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TRIBOLOGICAL CHARACTERISTICS OF HOB MILLING TOOLS FROM ECONOMICAL ASPECT

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ABSTRACT

The complexity of the procedure of determining tribological properties of tribo-mechanical system elements from an economic aspect is provoked by the presence of possibility to choose numerous parameters for monitoring the development process of their wear as well as selection of wear criteria. This paper presents part of research in real and laboratory conditions of the tribological properties of hob milling tools from an economic point of view during gear cutting.

Keywords: hob milling, tribological characteristics, tribo-mechanical systems, friction, wear.

AIMS AND BACKGROUND

Availability of the current information about the hob milling process gear teeth is an important precondition for economic handling of the process of spur gear cutting. In the tribological processes very low mass of tool material and the great mass of workpiece material take part during the gear cutting. The consequences of the development of tribological processes in the contact zones are friction occurence in that zones and phenomena of friction and wear of cutting elements of hob milling tools.

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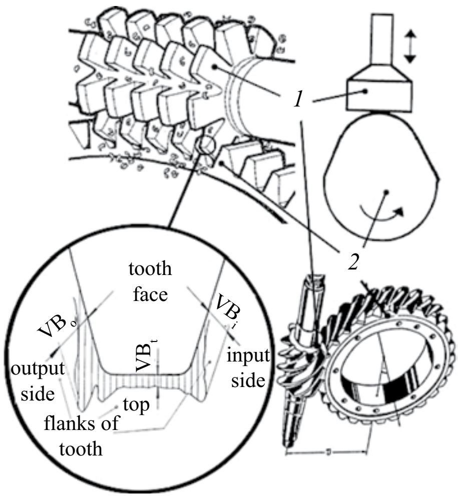


Fig. 1. Example of tribomechanical systems with basic elements *1* and *2* and details with wear parameters of hob milling tool

In designing of cutting tools, devices and machines in modern industrial engineering it is very important to know the impact of the materials types and procedures for improving the wear resistance of the contact layers as well as the roughness of contact surfaces on the wear intensity and friction coefficient in order to select the optimum material of elements of tribomechanical system[1–6].

In Fig. 1 examples of tribo-mechanical systems are given, and with number 1 is marked the critical element of system or element that, in the process of contact, wears most significantly.

Efforts by developed countries in reducing consumption of energy and materials, as well as in solving environmental problems can not lead to significant results without additional research in all fields of tribology and, therefore, also in the field of tribo-materials[6–8].

In this paper, based on studies in real and laboratory conditions, part of research of process of gear cutting by hob milling as one of the most complex systems in tribomechanical systems in the processes of material removal is given.

WEAR PROCESS OF HOB MILLING TOOLS

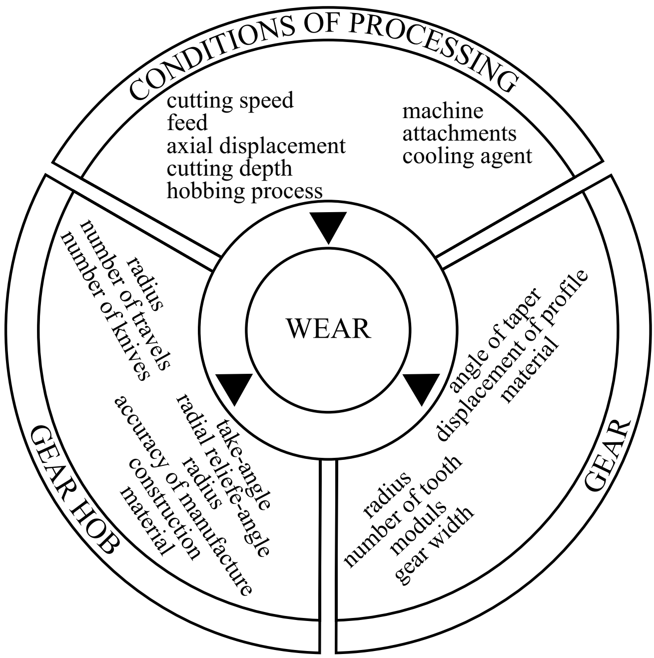
Hob milling process is a complex process with a very wide range of factors and process parameters which are important for finding the optimum machining conditions.

Insufficient state of scientific knowledge in the field of hob milling requires further development and research of this kind of machninig. Lack of information is increased by applying a variety of tools and materials of hob milling in the machining of gears teeth which are made of various materials.

Economy of gear cutting depends primarily on the character of teeth wear of hob milling cutter. Numerous factors and their alternating effects make the research of wear process of hob milling cutter very difficult (Fig. 2.)[9,10].

Detailed analysis of the most influential factors and parameters can serve as a basis for understanding the ways of increasing economy of gear cutting by hob milling. Wear is one of the ending negative phenomena in the machining processes. It is believed that the relatively high pressures and high temperatures on contact surfaces of coupled pairs, and the high relative velocity of the coupled

Fig. 2. Influential parameters on wear process of hob milling tool



pairs are the basic conditions for the occurrence and intensive development of tool wear process. Wear of cutting elements of hob milling tools takes place continuously in all moments of contact, and also in all technological conditions and machining regimens[8–10].

The development of wear process on the teeth of hob milling tool depends on the combination of tool and workpiece materials[11], machine and applied coolant and lubrication, and also depends on the treatment conditions and machining parameters. Geometry of hob milling tool, gear geometry and hob milling procedures also affect the process of hob milling. The problem of identifying a machining process or mathematical dependencies by which they are characterised is very complex.

The absence of reliable mathematical dependences of the process parameters or state function and limitations of hob milling process of gear teeth is the main problem of techno-economics optimisation. Nowadays, there is a tendency to create a database of reliable, first of all, statistical input–output dependences by applying multi-factors plans of experiment. When defining the function of tool wear and function of tool life as state function, it is necessary to perform experimental studies that require significant resources and efforts. This is very difficult to implement them in the real production process[9–10].

EXPERIMENTAL

A method was developed and the tool for taking a cutting element (teeth) for model testing in the laboratory that was designed and manufactured for gear cutting process (Fig. 3.).

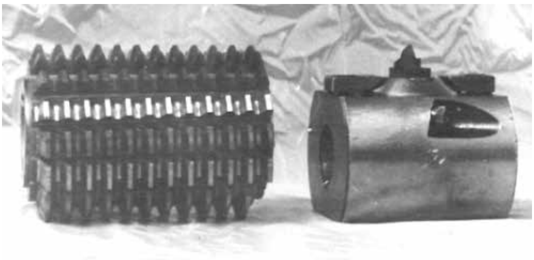


Fig. 3. Integral and model tools

Research of state functions and limitations of spur gears cutting process included determining the function of tool wear and tool life in real and laboratory conditions.

Analysis of gear application in modern industrial engineering made it possible to adopt two tested materials: 20CrMo5 and 18CrNi8 (Table 1) as representative workpiece materials. Samples (gears) of 20CrMo5, 18CrNi8 have the following characteristics:

- number of teeth: $z_{2_1} = 25$ and $z_{2_2} = 50$ and $z_{2_3} = 32$;
- module: $m_1 = m_{n_1} = 3/\mathrm{mm}$ and $m_2 = m_{n_2} = 5/\mathrm{mm}$.

The studies were performed on a hob milling machine ZFWZ-MODUL-250X5A with hob milling tools which are made from HS18-1-1-5 and HS6-5-2-5 materials.

Coating of model hob milling tools with TiN was performed on an ATC device manufactured by VAC TECSYST, USA.

Coolant and lubrication oil was Texaco Oil CLERTEX-D and cutting oil was REZANOL 20EP, Refinery Modrica.

Based on the analysis of the experimental conditions it can be concluded that the researches carried out on 2 types of gear and tool material, 2 modules of coated and uncoated hob milling tools as elements of tribomechanical system of a process of gear cutting. Their tribological properties were determined in real and laboratory conditions. Measuring the wear parameters (VB_t, VB_i, VB_o defined in Fig. 1)

Table 1. Properties of workpiece material

Tag	Chemical composition	State and mechanical characteristic		
		heat treatment	$R'_m \left(\frac{kN}{mm^2}\right)$	$HB \left(\frac{kN}{mm^2}\right)$
20CrMo5	14%Cr; 0.3%Mo; 0.35%Si; 12%Mn; 0.35%P; 0.035%S	annealed	412	1177
18CrNi8	2.1%Ni; 2.1%Cr; 0.6%Mn; 0.35%Si; 0.035%P; 0.35%S	annealed	392	1412

was performed on an universal microscope Zeiss Jena. Identification of machined surface quality was carried out on a TAILOR HOBSON TALYSURF 6. Processing of experimental results was performed on a computer.

During the determination of tool life as tool wear criterion, the size of wear on the output side was $VB_o = 0.2$ mm for final machining and $VB_o = 0.6$ mm for semi-rough machining.

RESULTS AND DISCUSSION

Based on the general model of state process functions using a defined 3-factors plan of experiment (Fig. 4) in the machining of samples of materials 20CrMo5, module $m = 3$/mm and $z_{2_1} = 25$ and uncoated tool HS6-5-2-5 for each experimental point, with defined input parameters (Table 2), the output values of the characteristics of the process were obtained: tool wear (VB_t, VB_i, VB_o).

The general model of wear function on the top, the input and the output sides, for a particular case, were

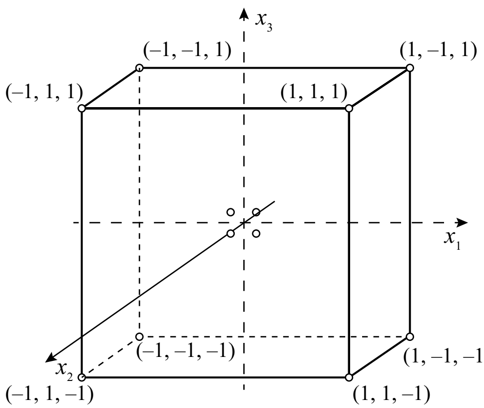


Fig. 4. Multifactor (3 factors) plans of experiments

Table 2. Matrix plan with input and output parameters

Regimes parameters of process			High level / medium level / low level		45.24 / 39.58 / 35.34	1.6 / 1.28 / 1.0	266 / 250 / 236	Measured values of output parameters		
v_c (m/min)	f (mm/rev)	t (min)	order of experim. realisation	x_0	x_1	x_2	x_3	VB_t (mm)	VB_i (mm)	VB_o (mm)
45.24	1.0	236	8	+1	+1	-1	-1	0.049	0.306	0.257
45.24	1.6	236	11	+1	+1	+1	-1	0.061	0.469	0.376
35.34	1.6	236	12	+1	-1	+1	-1	0.116	0.251	0.295
35.34	1.0	236	1	+1	-1	-1	-1	0.054	0.186	0.206
45.24	1.0	266	10	+1	+1	-1	+1	0.165	0.366	0.299
45.24	1.6	266	2	+1	+1	+1	+1	0.183	0.619	0.605
35.34	1.6	266	4	+1	-1	+1	+1	0.095	0.388	0.287
35.34	1.0	266	5	+1	-1	-1	+1	0.085	0.269	0.283
39.58	1.28	250	3	+1	0	0	0	0.137	0.588	0.395
39.58	1.28	250	6	+1	0	0	0	0.065	0.362	0.293
39.58	1.28	250	7	+1	0	0	0	0.049	0.244	0.195
39.58	1.28	250	9	+1	0	0	0	0.111	0.260	0.215

obtained by methods of statistical processing of data on one computer and have the following form:

$$\mathrm{VB_t} = 0.1196 \times 10^{-14} v_c^{0.586} f^{0,637} t^{5.362} \quad (1)$$

$$\mathrm{VB_i} = 0.5528 \times 10^{-7} v_c^{1.280} f^{0.776} t^{1.916} \quad (2)$$

$$\mathrm{VB_o} = 0.1101 \times 10^{-9} v_c^{1.921} f^{0.861} t^{2.635} \quad (3)$$

During model tests in the laboratory conditions up milling procedure for machining the samples of material 20CrMo5 module $m = 3$ mm and $z_{2_2} = 50$ the hob milling tool of HS6-5-2-5 at varying speeds v_c, axial feed f and periodic axial displacement a_d along the axis of the tool (Table 3) was used.

In this study 3-factor experiment plan was applied (Fig. 4) and for each experimental point and defined input parameters (Table 3) the output values of typical wear ($\mathrm{VB_t}$, $\mathrm{VB_i}$, $\mathrm{VB_o}$) were obtained.

Tool life function obtained by processing of experimental data has the following form:

$$L_1 = 0.81059 \times 10^5 v_c^{-1.7402} f^{0.27648} a_d^{0.035218}. \quad (4)$$

Using geometric programming for determining optimum cutting regimes the following values were obtained: $v_{c_{op}} = 101.44$ m min^{-1} and $f_{op} = 1.862$/mm rev^{-1}.

Substituting the optimum values for v_c and f is obtained: $T_1 = 397.914$ min.

Taking into account the remaining length of the periodic axial displacement of hob milling tool mills along its own axis total tool life is obtained: $T_{op} = 2.4T_1$ = 955 min.

Table 3. Plan matrix with input and output parameters

Imput parameters of process			High level		123.7	4	2.5	Measured values of state function
			medium level		88.35	2	0.63	
			low level		62.83	1	1.157	
v_c (m/min)	f (mm/rev)	a_d (mm)	order of experim. realisation	x_0	x_1	x_2	x_3	L_1 (mm)
123.7	1	0.157	4	1	1	–1	–1	20
123.7	4	0.157	3	1	1	1	–1	24
62.83	4	0.157	12	1	–1	1	–1	89
62.83	1	0.157	10	1	–1	–1	–1	51
123.7	1	2.5	7	1	1	–1	1	18
123.7	4	2.5	5	1	1	1	1	29
62.83	4	2.5	1	1	–1	1	1	92
62.83	1	2.5	2	1	–1	–1	1	67
88.35	2	0.63	8	1	0	0	0	41
88.35	2	0.63	9	1	0	0	0	46
88.35	2	0.63	6	1	0	0	0	33
88.35	2	0.63	11	1	0	0	0	36

The obtained optimum cutting regimes were tested on the same machine and they satisfy the terms of its dynamic stability.

In laboratory conditions when machining of the samples of materials 18CrNi8 module m = 5 mm and z_{2_3} = 32 coated (Table 4) with TiN and uncoated (Table 5) model hob milling tools of HS18-1-1-5 material, the criterion of wear VB_o = 0.2 mm and applying 2-factor plan experiment (Fig. 5).

On the basis of statistical processing of experimental results (Tables 4 and 5) the expressions for tool life function in

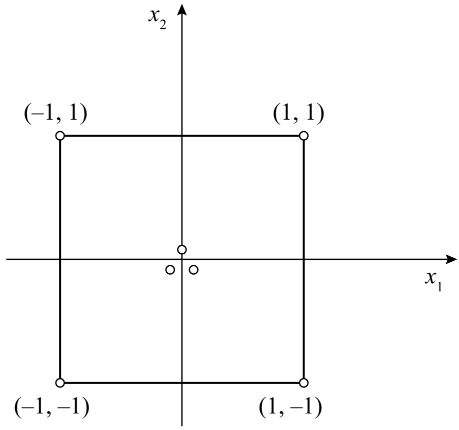


Fig. 5. Multifactor (2 factors) plans of experiments

Table 4. Plan matrix with input and output parameters for coated tool

Imput parameters of process		High level			139.33	7.0	Measured values of state function
		medium level			123.63	5.3	
		low level			109.90	4.0	
v_c (m/min)	f (mm/rev)	number of experiment	order of experim. realisation	x_0	x_1	x_2	L (mm)
109.90	4.0	1	1	+1	–1	–1	127
139.33	4.0	2	6	+1	+1	–1	46
109.90	7.0	3	2	+1	–1	+1	91
139.33	7.0	4	7	+1	+1	+1	54
123.63	5.3	5	3	+1	0	0	96
123.63	5.3	6	4	+1	0	0	127
123.63	5.3	7	5	+1	0	0	66

Table 5. Plan matrix with input and output parameters uncoated tool

Regimes parameters of process		High level			139.33	7.0	Measured values of state function
		medium level			123.63	5.3	
		low level			109.90	4.0	
v_c (m/min)	f (mm/rev)	number of experiment	order of experim. realisation	x_0	x_1	x_2	L (mm)
109.90	4.0	1	2	+1	-1	-1	40
139.33	4.0	2	6	+1	+1	-1	32
109.90	7.0	3	3	+1	-1	+1	39.5
139.33	7.0	4	5	+1	+1	+1	32
123.63	5.3	5	1	+1	0	0	43
123.63	5.3	6	4	+1	0	0	40
123.63	5.3	7	7	+1	0	0	26

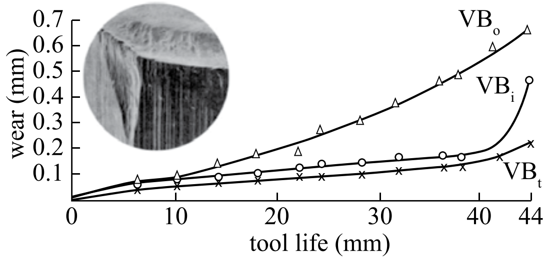


Fig. 6. Development of wear process of coated tool

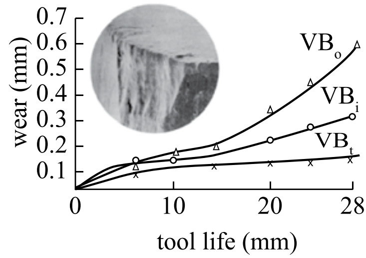


Fig. 7. Development of wear process of uncoated tool

dependence on cutting regimes parameters for uncoated and coated hob milling tools were obtained:

$$L_c = 6.2 \times 10^8 v_c^{-3.237} f^{-0.154} \tag{5}$$

$$L_{uc} = 2.9 \times 10^3 v_c^{-0.910} f^{-0.011} \tag{6}$$

Development of wear process of coated and uncoated tool is given in Figs 6 and 7.

The obtained state functions satisfy the condition of model adequacy and they can be used to optimise cutting regimes of the analysed process.

Based on the analysis of the experimental results the following facts can be noted:

– large number of controlled and uncontrolled factors affect the process of hob milling;

– numerous and intricate relations of these factors complicate investigations and mathematical defining of the state functions of machining process;

– cutting regimes have a major influence on the cutting process and wear and thus on the tool life of hob milling cutter;

– the method of hob milling process modelling using single tooth tool and application of multi-factors experiment plans reduces time and costs of testing;

– on the basis of the developed mathematical models of the objective function and application of reliable state functions and limitations for specific operations in serial production it is possible to effectively determine the optimum cutting data using geometric programming.

CONCLUSIONS

Based on the obtained results the following can be concluded:

- Testing was performed using the mathematical theory of experiment planning and tribological properties of coated and uncoated elements of tribomechanical system of gear cutting by hob milling in real and laboratory conditions were determined;

- Tool material, workpiece material, module, procedure of hob milling, coolant and lubrication and coating of tool have impact on the hob milling process of gear teeth and on the tribological characteristics of coated and uncoated elements of the tribomechanical systems;
- It can also be concluded, on the basis of previous and presented research, that tribological characteristics of model coated hob milling tools cutters, from an economic point of view, are better than the tribological characteristics of uncoated hob milling tools.

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