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Testing of the External Turning Tool Holder Equipped With Alternate Bars in Its Construction

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The paper focuses on testing the utility effect of a cutting tool holder with inserted alternate bars of different material structure in its construction. The different bars are made from rolled steel and have an anisotropic structure which also has different mechanical properties. This construction is considered as a method to improve the cutting stability of the cutting tool and helps to reduce the oscillations in the finishing turning. A method for the construction of the damped instrument holder is proposed. A series of comparative experiments was carried out with both the standard and the modified tool holder. In the cutting tests only the feed rate was changed, cutting speed and the depth of cud remained always the same. All tests were repeated three times. After each cutting the surface roughness of all the treated surfaces were measured and compared. Surface roughness measurements revealed that the average surface roughness improved 9 % with the use of the modified tool holder. Only in one case, at the feed rate of 0.1 mm r^{-1} a poorer surface roughness with the modified holder was achieved.

Keywords: chatter vibrations, metal cutting, turning tool holder, damping of oscillations.

1. INTRODUCTION

There are a lot of different tool holders available for a large variety of specific machining requirements. At the same time also the material of the tool holders can be different. For example in machining of hard workpiece materials very high stresses act on the tool holder through the cutting tool. These stresses require the tool holder to have some specific properties. Like high stiffness and it should be able to absorb the energy generated during the cutting process. It is also important that the material cost of the tool holder is taken into account because a lower cost provides a competitive advantage for manufacturers.

In addition, the material properties of the tool holder can have also a large influence on both the surface quality and dimensional accuracy of the machined workpiece, and on the life of the cutting tool [1]. The material properties of the workpiece and various other factors, can lead to excessive vibrations in the tool shaft, which in turn causes undesirable chattering. From the standpoint of dynamic stability we assume that the “tool” is the weakest subsystem of the turning process [2]. The impact of periodical external forces causing an oscillatory process with a frequency equal to the exciting forces or complex periodic processes caused by nonlinear properties of the system, having its own damped and forced oscillations of parametrically excited oscillations and self-oscillation system can violate the stability of the turning system [3]. The intensity of the forced vibrations is particularly great in the resonant region, which must be avoided in metal cutting machines as an operating method for finishing. One aspect of improving the dynamic stability of the subsystem "tool" is the creation of damped tools with increased resistance, with elastic and damping elements that do not change their appearance. It is important for the damped instruments to be characterized by its adaptation to the variable tolerances, load balancing between the cutting edges, as well as to prevent breakage of the cutting edge.

When examining the different techniques that are known for enhancing dynamic stiffness and chatter-resistance of cutting tools. We found that one possibility is to use different material bars with specifically assigned orientations to the stiffness axes in the tool. According to the studies made on boring bars by Eugene [4], the theory is that there is specific orientation of stiffness axes relative to the cutting forces, resulting in a significant increase in dynamic stability. It was decided to implement the same concept to external turning tool holders. Consequently the aim of the work was to create a passive vibration damping tool with insert bars of anisotropic material properties integrated into the tool holder shank to improve the dynamic behaviour of the cutting tool.

In the beginning the possible effects to external turning were questionable. Because the holder is quite rigid and chatters vibration is a problem only in some difficult situations where the cutting forces are high. So in order to determine the effect of reducing the level of oscillation when using the tool holder equipped with alternate bars in its construction we carried out a series of cutting experiments compared with an equivalent tool.

2. MATERIALS AND METHODS

The term chatter is known as self-induced or regenerated vibrations, which means that the movement of

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the cutting tool is affected by existing forces and occurring movements. The forces resonate because of the relatively little damping ability of the system and this leads to an unstable machining process [3, 5]. The removing of material from the workpiece with the lathe tool leaves a wave-cut surface, which is shown in Fig. 1. This is caused by the deflection in the direction of the cutting speed vector. The deflection leads to the displacement of the cutting edge in the feed direction [6]. As a consequence of this the spindle speed (n [rev/s]) and the chatter vibration frequency (ω_c) have a relationship that affects the dynamic chip thickness. Let us assume that the chatter vibration frequency is ω_c [rad/s] or f_c [Hz]. The number of vibration waves left on the surface of the workpiece is

$$f_c[Hz]\cdot T[s]=\frac{f_c}{n}=k+\frac{\varepsilon}{2\pi}, \tag{1}$$

where k is the integer number of waves and $\varepsilon/2\pi$ is the fractional wave generated. The angle ε represents the phase difference between the inner and outer modulations. If the spindle and vibration frequencies have an integer ratio, the phase difference between the inner and outer waves on the chip surface will be zero or 2π; hence the chip thickness will be constant despite the presence of vibrations (Fig. 1). In this case, the inner $(y(t))$ and outer $(y(t-T))$ waves are parallel to each other.

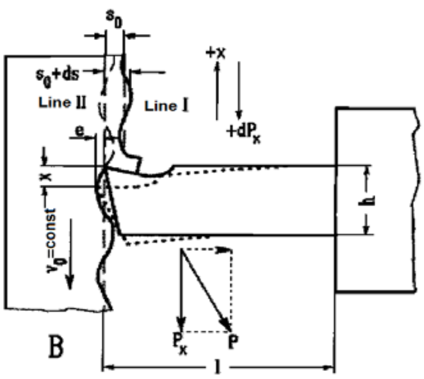

Fig. 1. Wave generation [6]

If the phase angle is not zero, the chip thickness changes continuously. Consider k integer number of full vibration cycles and phase shift

$$2\pi f_c T = 2k\pi + \varepsilon, \tag{2}$$

where the phase shift between the inner and outer waves is $\varepsilon = 3\pi + 2\psi$. The corresponding spindle period T[s] and speed n[rev/min] is found to be

$$T=\frac{2k\pi+\varepsilon}{2\pi f_c}\rightarrow n\frac{60}{T}. \tag{3}$$

In order to suppress the vibrations generated in such a way the turning tool holder with alternate bars will be introduced. The peculiarity of the tool fitted with the proposed method is to increase the damping ability and reduce the level of self-oscillations arising in the process of cutting. It is achieved through the orderly disorientation of alternate bars with anisotropic material textures that form the holder's core. This construction enables effectively dissipate the energy of the vibration waves at the boundaries of the transition points between the holder different bars. It also makes it more difficult for the emergence of the resonance frequency in the structure. The wave spread in different environments and materials are of a different nature. Flexible substrates oscillation to occur is called the mechanical wave. Therefore, it is necessary to take a closer look at the environmental impact of wave diffusion and wave interference phenomenon. By the transition from one material to another the parameters of the wave change and it is resulting from the material properties such as density and rigidity. In rigid materials is the wave diffusion speed significantly higher than in non-rigid materials and in high density materials is the rate of spread significantly lower than in low density materials. The wave dispersal speed is calculated by the following formula [7].

$$v_w=\sqrt{\frac{B}{\rho}}, \tag{4}$$

where v_w is the wave dispersal speed in the material m·s^{-1}, B is the compressibility modulus Pa, ρ is the material density kg·m^{-3}.

Another important feature of wave propagation from one medium to another is refraction. Refraction consists in the changes in wavelength by going from one medium to another [7]. This causes a change in the wave propagation velocity. The transition to a softer material leads to a shortening of the wavelength and direction change. The changes in direction result from the material properties and are material-specific [7]. The main vibration damping, however, is resulting from different deflections caused by vibrations in material pairs. The resulting situation can be described by the Hooke's law, according to which the elastic force generated in the body is proportional to the change of the body length x [7]. Hooke's law is written as follows:

$$F_e = -k\cdot x, \tag{5}$$

where F_e is the elastic force generated in the body N, k is the material stiffness factor N·m^{-1}, x is the lengthening m.

3. EXPERIMENTAL DETAILS

The basic principle behind the modified tool holder lies in the vibration energy change induced by the different materials structure and the emerging friction between the material pairs. An important role in the suppression of vibrations has the deflection of the material pairs resulting in different sized elastic forces. For further details, the material of the alternate bars is different from the tool holder material. The structure of the inserted bars is specified in the direction of rolling, and the direction of the structure is exactly known. In this way, the natural frequency of the tool holder is changed. This design should provide effective vibration energy dissipation in the contact surfaces between the different materials.

To bring out the differences in the structure of the tool holder and the additional components materials hardness tests and microstructure examinations were made (Fig. 2). On the left-hand part of the figure is the steel with ferrite-perlite structure, in which the light part is ferrite and darker part is perlite.

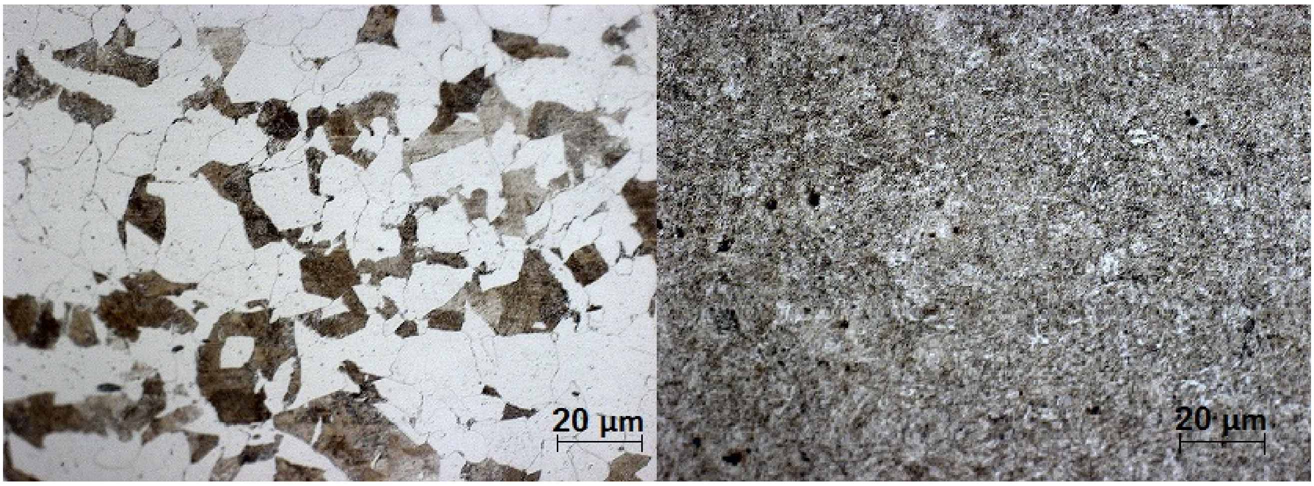

Fig. 2. Material structure of inserts (Hydax 25) and the tool holder (DCLNR2020K12)

The gray shades of material particles represent martensitic structure [8, 9]. The steel has a Rockwell hardness of 81.8 HRB. On the right-hand part of the figure is the tool holder steel which is very dense and fine-grained. The structure is characterized by high homogeneity and it has a tempered martensitic steel structure. The steel has Rockwell hardness of 114 HRB.

As discussed above we can assume that the combination of the structures with high hardness and medium plasticity will help to improve the vibration damping properties of the new tool holder.

In the research we tested the modified cutting tool holders (Fig. 3) for finishing turning at the optimum cutting depth at high cutting speeds. The turning tests were carried out on a Haas SL10-THE lathe. No coolant or other lubricants were used.

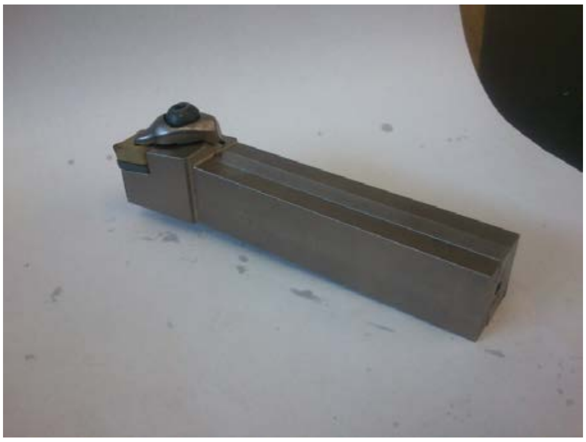

Fig. 3. The Modified cutting tool holder

Both the original and the modified holders were equipped with the Mitsubishi insert CNMG120404-SH UE6110, which is well suited for today increasingly growing dry processing. The inserts cutting edge radius was 0.4 mm and it is designed for finishing processing. The recommended cutting parameters were: a) cutting depth ap = 0.3 ... 2.0 mm; b) feed rate f = 0.1 ... 0.4 $mm \cdot r^{-1}$; c) cutting speed vc = 10 ... 355 $m \cdot min^{-1}$ [10].

During the tests, vibrations were measured with the piezoelectric acceleration sensor PCB 603C01 (Fig. 4) which meets the standard ISO 17025. In addition, the acceleration sensor signal was amplified with GUNT PT 500.04 amplifier. The amplified signal was send to the computer for recording via an analogue-to-digital converter BMCM AD16f USB.

Fig. 4. Acceleration sensor PCB 603C01

The roughness measuring device MarSurf PS1 was used for surface roughness measurement. The device is used to control the quality of products and the determined roughness Ra meets standard ISO 4287:1997 [11].

The turning test was performed with the original holder and then with the material Hydax 25 modified holder. During these tests the same workpiece of the material S335J2+AR and cutting parameters were used. Only the spindle speed increased because of the decrease of the workpiece diameter but the cutting speed reminded the same. Four different feed rates were used and with each feed rate three runs were made with both the modified and the original tool holder. This allowed obtaining comparable results by processing the workpiece. A total of 24 cutting test were made. In addition two tests were made to analyze the cutting tool holder’s natural frequency. For this purpose the tool holder which was attached to the lathe was hit with a hammer for a single time and the resulting vibration pulse was saved. Also a free running test was performed to investigate the value of the natural frequencies of the lathe. This operating state allows the analysis of the natural frequency of the lathe spindle, the workpiece and of the whole system to facilitate further analysis of the signals. The test setup is shown in the Fig. 5.

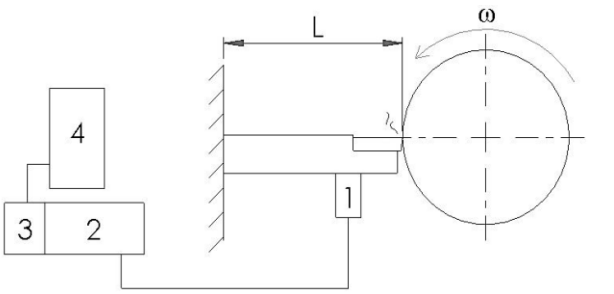

Fig. 5. The test setup: 1 – accelerometer; 2 – signal amplifier, 3 – analog-to-digital converter; 4 – data recorder (PC); L – tool holder protrusion

The vibration parameters obtained from the turning experiments were stored in a computer for future analysis. For evaluating the efficiency of the damping method the processed surface roughness is measured after each feed rate series. The obtained vibration sensor signals were recorded and analyzed with the program Nextview 4.

4. RESULTS

After the turning experiments the surface roughness of all the treated surfaces were measured. In one feed rate series the surface roughness created with both the holders was measured and their average values were calculated. Then the average value difference between them was calculated. A negative difference indicates a worse surface roughness crated with the modified tool holder compared to the original holder and positive difference means a better surface roughness crated with the modified tool holder. The average values of the surface roughness are listed in the following Table 1.

Table 1. Roughness measurements after all feed rate sequences

feed rate f,mm·r^{-1}	original	Hydax 25	variation	
	surface roughness *Ra*, µm			%
0.1	0.830	1.201	- 0.371	-30.9
0.2	2.851	2.681	0.170	6.0
0.3	4.933	4.314	0.619	12.5
0.4	6.730	6.103	0.627	9.3

Table 1 indicates that only in one case the obtained surface roughness with the modified cutting tool holders was worse than the surface roughness obtained with the original holder.

For the vibration analyze the computer software NextView was used, which allows the data reading from an analogue-to-digital converter and fast Fourier transform (FFT) conversion. In this way, the frequency of presentation of the resulting data enables the comprehensive analysis of the vibrations generated. For all the vibration signals a set of data points from one-second is used for the analysis. The data set is selected after the visual unification of the vibration signal. The amount of data includes 15,000 measurements, according to the Nyquist-Shannon theorem this is the minimum measurement points to achieve a measuring range of 7500 Hz [12]. First, to determine the natural frequencies of the different tool holders they were hit with a rubber hammer and the generated vibrations were measured and the FFT transform of the signal was performed. In the following Fig. 6, the test results are given. For all analysis the features are identified in the figures as follows: the thin line is for the modified tool holder equipped with Hydax 25 steel and the filled area is for the original tool holder.

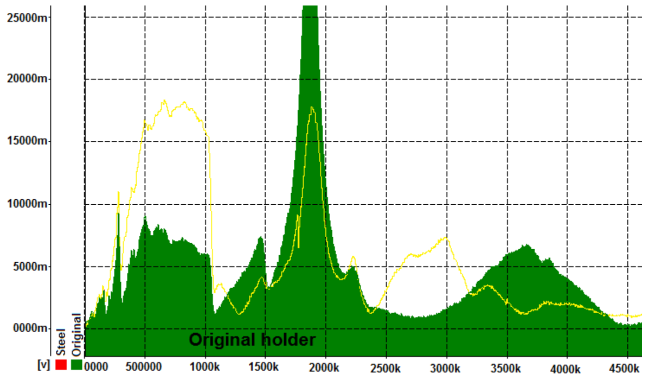

Fig. 6. Power pulses caused by the vibrations of the original holder and with the Hydax 25 steel modified holder

According to the Fig. 6 it can be seen that the installation of additional components from Hydax 25 steel made it possible to significantly reduce the vibrations in the region of 1000 to 2500 and 3200 to 4500 Hz, while creating new, low-amplitude vibration frequency in the region 500 to 1000 Hz and 2500 to 3200 Hz.

The best vibrations damping was reached at the feed rate of 0.3 mm·r^{-1}. Also the above-mentioned surface roughness variation was the best at this feed rate. The frequency representation of the vibrations is shown in the Fig. 7.

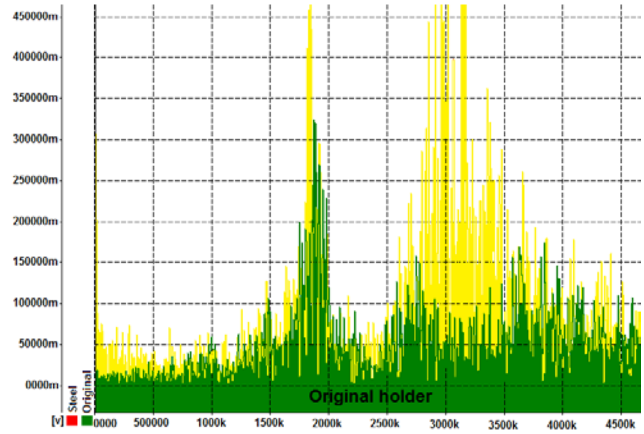

Fig. 7. The frequency representation of vibrations at the feed rate of 0.3 mm·r^{-1}

In the region 2500 to 3500 Hz relatively large vibrations are noticed in the case of the modified tool holder. However in the higher frequency spectrum an attenuation of vibrations from 4800 Hz is noticeable with the cutting tool holder with additional steel bars. Considering the achieved surface roughness and occurring vibrations it is possible to conclude that the most important influence in these experiments had high-frequency vibrations, which are above 4500 Hz.

5. DISCUSSION

According to the test results the modified tool compared to an analogue cutter improves the quality of treatment. The vibration data analysis concludes that the modified cutting tool holders has been able to suppress vibrations at high, frequencies above 4000 Hz. Practical issues related to the control selection of the cutting process, are depending on the requirements of dimensional and geometric accuracy of machined surfaces [13], which can be solved using an instrument equipped with alternate bars. According to the results of experimental studies using a fractional experiment obtained the functional dependence of the actual margin of accuracy of the processed surface. The functional dependence of the actual margin of accuracy in roundness φ_{06} (Eq. 6), ovality φ_{Nk} (Eq. 7) and cone φ_k (Eq. 8) are obtained as the ratio of tolerance to process parts to the field of geometrical deviations of the form of dispersion as a function of cutting speed, depth of cut and feed by using a modified instrument.

$$\varphi_{06} = 6.2 \cdot 10^6 \cdot \frac{t^{0.29} \cdot s^{0.22}}{v^{2.14}}; \tag{6}$$

$$\varphi_{Nk} = 83.09 \cdot 10^6 \cdot \frac{t^{0.0541}}{s^{0.0o41} \cdot v^{2.14}}; \tag{7}$$

$$4\,\varphi_k = 61.31 \cdot \frac{1}{t^{0.088} \cdot s^{0.258} \cdot v^{0.74}}. \tag{8}$$

The calculated values $\varphi = f(v, s, t)$ of the functions allow you to predict the actual value of the stock on the accuracy of the deviations of geometric shapes, machined surfaces, depending on the set of the cutting tools, as well as provide an opportunity to make a comparative analysis of the dependence of the actual margin of accuracy of the cutting conditions for finish turning cutting tools equipped with alternate bars in the holder and tools counterpart. The actual margin of accuracy in the processing with the proposed cutter holder design is higher than when operating with an analogue cutter on the same cutting conditions.

6. CONCLUSIONS

The developed method for increasing the stability of the cutting process by finishing turning is based on the use of anisotropic properties of plastically deformed structural steel and the effects of dissipation of vibration waves in the transition section between the bars which form the texture of the modified tool holder. Based on the studied physical properties of Hydax 25 steel and the original tool holder the modified cutting tool holder construction was created. First experimental research examining the influence of the damping properties of the holder to the parameters of cutting and quality of the processed surface were carried out. Surface roughness measurements of the test results revealed that only in one case a poorer surface roughness was achieved with the modified holder at low feed rate of 0.1 mm·r^{-1}. However, in other cases the results showed that the surface quality is better at higher feed rates. This means that the solution meets its objective to increase productivity without any loss of quality. Materials analysis and hardness results confirmed the suitability of the material properties for the modification of the tool holder. At the same time it must be consider that the passive vibration damping method is very specific to the cutting parameters and material properties. Based on this the making of further analyzes would need a larger and more voluminous experimental group. It would be important to carry out tests on turning of various materials and the use of additional details in the turning tool holder's construction which would require carrying out a greater volume of material-specific analysis. In addition, analysis of vibrations occurring at higher frequencies should be further analyzed and test with a variety of different cutting inserts should be carried out. For comparison, it would be useful to carry out tests on various lathe types for identifying their effect of properties. In addition future work is planned to be made on the identifying of the effects of wear resistance properties. It is also important to investigate the influence of different parameters to the dimensional and geometric accuracy of the workpiece using a modified instrument to find the best construction for vibration damping and product quality.

REFERENCES

1. **Brandon, C., Gegg, C., Steve, S., Albert, C. J. Luo.** Machine Tool Vibrations and Cutting Dynamics. Springer, New York, 2011: pp. 101 – 166.
2. **Tony, L., Schmitz, K. Smith, S.** Machining Dynamics. Springer, New York, 2009: pp. 7 – 98.
3. **Astakhov, V. P.** Tribolology of Metal Cutting. Elsevier, London, 2006: pp. 69 – 219.
4. **Eugene, I., Rivin Hongling, K.** Enhancement of Dynamic Stability of Cantilever Tooling Structures *International Journal of Machine Tools and Manufacture* 32 (4) 1992: pp. 539 – 561.
5. **Siddhpura, M., Paurobally, R.** A review of chatter vibration research in turning *International Journal of Machine Tools and Manufacture* 61 2012: pp. 27 – 47. http://dx.doi.org/10.1016/j.ijmachtools.2012.05.007
6. **Tobias, S. A.** Machine – Tool Vibrations. University of Birmingham, Blackie, 1965.
7. **William, C., Elmore, M., Heald, A.** Physics of Waves. Dover edition, New York, 1985: pp. 127 – 236.
8. **William D., Callister, D., Rethwisch, G.** Fundamentals of Materials Science and Engineering: An Integrated Approach, Publisher: Wiley, 2012: pp. 41 – 47.
9. **Bruce, L., Bramfitt, A., Benscoter, O.** Metallographer`s Guide. ASM International, 2002: pp. 307 – 316.
10. Mitsubishi CVD Coated Grade for Steel turning UE6110, https://www.mitsubishicarbide.com/mmc/en/ product/pdf/b/b089g.pdf, 2014.
11. Mahr. Marsurf PS1. 2014, https://www.mahr.com/en/Products/Metrology/By-Mahr-Product-Group/MarSurf/Systems/Portable-Instruments/ MarSurf-PS-1/, 2014.
12. **Schmitz, T. L., Smith, K., S.** Mechanical Vibrations, Springer, New York, 2012: pp. 1 – 277.
13. **Maksarov, V. V., Olt, J., Leemet, T.** Increase in the stability of technological system with control of the process of cutting *International Science Conference and Manufacturing Technology* 26-27 2008: pp. 1 – 5.