ENERGY CONCEPT FOR DIAGNOSTIC MONITORING OF PCBN CUTTING TOOLS TECHNICAL CONDITION IN TURNING OF HIGH-MANGANESE STEEL

MYKOLA KIYANOVSKY[1], NATALIIA TSYVINDA[1], YURII YAROVYI[2], INNA YAROVA[3], ANDREY PIKILNYAK[1], ANTON RYAZANTSEV[1], SVETLANA RADCHENKO[4], MARCEL LOJKA[4], MIROSLAVA SEKELSKA[4]

[1]Department of Technologies of Machine Engineering, Faculty of Mechanical Engineering and Transport, Kryvyi Rih National University, Kryvyi Rih, Ukraine

[2]Department of Hoisting and Transport Machines and Engineering of Port Technological Equipment, Educational and Scientific Marine Engineering and Technical Institute, Odesa National Maritime University, Odesa, Ukraine

[3]Department of Cyber Security and Software, Institute of Information Security, Radio Electronics and Telecommunications, Odessa National Polytechnic University, Odesa, Ukraine

[4]Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Slovakia

DOI: 10.17973/MMSJ.2025_12_2025107

svetlana.radchenko@tuke.sk

The purpose of the research is to solve the problem of adaptive control of operation life of cutting tool in turning of hard-to-machine materials. Adaptive control was performed in real time mode using the results of active diagnostic monitoring of tool cutting edge condition with the guarantee of proper precision and quality, for parts made of hard-to-machine materials, for the case of GX120Mn-13 steel. The method for identification of defects of tool cutting edge is considered and justified. Forecasting the dynamics of changes in technical condition of tool cutting edge is performed. Mathematical models of the process of changing the functional properties of tool cutting edge are proposed. The study confirms the possibility of using the resonance amplitude-frequency characteristics of the spectrum of fundamental and own frequencies of cutting edge vibrations for diagnostic monitoring of PCBN cutting tool efficiency in machining of high manganese steel. It has been established that cutting edge wear and fatigue damages occur at a frequency ranging from 1.6 kHz to 1.8 kHz and cutting edge volumetric fatigue destruction occurs at a frequency ranging from 3.6 kHz to 4.0 kHz. It has been proven that diagnostic monitoring of technical condition of tool cutting edge in the machining of hard-to-machine materials is advisable to be carried out by the means of technical diagnostic systems using energy characteristics of work. Just this method guarantees the acceptable degree of reliability of results, the minimal time consumption and the minimal expenses of determining the parameters of technical condition of a cutting tool.

KEYWORDS

active diagnostic monitoring, PCBN cutting tool, cutting tool technical condition, tool wear, cutting tool fatigue destruction, vibrations of cutting edge

1 INTRODUCTION

The needs of modern mechanical engineering make it possible to increase the use of parts made of hard-to-machine materials (alloyed steels, heat-resistant steels and alloys), including high-manganese steels, such as GX120Mn-13 steel. For mechanical processing of these steels and alloys, tool materials with high wear resistance are used. For a large number of modern cutting tool materials, the possibilities to increase cutting tool durability and, accordingly, processing efficiency, are actually exhausted.

The high cost of tool materials leads to increased costs for machining of hard-to-machine steels. The feasibility of using a particular tool material in machining is determined on the basis of technical and economic parameters [Lanen 2022] and energy parameters [Yarovyi 2020] of the technological process. At the same time, rational coating selection can contribute to machining efficiency [Loskutova 2025]. However, these parameters do not provide full forecasting the completion of parts machining with proper accuracy and quality because they don't take into account cutting tool wear. For better forecasting the accuracy and quality of machining, ongoing monitoring systems (current control systems) of tool cutting edge technical condition are used. These systems are designed to provide monitoring of cutting tool technical condition and for timely replacement of cutting plate or cutting tool itself. This ensures the required quality and accuracy of machining. Also, monitoring systems for the tool cutting edge condition are used to select the tool and cutting modes [Ivchenko 2022]. Such monitoring systems are used not only for cutting tools, but also for components of the technological system "machine tool – fixture – cutting tool – workpiece" [Ivanov 2018]. Theoretical and experimental studies confirmed each component impacts the whole technological system [Dehtiarov 2024].

Monitoring systems of cutting tool technical condition are used in drilling [Patra 2017], milling [Unal 2023], and turning [Hassan 2018]. Active control methods provide estimation of cutting edge condition in real time mode. Direct and indirect active control methods also enable the monitoring of the cutting tool during the cutting process.

The most common criterion for cutting tool blunting is the width of the contact pad wear on the back surface of the tool. When critical values of this parameter are reached, it is necessary to shut down the equipment and change the cutting tool, which may not always be possible in the machining process. The method for determining the cutting tool blunting is based on the systematic measurement of the wear on its back surface.

In direct (Fig. 1, a) active control systems optical, telemetric, and fiber-optic sensors are used. In indirect (Fig. 1, b) active control systems piezoelectric sensors are used [Mohamed 2022, Unal 2022].

In the direct active control, the parameters of contact pad wear on the surfaces of the tool are measured directly in the machining process. The direct measurements of tool wear cause difficulties, which are mainly related to the complexity of wear sensors design. Typically, the direct measurements of the wear are performed when the cutting tool exits the machining process. Since the direct measurements of the wear are performed with a certain regularity, this prevents timely detection of cutting tool failure. The required regularity of control is determined on the basis of experience in cutting tool using and on the basis of probabilistic estimates that take into account cutting tool life.

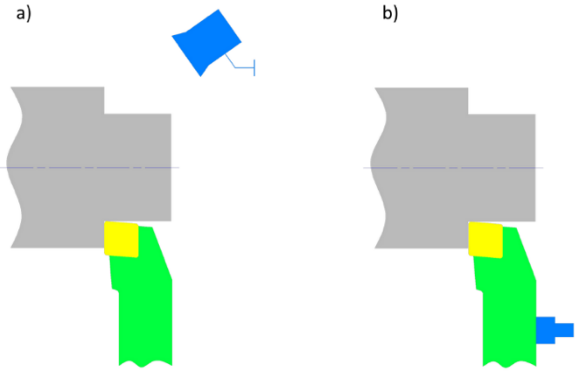

Figure 1. Operation schemes of control systems: (a) fiber-optic sensor in the direct active control system (b) opto-acoustic sensor in the indirect active control system

Most systems for the direct tool wear monitoring are based on machine vision applications, with tool wear areas identified using statistical filters [Sortino 2003].

Indirect control methods have become more widely used. Methods of this type are designed to control various characteristics of cutting process, which have correlations with wear amount and wear intensity of cutting tool. Using the piezoelectric sensors in indirect control methods provides continuous, real-time information about cutting edge wear in machining process.

The main disadvantage of indirect control methods is the impossibility of using correlations between measured factors and tool cutting edge wear for different sensors and processing methods. The correlation between measured factor and tool cutting edge wear is always determined experimentally for each specific processing case and for each specific sensor type. Based on such a relationship, cutting tool wear can be monitored in machining with a particular sensor [Pimenov 2022].

The most widespread indirect methods for cutting tool wear determination in processing of metals by cutting are the following: methods of acoustic emission signals analysis [Pimenov 2022], the method of analysis of vibrations of technological system elements [Hassan 2023], the method for measuring the drive power of the main cutting movement or measuring the feed force [Wang 2021].

Indirect control methods ensure to determine the patterns of elastic reactions of the cutting tool in the processes of its wear or damage or destruction, and thus to determine the methods of diagnostics of these processes.

The material of the tool cutting edge also affects the wear rate. The papers [Gutnichenko 2016, Matos 2023] study the processes of cutting tool life for the tools made of superhard polycrystalline materials based on cubic boron nitride. Polycrystalline cubic boron nitride (PCBN) is a superhard material that, because of its high temperature stability, high wear resistance and chemical inertness regarding ferrous metals, is used in machining of hard-to-machine materials such as hardened steels [Coelho 2007], nickel steels [Wang 2023], high-strength steels [Boing 2019], wear-resistant steels [Kiianovskyi 2021] and stainless steels [Bjerke 2025]. In turning, excessive thermomechanical loadings occur on the tool cutting edge. To ensure an economically acceptable tool life, cutting speeds of up to 200 m/min are generally required [Camargo 2014, Kiianovskyi 2021].

It is considered that the wear of PCBN cutting tool is described in terms of microwells formation and the wear on tool rear surface, which are caused by the combination of various simultaneous processes, such as abrasion, adhesion, diffusion, chemical wear [Tang 2019, Bar-Hen 2017, M'Saoubi 2013].

A distinctive feature of the wear of coatings of PCBN cutting tool is tool destruction, rather than its gradual abrasion with formation of a wear chamfer [Klimenko 2017, Manokhin 2020]. Thus, it can be concluded that the most informative parameter in diagnostics of cutting tool wear is the energy of the acoustic signal: it increases rapidly with increased wear and demonstrates the reallocation of energy levels. The intensity of acoustic signal depends on the mechanical properties of workpiece material, on the properties of cutting tool material, and most importantly, on the nature of wear or destruction of tool cutting edge.

At present, the acoustic emission method is not considered as the principal method in assessment of stability of cutting tool for high-strength materials processing. However, in the presence of mathematical relationships, these specifics of acoustic spectrum variations can be the basis for designing the automatic systems for diagnostic monitoring of technical condition of tool cutting edge.

2 MATERIALS AND METHODS

The diagnostic assessment of the process of tool cutting edge functional properties loss was carried out in the research. The study considered the impact of cutting tool material and the type of cutting edge damage: the wear and fatigue destruction.

The study of the wear of cutting tool with uncoated PCBN platins and monitoring of technical condition of cutting tool were carried out in the machining of samples of high-manganese steel GX120Mn-13 with a diameter of 70 mm and a length of 200 mm. The analysis of vibration in the machining was carried out for three types of damage of tool cutting edge. The scheme of the experimental setup to study the spectrum of mechanical oscillations (vibrations) of the tool system is shown in the Fig. 2a.

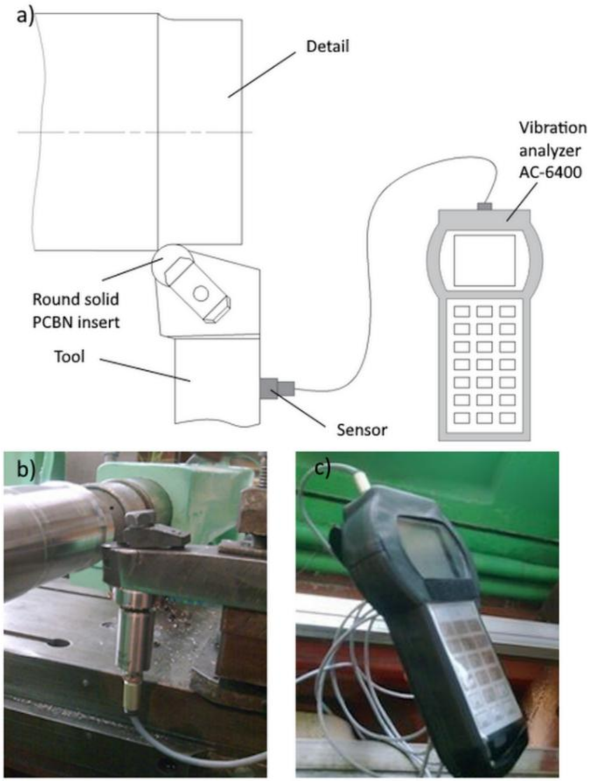

Figure 2. The scheme of the experimental setup (a), the turning cutter with attached sensor (b), the vibration analyzer AC-6400 model (c)

Experimental studies were performed on the lathe INDUSTRIE 2000/250 HD model. The following cutting modes were selected: cutting speed from 55 m/min to 158.25 m/min, cutting depth from 1 mm to 3 mm, cutting feed from 0.25 mm/rev to 0.5 mm/rev. The cutter bit with mechanical fastening of a PCBN cutting plate was selected as a cutting tool. The selected cutting plate shape is a circle, with a diameter of 19.05 mm and a height of 7.97 mm.

Monitoring of tool cutting edge condition in machining of experimental samples was carried out using the vibration analyzer AC-6400 model (Fig. 2c), which provides to obtain a spectrum of mechanical vibrations in real time mode from the sensor (Fig. 2b).

3 RESULTS

For hard-to-machine materials machining, tool materials are used, namely: tool alloy steels, hard alloys, hard alloys with PVD or CVD coating, synthetic superhard materials. Depending on the type of cutting edge damage in machining hard-to-machine materials, it is proposed to use several diagnostic mathematical models for diagnosing cutting tool technical condition, for forecasting its resource (its stability), and for determination the quantitative criteria for reaching its limit state.

Deterministic diagnostic mathematical model of cutting edge efficiency loss with accumulation its elementary damages in the form of the wear

In our opinion, process of mechanical wear of cutting tool has a predominant effect on the rate of blunting and erosion of its cutting edge. Summarizing the results of researches [Ludema 2019, Hutchings 2017], we can conclude, that the wear rate of the cutting edge can be described with the following empirical proportional dependence:

$$\gamma = kp^m v^m, \quad (1)$$

where k is the constant, depending on cutting tool material and wear conditions, p is the pressure on friction surface, v is the speed of relative movement of friction bodies.

This dependence quite clearly outlines core directions of minimizing the rate of cutting edge wear, but it prevents to do the following: to determine the effect of mechanical properties of cutting tool material and the effect of stress degree on the wear amount; to provide the monitoring of current condition of tool cutting edge; to determine the patterns of friction in visco-elastic deformations of the materials of friction pair. Consequently, the concept of empirical determination of the wear rate of the cutting edge does not fully take into account the physical nature of this process.

All of these fundamental provisions of the friction theory can be combined and thus we can describe the patterns of cutting edge wear as a process of accumulation of elementary damages. The intensity of this process is proportional to the intensity of cutting edge vibrations, according to D'Alembert principle. Stationary machines with spinning working parts are mainly used as technological equipment for machining. Therefore, cutting forces, as they are coercive, are of a cyclical nature, and thus they generate oscillations of elements of technological system; the parameters of cutting forces can provide information about actual current condition of tool cutting edge.

Thus, we conclude that the wear of cutting edge is proportional to the work of friction forces ($P_{fr} + \Delta P_{fr}$) generated by vibrations of tool system. The component P_{fr} depends on the parameters of machining process, and the component ΔP_{fr} depends on the condition of tool cutting edge.

It has been experimentally proven that the feature and parameters of vibrations of tool system vary with the wear (while accumulation of cutting edge elementary damages) from quasi-harmonic oscillations (Fig. 3), which are described by the dependence $A = f(P_{fr})$, to poly-harmonic oscillations (Fig. 4), which are described by the dependence $A = f(P_{fr} + \Delta P_{fr})$. So, the diagnostic assessment of technical condition of cutting edge by the feature of changes in parameters of vibrations of tool system is a promising area for scientific research.

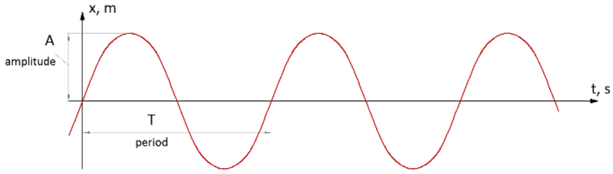

Figure 3. The feature of quasi-harmonic oscillations of new cutting edge

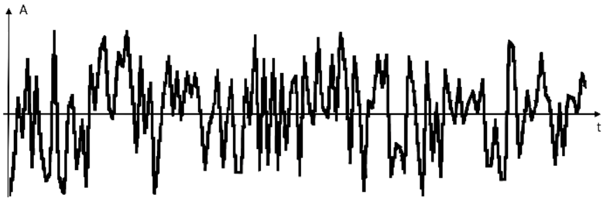

Figure 4. The feature of poly-harmonic oscillations of cutting edge with accumulation of defects caused by wear

Accordingly, deterministic diagnostic mathematical model of cutting edge wear is considered. Such a model takes into account the nature and magnitude of the main energetic parameters of oscillatory effect of friction forces. These parameters provide information about the condition of cutting edge. The increase in the energy of oscillatory process, which arises as a result of cutting edge damages, is expressed through the value of an average power of friction force $N_{xx}(T)$, that causes the wear of cutting edge:

$$N_{xx}(T) = \frac{1}{T}\int_0^T |x(t)|^2 \, dt, \quad (2)$$

where x is the amplitude of oscillatory changes in the friction force in the time interval (0, T).

Actually the energy of oscillatory force (E), arising as a result of cutting edge damages, can be defined by the following expression:

$$E = \int_{-\infty}^{+\infty} N_{xx}(T)\, dt = \int_{-\infty}^{+\infty} |x(t)|^2 \, dt. \quad (3)$$

Here the energy of oscillatory force, which leads to the tool wear, is viewed as a function of time. Calculation results in diagnostic monitoring operations indicate the overall level of the damage (the wear) of cutting edge without referring to any particular factors causing this damage. But namely these factors change the feature of poly-harmonic oscillatory process, which is detected by acoustic sensor, and increase its energetic parameters. Consequently, identification of damages and their causes can be performed by evaluation of the power (or of the energy) of spectral components of oscillatory process using the Parsenval equation. It is assumed that each damage forms its own spectral component (f_i) in that process, the relation (3) [Bhushan 2013].

Therefore, modeling and forecasting of durability of cutting edge can be carried out on the basis of increase (or change) in the energy ΔE of spectral components of oscillatory process $X(t)$, which have a certain relationship with the changes in the geometry of cutting edge, caused by its wear. Mentioned informative spectral components of vibration are determined experimentally for each tool system, because of significant difference between the elastic characteristics of its elements.

It has been experimentally found that the change in the condition of cutting edge during parts machining (Fig. 5a), the appearance of damage in the form of a crack (Fig. 5b), the appearance of local volumetric fatigue destruction (Fig. 5c) and multiple volumetric fatigue destruction (Fig. 5d) causes the appearance of informative spectral components of vibration $X(t)$. Figure 6 presents three levels of informative spectral components of vibration: level 1 – the amplitude and the frequency of the workflow; level 2 – the amplitude and vibration frequency within the range of cutting tool own frequencies; level 3 – the amplitude and vibration frequency within the range of tool system own frequencies.

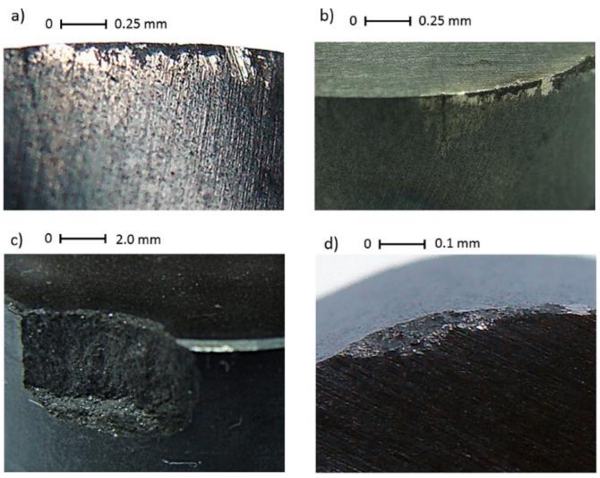

Figure 5. The condition of the cutting edge in machining process (a), the damage in the form of a crack (b), local volumetric fatigue destruction (c), multiple volumetric fatigue destruction (5d)

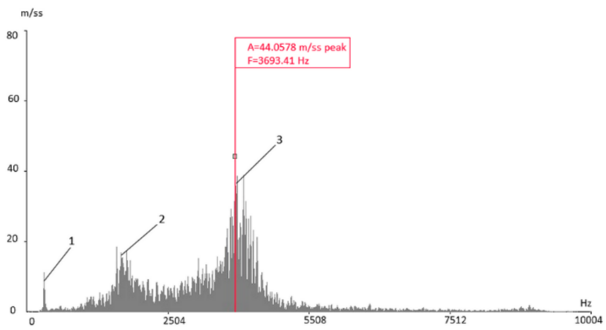

Figure 6. The informative spectral components of vibration, related to the wear damages in the cutting edge

It follows from this, that minimization of the rate of cutting edge wear, as well as monitoring of cutting tool condition and forecasting the dynamics of changes in cutting edge when approaching the limit state, are primarily connected with minimization the parameter ΔE. This parameter integrally describes the influence of all degradation processes, it can be quite easily controlled instrumentally, and can be corrected in adaptive control of machining process. In the relevant research on acceptable levels of energy, ΔE can be used as an energy criterion for technical condition and wear rate of a cutting tool. Other parameters are derived from equipment design features and machining technology, and their adjustment is more difficult.

Deterministic diagnostic mathematical model of cutting edge efficiency loss with accumulation its elementary damages in the form of the local damages of various origin

For cutting tools manufacture, materials of various mechanical and operational properties are used, namely: tool alloy steels, hard alloys, tool alloy steels with PVD and CVD coating, mineral-ceramic materials, natural crystalline materials, artificial superhard materials. Their mechanic and operational features increase, but there is a significant risk of cutting tool damage caused by specific reaction to dynamic conditions of machining, in the form of the wear or of local damages of various origin. The current task is the development of mathematical model of cutting edge efficiency loss process, taking into account the type and the structure of cutting tool material.

In this case, the selection and justification of criterion for estimation of cutting edge wear, to model and forecast cutting edge operational properties, is advisable to conduct using modern concepts, describing the process of cutting edge efficiency loss with energy characteristics of machining.

For each process of destruction or damage to elements of a technological system, there are energy limits, the excess of which causes an increase in the rate of cutting tool wear. That’s why, when performing the diagnostic monitoring of tool cutting edge condition, first of all it is necessary to plan the technological parameters of machining. The purpose of such a planning is to minimize the energy level of mutual influence for the elements of technological system, in accordance with the prevailing process of their damage. In this case, it is necessary to relate the physical nature of damage process and an energy barrier of the phase of its intensive development.

It should be noted that tool cutting edge destruction can take various forms. The appearance and development of damage in the form of a single crack requires the mathematical model for the process of crack formation for forecasting the durability of tool cutting edge (Fig. 5b).

To develop that model of damage of tool cutting edge and to forecast the dynamics of damages appearance, the energy concept of the theory of crack development is proposed to use [Zehnder 2012, Janssen 2024].

The appearance and development of damage in the form of a single crack can occur at stresses under material yield strength. This happens if the release rate of the energy of elastic deformation exceeds the increase in the surface energy of the crack. The term for a single crack development for a flat plate has the form:

$$\frac{\sigma^2 \pi l^2}{E} \geq 4l\left(W_n + W_p\right), \tag{4}$$

where E is the modulus of elasticity, σ is the stress within the plate, l is the crack length in the direction, perpendicular to the stress vector, W_n is the energy of surface tension of the crack, W_p is the work of plastic deformation.

Prevention of such a destruction is possible when providing loads, for which the operating stresses in the cutting tool material will not exceed the specified level in the diagnostic monitoring of energy criterion ΔE, in the spectrum of the own vibrations of cutting edge:

$$|\sigma| \geq 2\sqrt{\frac{E\left(W_n + W_p\right)}{\pi l}}\,. \tag{5}$$

It has been experimentally established that the appearance and development of a single crack at the tool cutting edge leads to an amplitude surge in the spectrum of the own vibrations of cutting edge (Fig. 7).

Volumetric fatigue destructions of cutting edge occur under the cyclic loading of cutting tool as a result of the fact that the elastic deformation of cutting tool exceeds the endurance limit of its material. In the experimental study, local (Fig. 5c) or multiple (Fig. 5d) volumetric fatigue destructions were registered on the cutting plates.

Forecasting of this type of destruction relies on the use of WOhler curve for the relevant loading conditions of cutting edge material. This makes it possible to correct the influence of technological factors that determine the level of actual stress, and to promptly replace cutting tool when a critical number of loading cycles is reached.

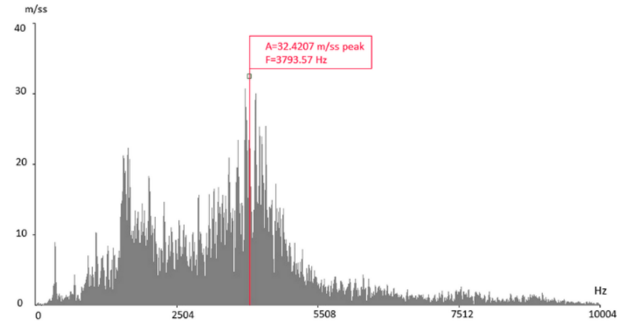

Figure 7. The spectrum of the own vibrations of cutting edge with a single crack

Local volumetric fatigue destructions are jointly caused by operating loading and stress state of the surface layer of cutting tool material. In this case, maximum cyclic stresses are determined as a sum of the stresses defined by Hertz-Belyaev equation, and of the residual stresses of the 1st, 2nd, 3rd kind. The diagnostic prevention of such the destructions is achieved by eliminating the increase in operating stresses caused by the influence of an incipient fatigue crack or by using technological measures to minimize the residual stress. These measures provide a change in the hardness of cutting tool material, and accordingly, change the frequency of its own vibrations. The Fig. 8 shows the spectral response to the presence of local volumetric fatigue destructions.

Local volumetric destruction can arise not exactly in accumulation of fatigue damages, but also suddenly, with a sharp increase in energy, usually as a result of an effect of thermal factors. In this case, the change in the stress state of the surface layer of the material arises as a result of an increase in activation energy of elementary particles of cutting tool material. The rate of change in the stress state of surface layer of cutting edge material is described by the equation:

$$\gamma = c \times \exp\left(-\frac{E_a}{K\theta}\right), \qquad (6)$$

where c is the coefficient depending on the course of the process, E_a is activation energy, K is Boltzmann constant, θ is the temperature of cutting edge material.

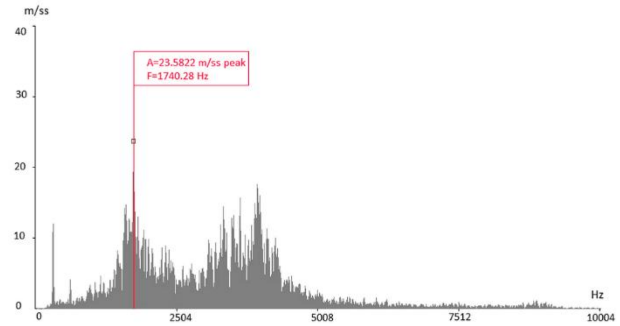

Figure 8. The spectrum of the own vibrations of cutting edge with local volumetric fatigue destructions

This phenomenon is the reason of structural changes in cutting tool material, such as decomposition of martensite, an increase in residual stresses of the 1st and 2nd kind, ‘seizing’, ‘setting’ and detachment of some surface sites of contacting materials. Diagnostics and prevention of such the occurrences are achieved by stabilizing the thermal state and, accordingly, by stabilizing energy relations between the structural components of contacting materials, which effect the frequency of fundamental and of own vibrations of the cutting edge. The amplitudes and spectrums of fundamental and own vibrations can be considered in general vibration spectrum as diagnostic indicators of the influence of this factor (Fig. 9).

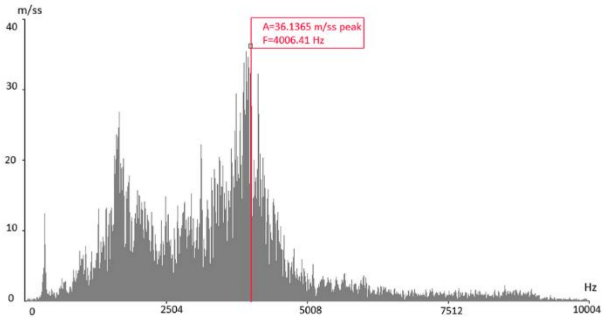

Figure 9. The spectrum of the own vibrations of cutting edge with multiple volumetric destruction caused by elastic and thermal loadings

Multiple volumetric destruction of cutting edge could stem from corrosion process caused by moisture and corrosive technological substances entering the cutting zone. These process proceeds according to the laws of chemical-thermal dynamics if isobaric-thermal potential of cutting edge material is above zero, according to the relation:

$$\Delta G_{298} = \Delta G_{298}^{0} + R\theta \times \ln\frac{c^1}{c}\ , \qquad (7)$$

where ΔG_{298} is the standard magnitude of the change of Gibs function potential for oxidation-reduction reaction at the temperature $\theta = 298\ K$, c and c^1 are the concentrations of substances in the reaction, depending on the activity and partial pressure, R is gas constant.

If the parameter ΔG_{298} is above zero, corrosion destruction of metal surface occurs, with the speed determined by Evans equation:

$$\frac{y^2}{K_{dif}} + \frac{2y}{K_c} = 2c_0 t\ , \qquad (8)$$

where y is the thickness of the layer of damaged metal, K_{dif} is diffusion coefficient, K_c is the constant of the rate of chemical reaction, c_0 is reagent concentration, t is the duration of reaction.

The layer of damaged metal changes the characteristics of cutting edge material, that affect the frequency of the own vibrations of cutting edge. The amplitude and the spectrum of the own vibrations of cutting edge can be considered as diagnostic indicators of this factor in general vibration spectrum (Fig. 10).

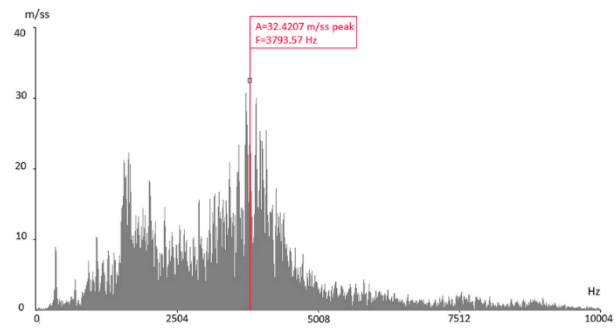

Figure 10. The spectrum of the own vibrations of cutting edge with multiple volumetric destruction caused by corrosive destruction of its surface

4 CONCLUSIONS

The study on the machining of parts of high-manganese steel GX120Mn-13 with a PCBN cutting tool confirmed the possibility of using resonant amplitude-frequency parameters of vibration spectrum of tool cutting edge in active diagnostic monitoring of cutting tool condition. In assessing the condition of a cutting tool, the spectra of both the fundamental and own frequency of vibrations of the cutting edge should be taken into account.

The constancy of diagnostic reaction to the condition of a cutting tool in the spectrum of the fundamental and own frequencies of vibration of tool cutting edge has been established in machining of parts. The appearance of wear and damages of cutting edge occurs at a frequency from 1.6 kHz to 1.8 kHz, and the destruction of cutting edge surface occurs at a frequency from 3.6 kHz to 4.0 kHz.

It is experimentally established that the onset of intensive destruction of tool cutting edge occurs when its maximum resonant value of vibration amplitude at the frequency of fundamental oscillations increases by 2.5 times. Some experimental results correlate with the research [Gutnichenko 2016], which did not consider the amplitude of vibrations as a monitoring parameter.

The study also strengthens the possibility of using the amplitude of vibrations of a tool cutting edge as a parameter for active diagnostic monitoring of cutting tool condition. The obtained results make it possible to proceed to the next step: the development of active diagnostic monitoring system based on neural systems.

ACKNOWLEDGMENTS

This work was funded by the Slovak Research and Development Agency under contract No. APVV-21-0228. The projects VEGA 1/0391/22 and KEGA 017TUKE-4/2023 were granted by the Ministry of Education, Research, Development, and Youth of the Slovak Republic. This article is the result of the following project implementation: Development of excellent research capacities in the field of additive technologies for the Industry of the 21st century, ITMS: 313011BWN5, supported by the Operational Program Integrated Infrastructure funded by the ERDF.

REFERENCES

[Bar-Hen 2017] Bar-Hen, M. and Etsion, I. Experimental study of the effect of coating thickness and substrate roughness on tool wear during turning, Tribology International, 2017 Vol. 110, pp. 341-347. https://doi.org/10.1016/j.triboint.2016.11.011

[Bhushan 2013] Bhushan, B. Introduction to Tribology. 2nd edition. John Wiley & Sons, 2013. ISBN 978-1-119-94453-9.

[Bjerke 2025] Bjerke, A., et al. On the wear mechanisms of uncoated and coated pcBN tools during turning of 17–4 PH martensitic stainless steel. International Journal of Refractory Metals and Hard Materials, 2025, Vol. 127, 106984. https://doi.org/10.1016/j.ijrmhm.2024.106984

[Boing 2019] Boing, D., Zilli, L., Fries, C.E., Schroeter R.B. Tool wear rate of the PCBN, mixed ceramic, and coated cemented carbide in the hard turning of the AISI 52100 steel. Int. J. of Advanced Manufacturing Technology, 2019, Vol. 104, pp. 4697-4704. https://doi.org/10.1007/s00170-019-04295-9

[Camargo 2014] Camargo, J.C., Dominguez, D.S, Ezugwu, E.O., Machado, A.R. Wear model in turning of hardened steel with PCBN tool. International Journal of Refractory Metals and Hard Materials, 2014, Vol. 47, pp. 61-70. doi.org/10.1016/j.ijrmhm.2014.06.019

[Coelho 2007] Coelho, R.T., Ng, E., Elbestawi, M.A. Tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions. Int. J. of Machine Tools and Manuf., 2007, Vol. 47, Issue 2, pp. 263-272. doi.org/10.1016/j.ijmachtools.2006.03.020

[Dehtiarov 2024] Dehtiarov, I., Ivanov, V., Evtuhov, A., Ostroha, R., Ciszak, O. Research of Static Stiffness of Flexible Fixtures for Y-Type Fork Parts. In: Ivanov, V., Trojanowska, J., Pavlenko, I., Rauch, E., Pitel, J. (eds) Advances in Design, Simulation and Manufacturing VII. DSMIE 2024. Lecture Notes in Mechanical Engineering, 2024, pp. 164-177. https://doi.org/10.1007/978-3-031-61797-3_14

[Gutnichenko 2016] Gutnichenko, O., Bushlya, V., Zhou, J.M., Stahl, J.-E. Tool Wear and Vibrations Generated When Turning High-chromium White Cast Iron with pCBN Tools. Procedia CIRP, 2016, Vol. 46, pp. 285-289. https://doi.org/10.1016/j.procir.2016.04.005

[Hassan 2018] Hassan, M., Sadek, A., Damir, A., Attia, M.H., Thomson V. A novel approach for real-time prediction and prevention of tool chipping in intermittent turning machining. CIRP Annals, 2018, Vol. 67, Issue 1, pp. 41-44. https://doi.org/10.1016/j.cirp.2018.04.065

[Hassan 2023] Hassan, M., Sadek, A., Attia, H. A Real-Time Deep Machine Learning Approach for Sudden Tool Failure Prediction and Prevention in Machining Processes. Sensors, 2023, Vol. 23, 3894. https://doi.org/10.3390/s23083894

[Hutchings 2017] Hutchings, I. and Shipway, P. Tribology: Friction and Wear of Engineering Materials. Butterworth-Heinemann, 2017. ISBN 9780081009512

[Ivanov 2018] Ivanov, V., Dehtiarov, I., Denysenko, Y., Malovana, N., Martynova, N. Experimental diagnostic research of fixture. Diagnostyka, 2018, Vol. 19, No. 3, pp. 3-9. https://doi.org/10.29354/diag/92293

[Ivchenko 2022] Ivchenko, O., et al. Method for an Effective Selection of Tools and Cutting Conditions during Precise Turning of Non-Alloy Quality Steel C45. Materials, 2022, Vol. 15, No. 2, 505. https://doi.org/10.3390/ma15020505

[Janssen 2024] Janssen, M., Zuidema, J. and Wanhill, R.J.H. Fracture Mechanics: An Engineering Primer. TU DelftOPEN Publishing, 2024. ISBN 978-94-6366-818-7. https://doi.org/10.59490/tb.86

[Kiianovskyi 2021] Kiianovskyi, M., Tsyvinda, N., Laukhina, L., Chernyavskaya, O., Zuiev, I. Analysis of cutting mode levels selection by production criteria. Journal of Kryvyi Rih National University, 2021, Vol. 19, No. 1, pp. 54-58. https://doi.org/10.31721/2306-5451-2021-1-52-54-58 (in Ukrainian)

[Klimenko 2017] Klimenko, S.A., Klimenko, S.A., Manokhin, A.S., Beresnev, V.M. Special features of the applications of cutting tools from polycrystalline cubic boron nitride with protective coatings. Journal of Superhard Materials, 2017, Vol. 39, pp. 288-297. https://doi.org/10.3103/S1063457617040098

[Lanen 2022] Lanen, W.N., Anderson, S.W., Maher, M. Fundamentals of Cost Accounting. 7th ed. New York: McGraw Hill, 2022. ISBN 9781264927289.

[Loskutova 2025] Loskutova, T., et al. Influence of Diffusion Siliconizing and Boron–Siliconizing in Chlorine-Containing Environments on the Structure, Composition, and Protective Properties of TZM Molybdenum Alloy. Applied Surface Science Advances, 2025, Vol. 27, 100769. https://doi.org/10.1016/j.apsadv.2025.100769.

[Ludema 2019] Ludema, K.C., Ajayi, L. Friction, wear, lubrication: a textbook in tribology. 2nd edition. Boca Raton: Taylor&Francis. CRC Press, 2019. ISBN 9781482210170.

[M'Saoubi 2013] M'Saoubi, R., Johansson, M.P., Andersson, J.M. Wear mechanisms of PVD-coated PCBN cutting tools., Wear, 2013, Vol. 302, Issues 1-2, pp. 1219-1229. https://doi.org/10.1016/j.wear.2013.01.074

[Manokhin 2020] Manokhin, A., Klymenko, S., Beresnev, V., Zakiev, V., Klymenko, S. To the Question of the Mechanism of the Effect of Coating on the Durability of Tools from PCBN. Lecture Notes in Mechanical Engineering, 2020, pp. 206-2015. https://doi.org/10.1007/978-3-030-40724-7_21

[Matos 2023] Matos, F., et al. On the Influence of Binder Material in PCBN Cutting Tools for Turning Operations of Inconel 718. Metals, 2023, No. 13, 934. doi.org/10.3390/met13050934

[Mohamed 2022] Mohamed, A., Hassan, M., M'Saoubi, R., Attia, H. Tool Condition Monitoring for High-Performance Machining Systems—A Review. Sensors, 2022, Vol. 22, No. 6, 2206. https://doi.org/10.3390/s22062206

[Patra 2017] Patra, K., Jha, A.K., Szalay, T., Ranjan, J., Monostori, L. Artificial neural network based tool condition monitoring in micro mechanical peck drilling using thrust force signals. Precision Engineering, Vol. 48, 2017, pp. 279-291. https://doi.org/10.1016/j.precisioneng.2016.12.011

[Pimenov 2022] Pimenov, D.Yu., et al. Application of measurement systems in tool condition monitoring of Milling: A review of measurement science approach. Measurement, 2022, Vol. 199, 111503, ISSN 0263-2241. doi.org/10.1016/j.measurement.2022.111503

[Sortino 2003] Sortino, M. Application of statistical filtering for optical detection of tool wear, International Journal of Machine Tools and Manufacture, 2003, Vol. 43, Issue 5, pp. 493-497. https://doi.org/10.1016/S0890-6955(02)00266-3

[Tang 2019] Tang, L., Sun, Y., Li, B., Shen, J., Meng, G. Wear performance and mechanisms of PCBN tool in dry hard turning of AISI D2 hardened steel. Tribology International, 2019, Vol. 132, pp. 228-236. https://doi.org/10.1016/j.triboint.2018.12.026.

[Unal 2022] Unal, P., Deveci, B.U., Ozbayoglu, A.M. A Review: Sensors Used in Tool Wear Monitoring and Prediction. In: Mobile Web and Intelligent Information Systems. MobiWIS 2022. Lecture Notes in Computer Science. Cham: Springer, 2022, pp. 193-205. https://doi.org/10.1007/978-3-031-14391-5_15

[Unal 2023] Unal, P., Temel, S., Ummak, E., Ozbayoglu, A.M. Condition Monitoring and Remaining Useful Life Prediction for Tool Wear in CNC Machines. In: 10th Int. Conf. on Future IoT and Cloud (FiCloud), Marrakesh, Morocco, 14-16 August 2023, pp. 264-269. doi.org/10.1109/FiCloud58648.2023.00046

[Wang 2021] Wang, Q., Wang, H., Hou, L., Yi, S. Overview of Tool Wear Monitoring Methods Based on Convolutional Neural Network. Applied Sciences, 2021, Vol. 11, 12041. https://doi.org/10.3390/app112412041

[Wang 2023] Wang, Z., Wang, Y., Lv, D. and Gao, Y. Performance and wear mechanisms of coated PCBN tools in high-speed turning superalloy GH4202. International Journal of Advanced Manufacturing Technology, 2023, Vol. 127, pp. 5083-5097. https://doi.org/10.1007/s00170-023-11803-5

[Yarovyi 2020] Yarovyi, Y. and Yarova, I. Energy Criterion for Metal Machining Methods. Advances in Design, Simulation and Manufacturing II. DSMIE 2019. Lecture Notes in Mechanical Engineering. Cham: Springer, 2020, pp. 378-387. https://doi.org/10.1007/978-3-030-22365-6_38

[Zehnder 2012] Zehnder, A.T. Fracture Mechanics. Springer Science & Business Media, 2012. ISBN 9789400725942

CONTACTS:

Svetlana Radchenko, PhD.
Technical University of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Bayerova 1, 080 01 Presov, Slovakia
svetlana.radchenko@tuke.sk