STATIC DEFORMATION OF A WORKPIECE FIXED IN UNIVERSAL CHUCK AND LIFE CENTRE

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Abstract: The rigidity could be defined as the capacity of a system or subsystem to oppose to the elastic deformation generated by the action of external forces. In this paper, the authors highlight some possibilities to evaluate the static rigidity of the technological system corresponding to a turning process. Some remarks were elaborated by considering the workpiece as a bar fixed at one end and simply supported at the other end. Experimental tests were developed to measure the static elastic deformation of the workpiece under the action of a variable loading force.

Keywords: *elastic deformation, rigidity, turning process, deflection, applied force*

1. Introduction

The rigidity of a solid body is the capacity of this body to oppose to the deformation generated by the action of external forces [2, 3, 4]. Of course, there is the possibility to evaluate the rigidity of an individual part, but there is also the possibility to take into consideration the rigidity of a system or subsystem. In the case of the so-called classical technological system constituted of the machine tool – tool – device – workpiece, the rigidity will refers to its capacity to oppose to the deformation generated by the cutting process.

There are various methods of evaluating the rigidity of the technological systems; thus, there are *static* and *dynamic* methods. In the case of *the static methods*, a way to generate a force similar to that appearing during the cutting process is used. As known, in the case of turning process, the main cutting force can be decomposed in components along the main axes belonging to a coordinate axis system attached to the technological system. The deformations appear for each axis along which a component of the cutting force acts. These deformations can be measured and by determining the ratio between the force F and the deformation x generated along the direction of the force, an image about the static system rigidity along the axis Ox is obtained. In some countries, there are standardized methods for the static evaluation of the technological system; some recommendations concerning the static evaluation of the lathe are included in an old Romanian standard.

On the other hand, there are methods in which the deformation generated by a real cutting process are determined; because there are some difficulties in measuring the deformation during the cutting process, the experimental researches were directed to the measuring the dimensions of the machined surfaces. By taking into consideration the results of the measuring the dimensions of the machined surfaces, a certain mathematical processing of these results allows the evaluation of the technological system rigidity in dynamic conditions.

Information concerning the rigidity of the technological system are important when some precise machining processes must to be applied; this means that during the design of the cutting process, the establishing of the depth of cut a_p has to take into consideration the deformation of the workpiece, so that finally the dimensions of the machined surfaces be inscribed in a narrow tolerances field.

Some decades ago, Korsakov developed a thorough theoretical study concerning the elastic deflection of the technological system in the case of the turning process; various possibilities of fixing the workpiece were taken into consideration [2]. Jianliang and Rongdi [1] proposed a united model for predicting diametral error of slender bar, by applying a finite analysis to highlight the workpiece deflection, when a follower rest is used during a turning process. They concluded that the diametral error mainly depends on the location of follower rest, depth of cut and feed rate.

Having the intention to more detailed study the influence exerted by the technological system rigidity on the machining accuracy, this paper presents some considerations concerning the static evaluation of the technological system in the case of a turning process.

2. Initial hypothesizes

One of the machine tools existing in the majority of the mechanical workshops is the lathe; essentially, the turning supposes a main rotation motion of the workpiece, while the tool materializes a feed motion in the axial plane of the workpiece. In such a situation, the turning accuracy depends on the accuracy of the motions performed by the workpiece and the tool in relation with a fix coordinates system; in our case, such a coordinates system could be defined by considering the rotation axis of the workpiece as *Oz* axis (fig. 1, *a*).

There are three ways to clamp the workpiece. Thus, although it does not ensure a high alignment

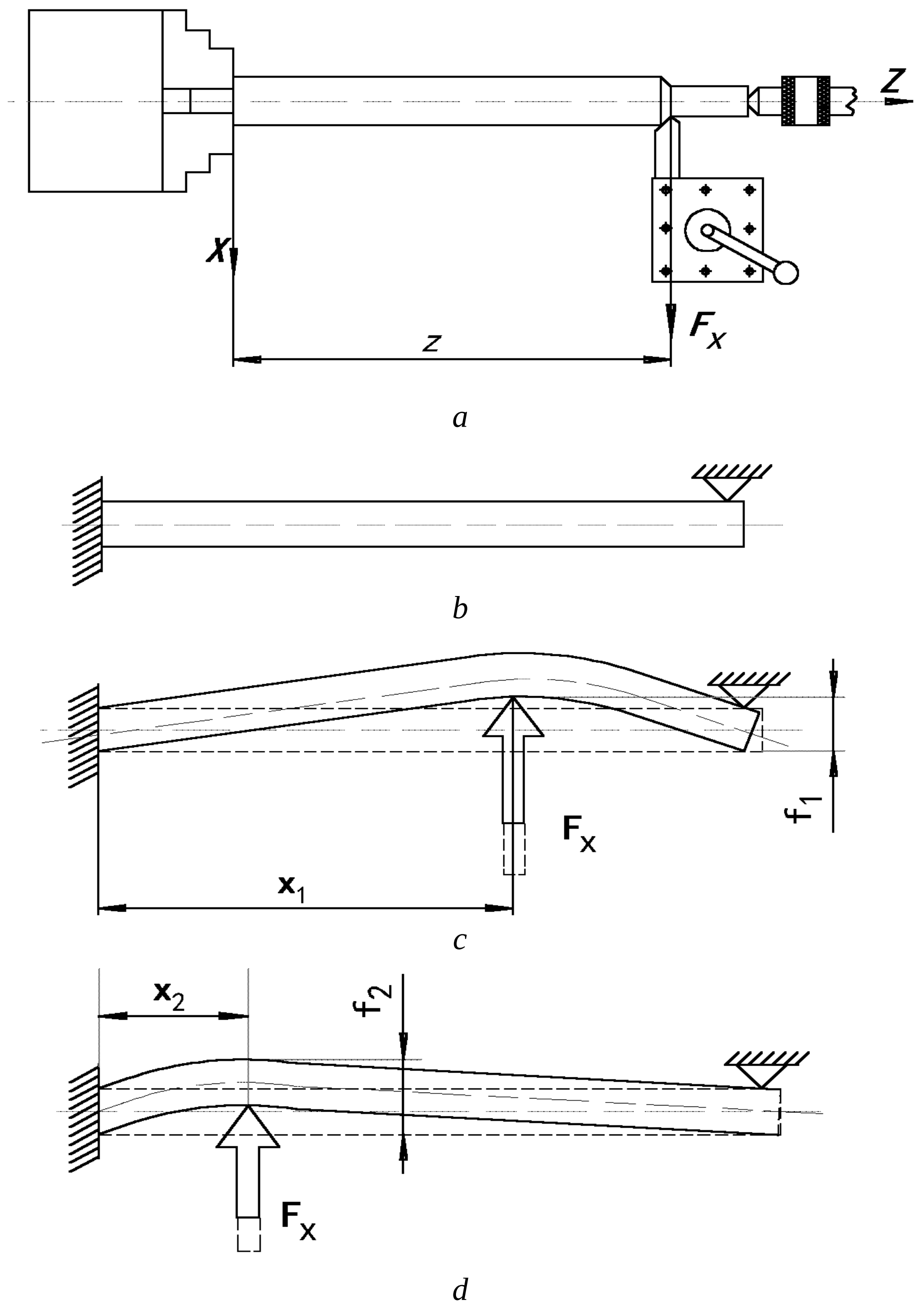

Figure 1: *Workpiece deformation as a bar rigid fixed at one end and simply supported at the other end*

of the machined surfaces when the workpiece must

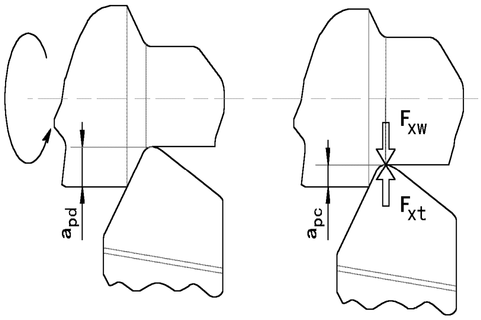

Figure 2: *Decreasing of the depth of cut during the elastic deformation during the turning process*

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be twice clamped, the positioning of the workpiece in the universal chuck and the life centre is the most frequently used in the case of the long workpieces. A better accuracy from the point of view of alignment when two positions of the workpiece are necessary and the workpiece is long enough corresponds to the positioning between life centres; for such reasons, the workpiece clamping between the life centres is preferred within the finishing cutting operations (turning, grinding). The both above mentioned ways of the workpiece positioning suppose the existence of the centre holes on the frontal surfaces of the workpieces. The third way to clamp the workpiece, applicable in the case of short workpieces is by means only of the universal chuck; obviously, if two clampings are necessary, there is a high probability that the alignment of the machined surfaces at the two clampings not be high enough.

Within this paper, only the case of the workpiece clamping in the universal chuck and life centre will be considered, this being widely used way in industrial practice, although, as above mentioned, this way does not ensure a high accuracy from the point of view of the alignment of the surfaces obtained by two clampings.

During the turning process, the workpiece and the other components of the technological system (machine tool, devices, tools) are affected by deformation phenomena; the presence of the cutting forces determines the deformation of the above mentioned mechanical components. Of course, only elastic deformation could be accepted; the operation conditions must be established so that the internal stresses to not exceed the limit of elastic deformation of the material from which the components of the technological system are made.

Due to this elastic deformation of the technological system components, the size of the actual depth of cut is not the same with the desired one; under the action of the cutting forces, the components are affected by elastic deformations and the current depth of cut a_{pc} is lower that the designed depth of cut a_{pd} (fig. 2):

$$a_{pc} < a_{pd} \tag{1}$$

This relation could suggest a way of increasing the machining accuracy; if the differences between the current depth of cut a_{pc} and the desired depth of cut a_p are known, the designed depth of cut could be so established that even by taking into consideration the elastic deformation of the technological system components, an increased machining accuracy be obtained. A way used to obtain information concerning the elastic deformation of the technological system components is based on the study of the *static rigidity* which characterize the technological system. It is expected that the bigger the technological system rigidity is, the higher the machining accuracy is.

The situation of the workpiece fixed in the universal chuck and the life centre (fig. 1, *a*) could be considered as similar to a bar rigid fixed at one end and simply supported at the other end (fig. 1, *b*). A coordinate system *xOyz* could be taken into consideration; the origin of this coordinate system could be placed at the intersection of the rotation axis with a frontal plane corresponding to the free surface of the jaws of the universal chuck; this is the case of the turning an external cylindrical surface on a lathe, by using the mechanical longitudinal feed.

The cutting force generated by the turning process can be decomposed in components directed along the axes corresponding to the coordinate system *xOyz* (fig. 3).

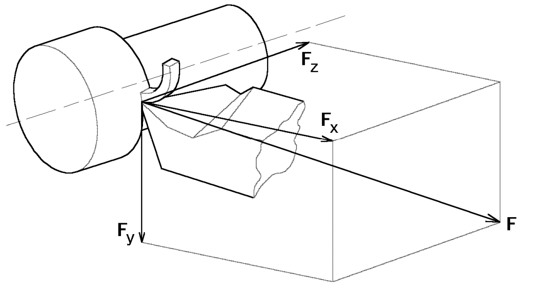

Figure 3: *Components of the cutting force which acts on the lathe tool during the turning process.*

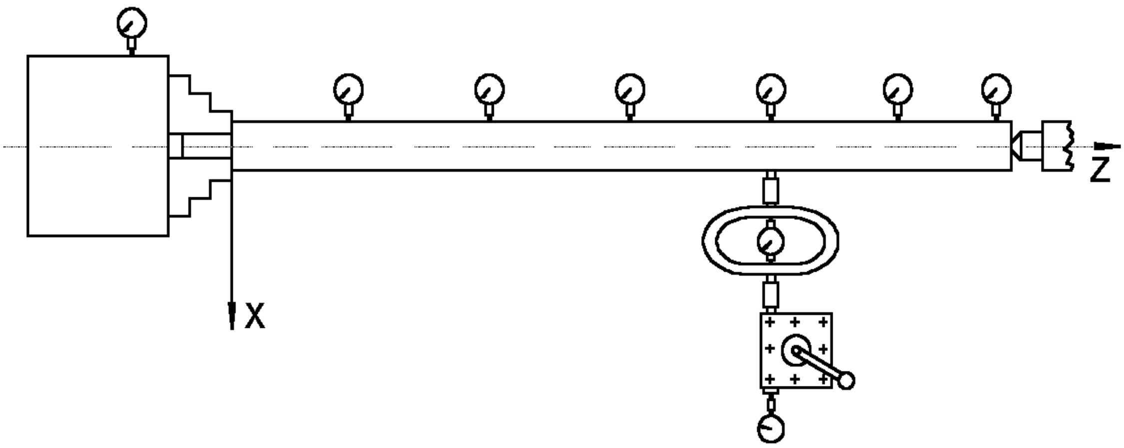

Figure 4: *Measuring the elastic deformation of the technological system components*

The position of the point where the cutting force is applied changes during the turning process simultaneously with the position of the lathe tool tip; this means that just the deformation of the technological system changes, by taking into consideration the position of the lathe tool tip.

As consequence of the turning process, the cross section of the workpiece is not the same along the workpiece (the machined surface has a low diameter in comparison with the not machined surface), but in order to simplify the theoretical modeling, one can consider a workpiece having the same diameter along all its length. In fact, in the case of the workpieces having big diameters, the decrease of the diameter as consequence of the turning process is not significant and the considering the same diameter along the entire workpiece does not generate significant errors.

Also in order to simplify the mathematical model, only the action of the cutting force component F_x will be considered; in real turning conditions, elastic deformations are generated yet along the axis *Oy* and *Oz*, but one can appreciate that from the point of view of the diametral accuracy, they exert a less significant influence.

For a bar rigid fixed at one end and simply supported at the other end, the relation valid for the elastic radial deflection is given [4] by the relation:

$$f = \frac{F_x z^3 (l-z)^2 (4l-z)}{12EI_z l^3} \tag{2}$$

where F_x is the size of the cutting force component developed along a direction parallel to the *Ox* axis, *z* is the distance along the *Oz* axis from the coordinate system origin to the tool lathe tip, *l* - the total length of the bar, *E* - the bar material elasticity modulus and I_z – the second moment area of the cross section corresponding to the bar workpiece.

The elastic deformation is not the same along the workpiece; just the different fixing of the workpiece at the two end (considered as a bar rigid fixed at one end and simply supported at the other end) determine the changing of the elastic deflection along the workpiece. On the other hand, just the universal together with the main shaft of the lathe are affected by an elastic deformation; this means that the points where the workpiece is fixed at the two ends have not a fix position. This means that if one tries to measure the elastic deformation of the workpiece near the universal chuck, this deformation will be different in comparison with the elastic deformation generated near the life centre (fig. 1, *c* and *d*).

3 Experimental testing

In order to verify the validity of some of the previous mentioned considerations, an experimental testing was developed [5]. A universal lathe type SNA 500x1000 was used (workpieces having diameter up to 500 mm and a length up to 1000 mm can be machined on such a lathe); a workpiece having the diameter of 45 mm and a length of 817 mm was clamped in the universal chuck and the life centre (fig. 4).

Several dial gauges were placed in order to obtain an image concerning the elastic deformation of the workpiece (fig. 5), of the lathe main shaft in the position corresponding to the universal chuck and of the life centre. We tried to place the holder of the dial gauges on the lathe bed. An elastic deflection could also affect the lathe bed, when a force is exerted on the technological system, but due to the high rigidity of the lathe bed, this elastic deformation is very low and one can consider that this deformation can be neglected.

Table 1: Elastic deformations during the increasing and decreasing of the radial force applied at the distance z=470 mm

Exp. No.	Force F_x, daN	Elastic deformations													
		Universal chuck		Life centre		Tool holder		z=70 mm		z =240 mm		z =470 mm		z =770 mm	
		Loa-ding	Un-loa-ding	Loa-ding	Un-loa-ding	Loa-ding	Unloa-ding	Loa-ding	Unloa-ding	Loa-ding	Unloa-ding	Loa-ding	Unloa-ding	Loa-ding	Unloa-ding
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	0	0	0.0195	0.00	0.000	0	0.003	0	0.00	0.000	0.000	0.0000	0.0076
2	20	0.0005	0.003	0.002	0.026	0.00	0.033	0.010	0.0135	0.025	0.030	0.025	0.040	0.0203	0.0267
3	40	0.002	0.0045	0.006	0.033	0.025	0.050	0.020	0.0240	0.050	0.059	0.060	0.075	0.0356	0.0457
4	60	0.004	0.0065	0.010	0.037	0.035	0.058	0.029	0.033	0.075	0.075	0.093	0.110	0.0533	0.0635
5	80	0.006	0.009	0.018	0.040	0.040	0.065	0.039	0.042	0.100	0.110	0.130	0.150	0.0711	0.0826
6	100	0.0082	0.011	0.020	0.045	0.050	0.070	0.039	0.044	0.125	0.140	0.170	0.190	0.0876	0.0991
7	120	0.0105	0.013	0.028	0.050	0.055	0.076	0.040	0.044	0.155	0.165	0.210	0.220	0.1087	0.1168
9	160	0.0155	0.0175	0.036	0.060	0.065	0.083	0.040	0.044	0.210	0.220	0.290	0.300	0.1448	0.1562
10	180	0.0175	0.0195	0.044	0.064	0.070	0.087	0.040	0.044	0.235	0.245	0.325	0.340	0.1638	0.1753
11	200	0.0195	0.022	0.051	0.065	0.075	0.089	0.044	0.044	0.250	0.270	0.365	0.380	0.1829	0.1930
12	220	0.022	0.024	0.056	0.065	0.080	0.090	0.044	0.044	0.250	0.295	0.405	0.415	0.2007	0.2083
13	240	0.0242	0.0242	0.065	0.065	0.090	0.090	0.044	0.044	0.295	0.295	0.440	0.440	0.2172	0.2172

The experiments were developed by applying an increasing force F_x in various points along the workpiece fixed in the universal chuck and live centre; some of the experimental results were included in the table 1. As one can see, in the columns no. 3, 4, 5, 6, 7, 8 there are the sizes of the deformations corresponding to the universal chuck, to the life centre and to the tool holder; the deformation registered by the dial gauges used to measure the deformations of the test piece in four established places were inscribed in the columns no. 9, 10, 11, 12, 13, 14, 15 and 16. For each case, there were measured the deformations both during the system loading (when the force increases) and unloading (during the decrease of the force size).

In order to obtain an image about the rigidity of the technological system at the level of the universal chuck and the live centre, the force exerted on the test piece can be devised in two components which act on the universal chuck and on the live centre, by taking into consideration the distances among the point of applying the force and the points where the test piece is supported. The moment equations allows the determining the component F_{x1}=102 daN which acts on the universal chuck and F_{x2}=138 daN (this component acts on the live centre) when the force applied to the workpiece has the size F_x=240 daN.

Knowing the maximum sizes of the force F_x components and of the elastic displacements x (from table 1) affecting the universal chuck (x_{1max}=0.0242 mm) and the live centre (x_{2mx}=0.065 mm), the system rigidity at the level of these subassemblies could be estimated:

$$R_x = \frac{F_x}{x} \qquad (3)$$

By means of the relation (3), one obtain R_{x1}=4214 daN/mm for the universal chuck and R_{x2}=2123 daN/mm for the life centre. Taking into consideration the maximum elastic displacement of

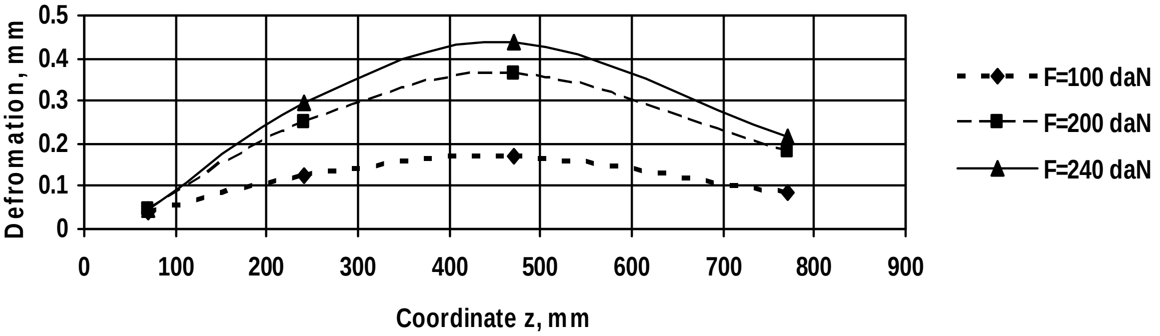

Figure 5: *Workpiece deformation under the action of the force*

the tool holder (x_{3max}=0.090 mm) and the

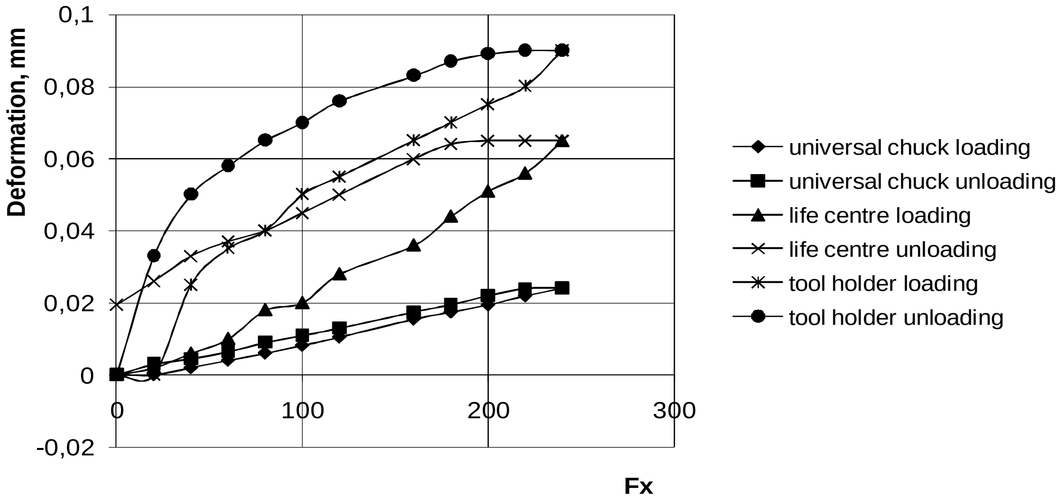

Figure 6: *Elastic displacement of some subassemblies of the technological system*

maximum size of the F_x force (F_x=240 daN), the rigidity of this subsystem could be considered as being R_{x3}=2666 daN/mm. These values highlights a relatively low rigidity of the considered subassemblies (it is known that for a machining of high accuracy, the rigidity must have values close to 20000 daN/mm) and this fact could be generated both by the clearances between various components of the subassemblies and by the wear of the same subassemblies. An image concerning the elastic displacements of the universal chuck, life centre and tool holder is presented in figure 6, where the mechanical hysteresis could be also remarked.

4 Conclusions

The study of the technological system rigidity is important due to its influence exerted on the machining accuracy; it is expected that a bigger rigidity of the technological system allows obtaining a higher machining accuracy. A workpiece fixed in the universal chuck and the life centre could be considered as a bar fixed at one end and simply supported at the other end; for such a case, the elastic deflection of the workpiece could be estimated by means of mathematical relations used in the strength of materials. In such a case (workpiece fixed in the universal chuck and the life centre), the rigidity is not the same along the workpiece. Theoretical considerations and experimental results showed that the rigidity is higher near the universal chuck and lower near the life centre. In order to measure the elastic displacements of the universal chuck and life centre and the elastic deformation of the test piece, a set of dial gauges were used. The experimental research proved also the presence of the mechanical hysteresis phenomenon.

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