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Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
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Yaroslav Kusyi,
Andrij Kuk,
Volodymyr Topilnytskyy,
Dariya Rebot,
Mykhailo Bojko

INFLUENCE OF CONSTRUCTIVE AND GEOMETRIC PARAMETERS OF THE END CUTTERS ON THE MICROPROFILE CHARACTERISTICS OF CASTING SURFACES

The object of research is the technological route of machining of an aluminum alloy casting. The research carried out is based on the basic principles of functionally oriented design of technological processes in the manufacture of products. The main hypothesis of the study is the need for a systematic approach to study the effect of cutting modes of a certain method of machining on the provision of quality parameters in the technological system (machine – device – tool – workpiece). In traditional automated systems for technological preparation of production, an object-oriented principle of designing technological processes is implemented, which provides for the step-by-step implementation of interrelated stages based on a prototyping algorithm without a functional analysis of the operational characteristics of the product. The processing of functional, mating surfaces, ensuring that the product performs its service purpose, must be implemented according to the principle of function-oriented design (FODT). A characteristic feature of FOT is the technological provision of effective operational characteristics of the product in compliance with the parameters of accuracy and quality of the surface layer of the product intended by the designer. The paper deals with the influence of the structural and geometric parameters of end mills manufactured by Sandvick (Sandviken, Sweden) on the formation of microrelief parameters of an aluminum alloy casting profile during machining on a numerically controlled vertical milling center (CNC) HAAS MINIMILL (USA). An atypical option for the FOT principle of the technological route of machining the surfaces of workpieces of machine-building products has been applied. Its feature is ignoring the requirements of the manufacturer of metal-cutting tools, which is an important element of the technological system (machine – tool – device – workpiece), regarding its use for a particular machine tool at a certain technological transition of machining. The performance criteria were the height and step characteristics of the microrelief of the profile of the surface layer of the workpiece being processed. The operating conditions of machine-building products have been determined, which make it possible to establish, in case of deviation from the manufacturer's recommendations at the stage of technological preparation of production, the rational elements of a certain technological system: a metal-cutting machine – a device – a metal-cutting tool – a workpiece and processing modes to ensure the necessary operational characteristics.

Keywords: *mechanical surface treatment, surface quality parameters, surface microprofile, functionally oriented design, technological route.*

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1. Introduction

Technological support of the quality parameters of parts regulated by design and technological requirements is an important task for the modern machine-building industry with the use of effective technologies in conjunction with the stages and stages of product life cycles [1–3]. The economic feasibility of comprehensive quality assurance of engineering products at all stages of the life cycle necessitated a similar approach to the working surfaces of machine parts [4, 5]. This has formed a new direction of research – surface engineering with an integrated approach to solving the assigned tasks [6]. When providing machine-building products for service purposes in accordance with the operating conditions, a lot of causal-hereditary relationships is formed. This set represents the response functions of the technological processing system (machine – device – tool – workpiece (MDTW)). Causal and hereditary relationships lead to the transformation of quality indicators of products at important stages and stages of their life cycles, deterioration of starting characteristics, the formation of conditions for physical and moral wear and tear of machine parts [1, 7]. The proposed methods are based on comprehensive studies of object-oriented and functionally-oriented technological processes of manufacturing products, taking into account the technological inheritance of material properties to increase the competitiveness of parts and machines [1, 8, 9]. Therefore, the analysis of the influence of the design of metal-cutting tools as a component of the MDTW system on the parameters of the micro-profile of the executive surfaces of machine parts is an urgent task.

Thus, the object of research is the technological route of machining of an aluminum alloy casting. The aim of research is to analyze the influence of design, geometric parameters and types of end mills on the parameters of the micro-profile of the surfaces of aluminum alloy castings during their machining.

2. Methods of research

The research carried out is based on the application of the approaches described in the works [10–12]. The main hypothesis of the study is the need for a systematic approach to study the effect of cutting modes of a certain method of machining on the provision of surface quality parameters in the technological system (MDTW) [12, 13].

In traditional automated systems for technological preparation of production (MDTW), implemented on the principles of object-oriented design, a step-by-step implementation of interrelated stages of the development of routes for the manufacture of machine parts is carried out. At the stage of calculating cutting conditions, a metal-cutting tool is selected. Based on the power parameters of the cutting process, the model of the machine is established. According to the technical characteristics of a certain machine, the cutting modes are specified, which, with a stepwise adjustment of the drive of the main movement and feeds, will differ from the calculated ones [14].

Modern technological systems (MDTW) are characterized by the application of the principle of integration at all stages of design and technological preparation of production. It consists in the fact that for a specific method of machining, a specific metal-cutting machine from a specialized manufacturer is selected. For a given machine model, a rational metal-cutting tool is chosen with cutting modes adapted for a given machine, optimal for this processing method. This algorithm eliminates the time-consuming calculations typical for object-oriented design of technological processes. For a certain processing method for a specific workpiece, a rational combination of elements of the technological system metal-cutting machine – technological equipment – metal-cutting tool – workpiece is provided with the implementation of mechanical processing at optimal processing modes [1, 8, 15].

The roughness parameters normalized by the designer are directly related to the performance characteristics of the products. In particular, the arithmetic mean deviation of the profile Ra, the average step of the profile irregularities along the centerline Sm and the relative reference length of the profile tm primarily ensure the wear resistance of the mating parts. The highest profile height *S* determines the product's operating conditions under fatigue conditions. The *Rz* parameter provides the specified adhesion to the coating, etc. [16–18]. Empirical relationships between the parameters of the main methods of machining and the quality of the surface of the manufacture of the product are established on the basis of statistical processing of the results of experimental studies [17–19].

An important task in the development of effective technologies for the manufacture of products is to ensure the optimal parameters of the roughness of their functional surfaces in accordance with the operational requirements.

3. Research results and discussion

A flat billet with dimensions of 165×155×20 mm made from the material AK21M2.5N2.5 GOST 1853-93 was cast into a sandy-clay mold (Table 1). The edge of the casting, its gates and sprues were cut off with a saw when the cutting fluid was supplied to the cutting zone. The temperature regime for cooling the casting was 690–710 °C [1, 10].

The surface of the casting material was finished by milling. End mills for rough (Table 2) and semi-finishing (Table 3) milling by Sandvick (Sandviken, Sweden) ∅6 mm, ∅8 mm, ∅10 mm, ∅12 mm were used for experimental studies. The experimental sample was processed on a HAAS MINIMILL vertical milling center with numerical control (CNC) (USA) [10].

Table 1

The chemical composition of the casting material

Chemical element	Percent, %	Chemical element	Percent, %
Al	70.953±0.080	Mn	0.255±0.008
Si	23.219±0.078	Cr	0.184±0.008
Cu	2.895±0.012	S	0.114±0.007
Fe	1.119±0.011	Ni	0.084±0.003
Zn	1.096±0.006	Ti	0.083±0.013

Table 2

Design and geometric parameters of end mills for roughing

Constructive/geometric parameter of the cutter	Cutter designation			
	1P240-0600-XA 1630	1P240-0800-XA 1630	1P240-1000-XA 1630	1P240-1200-XA 1630
Design parameters, mm				
Nominal diameter	6.00	8.00	10.00	12.00
Cutting diameter	5.74	7.74	9.60	11.60
Functional length	57.00	63.00	72.00	83.00
Working length	13.50	19.50	22.50	26.50
Chamfer size	0.13×45°	0.13×45°	0.2×45°	0.2×45°
Number of cutting edges	4	4	4	4
Geometric parameters, deg.				
Insertion angle (max)	5	5	5	5
Rake angle (radial/axial)	9/5.5	9/5.5	9/5.5	9/5.5
Flute ascent angle	35	35	35	35
Alloy: base/coating	1630: HC/PVDALCRN			
Accuracy	h6			

Table 3

Design and geometric parameters of end mills for semi-finishing machining

Constructive/geometric parameter of the cutter	Cutter designation			
	1P330-0600-XA 1620	1P330-0800-XA 1620	1P330-1000-XA 1620	1P330-1200-XA 1620
Design parameters, mm				
Nominal diameter	6.00	8.00	10.00	12.00
Cutting diameter	5.80	7.80	9.80	11.80
Functional length	57.00	63.00	72.00	83.00
Working length	10.00	16.00	19.00	22.00
Chamfer size	0.1×45°	0.1×45°	0.1×45°	0.1×45°
Number of cutting edges	3	3	3	3
Geometric parameters, deg.				
Insertion angle (max)	8	8	8	8
Rake angle (radial/axial)	10.5/13.5	10.5/13.5	10.5/13.5	10.5/13.5
Flute ascent angle	45	45	45	45
Alloy: base/coating	1620: HC/PVD TIALN			
Accuracy	h6			

Two series of studies were planned for varieties of mechanical processing of experimental samples. Firstly, the surfaces of the test piece were roughly cut alternately with four end mills for semi-finishing. In the next step, the surfaces of the sample were determined and machined semi-finished with four end mills for rough milling. For real production, cutters for rough milling are used for preliminary (rough) processing of a workpiece, cutters for semi-finishing milling are used for intermediate processing between rough and finish milling. The cutting parameters were selected in accordance with the recommendations of the tool manufacturer [10]. Cutting parameters consisted of cutting width (B), cutting depth (t), feed per tooth (Sz), rotation speed (n), cutting speed (V). The cutting parameters were:

- for ∅6 mm: $B=3{,}0$ mm, $t=6{,}0$ mm, $Sz=0{,}1$ mm/tooth, $n=3100\ \text{min}^{-1}$, $V=58{,}43$ m/min;
- for ∅8 mm: $B=3{,}0$ mm, $t=8{,}0$ mm, $Sz=0{,}1$ mm/tooth, $n=4000\ \text{min}^{-1}$, $V=100{,}53$ m/min;
- for ∅10 mm: $B=3{,}0$ mm, $t=10{,}0$ mm, $Sz=0{,}1$ mm/tooth, $n=5800\ \text{min}^{-1}$, $V=182{,}21$ m/min;
- for ∅12 mm: $B=3{,}0$ mm, $t=12{,}0$ mm, $Sz=0{,}1$ mm/tooth, $n=5800\ \text{min}^{-1}$, $V=218{,}65$ m/min [1].

During experimental studies, the main characteristics of surface roughness were determined according to GOST 2789-73, GOST 25142-82 and ISO 4287:

Ra – the arithmetic mean deviation of the roughness profile from the midline within the base length, µm;

Rz – the height of the roughness profile irregularities at ten points within the base length, µm;

$R\max$ – the maximum height of the roughness profile (the distance between the line of protrusions and the line of grooves) within the base length, µm;

Rp – the smoothing height (distance from the line of protrusions in the middle line), µm;

Rq – the standard deviation of the profile;

Sm – the average pitch of the profile irregularities;

S – the average step of irregularities along the tops;

tp – the relative reference length of the roughness profile at the level p of the profile section.

To determine the roughness parameters, a control and measuring complex was used, developed at the Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine (Lviv, Ukraine). The measuring complex consists of a profilograph-profilometer mod. «Caliber S-265» (Russia), matching devices, analog-to-digital converter, personal computer and application software – the *Roughness Plot Analyzer* computer program [20, 21].

The results of experimental studies are shown in Table 4, and statistical processing of experimental studies – in Fig. 1.

An increase in the geometric parameters of end mills for semi-finishing (Table 3), in comparison with mills for roughing (Table 2), provides the formation of the height parameters of the micro-profile (Ra, Rq), typical for semi-finishing/finishing. With an increase in the cutter diameter from ∅6 mm to ∅12 mm, the quality of the surface layer of the casting deteriorates in terms of the parameters Ra, Rq. The smoothing height Rp sharply decreases from the cutter diameter ∅6 mm to ∅8 mm, then increases from ∅8 mm to ∅12 mm. The value of the step characteristics of the micro-profile $S=0.136–0.183$ µm, $Sm=0.196–0.253$ µm indicates the absence of «oil pockets» on the existing microrelief.

Table 4

Changing the microrelief parameters of the casting surface after milling

Microrelief parameters	∅6 mm		∅8 mm		∅10 mm		∅12 mm	
	1 series	2 series	1 series	2 series	1 series	2 series	1 series	2 series
Ra, µm	0.971	3.125	1.212	3.087	1.395	2.148	1.509	2.012
Rz, µm	5.746	12.68	5.392	11.312	6.521	7.648	6.345	9.200
$R\max$, µm	8.582	15.046	6.925	14.500	8.458	9.701	8.523	15.628
Rp, µm	6.683	6.412	2.634	8.179	2.927	3.908	5.534	5.504
Rq, µm	1.533	3.693	1.507	3.572	1.789	2.475	1.848	2.57
Sm, µm	0.253	19.987	0.226	24.685	0.196	15.558	0.243	23.442
S, µm	0.183	15.556	0.156	19.581	0.136	12.84	0.159	14.988
tm	0.402	0.617	0.575	0.558	0.601	0.551	0.518	0.569

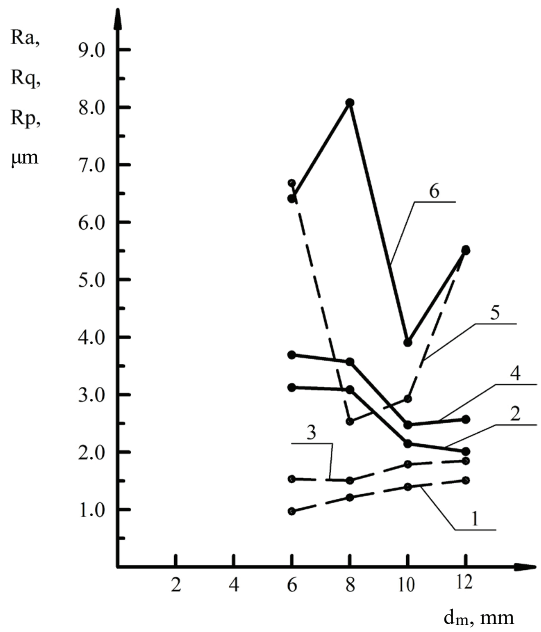

Fig. 1. Changing the height parameters (Ra, Rq, Rp) of the micro-profile of the surface of the casting from an aluminum alloy after milling with end mills of the «Sandvick» company: 1, 2 – change of the Ra parameter, respectively, for the first and second treatments; 3, 4 – change of the Rq parameter for the first and second treatments, respectively; 5, 6 – change of the Rp parameter for the first and second treatments, respectively

A decrease in the geometric parameters of end mills for rough machining (Table 2), in comparison with mills for semi-finishing machining (Table 3), at the second transition of casting machining is accompanied by a deterioration in the quality of the surface with height characteristics (Ra, Rq, Rq). At the same time, with an increase in the cutter diameter from ∅6 mm to ∅12 mm, the quality of the surface layer of the casting improves in terms of the parameters Ra, Rq. The smoothing height Rp increases from the cutter diameter ∅6 mm to ∅8 mm, then drops sharply from ∅8 mm to ∅10 mm, and again rises from ∅10 mm to ∅12 mm. The step characteristics of the micro-profile (S, Sm) change dramatically in comparison with the first transition: from $S=0.136$–0.183 µm, $Sm=0.196$–0.253 µm for roughing in $S=14.988$–19.581 µm, $Sm=15.558$–24.685 µm for semi-finishing, which, along with the deterioration of the parameters Ra and Rz, indicates the formation of «oil pockets» the existing microrelief.

The relative reference length of the profile along the centerline of the profile tm increases with the transition from roughing to semi-finishing for milling cutters ∅6 mm and ∅12 mm and slightly decreases for milling cutters ∅8 mm and ∅10 mm.

The use of a type of metal-cutting tool, which is atypical for this type of machining, in the technological routes of machining castings from an aluminum alloy leads to an improvement in the height parameters of the profile microrelief during rough machining. At the same time, this leads to deterioration in the parameters of the microrelief of the profile during beer processing and to a significant increase in the values of the step characteristics (S, Sm) during the transition from rough to semi-finishing processing.

For work in wear conditions, the combination of Ra, Sm, tm is provided for an end mill ∅12 mm. For cyclic alternating loads during fatigue, the maximum value of $S=19.581$ µm is obtained for an end mill ∅8 mm, and the specified adhesion strength to the coating will be provided by an end mill ∅10 mm.

4. Conclusions

The article deals with the influence of the design and geometrical parameters of the «Sandvick» end mills on the formation of the parameters of the microrelief of the profile of an aluminum alloy casting during machining on a vertical milling center with CNC HAAS MINIMILL. An atypical option for a functionally-oriented principle of implementing the technological route of machining the surfaces of workpieces of machine-building products has been applied. Its feature is ignoring the requirements of the manufacturer of metal-cutting tools, which is an important element of the technological system (machine – device – tool – workpiece), regarding its use for a particular machine tool at a certain technological transition of machining. The use of a metal-cutting tool, which is atypical for this type of machining, in the technological routes of processing an aluminum alloy casting leads to an improvement in the surface quality of the product at rough transitions of machining of the workpiece and their deterioration at semi-finishing transitions. In particular, the parameter Ra in absolute value increases with the transition from rough to semi-finishing milling from 1.33 times for milling cutters ∅12 mm to 3.22 times for milling cutters ∅6 mm. At the same time, during the transition from rough to semi-finishing milling, the step characteristics of the micro-profile sharply increase: Sm by 79–109.23 times, S by 85–125.52 times. Further research in this direction will concern the analysis of the evolution of the technological damageability of the casting when changing the elements of the technological system of machining on an expanded range of engineering products.

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Yaroslav Kusyi, *PhD, Associate Professor, Department of Robotics and Integrated Mechanical Engineering Technologies, Lviv Polytechnic National University, Lviv, Ukraine, e-mail: jarkym@ukr.net, ORCID: https://orcid.org/0000-0001-5741-486X*

Andrij Kuk, *PhD, Associate Professor, Department of Robotics and Integrated Mechanical Engineering Technologies, Lviv Polytechnic National University, Lviv, Ukraine, e-mail: andrij.kuk@gmail.com, ORCID: https://orcid.org/0000-0001-9145-243X*

Volodymyr Topilnytskyy, *PhD, Associate Professor, Department of Designing and Operation of Machines, Lviv Polytechnic National University, Lviv, Ukraine, e-mail: topilnvol@gmail.com, ORCID: http://orcid.org/0000-0002-5191-326X*

Dariya Rebot, *PhD, Assistant, Department of Designing and Operation of Machines, Lviv Polytechnic National University, Lviv, Ukraine, e-mail: dasha_kotlyarova@ukr.net, ORCID: https://orcid.org/0000-0002-3583-0800*

Mykhailo Bojko, *Senior Lecturer, Department of Designing and Operation of Machines, Lviv Polytechnic National University, Lviv, Ukraine, e-mail: osnastka@ukr.net, ORCID: https://orcid.org/0000-0002-7955-5062*