International Journal of
INNOVATIVE AND INFORMATION
MANUFACTURING TECHNOLOGIES
Donetsk National Technical University & International Union of Machine-Builders
International Journal of Innovative and Information Manufacturing Technologies, Donetsk National Technical University; 58, Artyoma Street, 283001 Donetsk, UKRAINE, Tel.: +38 062 305 01 04, Fax: +38 062 301 08 05, E-mail: tm@mech.dgtu.donetsk.ua, http://iimt.donntu.org

# OPTIMIZATION OF THE BASIC QUALITY MEASURE OF THE CUTTING TOOL AT ITS EXPLOITATION

**IVCHENKO Tatiana**

[1] The Department "Manufacturing Engineering"; SHEI "Donetsk National Technical University"; 58, Artyoma Street, 83001 Donetsk, UKRAINE
*Corresponding author: IVCHENKO Tatiana, e-mail:* ivchenko.sovet@gmail.com

*Submitted 18.02.2016; accepted 29.03.2016*

**Abstract**. The questions of the optimization of the cutting tool quality level are considered. The technique for optimization of the basic quality measures of the cutting tool at its exploitation, based on definition of the absolute and relative integral quality indexes, is developed. The criterion of the optimization is set and the optimum level of the non-failure operation and longevity is determined. The way of the account of the dissipation of the non-failure operation and longevity measures in the real exploitation conditions at optimization of the cutting tool quality level are set. Analytical dependences of the basic non-failure operation and longevity measures on the conditions of tool exploitation are obtained.
**Keywords:** quality, non-failure operation, longevity, maintainability, optimization.

## 1. Introduction

The successful solving of the task of the quality increase alongside with search of the new technical decisions requires creation of the complex system estimation and optimization of the quality measures, both at creation of the cutting tool, and at its exploitation. The improvement of the quality measures at exploitation of the cutting tool requires increase of expenses at its creation. In this connection the definition of the optimum level of the cutting tool quality measures ensuring the greatest effect from its exploitation at least expenses is rather urgent.

The presently successful task of the cutting regimes optimization at the cutting tool exploitation is solved on the criteria of the productivity and the prime price [1, 2]. The existent method of estimation and optimization of the basic reliability measure on integral quality creation is successfully used on the stage of the cutting tool creation [3, 4]. Presently the necessity of account of random character of the basic reliability measures at optimization of the cutting tool quality level [5, 6] is substantial. The further development of this method as it applies to optimizations of quality measures on the stage of the cutting tool exploitation is of interest.

The purpose of the present work is the definition of the optimum level of the basic cutting tool quality measure taking into account random character of both parameters and optimization criterion.

## 2. Basic contents and results of probe

Quality of the cutting tool is an aggregate of properties, which determine ability of the cutting tool to carry out a cutting process. The properties of the setting, reliability and technological effectiveness are the most essential for the cutting tool quality (fig.1). The basic groups of the reliability properties are non-failure operation, longevity and maintainability. At the cutting tool exploitation, the reliability properties are set as the result of the tests in the real exploitation conditions.

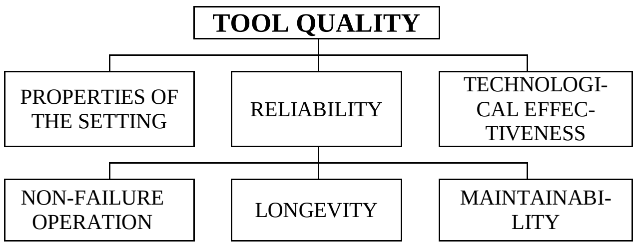

**Fig. 1.** Diagram of the basic properties of the tool quality

In present work the criterion of optimization is the integral quality index $K_I$, being a relation of useful effect from the cutting tool exploitation $P_\Sigma$ tothe total expenses on its creation $E_{CR}$ and exploitation $E_{EX}$:

$$K_I = P_\Sigma / (E_{CR} + E_{EX}). \tag{1}$$

The useful effect from the cutting tool exploitation in the machining productivity is the area of the work surface. Expenses on the cutting tool creation are the prime price of its making. Expenses on the cutting tool exploitation are the expenses on equipment work Expression for the absolute integral index of the cutting tool quality is:

$$K_I = \frac{1000VS}{(1+t_r/T)(C_m + C_t/KT)} \text{ (mm}^2\text{/cop)}, \qquad (2)$$

$V$ – cutting speed; $S$ – feed; $T$ - the mean tool life; $K$ - the mean number of the tool life periods; $t_r$ - the mean restoration time; $C_m$- the expenses for 1 minute of the equipment work; $C_t$- the tool prime price.

The set index summarizes and plugs in itself all basic properties of the cutting tool quality. The machining productivity in it is the setting properties. The mean tool life (mean operation time to failure) is the non-failure operation measure. The mean number of the tool life periods (mean lifetime) is the longevity measure. The mean restoration time is the maintainability measure. The tool prime price is the technologicalness measure.

The measures of the cutting tool reliability are related to the measures of the productivity. The following dependences are most widespread:

$$V = C_V / T^m \,;\; K = C_K / S^{m_k} \,;\; V = C_S / S^{y_v} \,, \qquad (3)$$

$C_V$, $C_K$, $C_S$ - constant coefficients, depending on properties of the processed material; $m$, $m_k$ - indexes of relative tool life, numbers of the tool life periods; $y_v$ - index of degree, characterizing dependence of the cutting speed on the feed.

The absolute integral quality index of the cutting tool (2) looks like recognition (3) and is:

$$K_{IA} = A / T^m K^n (1+t_r/T)(C_m + C_t/KT), \qquad (4)$$

$A = 1000 C_V C_K C_S$ - constant coefficients; $n = m_k(1\text{-}y_v)$.

At the cutting tool exploitation, the non-failure operation and longevity are the most important reliability properties, which depend on the exploitation conditions. The maintainability and technological effectiveness in this case are constant.

Diagram of the dependence of the absolute integral quality index $K_{IA}$ on the non-failure operation measure – $T$ and the longevity the measure – $K$ (fig 2) testifies to extreme character of absolute integral quality index of the cutting tool.

The system of equalizations for simultaneous two-parameter optimization of the non-failure operation and the longevity measures has the following appearance:

$$\begin{cases} \frac{\partial}{\partial T}\left[A / T^m K^n (1+t_r/T)(C_m + C_t/KT)\right] = 0; \\ \frac{\partial}{\partial K}\left[A / T^m K^n (1+t_r/T)(C_m + C_t/KT)\right] = 0. \end{cases} \qquad (5)$$

Solving of this system by numeral methods, which provides the global maximum of the absolute integral index of the cutting tool quality, is: $T_o$ = 24; $K_o$ = 2. 67.

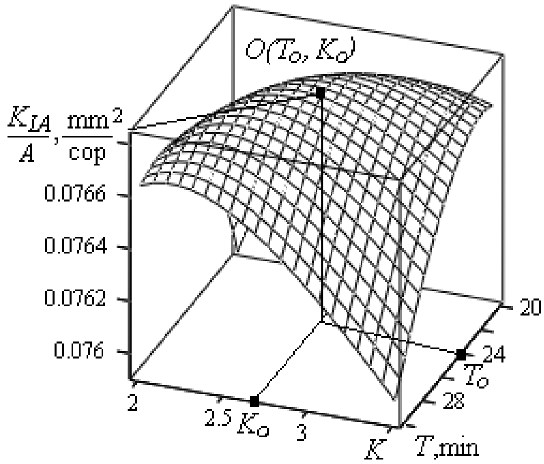


**Fig. 2.** Diagram of the dependence of the absolute integral quality index of $K_{IA}$ on the measure of the non-failure operation measure – $T$ and the longevity measure - $K$

The ddiagram is built for the next modular cutters exploitation conditions: $m$ = 0.2; $n$ = 0,1, $t_r$ = 3min; $C_m$ = 5, $C_t$ = 40.

In that case, when one of the reliability measures changes insignificantly and can be accepted as constant, it is expedient to execute one-parameter optimization. In case of one-parameter optimization on each of separate measure, the optimum levels of the non-failure operation and the longevity are determined analytically.

The optimum non-failure operation measure - the tool life $T_{opt}$ is determined from a condition $\partial K_{IA}/\partial T = 0$ ($K$ = constant):

$$\frac{\partial}{\partial T}\left[A / T^m K^n (1+t_r/T)(C_m + C_t/KT)\right] = 0 \,.$$

$$T_{opt} = \frac{(1/m - 1)}{(t_r + C_t/C_m K)} \,. \qquad (6)$$

The optimum longevity measure - mean number of the tool life periods $K_{opt}$ is determined from a condition $\partial K_{IA}/\partial K = 0$ ($T$ = constant):

$$\frac{\partial}{\partial K}\left[A / T^m K^n (1+t_r/T)(C_m + C_t/KT)\right] = 0 \,.$$

$$K_{opt} = \frac{(1/n - 1)}{(t_r + C_t/C_m T(1+t_r/T))} \,. \qquad (7)$$

For the exploitation conditions set before the next optimum values of non-failure operation and longevity measures are set: $T_{opt}$ = 22.7min; $K_{opt}$ = 2.18.

The set analytical dependences allow setting character and degree of the exploitation conditions influence on optimum the tool life $T_{opt}$ and - the mean number of the tool life periods - $K_o$.

Diagram of the dependence of the optimum mean tool life $T_{opt}$ and the mean number of the tool life periods $K_{opt}$

from correlation the expenses for 1 minute of the equipment work and the tool prime price $C_m/C_t$ for different the mean restoration time $t_r$ are presented in fig 3.

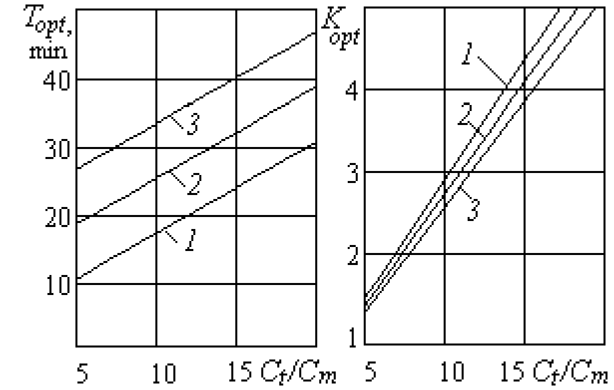


**Fig. 3.** Diagram of the dependence of the optimum mean tool life $T_{opt}$ and the mean number of the tool life periods $K_{opt}$ from correlation $C_m/C_t$ for different the mean restoration time $t_r$:
$t_r$ = 1min – 1; $t_r$ = 3min – 2; $t_r$ = 5min – 3.

At research of the cutting tool quality, it is expedient to determine the relative integral quality index of the cutting tool $K_{IRo}$ in comparison with the absolute integral quality index $K_I$ with base integral quality index $K_{IB}$:

$$K_{IRo} = \frac{K_I}{K_{IB}} = \frac{X_1^{-m} X_2^{-n} (1+B)(1+C)}{(X_3/X_1 + B)(X_4/X_1X_2 + C)} \qquad (8)$$

$X_1 = T/T_b$; $X_2 = K/K_b$; $X_3 = t_r/t_{rb}$; $X_4 = C_t/C_{tb}$ – relative measures of the non-failure operation, longevity, maintainabity and technologicaleffectiveness accordingly in comparison of the absolute measures with the base measures; $C = C_m K_b T_b / C_{tb}$, $B = T_b/t_{rb}$ - the constant coefficients, which depend only on the base measures.

At the cutting tool exploitation, the non-failure operation and longevity are the most important reliability properties, which depend on the exploitation conditions. The maintainability and technological effectiveness in this case is constant: $X_3 = 1$, $X_4 = 1$. Consequently, the relative integral quality index of the cutting tool is:

$$K_{IR} = \frac{X_1^{-m} X_2^{-n} (1+B)(1+C)}{(1/X_1 + B)(1/X_1X_2 + C)}, \qquad (9)$$

The system of equalizations for simultaneous two-parameter optimization of the non-failure operation and longevity relative measures has the following appearance:

$$\begin{cases} \dfrac{\partial}{\partial X_1}\left[\dfrac{X_1^m X_2^n (1+B)(1+C)}{(1/X_1 + B)(1/X_1X_2 + C)}\right] = 0; \\ \dfrac{\partial}{\partial X_2}\left[\dfrac{X_1^m X_2^n (1+B)(1+C)}{(1/X_1 + B)(1/X_1X_2 + C)}\right] = 0. \end{cases} \qquad (10)$$

Solving of this system by numeral methods, which provides the maximum of the relative integral quality index of the cutting tool, is: $X_{1o} = 0.88$; $X_{2o} = 0.91$.

In case of one-parameter optimization on each of separate measures, the optimum levels of the reliability measures are determined analytically.

The optimum relative measures of the non-failure operation $X_{1opt}$ is determined from a condition $\partial K_{IR}/\partial X_1 = 0$, (the relative measures of the longevity $X_2 = 1$):

$$\frac{\partial}{\partial X_1}\left[\frac{X_1^{-m}(1+B)(1+C)}{(1/X_1 + B)(1/X_1 + C)}\right] = 0 .$$

$$X_{1opt} = \left(\frac{1}{m} - 1\right)\left(\frac{B+C}{BC}\right). \qquad (11)$$

The optimum relative longevity measures $X_{2opt}$ is determined from a condition $\partial K_{IR}/\partial X_2 = 0$, (the relative measures of the non-failure operation $X_1 = 1$):

$$\frac{\partial}{\partial X_2}\left[\frac{X_2^{-n}(1+C)}{(1/X_2 + C)}\right] = 0 .$$

$$X_{2opt} = \left(\frac{1}{n} - 1\right)\left(\frac{B}{(B+1)C}\right) \qquad (12)$$

Diagrams of dependence of the relative integral quality index of the cutting tool $K_{IR}$ on relative measures of the non-failure operation - $K_{IR}(X_1)$ and longevity- $K_{IR}(X_2)$ are presented in fig 3.

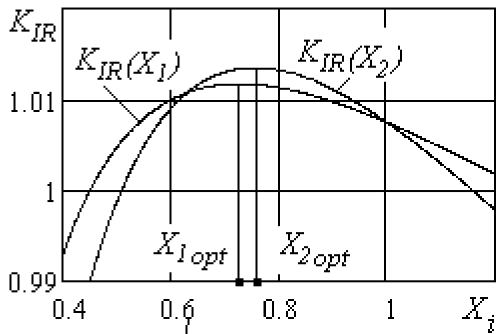


**Fig. 4.** Diagrams of dependence of the relative integral index of quality $K_{IR}$ on relative measures:
1 - non-failure operation, 2 - longevity

The diagram is built for the following exploitation conditions:
$m$ = 0.2; $n$ = 0,1; $B$ = 10 ($T$ = 30min, $t_r$ = 3min); $C$ = 11.25 ($C_m$ = 5, $C_t$ = 40, $K$ = 3).

The diagram of the dependence of integral quality index of the cutting tool $K_{IR}$ from relative measures of the non-failure operation - $X_1$ and longevity - $X_2$ (fig 4), testifies to extreme character of integral quality index.

For the exploitation conditions, set before the following values of relative measures of the non-failure operation $X_{1opt}$ and longevity $X_{2opt}$ are set: $X_{1opt}$ = 0.756; $X_{2opt}$ = 0.727. The values of absolute measures of the non-failure operation $T_{opt}$ and longevity $K_{oot}$, which are set before: $T_{opt}$ = 22.7; $K_{opt}$ = 2.18. At the accepted base values ($T$ = 30min, $K$ = 3) they coincide with the pre-established relative indexes: $T_{opt}/T$ = 0.756; $K_{opt}/K$ = 0.727.

The set dependences (6), (7), (11), (12) allow to determine the optimum level of basic reliability measures for any exploitation conditions.

The indicated values of the optimum level of basic reliability measures are set without the account of their mean values and close approximation of random models determined.

It is known that the cutting tool measures of the non-failure operation and longevity - mean tool life and number of the tool life periods are random variable that has the considerable dissipation at the real exploitation conditions. The variation coefficients (the relation of random variable standard deviation to it the mathematical expectation) of the cutting tool measures of the non-failure operation can make $V$ = 1. In this case, random nature of the basic reliability measures is necessary to be taken into account at optimization.

The numerical descriptions and laws of distributing of the basic reliability measures are determined on results experimental researches. The relative measures of the non-failure operation $X_1$ and longevity $X_2$ the cutting tools also are by random variable.

The integral quality index of the cutting tool is the function of random arguments and is random variable. Presentation of the integral quality index of the cutting tool as the function of random arguments allows calculating its numerical descriptions - mathematical expectation and dispersion taking into account descriptions of random arguments [7].

There is the system of random arguments $X_i$ with the set numerical descriptions - the mathematical expectations $m_{xi}$ and dispersions $D_{xi}$:

$$\left(X_1, X_2,..,X_n\right);\left(m_{x_1}, m_{x_2},..,m_{x_n}\right);\left(D_{x_1}, D_{x_2},..,D_{x_n}\right). \quad (13)$$

Random variable $Y$ is nonlinear function of random arguments $X_1, X_2, ..., X_n$:

$$Y=\varphi\left(X_1, X_2,....,X_n\right). \quad (14)$$

Decomposing the function $Y = \varphi(x_1,x_2,...,x_n)$ in the Taylor expansion in the vicinity of a point ($m_{x1}, m_{x2},...,m_{xn}$) and saving in decomposition members not higher the second order, we have:

$$Y\approx\varphi\left(m_{x_1}, m_{x_2},....,m_{x_n}\right)+\sum_{i=1}^{n}\left(\frac{\partial\varphi}{\partial x_i}\right)_m\left(X_i-m_{x_i}\right)$$
$$+\frac{1}{2}\sum_{i=1}^{n}\left(\frac{\partial^2\varphi}{\partial x_i^2}\right)_m\left(X_i-m_{x_i}\right)^2. \quad (15)$$

The mathematical expectation $m_y$ and the dispersion $D_y$ of random variable $Y$ is:

$$m_y=\varphi\left(m_{x_1}, m_{x_2},....,m_{x_n}\right)+\frac{1}{2}\sum_{i=1}^{n}\left(\frac{\partial^2\varphi}{\partial x_i^2}\right)_m D_{x_i}. \quad (16)$$

$$D_y=\sum_{i=1}^{n}\left(\frac{\partial\varphi}{\partial x_i}\right)_m^2 D_{xi}+\frac{1}{2}\sum_{i=1}^{n}\left(\frac{\partial^2\varphi}{\partial x_i^2}\right)_m^2 D_{xi}^2. \quad (17)$$

The mathematical expectations $m_{xi}$ and the dispersions $D_{yi}$ of random arguments $X_i$ - the relative cutting tool measures of the non-failure operation $X_1$ and the longevity $X_2$ have the following appearance:

$$m_{x_1}=X_1; m_{x_2}=X_2;\ D_{x_1}=\left(V_1X_1\right)^2; D_{x_2}=\left(V_2X_2\right)^2, \quad (18)$$

$V_1$, $V_2$ – the variation coefficients of the relative cutting tool measures of the non-failure operation $X_1$ and the longevity $X_2$, which characterize the dissipation of the indicated reliability measures.

The mathematical expectation $m_{KIR}$ and the dispersions $D_{KIR}$ of the relative integral index of the cutting tool quality as the function of random arguments are:

$$m_{K_{IR}}=\frac{X_1^m X_2^n(1+B)(1+C)}{(1/X_1+B)(1/X_1X_2+C)}+$$
$$+\frac{1}{2}\left[\left(\frac{\partial^2 K_{IR}}{\partial X_1^2}\right)\left(V_1X_1\right)^2+\left(\frac{\partial^2 K_{IR}}{\partial X_2^2}\right)\left(V_2X_2\right)^2\right]. \quad (19)$$

$$D_{K_{IR}}=\left[\left(\frac{\partial K_{IR}}{\partial X_1}\right)\left(V_1X_1\right)^2+\left(\frac{\partial K_{IR}}{\partial X_2}\right)\left(V_2X_2\right)^2\right]+$$
$$+\frac{1}{2}\left[\left(\frac{\partial^2 K_{IR}}{\partial X_1^2}\right)\left(V_1X_1\right)^2+\left(\frac{\partial^2 K_{IR}}{\partial X_2^2}\right)\left(V_2X_2\right)^2\right]^2. \quad (20)$$

The set dependence testifies that the mathematical expectation of the integral quality index of the cutting tool as the function of random arguments differs from his value, expected by the generally accepted method on the mathematical expectation of these arguments. This difference is quantitatively characterized by the value of the second element in a formula (19), which with the sufficient degree of exactness can serve as the estimation of error of close approximation of the determined random models. The set dependence sets intercommunication of the mathematical expectation of integral quality index of the cutting tool as the function of random arguments with dissipation of the cutting tool reliability measures.

The charter and degree of joint influence of variation coefficients of the cutting tool relative measures of the non-failure operation and the longevity on the mathematical expectation and the dispersion of the relative integral quality index of the cutting tool are presented in fig 5 ($K_m$ = $m_{KIR}/K_{IR}$; $K_D$ = $D_{KIR}/K_{IR}$). The diagram testifies that mathematical expectation diminishes and dispersion increases with growth of variation coefficients of the cutting tool reliability measures.

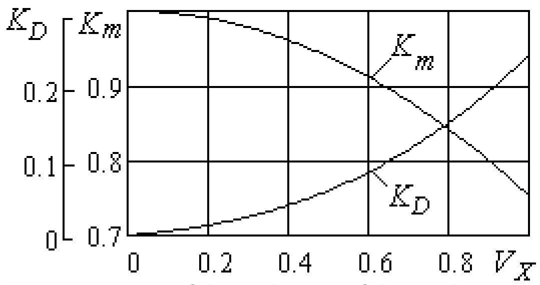


**Fig. 5.** Diagrams of dependences of the mathematical expectation and dispersion of the relative integral quality index from the variation coefficients

For the search of optimum values of optimization parameters - the cutting tool measures of the non-failure operation and the longevity of the system of differential equalizations is solved with taking into account random character of criterion and parameters of optimization:

$$\begin{cases} \dfrac{\partial}{\partial X_1}\left[\begin{array}{l}\dfrac{X_1^m X_2^n (1+B)(1+C)}{(1/X_1+B)(1/X_1X_2+C)}+\\ +\dfrac{1}{2}\sum\limits_{i=1}^{n}\left(\dfrac{\partial^2 K_{IR}}{\partial x_i^2}\right)_m (V_i m_{x_i})^2\end{array}\right]=0,\\ \dfrac{\partial}{\partial X_2}\left[\begin{array}{l}\dfrac{X_1^m X_2^n (1+B)(1+C)}{(1/X_1+B)(1/X_1X_2+C)}+\\ +\dfrac{1}{2}\sum\limits_{i=1}^{n}\left(\dfrac{\partial^2 K_{IR}}{\partial x_i^2}\right)_m (V_i m_{x_i})^2\end{array}\right]=0. \end{cases} \quad (21)$$

The solving of this system by numeral methods, which provides the global maximum of the relative integral quality index of the cutting tool at the values of the variation coefficients $V_1 = V_2 = 0.25$, is: $X_{1o} = 0.98$; $X_{2o} = 0.94$.

Presentation of the integral quality index of the cutting tool as the function of random arguments is given by possibility number to estimate influence of dissipation of reliability measures, characterized by the variation coefficients $V_X$, on their optimum level. The diagrams of dependences of the optimum measures of the non-failure operation and longevity on the variation coefficients $V_X$, which are set as result one-parameter optimization on each of separate measures, are presented on fig 6.

As results of regressive analysis the dependences of the optimum relative measures of the non-failure operation $X_{1o}$ and longevity $X_{2o}$ on the variation coefficients $V_X$ are set analytically (error does not exceed 5%)

$$\frac{\partial}{\partial X_1}\left[\frac{X_1^{-m}(1+B)(1+C)}{(1/X_1+B)(1/X_1+C)}+\frac{1}{2}\left(\frac{\partial^2 K_{IR}}{\partial X_1^2}\right)(V_1X_1)^2\right]=0;$$

$$X_{1o}=\left(\frac{1}{m}-1\right)\left(\frac{B+C}{BC}\right)+0{,}44V_{X_1}. \quad (22)$$

$$\frac{\partial}{\partial X_2}\left[\frac{X_2^{-n}(1+C)}{(1/X_2+C)}+\frac{1}{2}\left(\frac{\partial^2 K_{IR}}{\partial X_2^2}\right)(V_2X_2)^2\right]=0;$$

$$X_{2o}=\left(\frac{1}{n}-1\right)\left(\frac{B}{(B+1)C}\right)+0{,}42V_{X_2}. \quad (23)$$

The set analytical dependences allow setting of the optimum level of the basic cutting tool reliability measure taking into account the variation coefficients of these measures.

## 3. Conclusion

The technique for optimization of the basic quality measures of the cutting tool at its exploitation, based on definition of the absolute and relative integral quality index, is developed. The criterion of the optimization is set and the optimum level of the non-failure operation and the longevity of the cutting tool are determined. The way of the account of the dissipation of the non-failure operation and the longevity measures in the real exploitation conditions at optimization of the cutting tool quality level are set. The analytical dependences of the basic non-failure operation and longevity measures on the conditions of the cutting tool exploitation are received taking into account random character of both parameters and optimization criterion.

## References

1. Ivchenko, T.G. Increase of the fine turning efficiency of hard-tempered steels for an account of cutting regimes optimization. Progressive technologies and systems of engineer. Donetsk: DonNTU, 2014, **50**(4), pp. 107-112.

2. Ivchenko, T.G. Optimization of cutting regimes in terms to changeability of operating limitations. Reliability of cutting tool and optimization of the technological systems. Kramatorsk: DDMA, 2014, **34**, pp.90-96.

3. Ivchenko, T. The complex Approach to Estimation and Optimization of the cutting Tool Quality Indexes. Enttwicklungsmethoden und Entwicklungsprozesse im Mashinenbau Tagungsband / Magdeburger Mashinenbau-Tage, Otto-von-Guericke-Universitat Magdeburg. – Berlin: Logos-Verl, 1999, pp.63-70.

4. Ivchenko, T. The estimation and the optimization of the cutting tool quality. Buletinul institutului politehnic din iasi, Tomul XLVI(L), Suplimtnt 1, Publicat de Universitatea Technicca, Iasi, 2000., pp. 59-63.

5. Ivchenko, T. Providing of the assured level of the tool reliability taking into account probability of its destruction. Reliability of cutting tool and optimization of the technological systems. Kramatorsk: DDMA, 2003, **12**, pp.39-41.

6. Ivchenko, T. Determination of optimum level of the indexes quality of the cutting tool taking into account random character of the criterion and parameters of optimization. Progressive technologies and systems of engineer. Donetsk: DonNTU, 2004, **27**. pp. 97-104.

7. Venttsel, E.S. Theory of probability. Science, Moskow, 1969, 576 p.