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Empirical Evaluation of Technological Deformations for "Soft" Cutting Modes During Thin-Walled Parts Turning

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ABSTRACT

Introduction. The problem of thin-walled parts processing is actual for various areas: aviation and space industries, power machine building and others. The literature review shows that modern methods of thin-walled parts processing suppose applying additional technological equipment that increases product cost. Recently the researchers have suggested a "soft" cutting modes method, which proposes a rational pick of cutting and clamping parameters. The method allows parts processing without additional equipment due to the effective selection of the technological process parameters (feed, rotation frequency, cutting depth) based on deformations numerical modeling. In previous papers, researchers described a computer system which allows a technologist superficially estimate the applicability of the chosen cutting modes and take the suppleness into account. Due to this system, a technologist is able to pick the parameters to minimize deformation of the workpiece before the processing starts. **The purpose of the paper** is to estimate the efficiently of the developed software. **The article considers** the case of a hollow cylindrical workpiece clamped by a three-jaw chuck. **The methods of investigation:** the experiment was carried out on a dedicated facility, constructed on the basis of a lathe. A dial gauge was used to measure deformations in predefined points on the workpiece surface. **Results and Discussion.** The experimental results are presented as deflection graphs. The graphs show both theoretical and experimental curves for various sections of the workpiece. The behavior and periodicity of the experimental curves fit the theoretical. The conducted experiments show that the developed software system is effective and reliable.

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Introduction

Modern progress in aerospace and energy industries implies tough requirements to a thin-walled workpiece [1]. At the same time, the economic constraints dictated by both import substitution policy and the transition to modern digital manufacturing within the National Technological Initiative significantly influence the choice of the applied processing method. Therefore the thin-walled workpiece processing is a common object of consideration of a number of modern scientific and applied research. A number of experts in the particular narrow fields, associated with the formation of the parameters of production facilities are involved to work on the design of technological processes. The information the experts work with is represented as a number of tables and formulas, which requires regular access to handbooks and which in turn reduces labor productivity.

The development of thin-walled workpieces mechanical technology is always a difficult task for a specialist. Usually, it is impossible to apply traditional, well-mastered approaches of part clamping and cutting modes that do not take into account the flexibility of the workpiece [2]. The deformations, caused by cutting and clamping forces, significantly aggravates the resulting dimension accuracy and may become the decisive factor due to which the part will be rejected.

The literature review [3, 4, 5] shows that the technologist regularly applies one of manufacturing techniques to decrease the influence of plastic deformations. For example, this kind of techniques include: filling the hollow workpiece with a fusible aggregate, clamping the workpiece with soft jaws or expanding mandrels. But all the mentioned techniques are associated with costs growth as they use additional equipment. The cost growth is most expressed for single and small batch production.

The modern researchers in the field of flexible parts processing frequently deal with numerical modeling the technology deformations by CAE (Computer Aided Engineering) systems [6-10]. For example, in the paper [6] the authors demonstrate the applicability of the Abaqus system to analyze forces and deformations during milling a thin-walled workpiece. The potential for use of FEA (finite element analysis) method [11, 12] is also confirmed by good conformity of the theoretical and experimental results in the work [13]. Researchers are interested in finding a new method of flexible parts manufacturing: the authors of the paper [14] consider the applicability of modern additive technologies for it. Nevertheless, due to the novelty and relatively weak development of additive technologies, this method is not able to provide a satisfactory roughness and isotropic structure without additional mechanical processing, even with the use of heat treatment.

The paper [15] deals with influence of various tool path strategies and clamping methods to the quality of the resulting product.

Recently a new approach of “soft cutting modes” has been suggested [16]. As the basis of the method, the rational choice of cutting modes is proposed. The choice is based on numerical modeling of the technological deformations. With this approach, it is proposed to abandon the use of additional equipment, which will positively affect the cost of the part. As it is shown in the paper [17], to implement effectively the method of “soft cutting modes”, an information support system is required to automate the process of numerical simulation. The development of the system is described in the paper [18].

The approach proposed by the authors of the paper [16] is used to determine the cutting modes for hollow thin-walled cylindrical billets. In the future it is planned to extend the methodology to waffle type parts processing.

The aim of the study is to verify by experiment the feasibility of the developed system and the method of "soft" treatment regimes. The tasks solved during the study are the following: defining the way of caring out the experiments and deformations measuring as well as development the experimental assembly experimental assembly.

Methods

The "soft cutting modes" method is implemented in integrated information support system [19], which allows manipulating the product digital mockup: 3D parts modeling, virtual process simulation and engineering analysis. Nowadays the digital intellectual design is a tool that helps to create competitive products in all manufacturing fields.

To conduct a simulation one need to set the following parameters: the workpiece dimensions and material, jaws geometrical characteristics, clamping and cutting force. These parameters should be monitored during the experiment to provide equal condition both for experiment and process simulation. The graphical user interface is shown in the Figure 1. Numbers (1-5) indicate the following windows: 1) data input window for cutting modes calculating module; 2) output window of modes calculator module 3) parameter editor window 4) text and debug output 5) 3D model viewport. The works [17, 18] describes the functional and internal organization of the system in details.

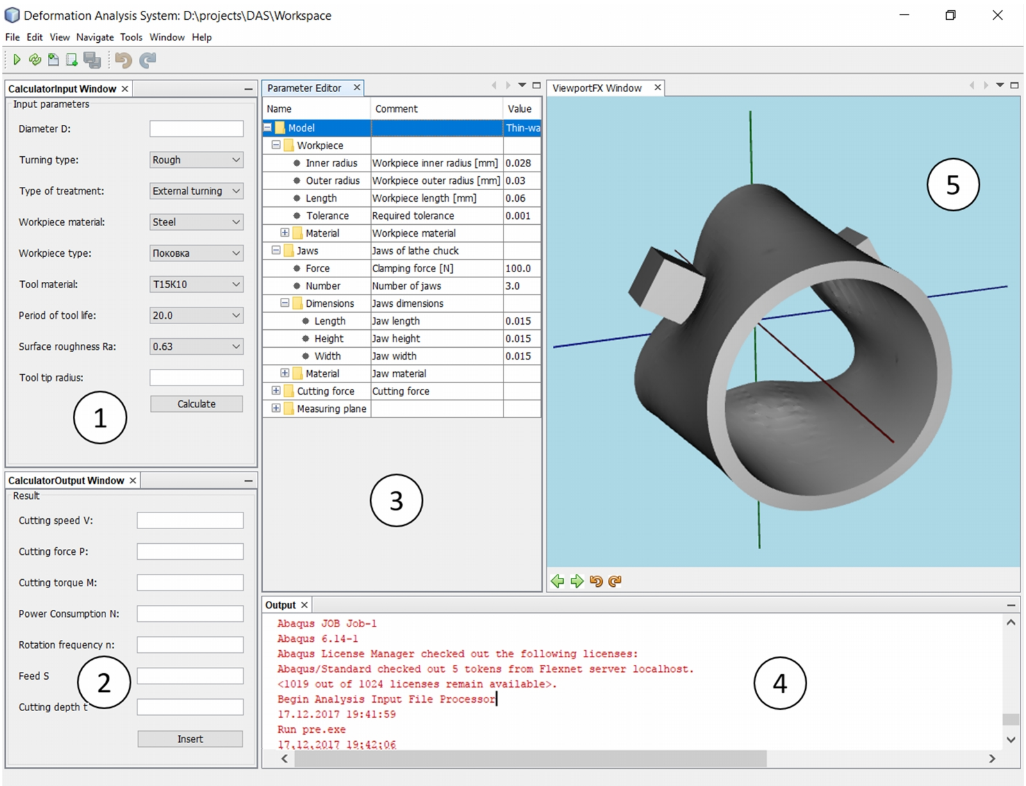

Fig. 1. Graphical user interface of the deformation analysis system

For the experiment, the simplest form of a thin-walled billet type – a hollow cylinder – is chosen. The workpiece dimensions are shown in the Figure 2. Material of the workpiece is alloyed steel with the chemical composition as specified in table 1.

Table 1

Chemical composition of the alloyed steel

Chemical element, %								
C	Si	Mn	Ni	S	P	Cr	Cu	Fe
0.28-0.35	0.9-1.2	0.8-1.1	<0.3	<0.035	<0.035	0.8-1.1	<0.3	~96

To compare the results of the simulation and experimental data it is required to measure the deviations in the shape of the workpiece, so checkpoints on the surface were determined as it is shown in the Figure 2. The checkpoints points are located 7 mm apart from each other in the direction of the workpiece axis and distributed uniformly along the circumference with an angular pitch of 30° (see Figure 2). The jaw grips the part by 15mm. The clamping force in the three-jaw chuck is calculated on the basis of the condition of the workpiece immovability after the construction of the equilibrium equations. The clamping force is controlled by means of a torque wrench.

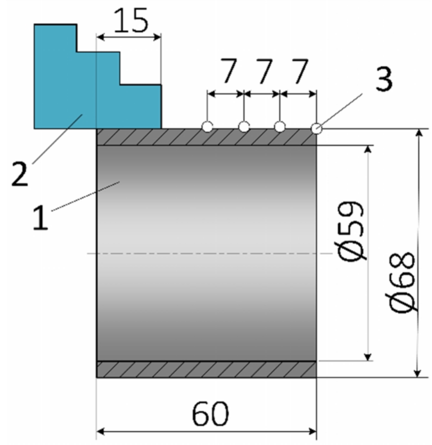

Fig. 2. Sketch of the workpiece:
1 – workpiece; 2 – jaw; 3 – checkpoints

Based on the general physical provisions and evaluation formulas of traditional tabular-analytical approach [20, 21] it can be concluded that the problem of technological deformations is most relevant for large feed and cutting depth. Therefore, for the experiment, the cutting regimes characteristic for roughing are selected. The cutting modes were calculated by the dedicated module of the developed software system. Results are shown in the Figure 3.

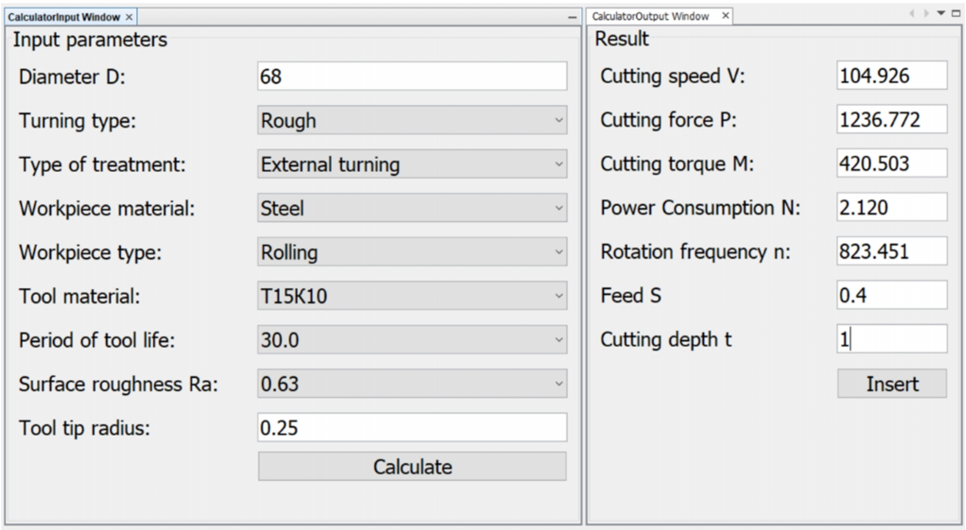

Fig. 3. The result of cutting modes calculation

The rotation frequency is rounded to closest that can be set on the lathe. As the dedicated module uses tabular-analytical approach, the feed and cutting depth are assigned from the range of admissible values and does not require the rounding. Final cutting modes are shown in the table 2.

Table 2

Cutting modes

Symbol	Parameter	Value	
		Cutting modes calculated by tabular-analytical approach	Soft cutting modes
n	Spindle rotation frequency	700 rev/min	800 rev/min
S	Feed	0,9 mm/rev	0,4 mm/rev
t	Cutting depth	1,25 mm	1 mm

The scheme of the experimental assembly is shown in the Figure 4. Workpiece deformations are measured by an indicator device, fixed on a stand. The checkpoints are uniformly located in four sections. The angular position of the part is adjusted by manual rotation of the spindle by 30°, which are measured by degree dial at the flange of a lathe chuck.

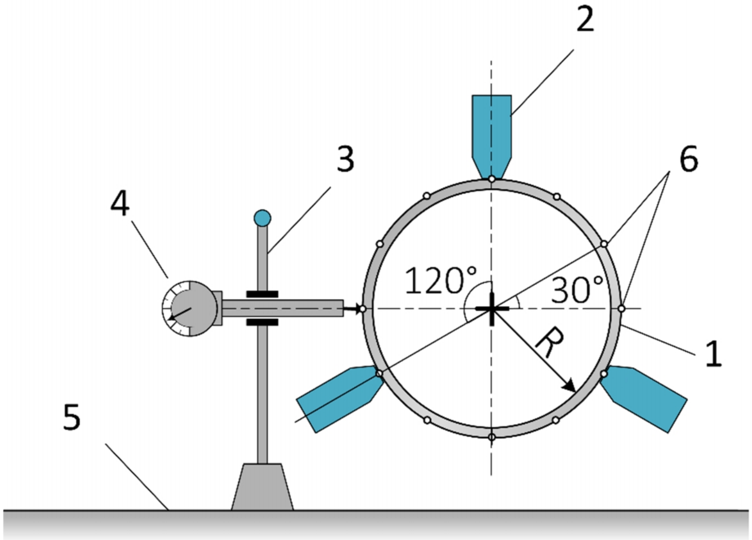

Fig. 4. The scheme of the experimental facility:
1 – cylindrical workpiece; 2 – chuck jaw; 3 – stand; 4 – indicator head;
5 – lathe base; 6 – checkpoints

Measurement of workpiece deformations occurs in four stages: a) before tough clamping the workpiece with jaws, while it is withheld by a minimal possible pinch, b) right after tough clamping the workpiece with a full load c) after the workpiece processing, before the clamping weakening d) after the clamping weakening in a free undeformed state.

Thus, the experiment is the following sequence of actions:
1) Set the workpiece to the three-jaw chuck with a minimal pinch;
2) Bring the probe tip of the measuring device to the end face of the workpiece;
3) Set 0 on the measuring device;
4) Rotate the lathe chuck by 30 degrees, measuring the angle by chuck dial;
5) Record the current readout;
6) Repeat steps 4, 5 while the probe will not return to the original position relative to workpiece;
7) Move the workpiece towards the feed by 7 mm;
8) Repeat the steps 4-6 for three other sections;
9) Clamp the workpiece and repeat measurements at steps 2-8;
10) Process the workpiece and repeat measurements at steps 2-8;
11) Free the workpiece so that is barely holed and repeat measurements at steps 2-8.

Results and Discussion

The samples of processed workpieces are shown in the Figure 5. The left part of the picture illustrates a workpiece processed with standard cutting modes and the right one is the workpiece treated with "soft cutting modes". One can compare the results and conclude that the new approach enhances the surface quality, but generally the specified surface quality is achieved at finishing stage of processing, so the actual aim of "soft cutting modes" approach is to minimize a lobing error.

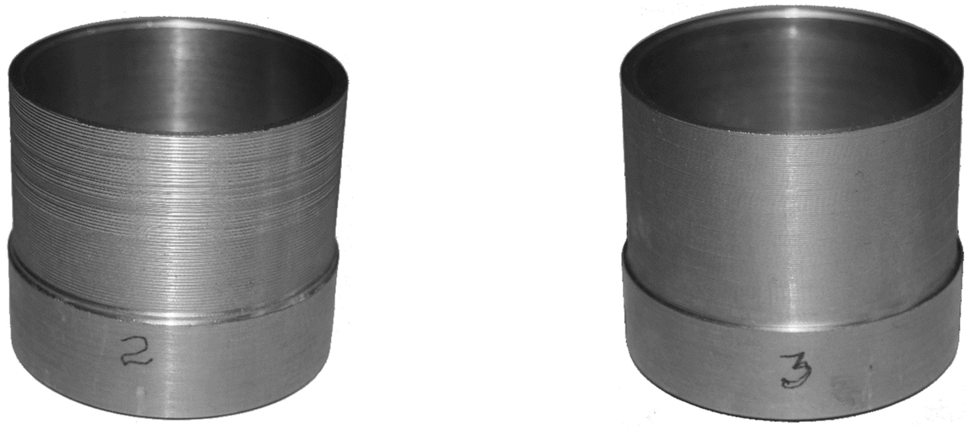

Fig. 5. The samples of processed workpieces

The Figures 6 and 7 show the typical values of deflections that describe elastic strain process for sections 0 and 21 mm respectively. The plots represent experimental deflections depending on the workpiece angular position. Theoretical curves were derived with numerical simulation by the software system [21].

The greatest discrepancies between theoretical and experimental result corresponds to the face section 0 mm and are caused by the non-stationary character of the initial stage of processing.

The hypothesis that thin-walled workpiece is deformed significantly during turning can be reinforced by the plots: the blue curve has local minima that are not expressed for the red one and these minima correspond to jaw interaction. This is most clearly seen in the Figure 7 for the section that is closest to the jaws.

Comparison of the numerical simulation results with experimental ones shows good agreement for a stationary cutting process, the relative error does not exceed 24%.

In general, shape and periodicity of the empirical curves correspond to the result of numerical simulation, which allows to speak about the confirmation of the operability of the software system for analyzing the cutting regimes of thin-walled workpieces.

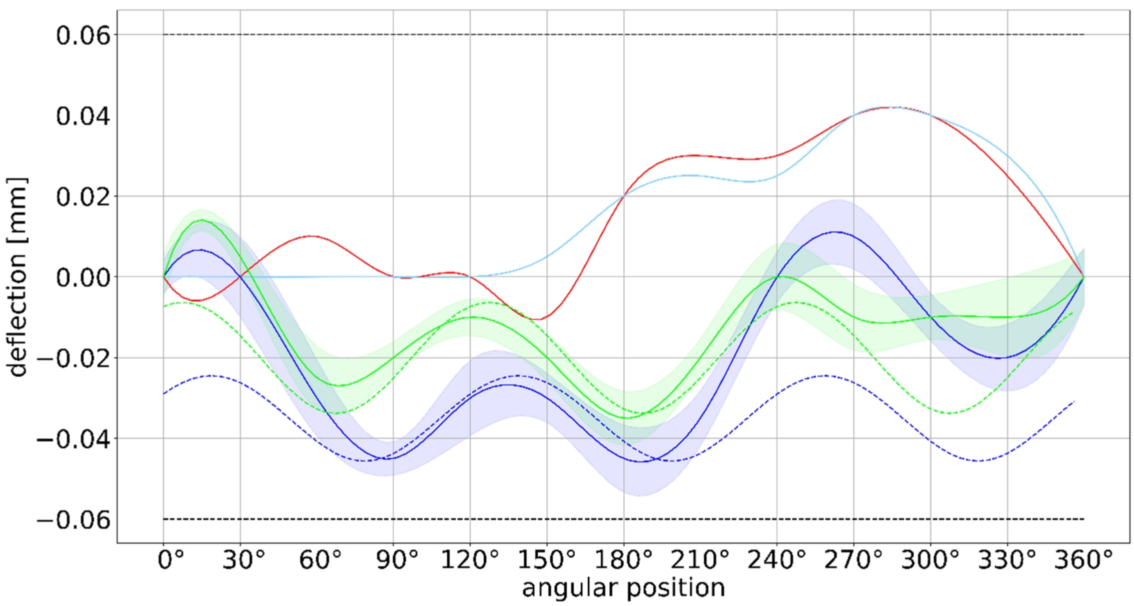

Fig. 6. The chart of measured deflections at 0 mm section

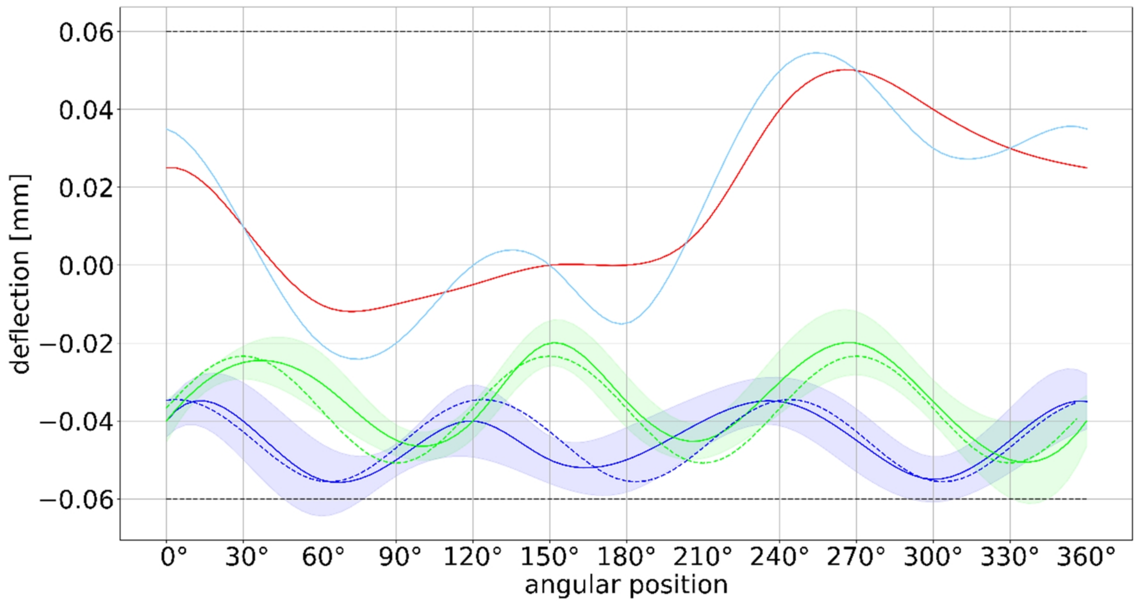

Fig. 7. The chart of measured deflections at 21 mm section

Notations on the graph:

Free before treatment

Chucked before treatment

Chucked after treatment

Free after treatment

Chucked after treatment (theoretical)

Free after treatment (theoretical)

Conclusions

Soft cutting modes method was suggested as an alternative approach for thin-walled workpieces processing and extend technologist capabilities of choosing the part manufacturing method firstly for single and small batch production. The application of the new method is advisable in order to avoid the acquisition of specialized technological equipment for a small number of parts. On the other hand, to implement the soft cut modes in production one should use a specific software system, which imposes restrictions on the informational infrastructure of the enterprise. The application of the soft mode method is recommended to be considered if the value of the springing (ie, the elastic deviation of the part without removing the material) is comparable with the cutting depth.

The experimental results described in the paper show that the developed integrated software system is workable and the models applied in the system are adequate. Finally, the obtained results confirm the prospects of the developed method of soft cutting modes for thin-walled parts processing.

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Conflicts of Interest

The authors declare no conflict of interest.