Aspects concerning verification methods and rigidity increment of complex technological systems

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Abstract. Any technological process and technology aims a quality and precise product, something almost impossible without high rigidity machine tools, equipment and components. Therefore, from the design phase, it is very important to create structures and machines with high stiffness characteristics. At the same time, increasing the stiffness should not raise the material costs. Searching this midpoint between high rigidity and minimum expenses leads to investigations and checks in structural components through various methods and techniques and sometimes quite advanced methods. In order to highlight some aspects concerning the significance of the mechanical equipment rigidity, the finite element method and an analytical method based on the use Mathcad software were used, by taking into consideration a subassembly of a grinding machine. Graphical representations were elaborated, offering a more complete image about the stresses and deformations able to affect the considered mechanical subassembly.

1. Introduction

The stiffness criterion of the machine tools together with resistance criterion are ones of the most important criteria to be followed during the process of designing a mechanical equipment. The role of the rigidity is steadily increasing, on the one hand, due to increasing of requirements for precision, and in connection with stopping the growth of the elastic modulus of the material, at the same time with the increasing of the resistance characteristics. In the machine tools building industry, the stiffness criterion has an especially important role. Precision machine tools must be designed more massive than conventional machines for one and the same forces and powers [1]. However, the rigidity should not be regarded as an independent criterion. It affects the work of machine tools by means of machining precision, resistance to vibrations and the durability related to the conditions of contact between parts.

The stiffness of the technological system along a given axis means the ratio of the cutting force on the respective axis and the elastic deformation in the same direction:

$$j = \frac{F}{y}, \ N/mm \qquad (1)$$

where F – deformation force and y – deformation, appeared from the action of the deformation.

Stiffness of the elastic technological system definitely affects the entire manufacturing process. The deformation of the system is directly proportional related to the size of forces and decisively to the cutting force component.

Thus, the permanent monitoring of this force variation during the cutting process could highlight the continuous deformation of the system. In order to optimize the grinding process and increase productivity, it is necessary to impose some major requirements aiming increasing system rigidity and keeping constant deformation, reducing the time needed to charge the system until adjusted parameters are equal to the real ones and also to reduce the time needed to detente phase.
Besides static stiffness, we can also mention the dynamic stiffness. Dynamic stiffness is very important in the correct study of the processing precision, especially when considering variations in cutting forces, these forces are compared to their nominal values.
In addition, there is a variation in the time (no inconsiderable):

$$\frac{dF_y}{d\tau} \neq 0 \qquad (2)$$

where dF_y is the variation of the force exerted along the y axis and $d\tau$- a short time interval.
In the study of dynamic stiffness, there is the dynamic component ΔFd that generates a dependence of the machining accuracy on the dynamic characteristic of elastic technological system, evaluated just by the dynamic stiffness and dynamic failure of this system.
The value of system rigidity significantly influences manufacturing accuracy, especially in case of high specific values of the cutting parameters (such is the case of roughing operations). It is evident that only some of the errors that occur during machining process are due to elastic deformations. It is correct that these errors must be only a fraction of the tolerance that has to be ensured. This condition can be expressed as:

$$y_{din} = y_{stat} \cdot \chi \leq y_{adm} \qquad (3)$$

where y_{din} - deformation of system taking into account the dynamic stiffness, y_{stat}- static deformation of system, χ - dynamic coefficient, y_{adm} - the allowable deformation of system.
Cutting machines are complex systems, whose constructive solutions depend on the direction of change of the cutting forces and the positions of the nodes in them can need a variety of joint surfaces, respectively, and various stiffness values could be necessary. Therefore, the experimental tests must be as close as possible concordant to the most realistic typically processing.
Over the years, the researchers were interested to obtain scientific information and to establish mathematical models able to highlight the significance of the concept of the rigidity for the behaviour of the mechanical components and to establish conditions in which a higher rigidity could be obtained.
Thus, Boca developed [1] a research concerning the influence of the rigidity of the universal lathe on the machining accuracy. He proposed some mathematical models able to highlight the influence of the elastic deformation on the machined surface shape in transversal sections and the change of the tool desired trajectory under the action of the cutting forces. Another research subject addressed in [1] referred to the shape error of the machined surface generated by the deformation of the technological system along a radial direction.
Kudoiarov et al. took into consideration the possibilities of diminishing the elastic deformations of the main shaft as a machine tool subassembly during the turning process [3]. A software able to determine the influence of turning conditions on the machined surface errors was proposed, by considering the technological system rigidity. The authors concluded that in order to obtain manufactured parts characterized by a high machining accuracy, information concerning the lathe rigidity must be known and used.
The objective of the research presented in this paper was to apply the finite element method and of an analytical method in order to study some aspects and identify optimized solutions for ensuring a high rigidity of the cutting machine tool components.

2. Verification methods

The research of the static rigidity is performed by experimental methods applied directly on the machine tools and developing spatial mechanical (physical) models or by using theoretical analyses. The total rigidity of the machine tool could be evaluated by measurements developed directly on the machine tool. The balance of the elastic deformations, namely the total amount of movements recorded by the measuring instruments on the workpiece, could be achieved by taking into consideration the individual movements of the support system elements (Figure1).

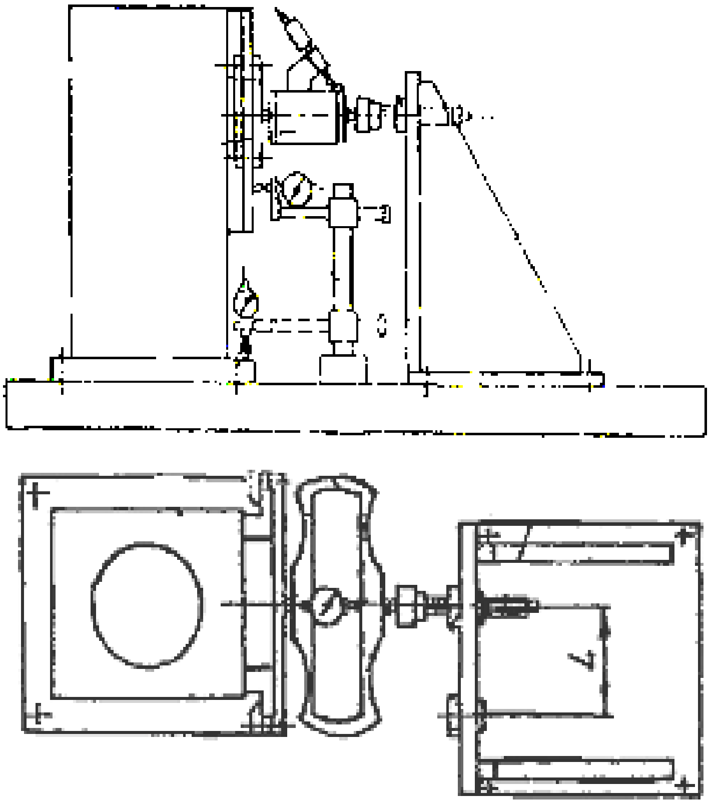

Figure 1. Stand for checking the static rigidity of the physical model

The balance of elastic displacements could be done in the following order:
1) Evaluation of the stiffness of individual elements;
2) Estimation of the rigidity effect of some elements on the total stiffness of the machine tool and subsequently the stiffness increasing of the weak elements;
3) Testing of hypotheses that have been put into the calculation and simplifying/ clarifying the calculation [2].

Depending on each purpose, the movements balance can be done at various levels of detail. In order to obtain an overall distribution of elastic displacements in nodes and to determine the main directions of increasing the rigidity, the overall balance of elastic movements is determined. At the same time, the measuring devices/instruments must be placed so that they ensure the possibility of determining the components of movement of the force application point compared to movements of the main nodes of the machine tool.

If it is necessary to improve the positions of machine nodes (this meaning an increase of machine tool rigidity), to take into consideration the information concerning elements rigidity and the verification of hypotheses initially formulated, the analysis of balance of elastic displacements could be developed in detail. At the same time, the displacements components of forces application points compared to own deformations in elements connections [3] should be considered.

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3. Grinding elastic system - verification

Another methods of checking the deformations are represented by effort method and displacement method used in the strength of materials and applied in order to establish dimensions and to test structures, bars and solid bodies; these methods could be considered as precise methods (figure 2). In order to highlight the deformation of parts that directly support the cutting forces, we will study the system consisting of the motor shaft and abrasive wheel (figures 2-3). We will use in our analysis two methods: finite element method (by means of SolidWorks 2010, Simulation 2010) and analytical method (by means of Mathcad14) software [4], respectively.

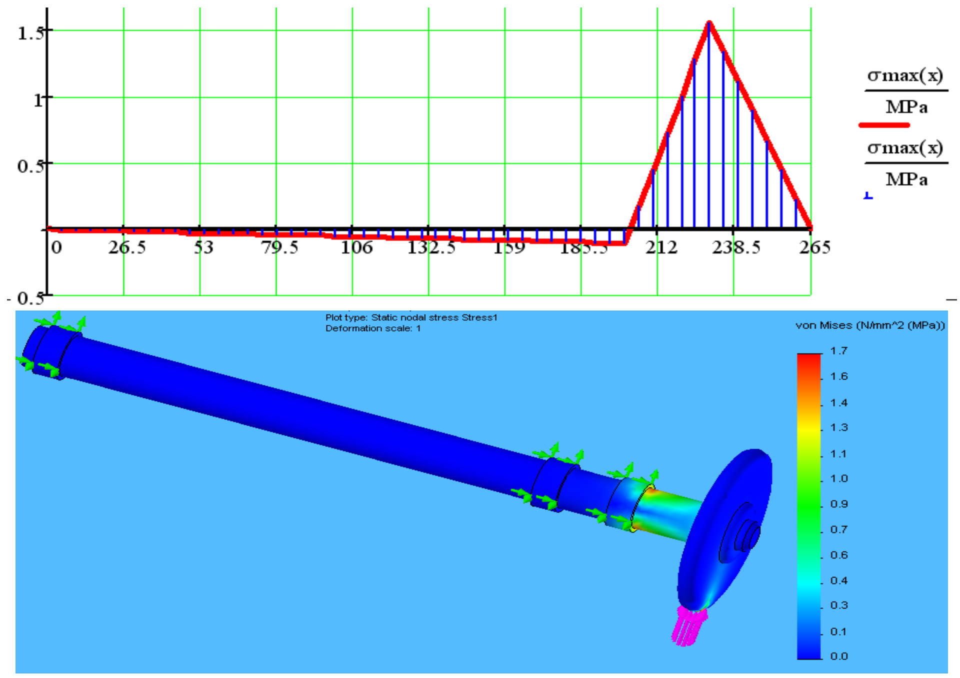

Figure 2. Stress distribution

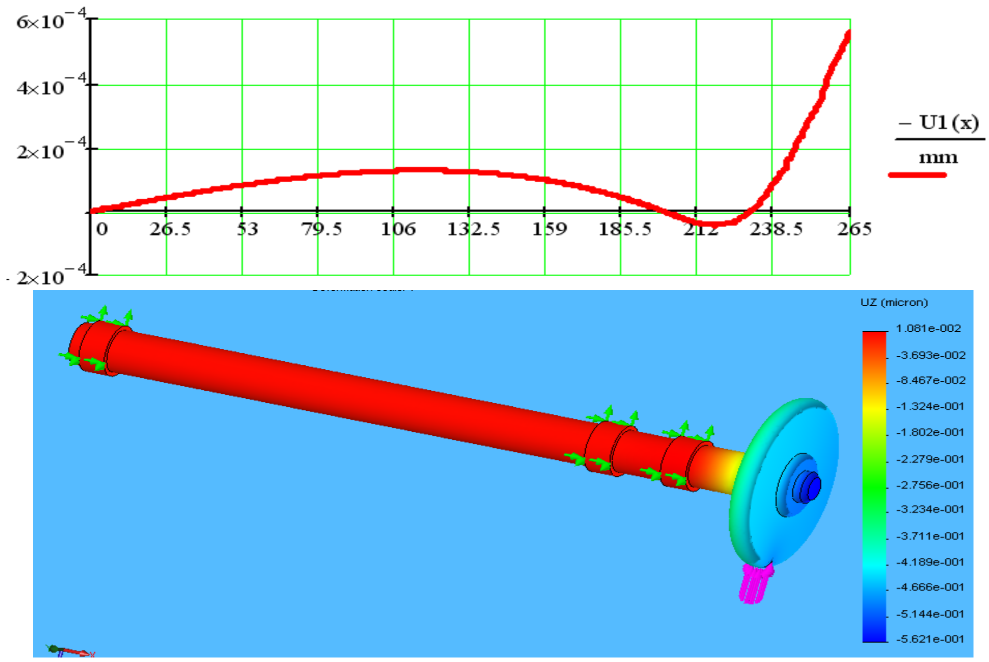

Figure 3. Displacements

The approximate solutions in analytic form are less used. Most often numerical solutions using computers were obtained (figure 4). The existence of a huge number of computer programs and of personal computers have made the numerical methods are very easy to be used obtaining results in a short time. One may show that the results could be offered in a very suggestive and easy to interpret form especially, namely in graphical form (figures 4-5).

The advantage of finite element method (FEM) are numerous and important. When planning a new design, we can model and study the behaviour of the structure in various load environments. Therefore, based on the obtained results, the model can be modified before the execution of the final drawings. Once the CAD model is developed, the design of structure can be analysed in detail applying FEM.

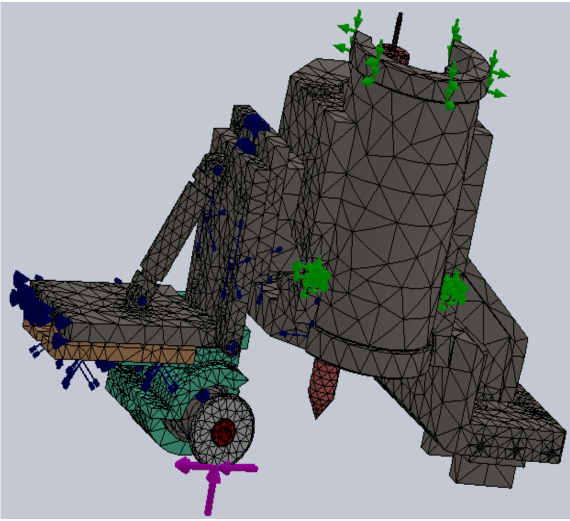

Figure 4. Meshing of CAE model

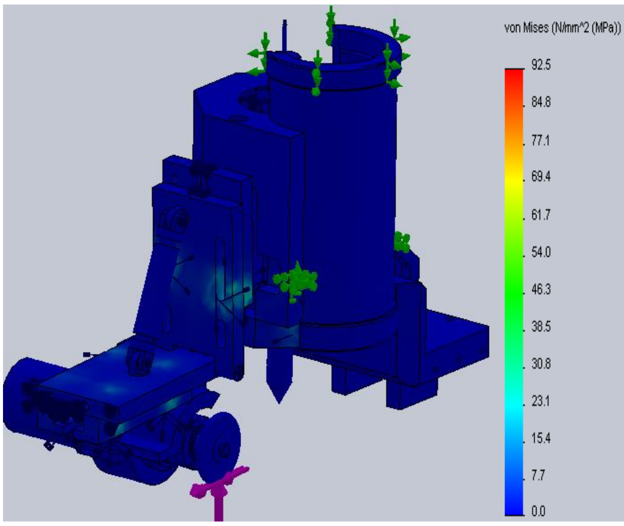

Figure 5. Stress (von Mises)

Using FEM, one can save time and money by reducing the number of required prototypes. In the case of an existing product with certain problems during use, or when improvements are required, the design model could be analysed using FEM, in order to accelerate the design changes and also to reduce design costs.

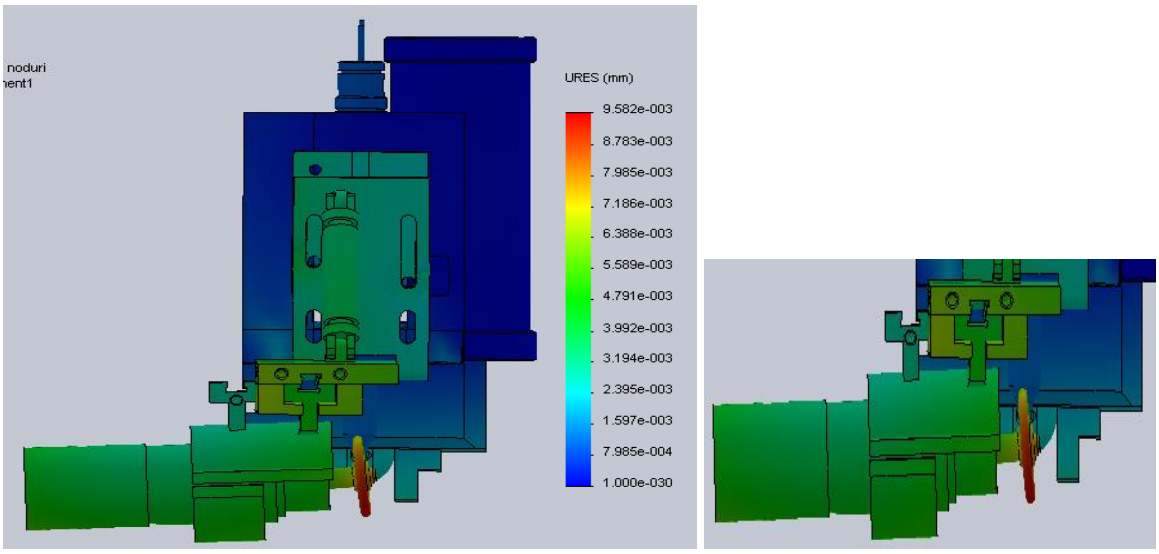

Figure 6. Total deformations of system (CAE model)

Usually the values obtained by means of CAE model (figure 6) and amounts obtained by the classic resistance calculation are very close to each other, and we can say with certainty that a calculation developed by means of FEM is no worse than a classic calculation (even sometimes it has superior advantages, if handled quite well).

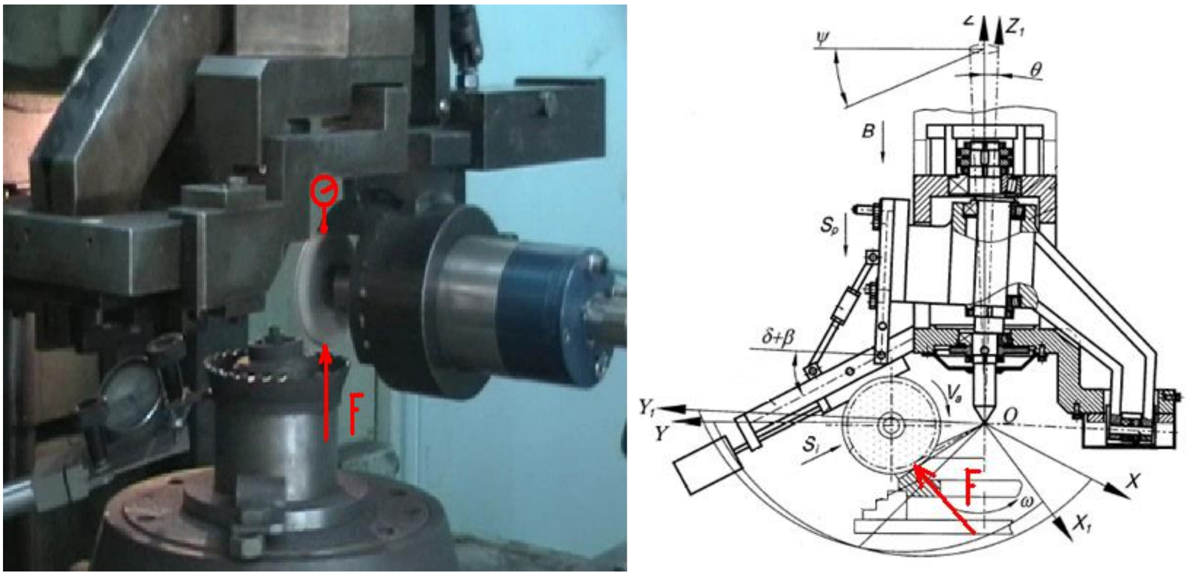

Figure 7. Determination of static displacements on the machine tool

Experimental methods for measuring the machine tool stiffness are limited to measuring the forces that act in loading nodes and corresponding elastic deformations. Loading nodes in machine tool is done by means of certain loading devices. Elastic deformations could be measured by using standard dial gauges (figure 7) [5]. Loading devices must ensure the possibility of generating in machine tool forces characterized by values and directions corresponding to the points where it can be considered as acting the cutting forces. The constructive solutions of loading devices and used parts, of methods of installation on the machine tool can be very various.

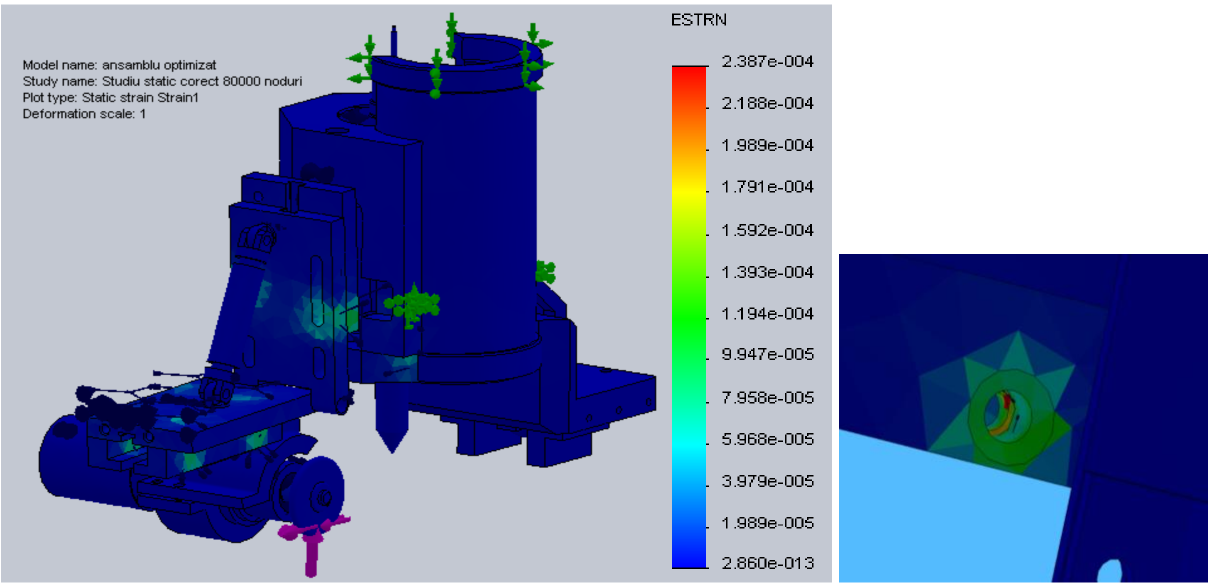

Figure 8. Equivalent strain for entire system and for the place of bolt

Complex universal devices allow to measure the joint stiffness for direct and indirect loading. For example, direct loading refers to exterior turning, and the indirect – to interior turning [6]. Direct and indirect loading give the possibility to evaluate not only the rigidity of nodes, but sometimes also to determine the value of clearances.
The safety verification of the system must be made taking into account the distribution of equivalent strains. For example, in figure 8, we can see the highest values of deformations [4] and thus we have information about the zones where the deformation are too high.
If the values corresponding to the deformations are analysed, it can say that they are less than offset values for the entire technological system and this demonstrates that the decrease of stiffness factor must be considered in places of parts and assemblies contacts.

4. Appendices

The importance of knowing stiffness values of technological systems components is limited in evaluation of quality and accuracy of the finished product. Often these values are low and, as a result, technological problems occur and the product is characterized by a low quality. If high values of the stiffness are necessary, the cost of technologic systems is high. Therefore, it is very important to find a middle value and this solution is almost impossible without application of verification methods and techniques. These methods and techniques should be studied and applied both individual and combined, in order to better understanding the system stiffness which is a feature quite complex.

Thus, the rigidity increase of the machine tools can be achieved [7] by:

- Increasing the intrinsic rigidity of machine tool parts, by selecting the most advantageous sections shapes and edges, frame structures, additional supports, materials with high value of modulus of elasticity;
- Reducing the number of joints in nodes and between them;
- Selection of adequate clearances, application of preload and compensators that automatically establish the clearances;
- Improving the quality (surface roughness) of the contact surfaces;
- Careful assembly of parts and the machine tool itself.

References

[1] M. Boca, *Cercetări teoretice şi experimentale privind eroarea de prelucrare cauzată de rigiditatea sistemului tehnologic la strunjire*, Doctoral thesis, Iaşi, 2011.
[2] Iu. V. Kirilin, *Ispitania i isledovania metalorejushih stankov: metodicheskie ucaznia k laboratornim rabotam*, UlGTU, Ulianovsk, 2012.
[3] R. G. Kudoiarov, R. R. Basharov, O. D. Pirkova, *Method of determining and increasing the technological rigidity of lathes* (in Russian), Vestnik Ufimskovo Gosudarstvennovo Aviatsionnnovo Technicheskovo Universiteta, vol. 18, no.3 (64), pp. 87-92, 2014.
[4] A. A. Alyamovskii, A. A. Sobachkin, Ye. V. Odintsov, A. I. Kharitonovich, N. B. Ponomarev, SolidWorks 2007/2008. *Computer modeling in engineering practice* (in Russian), BKHV-Peterburg, 2008.
[5] Bostan I., Mazuru S., Olevschi A., *Procedeu de prelucrare a dinţilor angrenajului precesional*. MD Patent 3532 (2006).
[6] Ia. N. Otenii, *Isledovania jestkosti tehnologhicheskoi sistemi: metodicheskie ucaznia c laboratornim rabotam*, RPK „Politehnic“ , Volgograd, 2004.
[7] Ryzhov E.V., Sagarda A.A., Il'inskii V.B., Chelovetskii I.Kh., *Kachestvo poverkhnosti pri almazno-abrazivnoi obrabotke [Surface quality when diamond abrasive machining]*. Kiev, Naukova dumka Publ., 1979.