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OPTIMIZATION OF PARTS CUTTING PROCESS PARAMETERS WORKING IN CONDITIONS OF CYCLIC LOADS

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Abstract. *The paper is devoted to questions of technological fatigue life assurance of parts working in conditions of cyclic loads by optimization their cutting conditions for finish turning process. In order to solve the task of optimizing the parts cutting conditions, the corresponding software, based on the previously created mathematical model of the finishing turning process, was developed in the C# programming language. With the purpose of technological providing the necessary fatigue life of the part, taking into account the real conditions of its operation for the maximum productivity of the finishing turning process, the methodical recommendations for determining the optimal parts cutting conditions at the phase of production technological preparation are given. An example application of the proposed solution is presented.*

Keywords: technological support, fatigue life, finishing turning process, optimization

OPTYMALIZACJA PARAMETRÓW PROCESU CIĘCIA CZĘŚCI PRACUJĄCYCH W WARUNKACH OBCIĄŻEŃ CYKLICZNYCH

***Streszczenie**. Artykuł poświęcony jest zagadnieniom zapewnienia technologicznej trwałości zmęczeniowej części pracujących w warunkach obciążeń cyklicznych, poprzez optymalizację ich warunków skrawania w procesie toczenia wykańczającego. W celu rozwiązania zadania optymalizacji warunków skrawania części, zostało opracowane odpowiednie oprogramowanie w języku C#, oparte na wcześniej stworzonym modelu matematycznym procesu toczenia wykańczającego. W celu technologicznego zapewnienia niezbędnej trwałości zmęczeniowej części, biorąc pod uwagę rzeczywiste warunki jej działania dla maksymalnej wydajności procesu toczenia wykańczającego, podano metodyczne zalecenia dotyczące określania optymalnych warunków skrawania części na etapie technologicznego przygotowania produkcji. Zaprezentowano przykładowe zastosowanie proponowanego rozwiązania.*

Słowa kluczowe: wsparcie technologiczne, trwałość zmęczeniowa, proces toczenia wykańczającego, optymalizacja

Introduction

Among these are shafts, axles, crank rods, pivot pins, gears [4, 6], rotors and their fastening elements [8], bearings, disks [5, 13, 14], etc., which have to work under loads that vary in magnitude and direction. As a result in the material of such parts stress (in size smaller than the limits of strength) vary in time arise. Shafts and axles, when running under constant external loading, experience symmetrical cycle alternating bending stresses that can cause fatigue failure of these parts. Fatigue life is one of the main fatigue strength properties of critical parts, which allows to determine the period of their exploitation.

More than 70% of all technological breakdowns are associated with fatigue failure. Local processes of origin and initial development of the crack do not have a visible effect on the deformation of the part as a whole and the accelerated development of the crack, as a rule, is not long lasting. As a result, the skin often occurs suddenly and becomes the cause of emergency situations. Thus, at insignificant stresses corresponding to multi-cyclic fatigue, the possibility of the origin of a crack after a given number of cycles is determined by fatigue life of the part's material and the state of it's surface layer.

On the part's fatigue strength three main groups of factors influence [7, 10]:

- constructive – parts geometry, stress concentrators, fit, safety margin, method of applying loads;
- operational – operating conditions (temperature, humidity and other physical and chemical properties of the environment), quality and frequency of lubrication and repair, compliance with the rules of operation of the product;
- technological – the process of obtaining the necessary material, the method of manufacturing the workpiece, the further processing methods of parts and assembly of the product.

In works [5, 13] the fracture distribution of the compressor blades according to the indicated factors is presented: 29% – constructive, 17% – technological, 11% – operational, 43% – from a combination of all factors. The destruction of turbine blades due to technological factors is 25.1%, constructive – 23.2%, the remaining 51.7% is due to an unfavorable combination of these factors.

Thus, one of the ways to ensure the trouble-free operation of the parts working under the influence of vary loads is to determine the optimal technological parameters of the processing and their use.

1. Formulation of the task

The purpose of the work is technological providing necessary part's fatigue life at their finishing turning process with maximum production efficiency by determining the optimal cutting conditions. To achieve this goal, it is necessary to develop a methodology for solving the optimization problem based on the mathematical model of the finishing turning process [8].

2. Task realization

The finishing turning process mathematical model of parts made from materials of the structural alloyed chromium steels group (1) [1, 11], is created in solving the optimization problem. The maximum productivity of the finishing turning process in the area specified by a set of constraints is chosen as the criterion of optimality.

The method of sliding admission, which relates to methods of nonlinear programming, is used to solve the optimization problem [12, 15]. Acceptable or almost acceptable solution for maximizing the optimality criterion found using the algorithm Neldera and Mead (deformed polyhedron).

$$\max f(S,V)=\begin{cases} S_{min}\le S\le S_{max}\\ \frac{\pi D_0 n_{min}}{1000}\le V\le \frac{\pi D_0 n_{max}}{1000}\\ P_{\max a.f.}\ge P_x=10C_{P_x}h^{X_{Px}}S^{Y_{Px}}V^{n_{Px}}K_{Px}\\ N_{eng}\eta\ge \frac{10C_{P_z}h^{X_{Pz}}S^{Y_{Pz}}V^{n_{Pz}}K_{Pz}}{1000\cdot 60}\\ 0.5\cdot TD\ge \Delta_\Sigma\\ T\le\left(\frac{C_vK_v}{Vh^xS^y}\right)^{\frac{1}{m}}\\ Ra_{req}\ge Ra\\ N_{req}\le K_p\cdot N \end{cases} \qquad (1)$$

where $f(S,V)$ – productivity of the finishing turning process, which is determined by the formula $f(S,V)=\frac{1000\cdot S\cdot V}{\pi\cdot D}$;

S – longitudinal feed, mm/rev; V – cutting speed, m/min; D – diameter of the part processed surface, mm; D_0 – diameter of the workpiece before finishing turning process, mm; S_{min} and S_{max} – respectively the minimum and maximum feedrate, mm/rev; n_{min}, n_{max} – respectively minimum and maximum spindle rotational speed, rpm; P_x – the axial component of the cutting force, N; $P_{\max a.f}$ – the maximum permissible value of the machine axial force, N; C_{P_x}, C_{P_z}, C_v – constants; X_{Px}, Y_{Px}, n_{Px}, X_{Pz}, Y_{Pz}, n_{Pz}, x, y, m – exponents, K_{Px}, K_{Pz}, K_v – correcting coefficients; N_{eng} – power of the machine-tool motor, kW; η – coefficient of efficiency of the machine-tool motor; h – cutting depth, mm; Δ_Σ – total processing error, μm; TD – dimension limit, μm; Ra_{req} – required part surface roughness, μm; Ra – machined part surface roughness, μm; N_{req} – required value of part fatigue life, cycles; N – calculated value of the 40Kh steel parts fatigue life, cycles; K_p – coefficient of generalized properties of the materials structural chrome alloy steel group.

After running the optimization program for execution, the main window of the program appears on the monitor. In this window, the user specifies in the relevant field the information about the tool, the part, the used equipment, the acceptable errors, parameters of finishing turning process recommended by normative data, the operational cycle stress and the required fatigue life [16].

After entering the initial data, clicking on the button "Calculate" a window with drop-down lists to select the structural material and the material of the cutting part of the instrument and the required qualification of the surface's accuracy.

The program initiates a window (Fig. 1) with a graphical representation of the admissible solutions area and the determined optimal cutting condition of finishing turning process by pressing the OK button.

The intermediate results of the optimization task solution and its final result are presented in the table 1, which includes the finishing turning process cutting condition, productivity and fatigue life. The results of the optimization task are saved as a text file at the specified address.

Table 1. Results of solving the optimization problem

Feed rate, S	0.11 mm/rev
Cutting speed, V	145.6 m/min
Cutting depth, h	0.2 mm
Productivity of the finishing turning process, f	217.488 m/min
Calculated value of the 40Kh steel parts fatigue life, N	80906 cycles

Thus, the created optimization method makes it possible, on the basis of experimental research and the processing of their results [2], to solve the problem of determining the optimal finish turning process cutting conditions of parts made from the materials of the structural alloyed chromium steels group, with a visual representation and preservation in a text file.

Implementation of the methodology for providing the necessary fatigue life of the parts at their finish turning process is carried out in the following sequence.

1. Analysis of the part construction and conditions of its operation.
2. Determination of maximum stresses in the part material during operation by finite-element analysis.
3. Determination of the initial data of the finishing turning process:
   - chemical composition, physical and mechanical properties of the processed material;
   - constructive data on the part and its workpiece;
   - instrument material the and its geometrical parameters;
   - the main technical characteristics of the processing machine.
4. Determination of the optimal finish turning process cutting conditions by a mathematical model of the finish turning process, which ensures the maximum performance of the finishing turning process of the part with its required fatigue life.

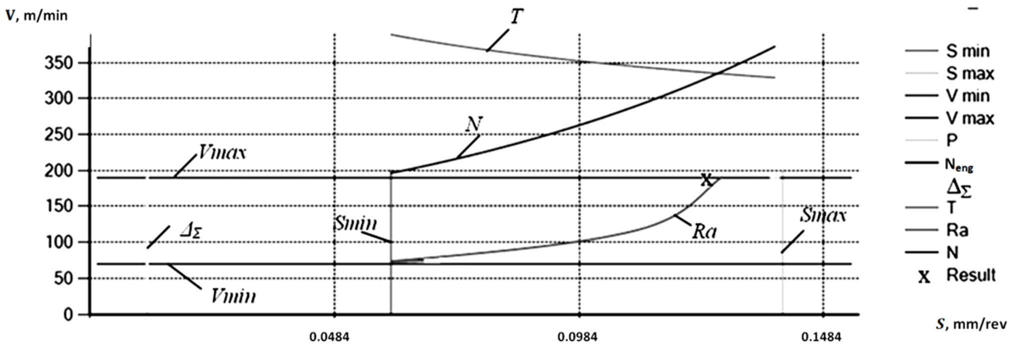

Fig. 1. Graphical representation of the admissible solutions area

3. An example of determining the optimal finish turning process cutting conditions of parts working in varying loads conditions

The part "Shaft" of a rotary mechanism operating in conditions of varying loads is considered as example of the application of the aforementioned methodology of providing the necessary fatigue life of the parts. The sketch of a shaft, made of steel 40Kh DSTU 7806:2015.

Production conditions of the rotary mechanism provide a abrupt change in the size and direction of loading on the output gear. This leads to the formation of cracks and subsequent fatigue failure of the shaft at the point of the shaft connection with a gear pin through the key. Consequently, the shaft is constantly in a complex stress-strain state.

The study of the operating conditions of the work of the part is made in the FEMAP 10.2.0 software program [3]. The boundary conditions that simulate the shaft fastening in the mechanism (boundary conditions of the 1st kind) on the model of the shaft are represented as triangles with a digital value, indicating a limited number of freedom degrees (Fig. 2). The torque acting on the conic surface of the shaft (boundary conditions of the 2nd kind) was determined by a pair of forces. The value of the operational load was 1000 H. The loading on the model is presented in the form of arrows in the direction of loading and its numerical value (Fig. 2). In Fig. 3 shows the finite-element model of the shaft in the deformed state.

A graph representing of equivalent tensile stresses or von Mises stresses for the for bulky KEs is presented on the right side of the software graphical interface. The distribution and stress values in the keyhole zone are shown in Fig. 3. The major stresses on a cylindrical surface were 400 MPa.

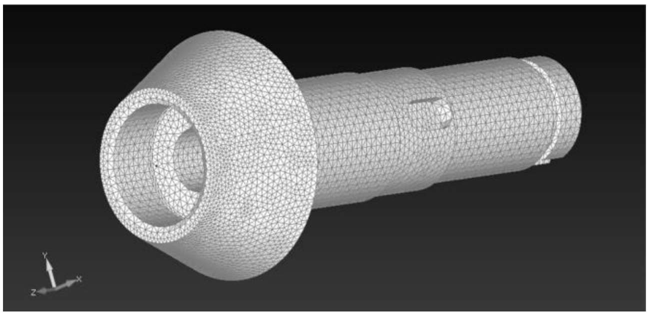

Fig. 2. General view of the finite-element model of the shaft

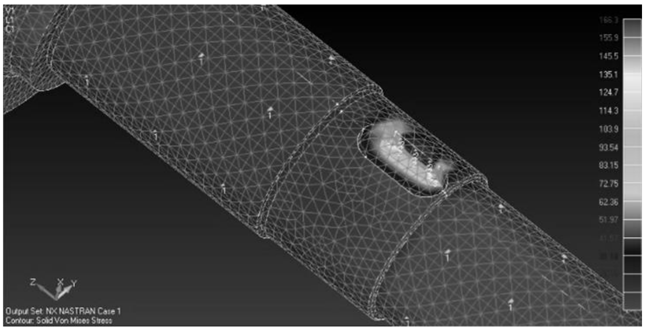

Fig. 3. Stress-strain state model of the shaft under operating conditions

The chemical composition, physical and mechanical properties of the part's material (steel 40Kh) are given in table 2. The required part fatigue life is $8.5 \cdot 10^4$ cycles. The finishing turning of the part was carried out at the Haas ST-20 CNC turning center, using the T15K6 tool material. The relative dimensional wear of the cutter is 0.7 μm/km. The required period of tool stability is 60 min [9]. The geometrical parameters of the tool cutting part are presented in table 3. The main technical characteristics of the machine-tool and part and workpiece data are induced in tables 4 and 5. The value of composite accuracy components of the turning process [9] is presented in table 6.

A set of initial data is used when forming the limitations of a mathematical model in a program for optimizing cutting conditions turning processing (Fig. 4).

Clicking the "OK" button initiates a window with the results of solving the optimization problem. The optimal cutting condition of the "Shaft" component (S = 0.138 mm/rev; V = 187.6 mm/min; h = 0.1 mm) are defined as a result of the use of the developed algorithm and the program for optimizing the finishing turning process by sliding admission and determined operational stresses in the part material, providing the necessary fatigue life (at least N = 16 104 cycles) during its operation and maximum production productivity (the value of the estimated target function is f = 217 m/min).

The given example shows that the proposed methodology of technological support allows determining the optimal cutting conditions, which provides the necessary fatigue life of the part with maximum productivity of its manufacturing process. According to this method, it is possible to predict the number of load cycles when operating the part before its destruction, which will avoid emergency situations.

Table 2. The chemical composition, physical and mechanical properties of the steel 40Kh

C, %	Mn, %	S, %	P, %	Cr, %	Si, %	Ni, %	Cu, %	N, %
0.44	0.8	0.035	0.035	1.1	0.37	0.3	0.3	0.008
E, MPa	G, MPa	ρ, kg/m3	σT, MPa	σB, MPa	δ, %	ψ, %	KCU, kJ/m2	HB
214000	85000	7850	785	980	10	45	590	217

Table 3. Geometrical parameters of the tool cutting part

Plan approach angle φ°	72.5
Face cutting edge angle φ_1°	72.5
Rake angle γ°	-14
Cutting edge inclination λ°	5
Tool nose radius r	0.4 mm

Table 4. Main technical characteristics of the Haas ST-20 CNC turning center

Maximum spindle power, $N_{шп}$	14.9 kW
Useful effect main drive of machine-tool, η	0.8
Maximum permissible value of the machine X axial force, $P_{x\,max}$	20.46 kN
Maximum spindle rotational speed, n_{min}	4000 rpm
Minimum spindle rotational speed, n_{max}	400 rpm
Maximum federate, S_{max}	6 mm/rev
Maximum system compliance, W_{max}	0.04 mm/kN
Minimum system compliance, W_{min}	0.035 mm/kN

Table 5. Details of the workpiece and workpiece

Diameter of the processing surface, D	∅ 38 mm
Surface roughness, Ra	1.25 μm
Diameter of processing workpiece, D_0	∅ 40 mm
Length of the processing surface, l_p	30.5 mm
Total length of tool passage in the direction of feed, L	40 mm
Quality accuracy processing surface	7
Batch size, n	25 p.

Table 6. Data for calculating the total error

Error of workpiece installation in the membrane cartridge, $\Delta\varepsilon_y$	5 μm
Error of the technological system adjustment, $\Delta_н$	4 μm

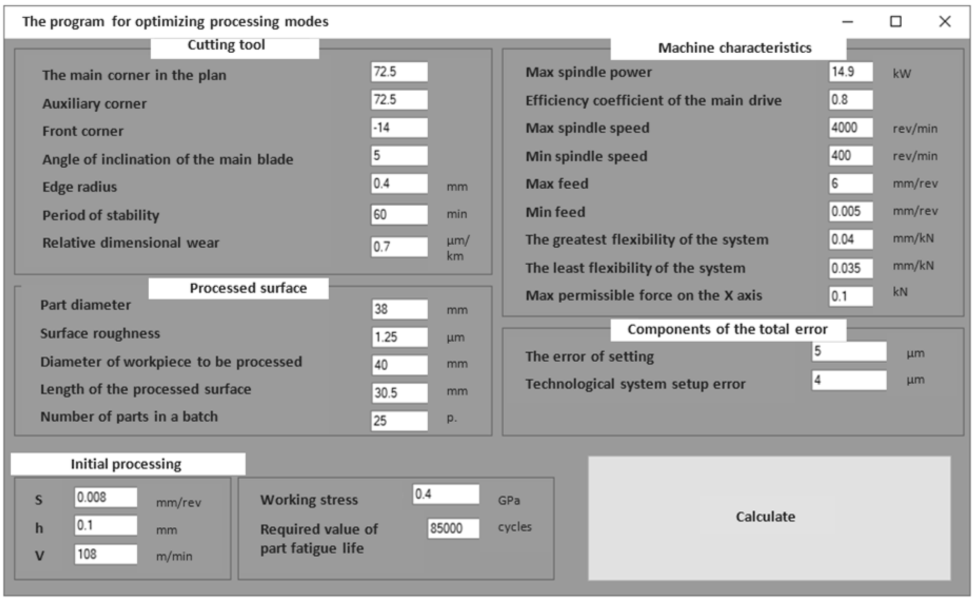

Fig. 4. The main window of the program optimal cutting conditions definition with the input data

4. Conclusions

1. The method of technological support of fatigue life of a part working in conditions of alternating loads is developed, by solving the problem of optimization of turning processing regimes, which allows to determine in a computerized mode the cutting mode which gives the maximum value of the productivity of the process of the finishing turning of the part in the necessary for its cyclic durability in the field of admissible solutions and takes into account the actual characteristics of the material of the part.
2. The sequence of the methodology implementation for providing the fatigue life of the parts at the stage of preproduction planning, which allows us to determine part's optimal cutting condition, is presented.
3. The application of the finite element method allows us to determine the location of localization and the values of stresses and deformations that arise under the action of loads during the operation of parts, and to use them in solving the problem of cutting condition optimization.
4. An example of practical use of the methodology of technological support of the necessary value of cyclic durability and maximum productivity of manufacturing of the "Shaft" component was given, which allowed to determine the rational regimes of its turning process, which are: S = 0.138 mm/rev; V = 187.6 mm/min; h = 0.1 mm, providing the required fatigue life of at least N = 16·104 cycles, which satisfies the requirements of the product developers regarding the work life of part , and the maximum productivity of manufacturing.

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