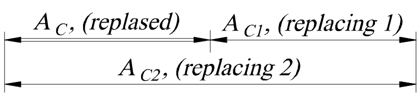

Fig. 8. The dimensional chain for resizing in the case of machining a part on the revolving table with external axis

3. THE DIMENSIONAL DEVELOPMENT OF MACHINING TECHNOLOGIES

Recently to traditional production are adapted also the corresponding methods of designing of technologies. Usually, there is a short period of time for the technological preparation to manufacture. Thus, it is possible to consider only a few variants of technology and to develop only one of them.

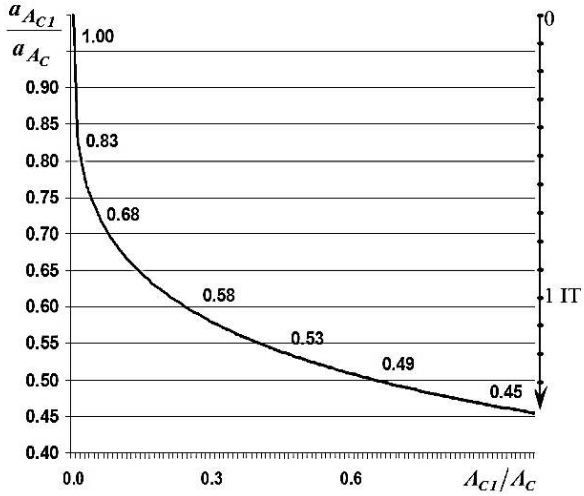

Fig. 9. Reducing number of units of tolerance depending on position of external axis (A_{C1}) of revolving table within size A_C

This variant of technology is the subject of improvement during application. It can be done by revealing weaknesses in the conditions of the limited field of allowable technological decisions (equipment is already provided, and adaptations and means of measurement are already made). First, the design drawing of the detail by the functional criterion is done (form, structure of surfaces, sizes, accuracy, roughness and technical requirements). Then, technological processes of machining with improvement of the general adaptability to machining without changing the functionality are developed. After approbation of the detail's working drawing, it involves the following series of tasks:

- analysis of design drawing of detail and of its technical requirements;
- improvement of adaptability to machining without changing functionality;
- choice of method of development, kind, form and accuracy of blank;
- choice of number of technological operations and sequences of machining of basic surfaces of detail;
- division of technological process into stages (rouging and finishing);
- development of variant of plan of operations;
- dimensional analysis of variant of technology;
- choice of machining equipment;
- choice of adjusting and measuring bases;
- development of operational sketches and of technical requirements on operation of technological process;
- calculation of machining allowances, operational sizes and tolerances;
- calculation of cutting conditions, norming of technological operations;
- economic analysis of technological operation;
- development of technological documentation.

The analysis of a working drawing of a detail and technical requirements is carried out by the technologist. It has a familiarization character, since it only overviews the elements of a detail's design. As a matter of fact, it can be only superficial as the working drawing is already authorized and serious grounds are necessary for its change, but they are still not present.

The dimensional analysis of technological processes is carried out at late stage of technology development and actually has a checking character and low efficiency. In the case of revealing discrepancies the new variant of technology without special guarantees on achievement of qualitative result is developed. The satisfactory result is achieved for some iterations. The big labour input required for constitution of the schemes of dimensional technological links and the dimensional increases the time of technology development and provides an acceptable (but not optimum from the point of view of sizes accuracy assurance) variant of technological process. The lack of such approach means that the dimensional structure of a detail is taken into account insufficiently and practically is not analysed. However, if such analysis is carried out, it has an ascertaining character.

Thus, the dimensional designing of technological processes results in an optimal (if it is possible to achieve) similarity of design and technological dimensional structures in the following order:

- creation of blank's dimensional structure similar to detail's dimensional structure;
- development of optimum technological dimensional links of first technological operations (roughing) by resizing if necessary of blank and detail;
- development of optimum technological dimensional links on subsequent technological operations by resizing (if necessary) detail in progress;
- development of optimum technological dimensional links on final technological operations by resizing (if necessary) detail;
- calculation of minimal machining allowances;
- dimensional analysis of technology with calculation of operational sizes, tolerances and deviation limits;

4. DESIGN OF THE MACHINING TECHNOLOGIES WITHIN THE CONCEPT OF CONCURRENT ENGINEERING

The concept of Concurrent Engineering implies simultaneous design of the parts and the processes of their machining. Favourable conditions for this exist when a 3D assembly is created from separate details (3D models). The structure and its parameters (including dimensions and accuracy), however, may undergo changes.

Figure 10 shows the schemes reflecting the differences between the various methodologies of design: sequential (linear), the pseudo-Concurrent Engineering and true-Concurrent Engineering.

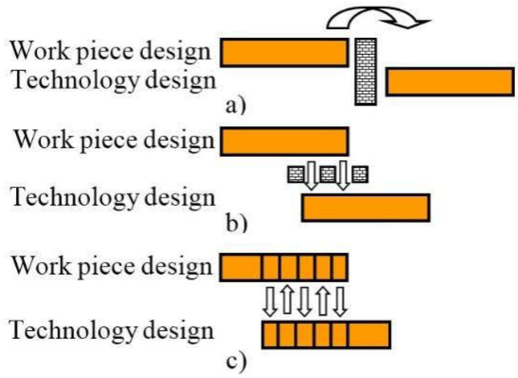

Fig. 10. Methodologies for development of technologies: a) linear; b) simultaneous – pseudo Concurrent Engineering; c) true Concurrent Engineering

The linear scheme of designing has an information barrier associated with the incompatibility of information presented in the different models etc.

Pseudo Concurrent Engineering scheme allows some overlap of project activities in relation to the piece and technology. At the same time, there are a variety of information barriers that slow down exchange the of information or the information has a high degree of variability.

Truly Concurrent Engineering methodology is characterized by the lack of any kind of information barriers. Moreover, the constructive elements of details and the elements of the technology have a high level of informational completeness and the variability refers to the interconnected parameters.

For realization of an effective process of technology development within the framework of Concurrent Engineering it is necessary to achieve the results for the individual steps and the images of their information in accordance with the principles of axiomatic design: independence of the output parameters and minimal information content.

The most important task, thus, is to determine the entities of details, appropriate entities of the technology, and connection and interaction between them.

The technological process as a system includes its own subsystems on the next level of decomposition – manufacturing operations. The decomposition process can be continued further, highlighting: mounting, working position, operation element etc.

The informational interaction between the piece and technological system can be traced by analysing the levels of the detail's description and technological system. Any technical object can be described functionally, structurally and technologically (Fig. 11). The functional description defines the content of the constructive (structural) description and the last in turn – the technological description.

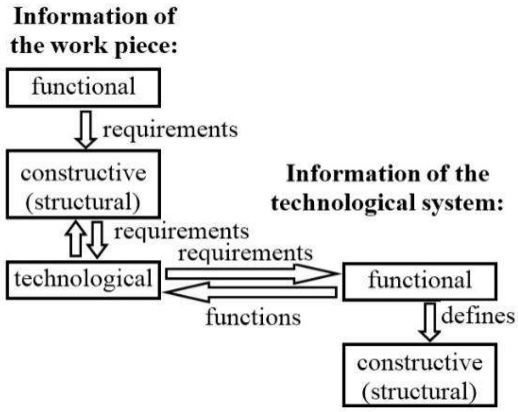

Fig. 11. Relationship between information about work piece and created technological system.

It can be argued that the design of the technological process initially acquires the character of a description of what should happen with a detail in the process of its transformation from a blank – the technological aspect of the piece. The preferred way to do this is establishing a pairs of "surface – operation element" in reverse chronological order, i.e. from the finished detail. This process is more uncertain when applied to the surfaces of the blank because the blank has a structural and qualitative variability depending on the method of obtaining. At this stage, it takes into account the influence of the equipment's characteristics on the characteristics of operation elements. However, in the computer-aided design the multiplicity of options makes it difficult. As mentioned above it is very important to follow the principles of axiomatic design.

Technological process may be built from operation elements, but they do not have the necessary characteristics to create the dimensional structures. These characteristics are not developed during decomposition, because the relevant details of dimensional structure are not taken into account.

5. CONCLUSIONS

1. General direction of development of optimum technological processes is similarity of graphs of constructive and technological dimensional links.
2. While machining on revolving tables, constructive resizing is imminent to make similarity of graphs of technological dimensional links with graph of constructive dimensional link possible.
3. Recalculation of sizes is on a line with least accuracy.
4. Traditional method of designing of machining technologies is directed to guarantee achievement of quality parameters.
5. Modern techniques of machining technologies development are based on principles of Concurrent Engineering and considerably early application of tools of dimensional analysis.
6. Method discussed in this paper aims to apply dimensional analysis as tool for dimensional designing.
7. For guaranteed assurance of dimensional accuracy it is necessary to adapt mutually technological dimensional structures of operations with design dimensional structures of entities (preparation, detail in process, detail) received after previous operations including resizing of these entities.

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Biographical note

Ion Stîngaci received BSc (2009), MSc (2011) and DSc (2012) at the Technical University of Moldova. Since 2006, he is a researcher at the Department of Machines Construction Technology at the Technical University of Moldova, where currently he works as a lecturer professor. His scientific interests focus on ensuring precision in machining and assembly using dimensional analysis. He participated in 1 international and 4 national research projects, presented results of his work at 4 international and 15 national conferences, published more than 46 scientific papers in international and national journals, book chapters, as well as conference proceedings. He is also the author of 2 methodical indications and 7 national patents.