ISSN 2078-7405 Cutting & Tools in Technological System, 2024, Edition 101

UDC 621.9. **doi: 10.20998/2078-7405.2024.101.09**

DETERMINATION OF THE STABILITY PERIOD OF TURNING CUTTERS FOR HEAVY MACHINE TOOLS

Galyna **Klymenko** [0000-0002-1022-6324], Yana **Vasylchenko** [0000-0002-4566-8827], Yevhen **Reva** [0009-0008-4723-9082] , Dmytro **Korchma** [0009-0000-1875-6285], Roman **Boroday** [0009-0009-6730-9540]

Donbass State Engineering Academy (DSEA), bul. Mashinostroiteley, 39,
Kramatorsk, Ukraine
wasilchenko.ua@gmail.com

Received: 30 October 2024 / Revised: 14 November 2024 / Accepted: 26 November 2024 / Published: 15 December 2024

Abstract. *To determine the optimal cutting modes under conditions of increased requirements for the stability of technological processes, it is necessary to take into account the value of the tool life with a given probability. In this paper, the stability dependence for prefabricated cutters used on heavy machine tools with maximum diameters Dmax = 1250-2500 mm is specified using the group argumentation method. The study presents a new mathematical model that establishes the relationship between tool fracture resistance and key operational parameters. This model incorporates the probabilistic nature of tool performance, which allows for a more accurate assessment of the impact of part size variation, cutting conditions, and process variability. The proposed relationship facilitates the determination of cutting modes that not only increase tool stability but also ensure the reliability and efficiency of heavy machine tools in industrial environments. This mathematical dependence makes it possible to take into account the variation of workpiece parameters and cutting modes, which is especially important when working with large-sized parts on heavy-duty machine tools. The results of the study are of practical importance for industry, as they make it possible to increase the sustainability and productivity of technological processes.*

Keywords: *cutting tool; tool life; reliability; failure probability; cutting insert; cutting force.*

1. Introduction

The issues of wear and durability of cutting tools, machinability of various materials by cutting have been considered to a greater or lesser extent by many studies [1–13] and others. To obtain a mathematical model of the machining process for determining rational cutting modes, the initial dependence is $T=f(V, S, t)$. Therefore, for a number of years, a large number of researchers have been engaged in the study of tool wear patterns and resistance dependencies. At present, there are a large number of formulas derived from experimental data and linking durability with the elements of the cutting mode. Cutting speed has the strongest influence on the durability period. At present, empirical dependences of durability on the elements of the cutting mode have been established practically for all types of cutting tools and most tool machined materials. The most frequently used equation is:

$$S_P = C_P \cdot T_P^{-mP}$$

However, the practice of using these formulas has shown that they are valid only in a limited range of changes in cutting modes.

The most complete studies of the stepped resistance dependence indices were performed in [6,11], which used multiplicative models of the resistance dependence, in which the degree indices are functions of the cutting tool parameters and machining conditions.

Despite the great variety of formulas describing the relationship between tool resistance and elements of the cutting mode, the required reliability and accuracy of the initial information for the calculation of cutting modes is not always ensured. The described dependencies are valid for those machining cases when tool failure occurs due to tool wear [3,8,9].

In real production conditions, carbide tool failure can occur not only as a result of wear of the cutting part, but also due to its destruction. In real production conditions, carbide tool failure can occur not only as a result of wear of the cutting part, but also due to its destruction. Therefore, for these cases, the steady-state dependences need to be clarified.

A number of works [12,13,14] have been devoted to the study of the tool fracture process. In works [12,13] the causes of cutting tool fracture on CNC machines are analysed. Failures of roughing cutters due to wear are only 60-70%, the remaining failures are related to tool breakages [13]. When turning on heavy machines, the percentage of cutting tool failures reaches 75% [14].

The most complete classification of the types of breakages of the working part of the tool is given in [14]. It is proved that during rough turning the destruction of a carbide plate mainly depends on the feed, and the wear depends on the cutting speed. The relationship between feed and the number of durability periods is expressed by the equation obtained on the basis of experimental and statistical data:

$$S_K = C_K \cdot K^{-m_k} \quad \text{, where}$$

S_K – the feed rate corresponding to a certain period of resistance;

m_k – degree index;

In the same work, a similar relationship between the tool endurance to fracture and the breaking feed rate is given:

$$S_P = C_P \cdot T_P^{-mP} \text{ ,}$$

where S_p is a coefficient characterising the average strength of the tool and depending on the processed material and working conditions;

m_P – value characterising the degree of influence of T_p on S_p.

When machining steel parts with cutters m_P = 0,08–0,28. These dependencies relate feed rate to the tool life before fracture and the number of tool life periods and are essentially similar to the *V–T* life dependencies. The former allows you to determine the tool life under conditions of wear, the latter – under conditions of its destruction. However, for practical use in the calculation of cutting modes, these dependences need to be clarified in relation to specific conditions, since the values of degree indices fluctuate in a wide range (especially m_k) and have been studied mainly for medium-sized machine tools.

It was shown in [10] that the number of tool life periods can be considered with some approximation as a value inversely proportional to the probability of tool fracture.

The authors [3,9,12] pointed out the necessity of taking into account the probability of tool fracture when determining the feed rate. However, due to the lack of relations reflecting the probabilistic nature of the cutting process, taking into account both tool wear and tool fracture, this problem has not been completely solved.

In [11], an attempt was made to establish the dependence of tool life period numbers on the feed rate. However, the experiments were carried out on medium-sized machine tools. Therefore, the peculiarities of machining on heavy machine tools could not be fully taken into account.

Taking into account the large dispersion of the tool life period during its operation on heavy machine tools, the study of tool reliability and its relationship with the parameters of the operation process is of particular importance.

2. Applied methods

The average tool life is a probabilistic value. It depends on the probability of a particular type of failure (wear or fracture). Tool life is defined as the time between failures of the corresponding type. In this case, these periods are conditional values that characterise the properties of a given tool. The average actual life of a cutting tool, which depends on its wear resistance and strength, is determined:

$$\overline{T} = q_s T_s + q_P T_P \,,$$

where T_s, T_p are the periods of stability due to tool wear and fracture, respectively; q_s, q_p are the probabilities of tool wear and fracture, respectively, $q_s + q_p = 1$.

To develop a mathematical model of the period of resistance to fracture of turning cutters for heavy machine tools, the method of group accounting of arguments was adopted [15].

This approach of self-organisation of models is fundamentally different from the commonly used deductive methods. It is based on inductive principles - finding the best solution by searching through various options.

By searching through different solutions, the role of assumptions about the modelling results is minimised. The algorithm determines the structure of the model and the laws that apply to the object. It can be used to create artificial intelligence to resolve disputes and make decisions.

The group argumentation method consists of several algorithms for solving various tasks. It includes both parametric and clustering algorithms, analogue complexity and probabilistic algorithms. This self-organising approach is based on searching through gradually increasingly complex models and selecting the best solution according to a minimum external criterion. Not only polynomials but also nonlinear, probabilistic functions or clustering are used as basic models.

In this paper, we used the following types of functions:

$$f(x) = x\ ,\ \ f(x) = 1/x\ ,\ \ f(x) = \ln(x)\ \ .$$

The next step is to determine the optimal complexity of the model structure, adequate to the level of errors in the data sample. It is guaranteed to find the most accurate or unbiased model – the method does not miss the best solution when trying all options (in a given class of functions).

This method automatically finds the relationships interpreted in the data and selects the most effective input variables, neglecting the least influential elements. The method uses information directly from the data sample and minimises the influence of the author's a priori assumptions about the modelling results. This approach of this method can be used to improve the accuracy of other modelling algorithms and makes it possible to find an unbiased physical model of an object (law or clustering) - the same for all future samples.

3. Results and discussion

According to laboratory tests (Figs. 1, 2), the type dependence was obtained for preliminary crust turning of steel with turning cutters with horizontally arranged T5K10 carbide inserts and for machining on machine tools with a maximum diameter of the workpiece above the bed (standard size) D_{max} = 1250–2500 mm:

$$f(S_p) = f(C_1 \ldots C_6, \ln V, \ln t, \ln D, \ln\sigma, t, V, D, \sigma),$$

where S_P is the average value of the fracturing feed, mm/rev; V is the cutting speed, m/min; t is the depth of cut, mm; D is the dimensional parameter of the machine tool, mm; σ is the tensile strength of the material being processed, *MPa*; C_1, …, C_6 are approximation factors.

In many cases, the period of resistance to fracture of a cutting tool is directly proportional to the number of cycles before fracture. When turning under the specified conditions, the stress on the front surface of the cutting element

$$\sigma = C_y N^{-m_y} = C_y \left(f T_p \right)^{-m_y} = C_y^{'} T_p^{-m_y} .$$

where: C_y is the coefficient characterising the strength of the tool,
N is the number of fracture cycles,
T_P is the period of resistance of the cutting tool to fracture.

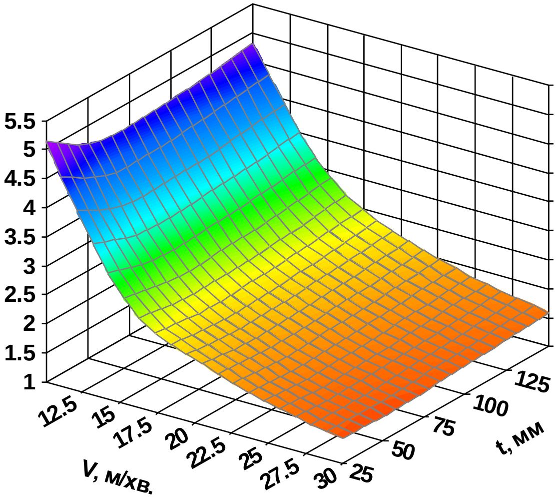

Fig. 1. Character of change in the breaking feed S_P with depth t and cutting speed V (D_{ma} = 1250 mm, 90XF - T5K10 (P30), on the crust)

Maximum principal stress

$$\sigma_{\max} = C_y^{''} S_p ,$$

$$S_p = \left(\frac{C_y^{'}}{C_y^{''}} \right) T_p^{-m_y} .$$

Based on the previous equation, the period of resistance to fracture can be determined by :

$$T_p = C_p \left(1.87 \frac{e^{1839.53 \frac{\ln V}{D} + 0.0336 \frac{D^2 \ln^2 t}{\sigma^2} (1 + \frac{89.583}{V^2})}}{e^{1071.21 \frac{\ln t}{\sigma} \left(1 + 9 \cdot 10^{-9} \frac{D^3 V \ln^2 t}{\sigma^2} \right)}} \right)^{m_p} ,$$

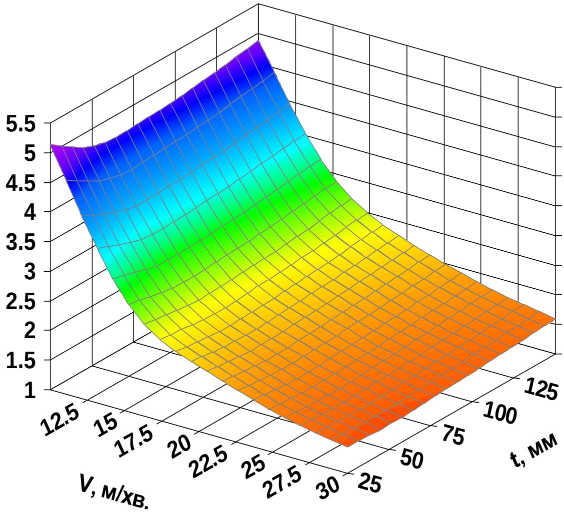

Fig. 1. Character of change in the breaking feed S_P with depth t and cutting speed V (D_{ma} = 2500 mm, 90XF - T5K10 (P30), on the crust)

where C_P is a coefficient characterising the average strength of the tool, depending on the processed material and working conditions; m_P is a value characterising the degree of influence of the T_P on S_R ($m_P = 1.6$ for $S = 1.2–1.6$ mm/rev, $m_P = 2.1$ for $S = 1.61–2.05$ mm/rev.)

In developing the mathematical model, a sample (N = 240) of statistical data from the information bank of failures of carbide tools on heavy machine tools with a maximum diameter of the workpiece $D_{\max}$= 1250 – 2500 mm was used. Mathematical processing of the data collected at different plants made it possible to determine the degree of dispersion of tool life and confirm the probabilistic nature of tool failures. This proves the need to take into account the destruction, not just the wear of the tool when determining its durability.

4. Conclusions

The stability dependence for prefabricated cutters of heavy machine tools with $D_{\max}$ = 1250–2500 mm is specified using the method of group argument accounting. The new mathematical dependence of tool fracture resistance on the most common operating conditions allows taking into account the probabilistic nature of tool operation, scattering of workpiece parameters, and cutting modes. Based on the research, a system of mathematical models and objective functions will be developed to optimise cutting modes and tool consumption rates according to the following criteria: reduced costs, productivity, tool consumption, and the level of reliability of a prefabricated turning cutter when machined on heavy machine tools.

References: 1. *Gaddafee M., Satish S.*, An Experimental Investigation of Cutting Tool Reliability and its Prediction Using Weibull and Gamma Models: A Comparative Assessment, Materials Today: Proceedings, Volume 24, Part 2, 2020, pp.1478–1487, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.04.467 **2**. *Letot, C., Serra, R., Dossevi, M. et al*. Cutting tools reliability and residual life prediction from degradation indicators in turning process. Int. J. Adv. Manuf. Technol., 86, 495–506 (2016). https://doi.org/10.1007/s00170-015-8158-z **3**. *Liu, Erliang & An, Wenzhao & Xu, Zhichao & Zhang*, Huiping. (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. pp. 34–42. https://doi.org/10.1016/j.jmapro.2020.02.006 **4**. *Karimi, B., Niaki, S.T.A., Haleh, H. et al*. Reliability optimization of tools with increasing failure rates in a flexible manufacturing system. Arab J Sci Eng44, 2579–2596 (2019). https://doi.org/10.1007/s13369-018-3309-9 **5.** *Bakša, Tomáš & Kroupa, Tomáš & Hanzl, Pavel & Zetek, Miroslav*. (2015). Durability of Cutting Tools during Machining of Very Hard and Solid Materials. Procedia Engineering. https://doi.org/10.1016/j.proeng.2015.01.51121 **6**. *Jaydeep M. Karandikar, Ali E. Abbas, Tony L. Schmitz*, Tool life prediction using Bayesian updating. Part 2: Turning tool life using a Markov Chain Monte Carlo approach, Precision Engineering, Volume 38, Issue 1, 2014, pp.18–27, ISSN 0141-6359, https://doi.org/10.1016/j.precisioneng.2013.06.007 **7.** *Karimi, B., Niaki, S.T.A., Haleh, H. et al*. Reliability optimization of tools with increasing failure rates in a flexible manufacturing system. Arab. J. Sci. Eng. 44, 2579–2596 (2019). https://doi.org/10.1007/s13369-018-3309-9 **8.** *AstakhovV.*, The assessment of cutting tool wear, International Journal of Machine Tools and Manufacture, Volume 44, Issue 6, 2004, pp. 637–647, ISSN 0890-6955, https://doi.org/10.1016/j.ijmachtools.2003.11.006 **9.** *Zhang, G., Wang, J., To, S.* (2023). Tool Fracture Wear Evaluation Method Using Cutting Chips. In: To, S., Wang, S. (eds) Fly Cutting Technology for Ultra-precision Machining. Precision Manufacturing. Springer, Singapore. https://doi.org/10.1007/978-981-99-0738-0_9 **10.** *Vagnorius, Z., Rausand, M., & Sørby, K.* (2010). Determining optimal replacement time for metal cutting tools. European Journal of Operational Research, 206(2), 407–416. https://doi:10.1016/J.EJOR.2010.03.023 . **11.** *Rathod N., Chopra M., Vidhate U., Gurule N., Saindane U*., Investigation on the turning process parameters for tool life and production time using Taguchi analysis, Materials Today: Proceedings, Volume 47, Part 17, 2021, Pages 5830-5835, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2021.04.199 . **12.** *Arif M., Rahman M., Wong Yoke San*, Analytical model to determine the critical feed per edge for ductile–brittle transition in milling process of brittle materials, International Journal of Machine Tools and Manufacture, Volume 51, Issue 3, 2011, pp. 170–181, ISSN 0890-6955, https://doi.org/10.1016/j.ijmachtools.2010.12.003 **13**. *Klymenko G. Kvashnin V.* Reliability assurance technological systems exploitation of heavy lathe Cutting & tool in technological system 2019; 91: pp. 78–86 https://doi.org/10.20998/2078-7405.2019.91.08 **14.** *Klymenko G., Kovalov V., Vasylchenko, Korchma D.,Boroday R.* Probabilistic approach to calculating the rational thickness of the tool`s cutting insert for heavy machine tools. Cutting & tool in technological system 2023; 99: pp 110–119 https://doi.org/10.20998/2078-7405.2023.99.1 **15.** *Ravskaya N., Kovaleva L*. Application of self-organisation methods for identification of processes and objects. Lucrârile ştiinţifice ale simpozionului internaţional 'UNIVERSITARIA ROPET 2002' - INGINERIE MECANICÂ /, Petroşani: Focus

Галина Клименко, Яна Васильченко, Євген Рева, Дмитро Корчма, Роман Бородай, Краматорськ, Україна

ВИЗНАЧЕННЯ ПЕРІОДУ СТІЙКОСТІ ТОКАРНИХ РІЗЦІВ ДЛЯ ВАЖКИХ ВЕРСТАТІВ

Анотація. *У статті доведено, що розробка регламентів експлуатації різальних інструментів на важких верстатах, формування цільових функцій оптимізації параметрів обробки деталей повинні здійснюватися виходячи із заданого рівня надійності різального інструменту. При цьому використовується велика кількість показників, що визначають окремо безвідмовність, довговічність та ремонтопридатність інструменту. На основі статистичних і теоретичних досліджень імовірнісного характеру властивостей різального інструменту і параметра розподілу навантаження на нього отримані кількісні залежності між параметрами розсіювання властивостей і товщиною інструментальної пластини збірного інструменту. Стохастичний характер процесу обробки на важких верстатах зумовлює великий розкид властивостей оброблюваних і інструментальних матеріалів та інших параметрів обробки. Це призводить до необхідності імовірнісного підходу до визначення конструктивно-технологічних параметрів різального інструменту. Надійність роботи збірного різця залежить як від його навантаження, так і від несучої здатності конструкції інструменту, яка є граничним напруженням, що характеризує міцність конструкції. Використовуючи імовірнісний підхід до розрахунку товщини ріжучої пластини різця, було визначено поправочний коефіцієнт на товщину з урахуванням рівня надійності інструменту. Під рівнем надійності розуміли ймовірність того, що максимальне напруження, яке виникає під дією навантаження, не перевищить тримальної здатності. Досліджувалися типові конструкції, які найчастіше використовуються на сучасних підприємствах важкого машинобудування. Закон розподілу сил різання визначався на основі статистичних даних про роботу твердосплавних різців. Товщина ріжучого елемента розраховувалася для релеївського закону розподілу навантаження, визначеного на основі статистичних даних про сили різання при токарній обробці для різних конструкцій різців. Розподіл тримальної здатності інструментального матеріалу пластин визначено на основі лабораторних випробувань.*

Ключові слова: *різальний інструмент; стійкість; надійність; ймовірність відмов; різальна пластина; сила різання.*