TESTING DURABILITY OF A BROACH

Badania trwałości eksploatacyjnej przeciągacza

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A b s t r a c t: In integrated manufacturing systems, a very important issue is the problem of ensuring the reliability of cutting tools, in particular high-speed steel broaches. To ensure the required quality of machining, the tool should be changed at specified intervals. Determining the tool replacement period and forecasting the tool's working ability is a difficult and complex issue due to the dispersion of the properties of the tool material and the workpiece. The paper presents the results of research on the dynamics of wear of HS 18-0-1 steel broaches, conducted under production conditions. Based on the analysis of the obtained results, it was shown that the scatter curves of the wear broach teeth VBalong its length and the standard deviation are in the form of a bathtub curve, which indicates uneven work of the broach teeth. In turn the teeth wear variance coefficient can be used to assess the effectiveness of its work. The research also shows that coated broaches are characterized by greater teeth wear stability and double reliable operation.
K e y w o r d s: broach, durability, HS 18-0-1 steel

S t r e s z c z e n i e: W zintegrowanych systemach wytwarzania bardzo ważnym zagadnieniem jest problem zapewnienia zdolności do pracy narzędzi skrawających, a w szczególności przeciągaczy ze stali szybkotnącej. Aby zapewnić wymaganą jakość obróbki należy w określonych odstępach czasu dokonać wymiany narzędzia. Wyznaczenie okresu wymiany narzędzia oraz prognozowanie zdolności do pracy narzędzia jest zagadnieniem trudnym i złożonym ze względu na rozrzut właściwości materiału narzędzia i przedmiotu obrabianego. W pracy przedstawiono wyniki badań dynamiki zużycia przeciągaczy ze stali HS 18-0-1 prowadzonych w warunkach produkcyjnych. Na podstawie analizy uzyskanych wyników wykazano, że krzywe rozrzutu zużycia zębów przeciągacza VB na całej długości i odchylenie standardowe mają postać krzywej wannowej, co wskazuje na brak identyczności pracy zębów na jego długości, natomiast do oceny efektywności jego pracy można wykorzystać współczynnik wariancji zużyci zębów. Wykazano również, że przeciągacze z pokryciem charakteryzują się większą stabilnością zużycia zębów oraz dwukrotnie większą niezawodnością pracy.
S ł o w a k l u c z o w e: przeciągacz, trwałość, stal HS 18-0-1

Introduction

During the organization of the machining process in an automated manufacturing system the most complex problems arise when assessing the performance and reliability of processing. High requirements on the quality of manufactured parts determine technological failures as the main research object in the theory of technological system reliability [14, 15, 16]. During operation, the technological system is subject to mechanical and thermal effects, which cause damage and change the value of parameters of its initial state. The proper functioning of all elements of the technological system enables the implementation of the technological process, however, the quality indicators of the machined parts are mainly determined by the technological equipment, the machine tool and the tool.

Emre et al. [13] applied the thermo-mechanical process model to improve the broach design.For the simulation and optimization of complex tool geometry, they proposed an innovative method of generating intermediate teeth.They showed that in this way it is possible to optimize several geometrical features of the tool.Similar studies related to the optimization of broach design were conducted by Radhakrishnan et al. [4] for unconventional tool material. In turn, Xu and Yongfeng [6] showed that the use of anappropriate microtexture on the side surface of the broach reduces the drag force and increases the quality of the machined surface, which also affects the tool life. At optimal tool operating conditions, the dominant factors affecting the quality of the workpiece are damages caused by the wear of its cutting surfaces [1, 9]. Currently, many works are devoted to the issue of developing models of the durability of cutting tools, including broaches, required for designing and monitoring the condition of tools in automated machining systems [9, 10]. Gaddafee and Chinchanikar [11] used for this purpose classical methods based on the Weibull and Gamma distribution, Chile Louizu et al. [15] used information from the vision system.However, determining the durability of broaches is still a current issue, the solution of which would contribute to the improvement of the tooling economy in manufacturing enterprises.

Assuring the performance quality of the tool

The cutting tool with the specified parameters of the initial state starts working under the given conditions for which it was designed. In the cutting process, with the passage of time, due to thermodynamic loads, the parameters of the initial state change their value. When the complex of geometric indicators describing the condition of the cutting part of the tool reaches its limit values, the tool is withdrawn from use [17, 18]. In order to ensure the required machining efficiency and the necessary performance, when calculating the tool wear costs at the design stage, its reliability indicators should be forecasted. Ensuring the quality of technological systems is therefore very important, and the basic feature of their quality is reliability. According to the ISO 9000 series standards, reliability is the ability of an object to fulfill its intended function under certain conditions and within a certain time. It follows that reliability is a quality feature that manifests itself in the expected lifetime. Tool life is characterized by the entire period of its use, taking into account the need for sharpening in order to ensure the state of readiness for the work performed. In calculating reliability, many quantitative indicators of the efficient operation of the tool are used. One of them is the probability of a reliable operation of the tool P (T_C), where T_C is the durability which is the probability that in the time interval ti decommissioning will not occur. Other indicators of reliability are durability, average durability, and the durability density function $f(t)$. Often, other reliability indicators are also used, such as decommissioning intensity $\lambda(T)$, γ-percentage durability or the durability variance coefficient. All quantitative indicators of reliability can be determined only as a result of the conducted experimental tests with the use of a tool with specific indicators of the initial state, as well as a result of statistical observations of the tool parameters in the process of its operation.

The current reliability theory develops in two directions [3, 5, 6, 8]:

– the physical direction deals with the description of the physical processes of the tool withdrawal models and solving tasks based on them regarding the improvement of reliability, tool diagnosis, etc.
– the mathematical or statistical direction deals with the elaboration of general mathematical models and the calculation of indicators of the reliable operation of the tool.

Thus, there are two approaches to solve reliability problems, although they are only conditional, because both directions often intertwine with each other, e.g. the creation of mathematical models is based on experiments and the physical reasons for decommissioning, and when solving physical problems, the mathematical apparatus of the probability theory is used [10].

Methodology

The study of the wear dynamics of broaches was carried out under production conditions when broaching a spline with a rectangular profile shown in Fig. 1. A 7B 510 horizontal broaching machine with a set of HS 18-0-1 steel broaches was used for the tests. The processed material was a C45 steel blank (HB = 260–320) with a length of 130 mm.

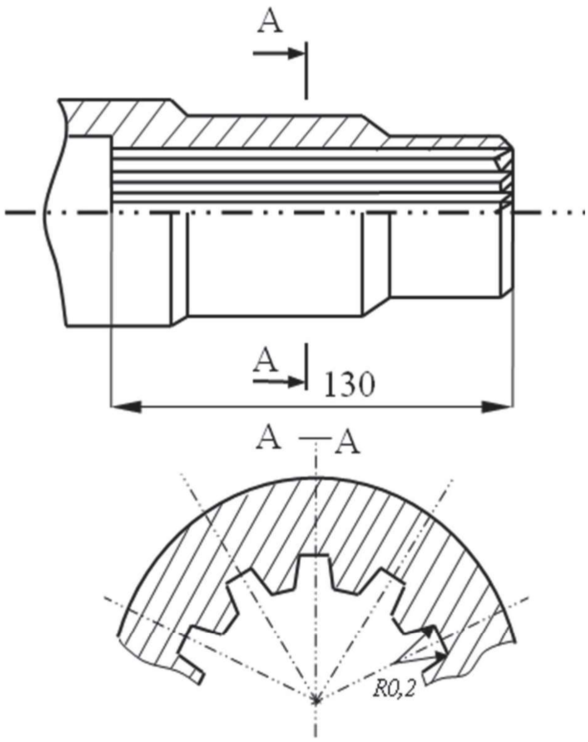

Fig.1. Workpieceests

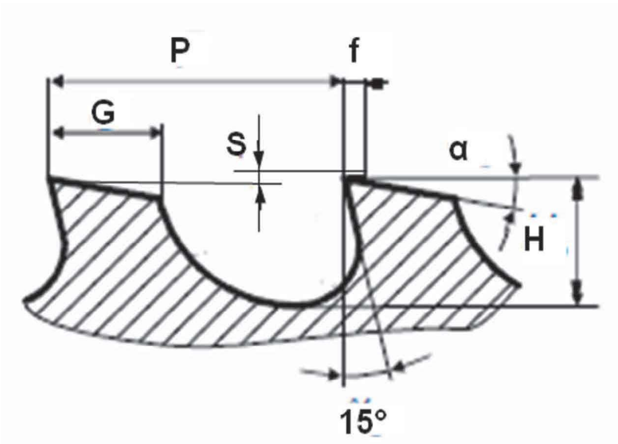

Fig. 2. The finishing broach used in the test

Table. 1. Geometric parameters of the broach

The broach tooth number	S	α	*f*	P	G	H	d
1-2	0.15	3°	0.05	16	5	5	33.5
3-6	0.35			22	6	7	
7-14	0.06	2°					
15	0.015						
16	0.01						
17-18	0	1°					
19-35			0.1-0.6				38,.1

Fig. 2 and Tab. 1 show the parameters of the cutting part of the finishing broach for which the tests were conducted. The study of the wear dynamics of the finishing broach was carried out at a cutting speed of *vc* = 7 m/min with the machining of 500 parts. Wear on the flank V_B = 0.4 mm was adopted as the wear criterion.

Results and analysis

The durability of a broach was determined on the basis of the number of machined parts. In order to obtain reliable wear characteristics, the obtained data was subjected to a mathematical analysis. It was established that the technological wear criterion of the broach, ensuring the required quality of the machined part, is the tool wear on the flank V_B equal to 0.4 mm. This value was adopted as the wear criterion. Based on the obtained data and its analysis, the diagrams of the teeth durability scatter and standard deviation along the broach length were developed (Fig. 3).

From the presented graphs, it can be concluded that the curves of the wear distribution of the broach teeth V_B along the entire length and the standard deviation σ have the form of a bathtub curve, which indicates the lack of identity of the teeth operation along its length.

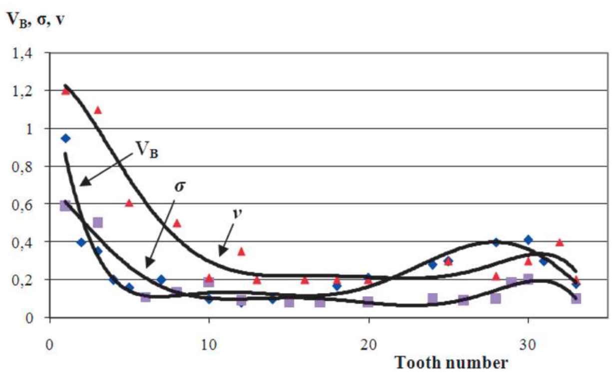

Fig. 3. Wear of a broach on the flank face V_B mm, standard wear deviation σ [mm] and wear variation coefficient *v* for individual teeth

This should be taken into account when designing and applying surface treatments. The finishing broach influences the quality of obtained parts, therefore it is subjected to increased reliability requirements. Therefore, a graphical dependence of the variance coefficient along its length was developed for it (Fig. 3).

By analyzing Fig. 3 it can be concluded that the reliability of the broach assessed by the coefficient of variation is not the same for all the teeth broach. Therefore, when determining the design and operational characteristics of the broach, especially in an automated enterprise, the criterion for its evaluation should be the coefficient of variance.

Increasing the reliability of the broach can be achieved by improving its design and manufacturing technology as well as by applying various types of surface treatments. The application of wear-resistant coatings removes surface defects of the tool material, reduces the surface roughness and the same reduces the friction force between the coating and the workpiece.

The factors influencing the durability and wear of coated tools include the destruction of the coating on the contact surface of the tool with the workpiece. The destruction of the coating occurs most intensively with the loss of the geometry of the cutting part as a result of elastic bending under loads, which leads to an increase of the dislocation density of the crystal lattice to the limit value, both in the tool material and its coating. This causes microscopic cracks which lead to the destruction of the coating. The stresses appearing in the deformation process are also a dangerous phenomenon that reduces the adhesion strength of the coating with the tool material. When designing broach, the nature of the stress in the life of the tool should also be taken into account. The amount of stress in the coating depends on various physico-mechanical and thermo-physical properties of the coating and tool material, such as: thermal conductivity, expansion coefficient, etc. Operation of the tool with a coating having a high level of surface stresses may lead to a stochastic destruction of the coating and a sudden reduction in operational reliability of the broach.

To assess the reliability of the broach's work with the TiN coating, the wear of the broaching teeth was measured and subjected to a mathematical analysis. Based on the amount of teeth wear, the standard deviation of teeth wear was determined along the entire length of the finishing broach. As can be seen from Fig. 4, the wear of the broach teeth along its length is the same for both uncoated and coated broaches. However, greater teeth wear stability can be seen for the coated broach on both the first cutting and sizing teeth. This is due to the coating that adheres well to the tool material and is more resistant to wear.

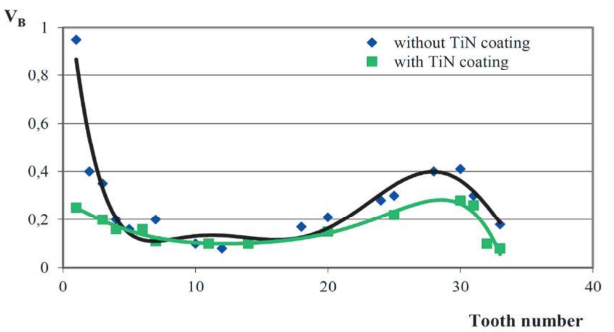

Fig. 4. Wear of the broaches on the flank surface V_B

During continuous operation of the broach, the standard deviation of wear depends on the amount of teeth wear (Fig. 5). The greater the wear on the teeth V_B, the greater the deviation value. Increasing the wear is favored by a higher value of the feed and spread of the allowance left after the previous operation. As a result, the standard deviation of the wear for the coarse broach is greater than for the finishing broach. This phenomenon is characteristic of both an uncoated and coated broach. However, for a coated broach, the difference in wear stability between rough and finish broaches is smaller.

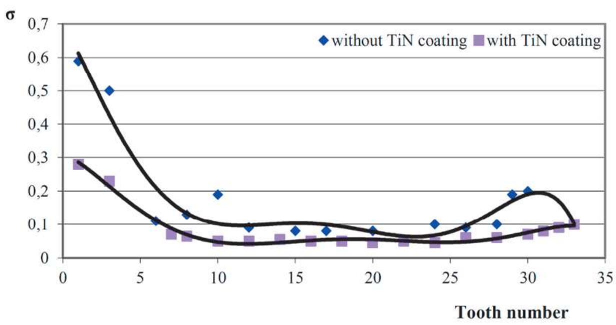

Fig. 5. Standard deviation of broach wear

During the tests, the values of the variance of the broach wear with and without the coating were compared at equal values of the average wear V_B. It allowed to notice that for broaches without coating, the value of the coefficient ranges from 0.06 to 0.16 (with an average wear value for a coarse broach of 0,88), while for a broach with coating v = 0.037. Similar results were obtained for finishing broaches. Analogically, the coated broaches had a much lower coefficient of variation than the uncoated ones. Note that by reducing the S_z feed from 0.15 to 0.05, the difference between the variance coefficient values for both coated and uncoated broaches. The mean value of the coefficient of variance for coated broaches is 0.2–0.3, while for uncoated broaches it is 0.3–0.55. For feed S_z = 0.12, the coefficient of variance for coated broaches is two times smaller than for uncoated broaches, while for feed S_z = 0.05 the difference between the coefficients is insignificant. Thus, by applying the coating to the broach, its reliability is doubled. Which, in turn, allows the use of broaches with surface treatment in an automated enterprise.

Effect of sharpening on broach work

In the process of operation, the broach is subject to repeated sharpenings. The service life of the sharpened tool ranges from 75 to 85% of the total service life of the broach. Therefore, the effectiveness of the broach work was tested throughout the entire period of its operation. Based on the statistical data obtained during the processing of C45 steel and its analysis, the dependence of the sharpening effect on the tool face on the total average wear value of the V_B teeth was developed. The tests were performed with the same number of processed parts (Fig. 6).

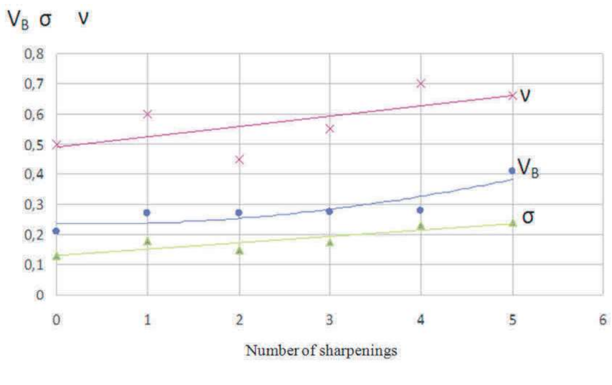

Fig. 6. Influence of the number of broaching sharpeners on the amount of wear of the teeth V_B [mm], standard deviation of wear σ [mm] and coefficient of wear variation v

The analysis of Fig. 6 shows that with the increase of the number of sharpenings, the wear of the broaching teeth and the spread of standard deviation of wear increase. As the number of sharpenings increase, the coefficient of variance also increases, which proves that the reliability of the broach's operation is reduced.

Conclusions

As a result of the research, it was concluded that:

- Scatter curves of broach teeth along its length as well as their standard deviation are in the form of a bathtub curve, which indicates uneven work of the broach teeth. This should be taken into account when designing the broach and applying surface treatments.
- When determining the design and operational features of the broach, the coefficient of variance should be used as a criterion for assessing the effectiveness of its work.
- Coated broaches are characterized by greater teeth wear stability and double reliable operation.
- The analysis of the test results shows that with the increase in the number of sharpenings, the average value of the teeth wear on the flank, the size of the standard deviation and the coefficient of variance increase, which proves the lowering of the broach's reliability.

References

[1] An W., Xu Z., Zhang H. Liu E. 2020. "Experimental study of cutting–parameter and tool life reliability optimization in inconel 625 machining based on wear map approach". Journal of Manufacturing Processes 53: 34–42.

[2] Artamonov E.V., Vasilega D.S., Ostapenko M.S. 2015. "Methods of considering reliability in the quality evaluation procedure for composite metal cutting tools". Applied Mechanics and Materials 770: 216–220.

[3] Cai G., Chen X., Li B., Chen B., He Z. 2012. "Operation reliability assessment for cutting tools by applying a proportional covariate model to condition monitoring information'. Sensors 12: 12964–12987.

[4] Courbona C., Arrietab I.M., Cabanettesa F., Rech J., Arrazola P.J. 2020."The contribution of microstructure and friction in broaching Ferrite–Pearlite steels". CIRP Annals – Manufacturing Technology 69: 57–60.

[5] Emre Ö, Arash E. A., Erhan B. 2020. "Broaching tool design through force odeling and process simulation". CIRP Annals – Manufacturing Technology 69, 53–56.

[6] Gaddafeea M., Chinchanikarb S. 2020. "An Experimental Investigation of Cutting Tool Reliability and its Prediction Using Weibull and Gamma Models: A Comparative Assessment". Materials Today: Proceedings 24: 1478–1487.

[7] Jaworski J., Kluz R., Trzepieciński T. 2016. "Operational tests of wear dynamics of drills made of low–alloy high–speed HS2–5–1 steel". Maintenance and Reliability 18 (2): 271–277.

[8] Kishawy H. A., Hosseini A., Imani B.M., Astakhov V.P. 2012. "An energy based analysis of broaching operation: Cutting forces and resultant surface integrity". CIRP Annals – Manufacturing Technology 61 (1): 107–110.

[9] Lauro C. H., Brandao L. C., Baldo D., Reis R. A., Davim J. P. 2014. "Monitoring and processing signal applied in machining processes – A review". Measurement 58: 73–86.

[10] Legrand C., Fromentin G., Poulachon G., Chatain R., Ranicic M. 2019. "A geometrical and mechanistic generalized model for complex shape broaching of super alloy". Procedia CIRP 82: 461–466.

[11] Loizou J., Tian W., Robertson J., Camelio J. 2015. "Automated wear characterization for broaching tools based on machine vision systems". Journal of Manufacturing Systems 37:558–563.

[12] Ortiz–de–Zaratea G., Selaa A., Ducobub F., Saez–de–Buruagaa M., Solera D., Childsc T.H.C., Arrazolaa P.J. 2019. "Evaluation of different flow stress laws coupled with a physical based ductile failure criterion for the odeling of the chip formation process of Ti–6Al–4V under broaching conditions". Procedia CIRP 82: 65–70.

[13] Pham M. D., Le H. G., Mai D. D., Do T. S. 2020. "An experimental study on the effect of tool geometry on tool wear and surface roughness in hard turning". Advances in Mechanical Engineering 12(9): 1–11.

[14] Radhakrishnan K., Nirmal Prabhu B., Bharath R. 2020. "Suitability of MC90 Intermet material for optimal design of carbon–free broach tool". Materials Today: Proceedings 21: 787–792.

[15] Terry W. R., Cutright K. W. 1986. "Computer aided design of a broaching process". Computers & Industrial Engineering 11(1–4): 576–580.

[16] Teti R., Jemielniak K., O'Donnell G., Dornfeld D. 2010. "Advanced monitoring of machining operations". CIRP Annals – Manufacturing Technology 59(2): 717–739.

[17] Xu R., Yongfeng Y. 2020. "Effect of Micro–texture of Flank Surface on Broaching Force andSurface Quality of Workpiece". Applied Surface Science 146558.

[18] Zoriktuev V. T., Nikitin Y. A., Sidorov A. S. 2008. "Monitoring and prediction of cutting–tool wear". Russian Engineering Research 28(1): 88–91.

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