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Models of Reliability for Cutting Tools: Examples in Manufacturing and Agricultural Engineering

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Reliability of machining systems depends to a great extent on the reliability of cutting tool performance with the latter being the weak link due to wear. Soil processing systems have many in common with machining systems and a major problem related to use of tillage equipment is ploughshare wear, as it markedly affects tillage quality and agricultural production economy. In the present study a machining and a soil processing example will be given for the determination and modelling of the reliability function R(T): for turning of 20CrMo5 steel alloy using Cubic Boron Nitride (CBN) and mixed ceramic cutting tools, and in a tillage operation using a straight toothed harrow. In the machining case, through comparative analysis of theoretical distribution models, which fit closer the experimental data, the Gaussian model is selected to represent the reliability function for both tool materials considered. In the tillage example, by carrying out an optimization procedure based upon the reliability function R(T) of the tillage system, a particular tool tooth geometry was found that establishes the maximum tooth working time possible for a reliable performance.

Keywords: machining systems, cutting tools, system reliability, agricultural engineering, tool wear

0 INTRODUCTION

Reliability of technological and production systems is considered of paramount importance regarding safe function and effective performance. The reliability of a machining system, e.g. a lathe with numerical control (NC), comprises the reliability of the following subsystems: machine tool, cutting tool and auxiliary accessories, which are connected in series. Nowadays studies on reliability of modern technological and machining systems: NC, CNC, DNC, FMS, RMS, IMS and so on, are certainly increasing.

The weakest link is the cutting tool, the excessive wear of which implies its ordinary replacement with obvious consequences on machining economy, and in this way the reliability of the tool expresses mostly the reliability of the whole system [1] to [4].

By the application of statistical methods, describing the breaking down of components of machining systems in the phase of effective performance, it is possible to determine the theoretical distribution, which fits best the experimental data.

The theoretical distribution models encountered more frequently are the following: linear, exponential, hyper-exponential, normal (Gaussian), logarithmic normal, Weibull, Rayleigh, gamma, Erlang and Gumball or extreme (minimum or maximum) value of type I. The choice of theoretical distribution is checked through non-parameter tests: Pearson, Romanovski, Kolmogorov, Kolmogorov-Smirnoff and Mises.

The methodology followed in the present study assists stochastic modelling of tool life and can be seen in combination to tool life mathematical expressions (simple and generalized Taylor, Kronenberg etc.).

In this regard, the theoretical model of reliability of components in technical systems can be defined in one of the three following ways, as proposed by Dasic [4] and [5]:

- on the basis of a previously defined theoretical distribution,
- via choice of a theoretical distribution, which fits better the experimental data and
- using distribution and complex [6] networks.

1 THE MACHINING CASE

The failures of cutting tools can occur at: cutting parts of the tool, tool holders, parts for

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mechanic fixation etc. However, it should be noted that the failures prevail at cutting parts of the tool. Under the term cutting tool failures are considered the facts, which have as a consequence the loosing of working capability. Besides, the cutting tool failures can be separated into:

- failures with the possibility of renewing cutting tools working capacity. This can be realized by sharpening cutting parts of high-speed steel or introducing a new cutting blade, when coated or uncoated indexable hard metal inserts are used; or by means of repairing tool holder or other parts of the tool, and
- failures without the possibility of renewing cutting tools working capacity i.e. failures, which cause rejection of cutting tools.

By observing the changes in time of some tool wear sensitive parameters during cutting process, for example flank wear width VB, a connection with deterioration of the process expressed by the reliability function $R(T)$ can be obtained (Fig. 1).

The distribution may be given as the function of distribution $F(T)$ related to the probability that the failure will appear until time instant t, i.e. the probability that the time of work without failures does not exceed a value t [1] to [3], [5] and [7] to [16]:

$$F(T) = P\{T \leq t\} \qquad (1).$$

It is evident that at $t=0$, the value $F(0)=0$, and that at $t \to \infty$ the value $F(T)$ tends to be unity, i.e. $F(\infty)=1$.

The probability of work without failures or the reliability function is a complement to the unreliability function and may be represented by the following equation:

$$R(T) = 1 - F(T) = P\{T \geq t\} \qquad (2).$$

It is evident that at $t=0$, the value $R(0)=1$, and that at $t \to \infty$ the value $R(T)$ tends to be zero, i.e. $R(\infty)=0$.

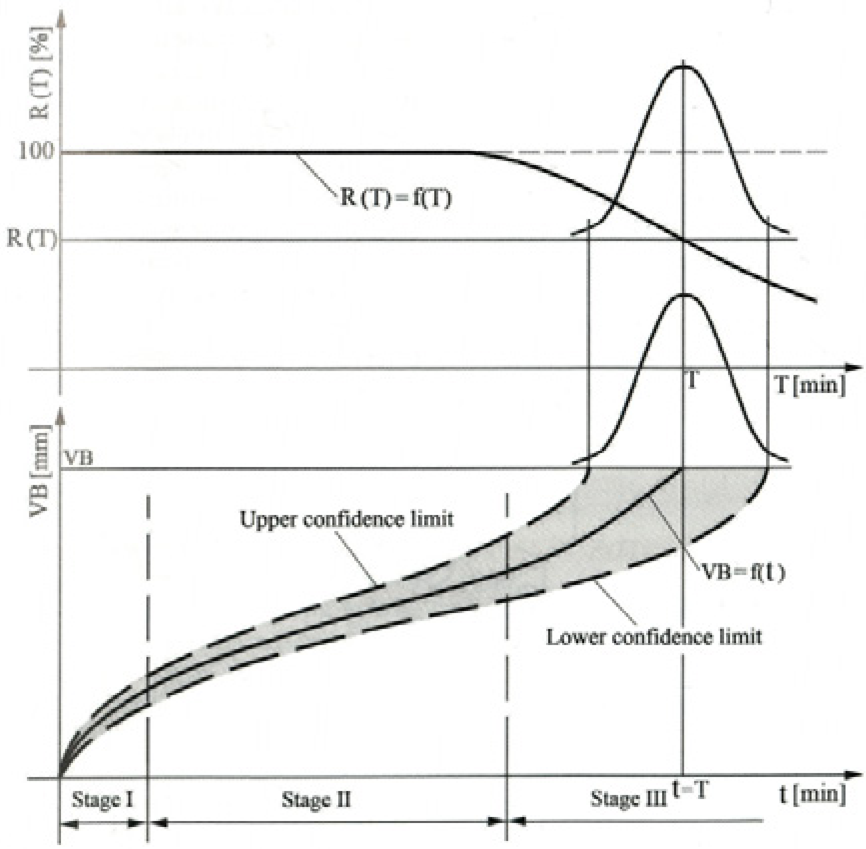

Fig. 1. *Graphical illustration of the interaction between tool wear and reliability within a tool cycle*

The failure frequency function is calculated according to the equation:

$$f(T) = F'(T) = -R'(T) \quad (3).$$

And the failure intensity function is defined as:

$$\lambda(T) = \frac{f(T)}{R(T)} \quad (4).$$

In references [1] to [5], [8] to [13] and [17] to [22] the reliability of cutting tools is analysed during machining and the reliability in the case of using ceramic materials is studied in [23] to [25].

Metal cutting causes several types of wear which can be ascribed to a few mechanisms as illustrated in Figure 2 [26] and these mechanisms are defined by the international standard ISO 3685:1993 [27].

In references [28] and [29] typical tool wear features are illustrated in finish turning and VB and VB_{max} measures are defined.

The dependence of tool wear VB on machining time t is represented by a function:

$$VB = f(t) \quad (5),$$

which is of complex form and is derived experimentally.

In literature are presented different approximations of experimental tool wear curve with corresponding regression equations of different form.

Modelling of tool wear is performed mostly with parabolic functions [30] to [44].

In References [30] to [33], [36] to [38], [40], [42] and [43] proposed power and exponential functions are used to describe cutting tool wear.

Also, complex power-exponential functions have been proposed [30] to [33] and [36] and of polynomial m-th order form [30], [36], [45] and [46].

The necessary criteria for cutting tool failures are chosen:

- for rough machining: on the basis of increased value of the cutting force or cutting temperature and
- for finish machining: prescribed limits for quality of the machining products should not been exceeded, expressed by: roughness parameters, macro geometrical deviations, tolerance field etc.

Summing up, the description, stochastic or deterministic, of the reliability function can lead to more effective exploitation of cutting tools, as well as optimized selection of cutting tool geometry and material.

By applying a similar concept to soil processing systems and tools, the determination of the reliability function can lead to improvement of anti-wear performance characteristics. A tillage system has many in common with a machining system and a major problem related to use of tillage equipment is ploughshare wear, as it markedly affects tillage quality and agricultural production economy. A tillage operation system possesses a similar structure to a machining system and the weak link is again the tool, as its wear controls the reliability of the whole system to a great extent. Of

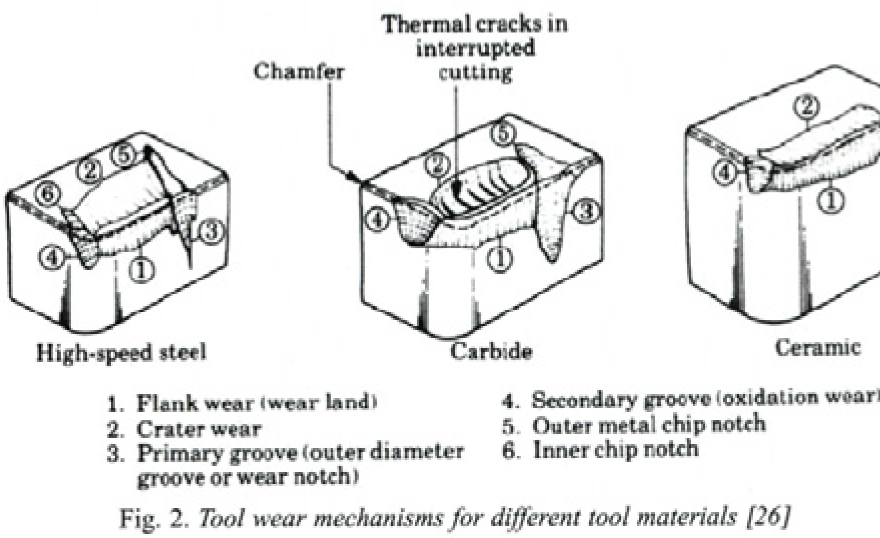

Fig. 2. *Tool wear mechanisms for different tool materials [26]*

course, in this case severe requirements for accuracy do not exist but excessive tool wear causes deterioration of technological and physiological parameters (power losses, insufficient cultivation depth etc.).

As aforementioned, by application of statistical methods describing the breaking down of cutting tools in the phase of their effective performance and exploitation, it is possible to determine the function of distribution that fits best the experimental data.

The present paper describes the introduction and relevant modelling of the reliability function in: firstly, machining by use of CBN and ceramic cutting tools, and secondly, in a tillage operation. In the first case a statistical approach is performed for finish turning of alloy steel 20CrMo5, which in the best way approximate experimental data on the basis of comparative analysis of the normal, logarithmic normal, Weibull and Gumbel extreme (minimum and maximum) distribution models. The selection of the suitable theoretical distributions is checked via the following non-parameter tests: Pearson, Romanovski, Kolmogorov, Kolmogorov-Smirnoff and Mises.

In the second case a deterministic analysis permits design optimization of the tillage tool. These two examples will be presented, separately, in the following.

Processing of experimental data by selecting a theoretical distribution is realized by DoRTSC2A software package [47].

1.1 Reliability Distribution of CBN Cutting Tools in Turning of Steel 20CrMo5

The cutting process in this case had the following characteristics:

- *cutting operation:* external longitudinal finish turning, working diameter D = 50 mm and working length L = 78 mm;
- *material:* steel 20CrMo5 (according to DIN standard) or C4721 (according to JUS standard) or 18CD4(S) (according to AFNOR standard), of 56-60 HRC hardness;
- *lathe:* CNC lathe Max Muller MD5S with driving power 25 kW;
- *cutting tools:* tool holder PTGNL2525M16 and the multi-bladed indexable inserts SPK-Feldmuhle TNMA160412T made of boron nitride WBN4 of special hexagonal microstructure;
- *tool nose radius:* r = 1.2 mm;
- *cutting conditions:* cutting depth a = 0.2 mm, feed s = 0.12 mm/rev and cutting speed v = 90 m/min;
- *wet turning*: processing with conventional coolant.

Failures of the CBN cutting tools have been observed during the turning operation, with the blunting of the cutting edge considered as a wear criterion (the maximum wear land width has been prescribed to VB = 0.4 mm).

The tests were replicated 11 times (sample size n = 11).

The time of work without failures t has been measured in [min] and has run from 18.08 min up to 23.60 min.

The resulting experimental distribution of the CBN cutting tools failures is positively skewed, i.e. asymmetrical on the left ($\beta_1 = 0.7156$) and close enough to normal ($\beta_2 = 3.3329$ or $\gamma_2 = 0.3329$).

For the scope of the present study the normal distribution is chosen owing to its symmetrical characteristics, simple form and unbiased character. The choice of the appropriate distribution model was checked by non-parameter tests: Pearson, Romanovski, Kolmogorov, Kolmogorov-Smirnoff and Mises and the best experimental data compliance was given by the normal distribution, the logarithmic normal distribution and the Guembel distribution of maximum values.

On the basis of comparative analysis [1], [5] and [47] of the distribution models: normal distribution, the logarithmic normal distribution and the Guembel distribution of maximum values, the chosen one is normal distribution, and its reliability function is as follows [3], [9] and [10]:

$$R(T) = 0.5 - \Phi\left(\frac{T - 20.1633}{1.8111}\right) \quad (6).$$

The basic theoretical indicators of the reliability normal model are illustrated in Figure 3.

1.2 Reliability Distribution of Mixed Ceramic Cutting Tools for Turning of Steel 20CrMo5

The cutting process in this case had the following characteristics:

- *cutting operation:* external longitudinal finish turning;

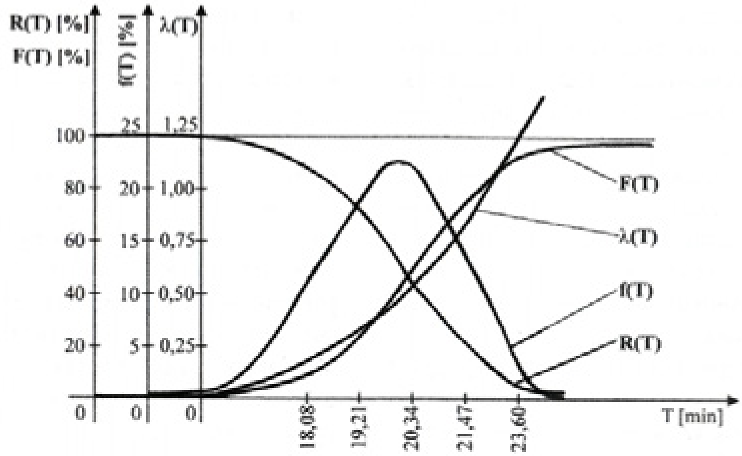

Fig. 3. *Graphic presentation of main indicators for the normal model of reliability of CBN cutting tools in turning of 20CrMo5 steel*

- *material*: steel 20CrMo5 (according to DIN standard) or C4721 (according to JUS standard) or 18CD4(S) (according to AFNOR standard), of 56-60 HRC hardness;
- *lathe*: universal lathe D-480;
- *cutting tools*: tool holder CCLNR2525M16 and the multi-bladed indexable inserts CNGN 160812T02020 made of mixed ceramic SH1 from the firm SPK-Feldmuhle;
- *tool nose radius*: r = 1.2 mm;
- *cutting conditions:* cutting depth a = 0.5 mm, feed s = 0.16 mm/rev and rotation speed n = 280 rev/min, i.e. cutting speed v = 68.61 to 95 m/min;
- *mode of lubrication:* dry cutting.

The trials were performed with sample size n = 27.

The time for work free of failures has been measured from 12.05 min up to 19.41 min.

The resulting experimental distribution of the mixed ceramic cutting tools failures is positive, i.e. asymmetrical on the left (β_1 = 0.1518) and close enough to normal (β_2 = 2.398 or γ_2 = -0.662).

The normal distribution was chosen again owing to its symmetrical characteristics, simple form and unbiased character.

The selection of the appropriate distribution model was checked by non-parameter tests: Pearson, Romanovski, Kolmogorov, Kolmogorov-Smirnoff and Mises and the best experimental data fitting was given by the normal distribution, the logarithmic normal distribution, Weibull distribution and the Guembel distribution of maximum values.

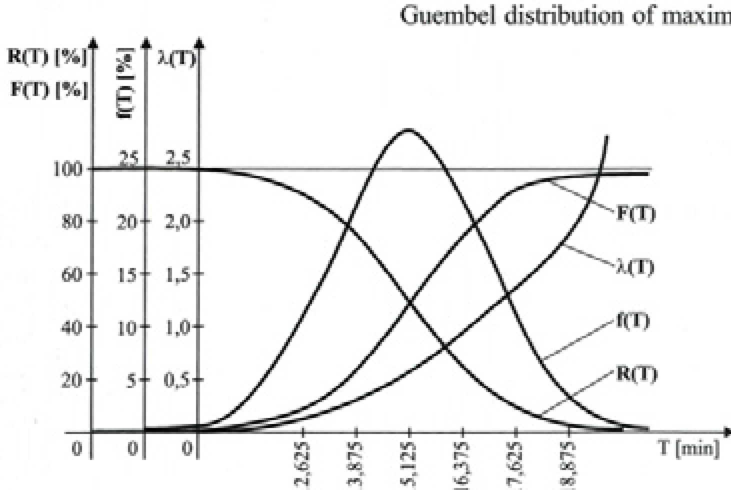

Fig. 4. *Graphical representation of the failure frequency function of the normal model of reliability for turning with mixed ceramic tool*

Based upon a comparative analysis [1], [5] and [47] of the theoretical distribution: normal distribution, the logarithmic normal distribution, Weibull distribution and the Guembel distribution of maximum values, the chosen one is normal distribution, and its reliability function is as follows [1]:

$$R(T) = 0.5 - \Phi\left(\frac{T - 15.0383}{1.7337}\right) \qquad (7).$$

The basic theoretical indicators of the reliability normal model are illustrated in Figure 4.

2 TILLAGE EXAMPLE

Soil tillage operations consume large amounts of energy and cause significant wear to tillage tools. The latter results in deterioration of the overall performance of the plough i.e. higher energy losses demanding for higher fuel consumption, lower rates of work, decrease in tillage depth, time consuming changeover of the cutting edge and as a consequence, higher operation and production costs [48] and [49]. From the standpoint of agricultural production the proper soil manipulation directly affects the quantity of the production and finally the production cost of agricultural products giving also potential for savings.

Tillage quality expressed by a reliability function $R = f(t, W)$ (t: working time, W: wear land on the tool) will be directly affected by the wear law followed. If the latter is known experimentally or theoretically, an optimizing approach is possible regarding the appropriate selection of tool and soil processing conditions.

The basic expression combining reliability to wear and a work factor like plough area or time is as follows:

$$\frac{dR}{d\tau} = \sum_{i=1}^{n} \frac{\partial R}{\partial W_i} \cdot \frac{dW_i}{d\tau} \qquad (8),$$

where n is the number of worn elements that affect the working life of the machine part each time considered.

The expression for working life considering reliability is deduced from (8) as:

$$T_d = \int_{R_0}^{R_d} \frac{dR}{\sum_{i=1}^{n} \frac{\partial R}{\partial W_i} \cdot \frac{dW_i}{d\tau}} \qquad (9),$$

where T_d is the working life and R_o, R_d the desired in the steady state and critical reliability values, accordingly.

Any change in the values of controlling parameters, such as tillage conditions (plough area, plough speed and tillage depth), the normal forces between the soil and the surfaces of the plough area, the proportion and mechanical properties of soil particles, the moisture content of the soil, and environmental effects and weather changes during the soil process will have an effect on the result of the integral (9), so we must consider both differentials of (9) separately.

Firstly, $dW_i/d\tau$ expresses the wear rate for every element and depends on the material wear resistance and may be determined experimentally [50]. Secondly, the partial differential $\partial R / \partial W_i$ may be determined analytically or experimentally on the basis of the wear behaviour; it is generally related to the element geometry and the material wear resistance.

Wear is related to the work factor by:

$$W = f(\tau) \qquad (10).$$

The wear gradient will be of the form:

$$\frac{dW}{d\tau} = \frac{1}{(w)} \qquad (11).$$

The optimum design of the tool geometrical characteristics in view of wear would allow a reliable use for a longer working time and prolongation of its effective life.

In this way, the Equation (12) must be fulfilled according to the principle of extremes of functions

$$\sum_{i=1}^{n} \frac{\partial R}{\partial W_i} \cdot \frac{dW_i}{d\tau} = 0 \qquad (12).$$

This equation denotes the conditions that rule the reliable performance of tillage machinery and considering the Equations (8) and (10), which provide the working time and wear rate, one can control the performance for varying process parameters. Also, it is evident that stabilization of the reliability function arises, when the latter is not affected by wear or if wear appears in many elements (surfaces).

Applying this concept to the anti wear behaviour of tillage tools an effective (minimum wear) tool geometric form can be selected. The main points of a relevant analysis for a straight toothed harrow is described next; the detailed analysis is presented elsewhere [50].

A tool form that could be regarded optimum for given tooth material and wear resistance should allow maximum soil removal for the area F_d (Fig. 5). The working part of the tooth is described by a parabola. For any section, the relationship between the worn area F and the linear wear W is of the form:

$$F = F_d\left[x^{\frac{1}{n}} + \frac{W}{H}\left(y^{\frac{1}{n}} - x^{\frac{1}{n}}\right)\right]^n \qquad (13),$$

where $x = F_o/F_d = (0.1, 0.2 - 0.5)$, $x = F_c/F_d = 2$ to 4, F_0 is the smallest obelisk surface, F_d is the limiting allowable tooth working surface area, F_c is the tooth body cross section ($16 * 16 = 256$ mm^2), $n = 0.5$ to 2.5, W is the allowable tooth length regarding wear and H the tool length.

For $0.15 \le x \le 0.25$, an empirically determined range combining the wear resistance of the tool material, the soil texture index and the geometry of the worn surface, a remarkable reduction in linear wear is achieved with regard to the maximum available material for re-sharpenings. According to this concept, to establish the maximum tooth working time possible for a reliable performance, the tooth must be of an "obelisk" shape with a limiting length corresponding to a final surface area equal to 20% of the limiting worn area. From the foregoing discussion, the introduction of the reliability function optimizes structural parameters of tillage tools allowing the prolongation of their reliable working duration.

3 CONCLUSION

The use of reliability function in metal machining and soil processing, although obeying to different constraints, can lead to optimized anti-wear performance and better exploitation of tool useful life.

The two diverse examples discussed in this paper show that the determination of the reliability function in statistical or deterministic form permits another approach of tool wear in materials processing.

The normal distribution has been chosen for both types of tools considered. This fact reflects the stability of working without failures with these advanced cutting tool materials. All of the failure values are approximately symmetrically disposed around the mean value. A desirable state of surface finish can be maintained, as roughness of the workpiece increases regularly when approaching the end of tool cycle and this last interval can be beneficially exploited. In this regard, the latter could be considered in conjunction to the form of the tool reliability function and the degree of scatter and a supplementary criterion for predicting surface roughness, at any cutting operation, may be set.

It is evident that stabilization of the reliability function arises, when the latter is not affected by wear or if wear appears in many elements (surfaces).

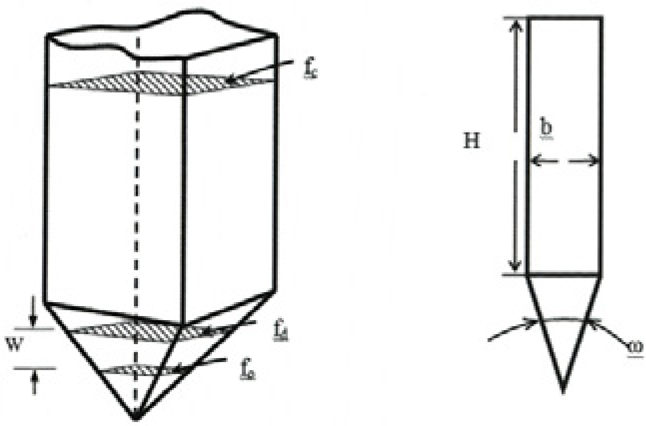

Fig. 5. *Harrow tooth modulation – Wear effects*
(ω/2: angle of the pyramidal modulation; H: tooth length; b: width of rectangular cross section; W: linear wear; f_c: cross section of the tooth holder; f_o: current tool cross section due to wear; f_d: critical tool cross section due to wear)

4 REFERENCES

[1] Dasic, P. Determination of reliability of ceramic cutting tools on the basis of comparative analysis of different functions distribution. *International Journal of Quality & Reliability Management (IJQRM)*, vol. 18, no. 4-5 (2001), p. 433-446.

[2] Dasic, P. Examples of analysis of different functions of cutting tool failure distribution. *Journal of Tribology in Industry*, vol. XXI, no. 2 (1999), p. 59-67.

[3] Dasic, P. Reliability analysis of the components of tribo-mechanical systems. *International Journal of Applied Mechanics and Engineering – IJAME*. vol. 7, Special issue (2002), p. 311-318.

[4] Hitomi, K., Nakamura, N. and Inoue, S. Reliability analysis of cutting tools, *Transactions of the ASME*, vol. 10 (1979), p. 1-6.

[5] Dasic, P. Algorithm approach to determination of reliability of components technical systems, Plenary and invitation paper. In: *Proceedings of 5th International Conference Research and Development in Mechanical Industy - RaDMI 2005*. Vrnjačka Banja, Serbia and Montenegro, 04.-07. September 2005, p. 34-45.

[6] Wang, H. and Pham, H. Survey of reliability and availability evaluation of complex networks using Monte-Carlo techniques. *Microelectronics and Reliability*, vol. 37, ins. 2 (1997), p. 187-209.

[7] Basu, A.P. *Reliability and quality control*. Amsterdam – New York – Oxford: Elsevier Science Publishers B. A., 1986.

[8] Dasic, P. Analysis of the logarithmic normal model of the reliability of cutting tools made of cubic boron nitride for finishing turning of hardened steel. In: *Proceedings of 7th International Conference on Accomplishments of Electrical and Mechanical Industries – DEMI 2005*. Banja Luka, Bosnia and Herzegovina, 27. and 28. May 2005, p. 209-216.

[9] Dasic, P. Analysis of the normal model of the reliability of cutting tools made of cubic boron nitride. In: *Proceedings of 1st DAAAM International Conference on Advanced Technologies for Developing Countries ATDC'02*, Slavonski Brod, Croatia, 12. - 14. September 2002. p. 173-179.

[10] Dasic, P. Reliability analysis of the cutting tools made of cubic boron nitride. In: *Annals of DAAAM for 2002 & Proceedings of the 13th International DAAAM Symposium*, Vienna, Austria, 23. - 26. October 2002. p. 125-126.

[11] Dasic, P. Reliability analysis of the cutting tools made of multi-coatings hard metal. In: *Proceedings of 3rd International Conference, The Coatings in Manufacturing Engineering and EUREKA Partnering Event*. Thessaloniki, Greece, 28. - 29. November 2002, p. 91-100.

[12] Dasic, P., Djordjevic, A. Analysis of different functions of cutting tools failure distribution at the processing on the deep boring. *Journal of the Balkan Tribological Association*, vol. 9, no. 3 (2003), p. 370-380.

[13] Dasic, P., Kuzin, V. V., Jecmenica, R. Reliability analysis of the ceramic cutting tools during turning. In: *Proceedings of 5th International Conference on Tribology – BALKANTRIB 2005*. Kragujevac, Serbia and Montenegro, 15.-18. June 2005, p. 273-276.

[14] Dhillon, B.S. *Quality control, reliability and engineering design*. New York – Basel: Marcel Decker, 1985.

[15] Kececioglu, D. *Reliability Engineering Handbook - Volume 1*. New Jersey: Prentice Hall, Englewood Cliffs, 1991.

[16] Kececioglu, D. *Reliability Engineering Handbook - Volume 2*. New Jersey: Prentice Hall, Englewood Cliffs, 1991.

[17] Klim, Z., Ennajimi, E., Balazinski, M., Fortin, C. Cutting tool reliability analysis for variable feed milling of 17-4PH stainless steel. *Wear*, vol. 195, no. 1-2 (1996), p. 206-213.

[18] Lin, W.-S. Reliability study of cutting tool based on the reliability-dependent hazard rate function, *Materials Science Forum*, vol. 505-507, No. 2 (2005), p. 913-918.

[19] Ning, F., et al. Study on reliability of ceramic cutting tools, *Tool Engineering*. Vol. 34, No. 8 (2000), p. 3-5.

[20] Sekulic, S., Nikolic, B. Influence of cutting conditions on reliability function parameters in turning. In: *Proceedings of 6th International Conference Research and Development in Mechanical Industy - RaDMI 2006*. Budva, Montenegro, 13.-17. September 2006, p. 345-349.

[21] Vigneau, J., Bordel, P. Reliability of ceramic cutting tools. *Ann. CIRP*, vol. 37, no. 1 (1988), p. 101-104.

[22] Wang, K.-S., Lin, W.-S., Hsu F.-S. A new approach for determining the reliability of a cutting tool. *International Journal of Advanced Manufacturing Technology*, vol. 17, No. 10 (2001), p. 705-709.

[23] Jacques, L. Ceramics reliability: Statistical analysis of multi-axial failure using the Weibull approach an the multiaxial elemental strength model. *Journal of the American Ceramic Society*, vol. 73, no. 8 (1990), p. 2204-2212.

[24] Jacques, L. Statistical analysis of bending strengths for brittle solids: A multiaxial fracture problem. *Journal of the American Ceramic Society,* vol. 66, no. 3 (1983), p. 177-182.

[25] Jacques, L. Statistical Approaches to Failure for Ceramic Reliability Assessment. *Journal of the American Ceramic Society,* vol. 71, no. 2 (1988), p. 106-112.

[26] Kalpakjian, S. *Manufacturing processes for engineering materials*. 3rd Edition. Menlo Park (California): Addison Wesley Longman Inc., 1997. 950 p.

[27] ISO 3685:1993 Tool life testing with single-point turning tools. Geneve: International Organization for Standardizations (ISO).

[28] Chou, Y. K., Evans, C. J. Hard turning of M50 steel with different microstructures in continuous and intermittent cutting. *Wear*, vol. 255 (2003.), p. 1388-1394.

[29] Chou, Y. K., Evans, C. J. Tool wear mechanism in continuous cutting of hardened tool steels. *Wear*, vol. 212 (1997), p. 59-65.

[30] Dasic, P. Analysis of wear cutting tools by complex power-exponential function for finishing turning of hardened steel 20CrMo5 by mixed ceramic tools. *The Annals of University "Dunarea de Jos" of Galati, Fascicle VIII Tribology*, vol. 5 (2006), p. 54-60.

[31] Dasic, P., Jecmenica, R., Radovanovic, M. Analysis of the wear tools for turning by modern cutting tools. *Journal of Optimum Technologies, Technologic Systems and Materials in the Machines Building Field – MSTM*, vol. 11, no. 1 (2005), p. 213-218.

[32] Dasic, P., Nedic, B., Jecmenica, R. Analysis of function approximation of the wear tools for turning of the cast iron GG-25 by nitride ceramic cutting tools. *Journal of Modelling and Optimization in the Machines Building Fields – MOCM*, vol. 12, no. 2 (2006), p. 46-60.

[33] Dasic, P., Radovanovic, M. Analysis of the wear cubic boron nitride for turning of the hardened steel. *International Journal of Applied Mechanics and Engineering – IJAME*, vol. 7, special issue (2002), p. 341-346.

[34] Dawson, G. *Machining hardened steel with polycrystalline cubic boron nitride cutting tools.* Dissertation. Georgia (Atlanta): Georgia Institute of Technology, 2002. 264 p.

[35] Dolinsek, S., Sustarcic, B., Kopac, J. Wear mechanisms of cutting tools in high-speed cutting processes. *Wear*, vol. 250, issues 1-12 (2001), p. 349-356.

[36] Ekinovic, S. *Cutting* (in Bosnian language). Zenica: Dom štampe, 2001, p. 307.

[37] Janáč, A., Bátora, B., Baránek, I., Lipa Z. *Machining technology* (in Slovakian language). Bratislava: Slovenská technická univerzita (STU), 2004. 288 p.

[38] Kalajdzic, M. *Tehnology of metalworking I* (in Serbian language). 9th Edition. Belgrade: Faculty of Mechanical Engineering, 2004. 407 p.

[39] Kopač, J. Cutting tool wear during high-speed cutting. *Strojniški vestnik – Journal of Mechanical Engineering*, vol. 50, no. 4 (2004), p. 195-205.

[40] Kopač, J. *Cutting* (in Slovenian language). Ljubljana: Univerza v Ljubljani, Fakulteta za strojništvo, 1991.

[41] Poulachon, G., Moisan, A., Jawahir, I.S. Tool-wear mechanisms in hard turning with polycrystalline cubic boron nitride tools. *Wear*, vol. 250, issues 1-12 (2001), p. 576-586.

[42] Radovanovic, M. *Metalworking technology, Cutting work* (in Serbian language). Niš: Faculty of Mechanical Engineering, 2002. – 328 p.

[43] Stanic, J. *Theory of metalworking I* (in Serbian language). 2nd Edition. Belgrade: Faculty of Mechanical Engineering, 1989. 268 p.

[44] Taylor, F. W. On the art of cutting metals, *Transactions of the ASME*, vol. 28 (1907.), p. 31-279.

[45] Soković, M., Mikuła, J., Dobrzański, L. A., Kopač, J., Koseč, L., Panjan, P., Madejski, J., Piech, A. Cutting properties of the Al2O3 + SiC(w) based tool ceramic reinforced with the PVD and CVD wear resistant coatings. *Journal of Materials Processing Technology*, vol. 164–165 (2005), p. 924–929.

[46] Tadic, B. Contribution to analztical definition of wear curves (in Serbian language). *Journal of Tribology in Industry*, vol. XII, no. 4 (1990), p. 117-120.

[47] Dasic, P. *DoRTSC2A: Methodology and Software package for Determination of Reliability of Technical System Components on the Basis of Choice of Theoretical Distribution, which in the best way Approximate Experimental Data, on the Base of Comparative Analysis.* ver. 3.0. Krusevac, 2002.

[48] Bhakat, A.K., Mishra, A.K., Mishra, N.S., Jha, S. Metallurgical life cycle assessment through prediction of wear for agricultural grade steel. *Wear,* vol. 257 (2004), p. 338-346.

[49] Natsis, A., Papadakis, G., Pitsilis, J. The influence of soil type, soil water and share sharpness of a mouldboard plough on energy consumption, rate of work and tillage quality. *Journal of Agricultural Engineering Research,* vol. 72 (1999), p. 171-176.

[50] Natsis, A., Petropoulos, G. Optimal tribological design of soil processing tools. *Journal of the Balkan Tribological Association*, vol. 11, no. 4 (2005), p. 491-498.