

Workpiece Surface Technological Quality Assurance with Levitation Tool Modules

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Abstract

Background/Objectives: The article considers the outcomes of experimental studies to establish the relationship of surface quality characteristics of parts with constructive and regime parameters of technical levitation devices – Levitation Tool Modules. **Methods:** The method for controlling microgeometry of the processed surface in the drilled holes with LTM-IV and the technologies applied in Finishing Antifriction Rotary Chamber Processing (FARCP) have been considered. **Findings:** The results of the experimental investigations of technological capabilities of four types of Levitation Tool Modules (LTM) have been presented. The optimal design and technological parameters of the modules have been established to control the characteristics of the surface layer quality. We have developed and experimentally investigated LTM for high-speed wire-brushing of materials. The possibility of ensuring the part surface quality by transportation of various lubricating and cooling technological means in the treatment zone was examined. The procedure for managing microgeometry of the machined surface of holes based on LTM technology and FARCP was studied. During experimental studies the LTM anti-vibration properties were assessed. In addition to controlling the process of part surface coat formation discussed the possibility of increasing efficiency of tools through the use of levitation tool modules. The presented experimental results suggest a high efficiency and expediency of applying LTM for technological quality assurance of the surface layer of parts. **Applications/Improvements:** The use of aggregated modular levitation devices will reduce the spread of surface quality parameters on average by 2-3 times and increase the machining quality through adaptive control of LTM based on the stabilization of the energy characteristics of the process.

Keywords: Contactless Mechanics, Levitation Tool Modules, Machining Processes, Surface Quality, Workpiece Surface

1. Introduction

Quality assurance is a fast developing scientific area instigated by the improved efficiency of modern production. Increased performance indicators of machines and mechanisms, their improved reliability and efficiency factors are predetermined by the service properties of their parts and connections (endurance strength, wear resistance,

friction ratio, corrosion resistance, contact stiffness, fit strength, tightness of joints, etc.). These properties, in turn, depend on the parameters of the surface layer of the processed parts and on different machining technologies¹⁻³.

Developing new technologies that ensure high accuracy of geometrical, physical and mechanical parameters of the workpiece surface under mechanical processing,

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creating stable running conditions for the cutting process and improving its reliability are the most important problems of mechanical engineering^{4,5}.

An important element of both high-tech processes and conventional machining is represented by technological tools. The problem of the workpiece surface technological quality assurance cannot be effectively solved as long as the industry employs conventional tools which operation principles are based on contact mechanics and do not meet the requirements of modern highly precise and highly efficient metalworking equipment. Solving the task of improving the functionality and reliability of the tools represents a potential capability for improving the quality and the competitive advantages of the products of the mechanical engineering sector⁶⁻⁸.

As science and technology progress, the upper limits of the achievable quality parameters are getting higher, the finishing process shifts closer to the precision technology. The possibility of obtaining, under mechanical processing conditions, the system of the surface layer parameters of high-precision quality depends on the whole complex of technological functions and on the development of technological tool modules (controlling the surface machining quality parameters, decreasing parameter variations and improving stability of the surface layer parameters, forming regular micro-relief, ensuring continuous chip breaking, fast processing, heat removal control, delivering lubricant-cooling agents to the processed area, technological process control, etc)⁹⁻¹¹.

In the mechanical engineering sector, there are examples when technological problems have been solved applying the elements of levitation contactless mechanics^{4,12}. These devices feature high-precision positioning, smooth run, good dynamic properties (rigidity and damping), possibility to adjust the parameters of the physical field of levitation devices and ability to operate reliably under the conditions of metal processing. Technological capabilities of the elements that realize the effects of technical levitation have not been fully discovered and have not been profoundly studied yet.

Tool modules that apply high-precision effects and technological potential of technical levitation seem to be an effective means for improving technological pro-

cesses in the mechanical engineering sector¹³. The study considers the results of the experimental investigations dedicated to establishing the interrelations between the workpiece surface quality characteristics and the structural and operation-related parameters of technical levitation devices, Levitation Tool Modules (LTM)^{14,15}.

2. Concept Headings

In the course of the scientific investigation the preliminary classification of the Tool Modules (TMs) employed by the machine tools to ensure the required quality of workpiece surfaces under different methods of processing has been developed. Classification attributes have been selected among the significant characteristics of TMs that determine their structural and technological affinity (Figure 1).

By contrast to conventional TMs, where the physical force is realized through the elements of contact mechanics, LTMs with levitation devices reveal the qualitatively new opportunities for the metal cutting machine tools. Kinematic attributes that determine the technological application areas have been used to subdivide LTMs in four classes: Static (LTM-I), those equipped with reciprocal tools (LTM-II), those featuring rotational movements (LTM-III) and those featuring combined movements (LTM-IV). The types of the physical field that enables the tool to establish the levitating interactions with the technological system were used to split LTMs in three groups: 1. Those with hydrostatic tool suspension bracket; 2. Those with gas-operated tool suspension bracket; 3. Those with magnet-operated tool suspension bracket.

Experimental investigations and the comparative analysis showed that in applying different technological methods of mechanical processing based on LTM one of the most important technological characteristics is represented by the possibility to control geometrical, physical and mechanical parameters of the surface. The controlling structural and operation-related factors in the technical levitation-based tool holder supports are represented by the parameters as follows: Feed pressure (P_f), relative hydraulic resistance of the compensating units (χ), effective support area (S_s), volume of the carrying pocket (V_p),

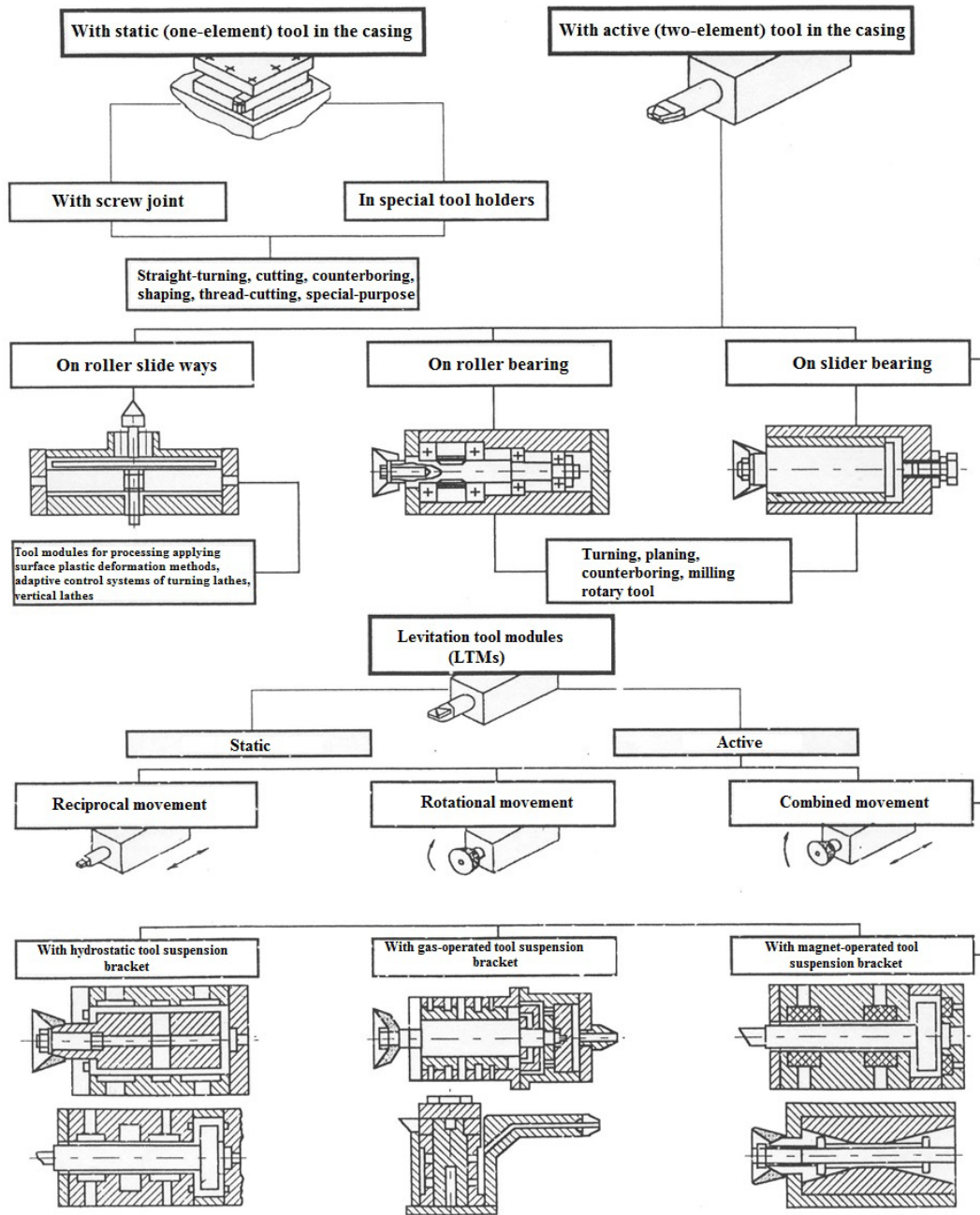


Figure 1. Tool modules classification.

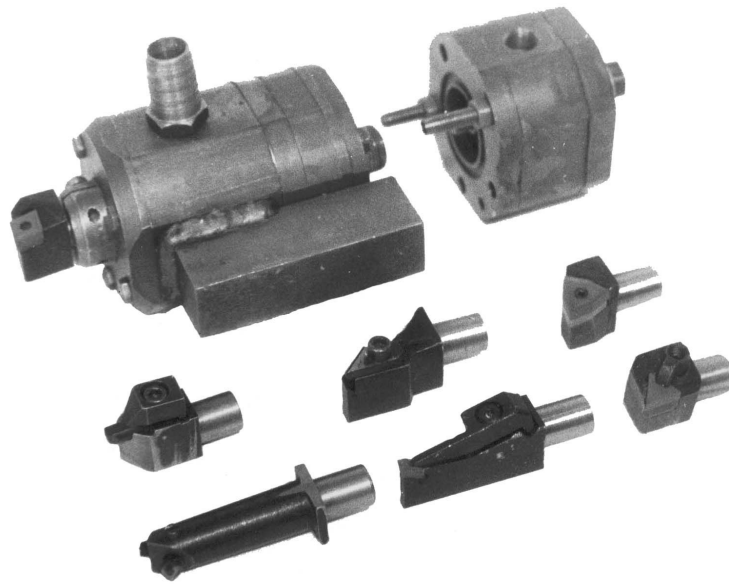


Figure 2. LTM-I with hydrostatic tool holder supports.

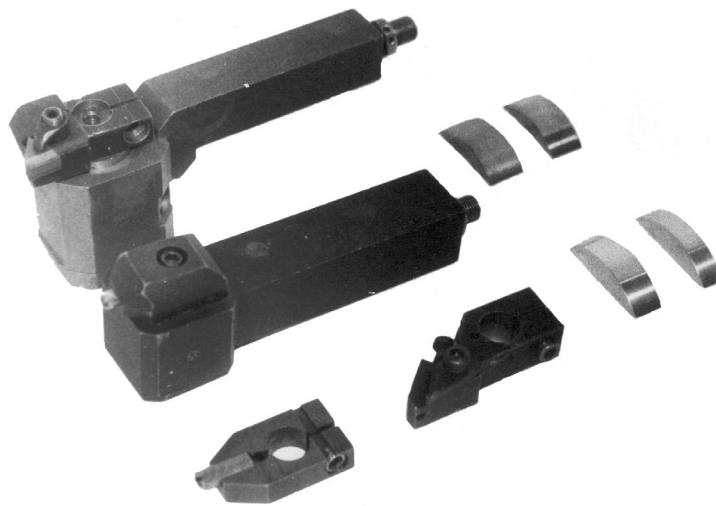


Figure 3. LTM-I with gas-static tool holder supports.

thickness of the regulator membrane (δ), regulator activity factor (K_m, K_r), gaps in the support and in the regulator (h_s, h_r), etc.

For the purposes of edge cutting machining at turning lathes, the configurations of LTM-I equipped with hydrostatic (Figure 2) and gas-static (Figure 3) tool holder supports and with different types of compensators have been designed.

3. Result

Figure 4 shows the results of the investigations on slotted throttle compensation system with the gap in the levitation support of $h_s = 30$ micron. When pressure P_f increases from 1 MPa to 3 MPa, the roughness parameter R_a decreases 1.7 times in the course of processing steel (curve 1) and 2.3 times in the course of processing dural-

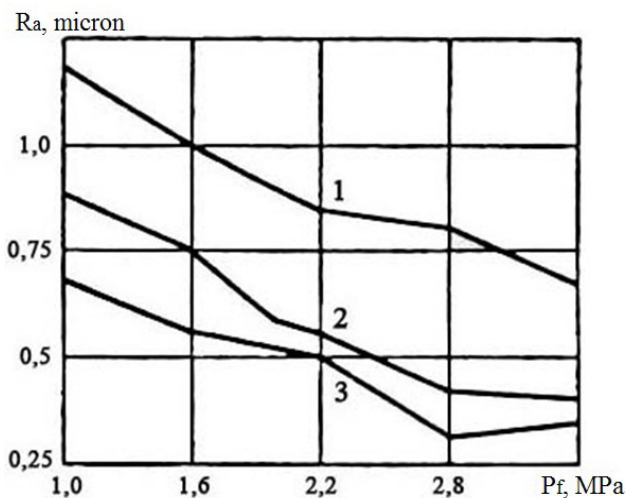


Figure 4. Effect of feed pressure P_f in LTM -I on the surface roughness.

umin and brass. Besides, due to the change of P_p LTM-I provides the possibility to control physical and mechanical parameters of the surface layer. Thus, in the course of processing 45 grade steel, the surface microhardness increased 1.4 times, thereat the processing technological modes were at the pre-set levels.

The possibility to control the roughness parameters and the parameters of hardening the surface layer with

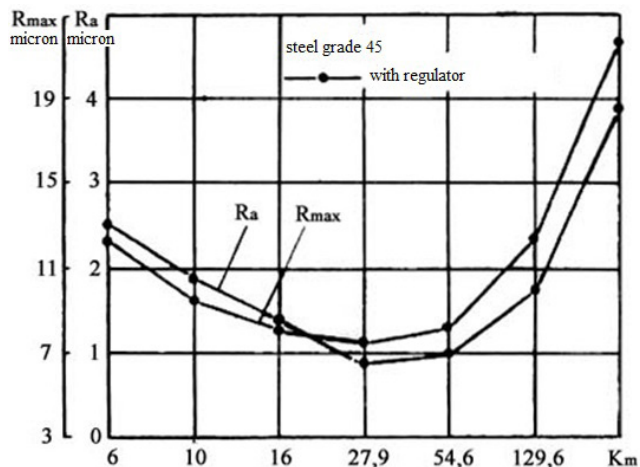


Figure 6. Effect of regulator activity factor on roughness characteristics in rotational turning.

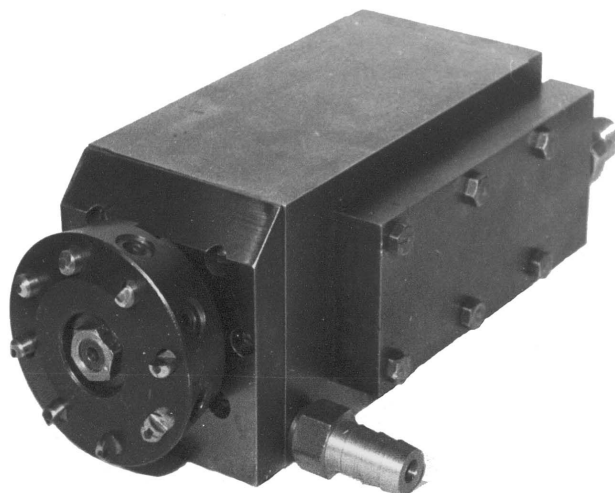


Figure 5. Exterior view of LTM -III.

LTM-III has been investigated for the processes of turning operations and rotational milling operations. Rotational modules with hydrostatic supports (Figure 5), with throttle compensation system and with “nozzle-valve” type regulators have been designed and investigated. The analysis of the effects produced by the structural factors of LTM-III (χ , h , K_m , V_p , h_p , etc.) on the roughness parameters R_a , R_p , R_{max} , S_m in turning operations showed that

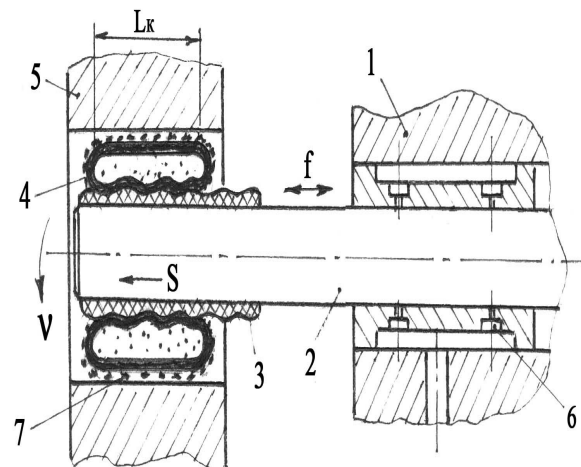


Figure 7. Structural layout of LTM -IV for FARCP method with rotary chamber tool and slide gate drive.

all dependencies were of nonlinear and extreme nature. For instance, in Figure 6 such dependency has been found for the activity factor of regulator K_m . This type of dependency can be explained by the degree of stability η of the levitation supports in LTM-III that could be adopted as a criterion for the process optimization. It is evident (Figure 6) that the minimal values R_a , R_{max} correspond to the well-defined value of $K_m = 27.9$. For this value K_m LTM-III shows the highest stability value η , at optimal $V_p = 4 \cdot 10^{-6} \text{ m}^3$. With the throttle compensation system, the minimal characteristics of roughness have been obtained for $\chi = 0.6 \div 0.65$. It has been established that the technology applied by LTM-III for the finish turning process ensures the hardening of the surface layer to the depth of 0.01-0.12 mm. Changing the feed pressure P_f from 1 MPa to 3 MPa results in 1.5 times deeper work-hardened layer, thereat, the microhardness increases by 30-40 %.

Technological capabilities of the fourth class tool modules shown in Figure 7 in realizing the physical levitation field rely on the combined (rotational and reciprocal) movement of the tool. Featuring complex kinematic displacement, LTM-IV makes it possible to create fundamentally new technological processing methods that ensure achievement of the required surface quality parameters at the finishing shape-making stages of the technological processes.

The method for controlling microgeometry of the processed surface in the drilled holes with LTM-IV and the technologies applied in Finishing Antifriction Rotary Chamber Processing (FARCP) have been considered. Relative approximation of the deforming tribotechnical elements of the rotary chamber tool to the surface of the workpiece depend on the dynamic tension and on the energy-related characteristics of the process. Experimental investigations of LTM-IV processes ($\chi = 0.3-0.8$; $P_f = 0.2-1 \text{ MPa}$) and of FARCP technological process have been carried out for machining the batch of rings (diameter 80 mm, width 40 mm) under the operational parameters as follows: oscillating movement velocity $V_{d.st} = 5-80 \text{ m/min}$, amplitude $A = 20-60 \text{ mm}$, line feed $S = 0.05-0.15 \text{ mm/rev}$, workpiece rotation velocity $V = 201-314 \text{ m/min}$. Preliminary, the holes in the rings made of steel grade 45 (HRC 40), steel grade 40X (HRC 35), bronze BrAZH 9-4, cast iron (HB 220) have been preprocessed by counter-boring and polishing to $R_a = 0.7-0.8 \text{ micron}$.

The surface roughness characteristics R_a , R_z , R_p , R_{max} , t_p after FARCP processing have been determined with profilograph-profilometer Hommel Tester^{16,17}. Typical profilograms of the hole surfaces in the rings made of steel grade 45 (a, b) and bronze Brazh 9-4 are shown in Figure 8.

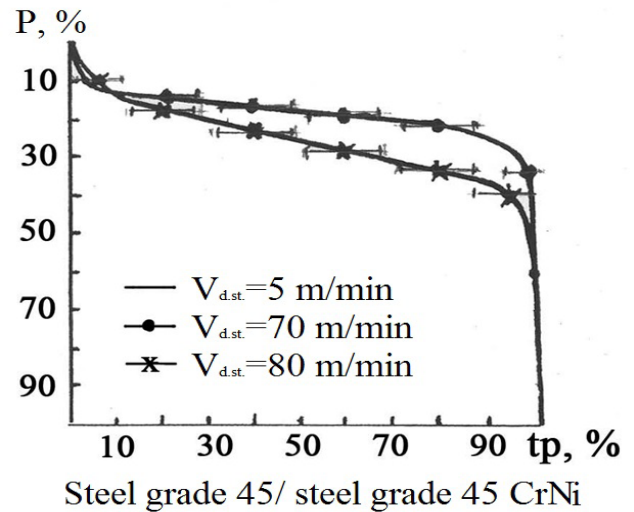


Figure 8. Surface profilograms before (a, b) and after (c, d) processing at LTM-IV.

The investigations show that the profilograms of the holes after processing at LTM-IV are of the shape that is characteristic for plateau honing, featuring the combination of smooth areas with deep notches for placing lubricants and antifriction materials. To obtain the specified microprofile, it is important that the characteristics of dynamic tension in LTM-IV and the constructive technological parameters of processing should be selected correctly.

To process the obtained roughness, the methods of wavelet-based fractal analysis have been employed assisted by software package Matlab^{8,18,19}. The profilogram represents a discrete series $\{x(t_i)\}_{i=1}^N$, micron, of the peak and depression values in the relief of the tribological pair surface. For the purposes of processing, the multi-level wavelet analysis was applied²⁰. First, the signal of the profilograms has been disintegrated to the level of $N = 3$, which provided the detailing factors. Then, to find the

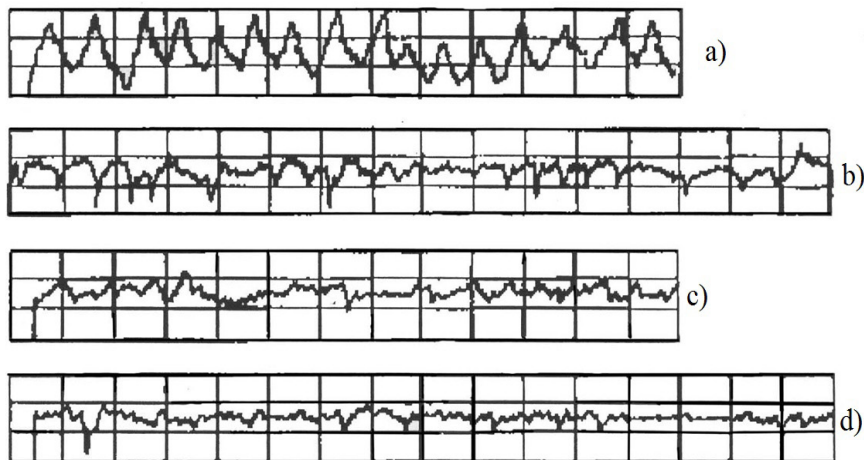


Figure 9. Curves of support areas after processing at LTM-IV with rotary chamber tool.

signal frequency components, reconstruction has been performed separately for each set of detailing factors. For each component of the signal spectral analysis has been carried out and the energy spectral density graphs and energy accumulation graphs have been obtained.

To evaluate the randomness of the components (wavelet-factors) the Hurst exponent was used. The Hurst exponent H describes the probability of the situation when two neighboring reports are identical. There is a formula:

$$H = 2 - D_F$$

Where D_F is fractal dimensionality that is defined as a limit²¹:

$$D_F = \lim_{\varepsilon \rightarrow 0} \frac{\ln M(\varepsilon)}{\ln (1/\varepsilon)}$$

Software program Fractan was used to calculate the Hurst exponent. To smooth the data of the profilogram in order to distinguish the wave profile with the least possible distortions of the shape and position of the obtained wave,

the smoothing algorithm with Gaussian nuclear functions *ksmooth* was used applying the mathematical software package Mathcad²². The built-in function creates the vector of the local weight average elements in the array using Gaussian kernel, width b , where b is the width of the band in the smoothing window. The band width b is usually set equal to several distances between the data points on axis x , depending on the desired degree of smoothing. In the course of determining the wave profile, it was assumed that $b = lr$ (or to the cutoff λ_C), i.e. the

band width b is equal to the basic length of the section where the roughness was detected. As a result of the data analysis, the trends of the roughness parameter evolution R_a , limit values of the cumulant and the Hurst exponents of the frequency components of the profilogram signals have been obtained.

It was established that FARCP method made it possible to obtain similar micro-profile at values $P_f = 0.4$ MPa, $\chi = 0.65-0.7$ in LTM-IV and at the pressure in the rotary chamber tool (RCT) of $P_c = 0.2-0.3$ MPa.

The deviation range of the relative reference profile length (Figure 9) and of the depth of the notches in

the course of processing different materials with different deforming tribotechnical elements is not the same. FARCP method continuously ensures the depth of the notches of 3-5 micron and the relative reference length of the profile of 50-70 % (at the level of 1-2 micron).

The following types of machine tools have been developed and studied: LTM-I for finish turning with composite materials;²³ LTM-I for turning with subsequent surface plastic deformation, LTM-II for diamond polishing, LTM-II for impulse hole expanding, LTM-III for planetary notch milling, LTM-III for spiral rotational-reeling turning, LTM-III for surface plastic deformation of tooth-wheels, LTM-IV for edge-cutting of rolls with RK profile.

For the whole range of modules under investigation, based on the multi-factor experiment carried out in line with quasi D-optimal designs type B_k , the mathematical optimization models for the surface quality parameters have been obtained.

The obtained models were used for selecting the optimal structural and technological factors of the levitation tool modules of classes I, II, III, IV; the initial data for calculating the surface quality parameters have been obtained at the stage of designing the technological processes.

The possibility to stabilize the status parameters of the surface layer of the workpiece has been analyzed based on LTM technology. Given the random character²⁴ of the

surface that comes from mechanical processing, the stability was evaluated from two perspectives: 1. Within one batch of the workpieces, 2. Within the nominal area of one workpiece.

Experimental investigations of the surface stability have been undertaken both in laboratory and in the production environment at finishing and polishing processing stages with the batch of the workpieces made of structural steel grade 45, of alloyed steels grades X18H10T and 30X13 within the range of the operational modes as follows: $V = 0.4 - 4 \text{ m/sec}$, $S = 0.05 - 0.20 \text{ mm/rev}$, $t = 0.01 - 0.5 \text{ mm}$ and with the structural parameters as follows: $P_f = 0.5 - 3 \text{ MPa}$, $\chi = 0.2 - 0.8$ on machine tools types 120 VM, 1И611П, TB-320, 1Б 625П and calculating such statistical evaluation criteria as: Pearson criterion (χ), Romanowski criterion (R), Bartlett's test (B), Cochran's test (G), Cramer's test (t_c), generalized Cowden's test (Λ)^{11,25}.

The investigations showed (Figure 10) that the levitation tool modules possess 1.8-1.9 times greater reserved stability of the obtained parameters of the surface roughness as compared to conventional tools that have stable parameters of roughness only within the light feed range (for criterion G). Thereat, it has been established that the largest stability reserve is observed in LTM when the value of the relative hydraulic resistance of the compensation device makes $\chi = 0.6 \div 0.65$.

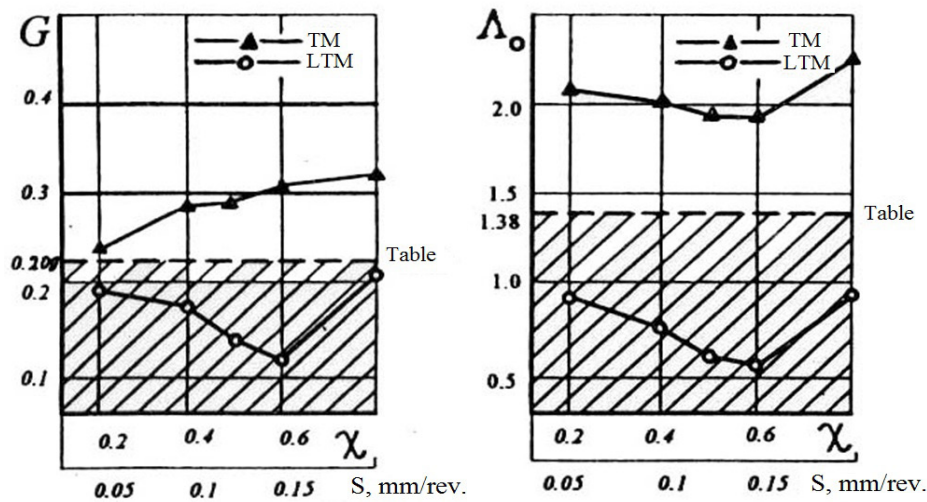


Figure 10. Statistical criteria of technological process stability in terms of quality parameters (shaded area means stability).

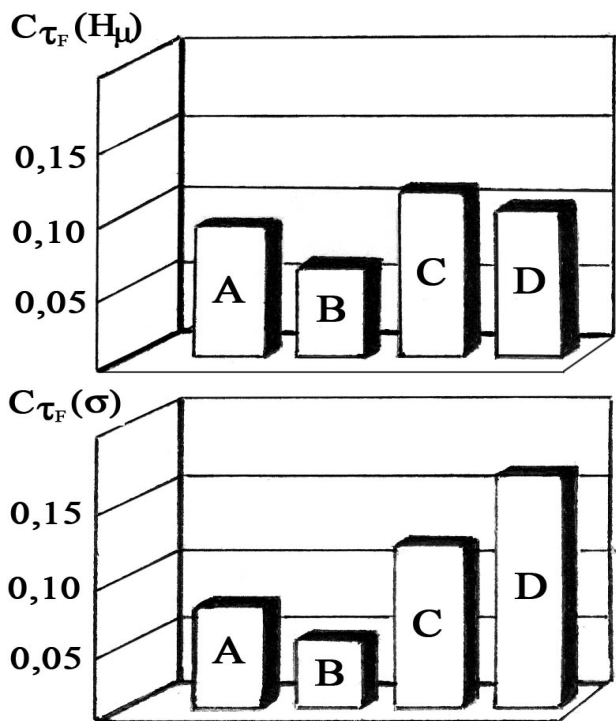


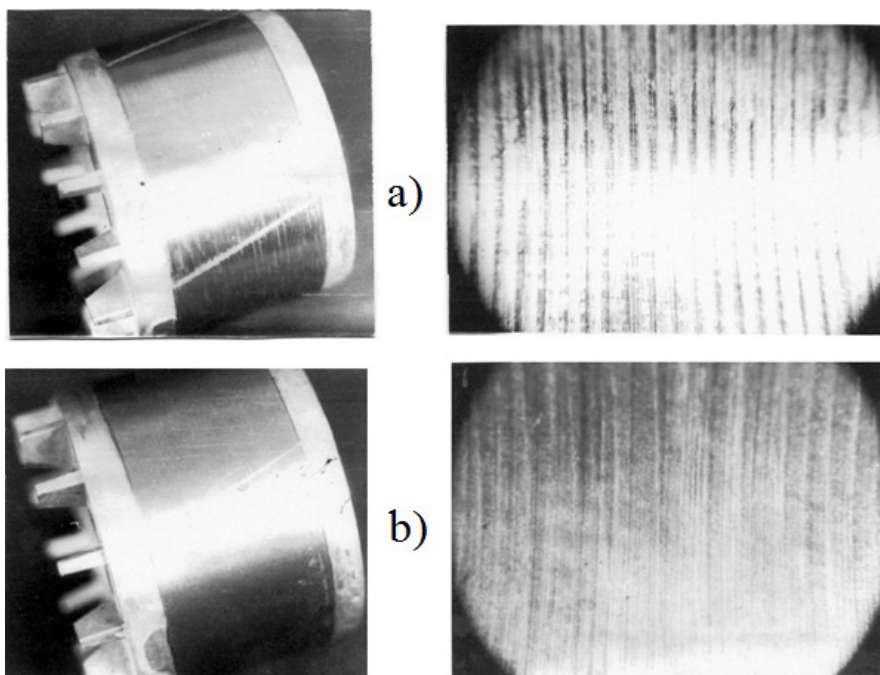
Figure 11. Diagrams of stability factor of surface layer parameters under different processing methods.

Figure 11 shows the comparison of LTM-I technology (A – finish turning, B – polish turning) with other types of finishing processes (C – finish polishing, D – fine polishing) according to the diagrams of the stability factor C_{τ_F} . The highest stability is ensured with finish turning

at LTM (diagram B). This made it possible (Figure 12), in the production environment and applying LTM technology, to exclude the polishing stage from processing the rotors of the motor-compressors due to the stable surface quality parameters and also to improve the electricity-related characteristics of these motor-compressors.

Based on the ensemble of the processes of forming the surface of the workpiece made of steel grade Y10A in the course of turning with composite material 10, the results of investigating the statistical characteristics of stationary and non-stationary random processes have been obtained.

The results of the experimental investigations of the scattered values of internal friction (IF) Q^{-1} show (Figure 13) that upon processing at LTM-I the center of group of IF values is shifted closer to smaller values in the range of $2.4 \cdot 10^4 \div 6.2 \cdot 10^4$, thereat, the variation factor $v_{Q^{-1}}$ is 1.3 - 1.7 times lower (Figure 14).



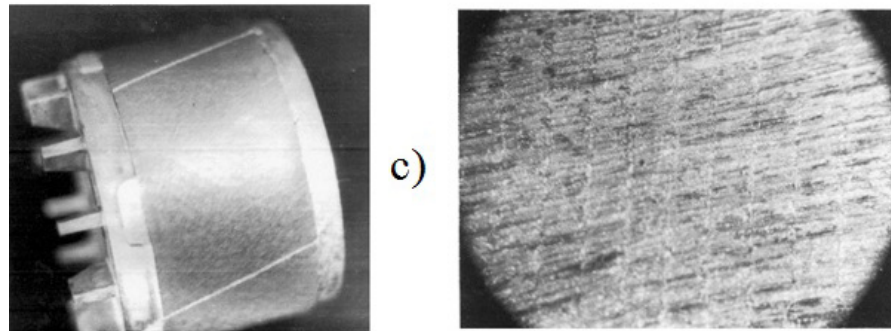


Figure 12. Surface of rotor of motor-compressor after processing with different technological methods. a. Turning at TM ($R_a = 2.5$ micron), b. Polishing ($R_a = 0.65$ micron), c. Rotational turning at LTM-III ($R_a = 0.70$ micron).

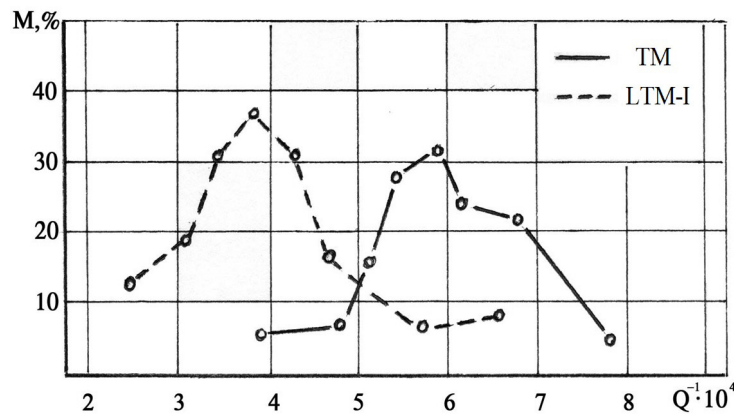


Figure 13. Scatter of values of internal friction Q^{-1} of workpiece surfaced made of steel grade Y10A in turning with composite material 10 applying LTM-I.

The dependency of IF level on the parameters of LTM adjustments has been found. Stabilization of IF values has been confirmed with LTM for different technological methods of processing (rotational turning, diamond polishing, FARCP technology, etc).

The possibility to create regular micro-reliefs on the workpiece surfaces has been studied applying LTM-II, III, IV due to simple principles of tool oscillation along axes X, Y, Z realized in these levitation devices. The method of turning with rotary cutting bits and with spindle oscilla-

tions ensuring different parameters of the Surfaces with Regular Micro-Reliefs (SRMR) with changing phase characteristics of the process and with changing structural and technological parameters of LTM (r_p , A, P_p , S, t) directly in the process of cutting has been considered.

To evaluate geometrical parameters of SRMR, the expressions of the height of elements R have been found in relation to the support area T_p , number of elements N, directional angles of locations of elements γ , β ; their analytical calculations have been carried out for various

4. Discussion

The experimental investigations have confirmed the possibility to obtain the surfaces (Figure 15) with completely Regular Micro-Relief (SRMR) by turning with rotary cutting bits with oscillating spindle and also to obtain the surfaces with microporous elliptical relief (Figure 15) with the planetary moving tools. Regular Micro-Relief is obtained directly in the process of cutting, including the cutting of low-plasticity materials: fiberglass and carbon fiber composite, textolite, hardened wood, rubber etc. The deviations between the theory and the experiment on the relief parameters amounted to 4-8 %.

Chip formation control and stable chip formation are among the most important technological characteristics of LTM that ensure high quality of mechanical processing. The chip breaking method founded on changing the energy-related characteristics of the attachable chip breaker has been investigated. The dependencies of the friction factor f of the discharged chip on changing dynamic tension in LTM-IV have been found to occur due to normal load P (Figure 16 a) and due to the shear velocity ratio V_1/V_{18} , associated with the energy flow distribution F_D/F_1 (different materials of drum lining).

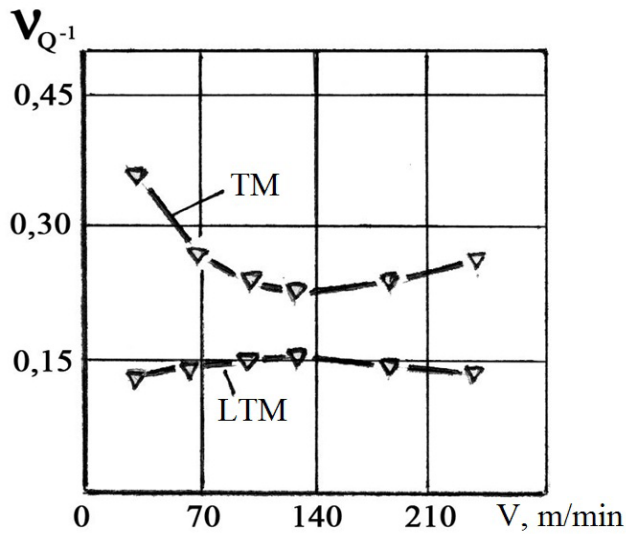


Figure 14. Effect produced by cutting velocity on internal friction background variation quotient.

combinations of structural and technological parameters of LTM-III with different oscillation modes.

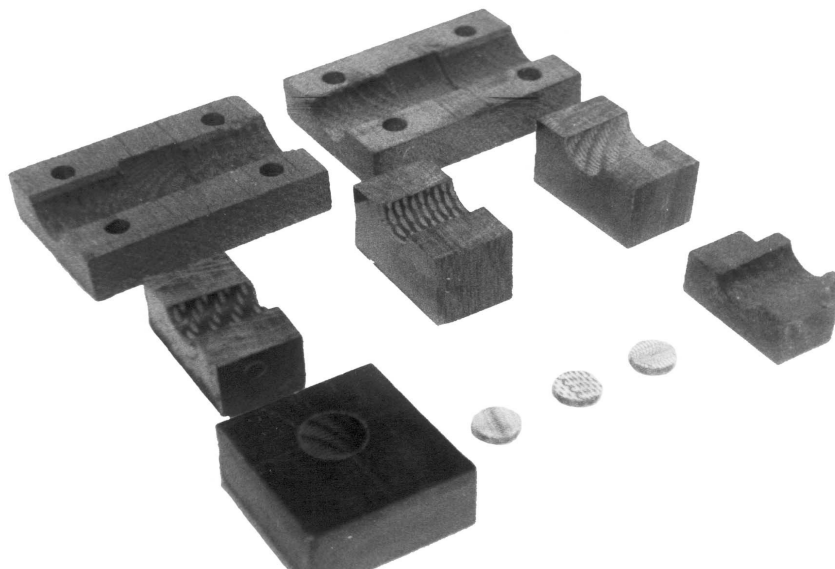


Figure 15. Sliding bearings with completely regular micro-relief and porous elliptical type relief (wood - for combine harvesters, textolite - for dyeing machines in textile industry, rubber - for shipbuilding)

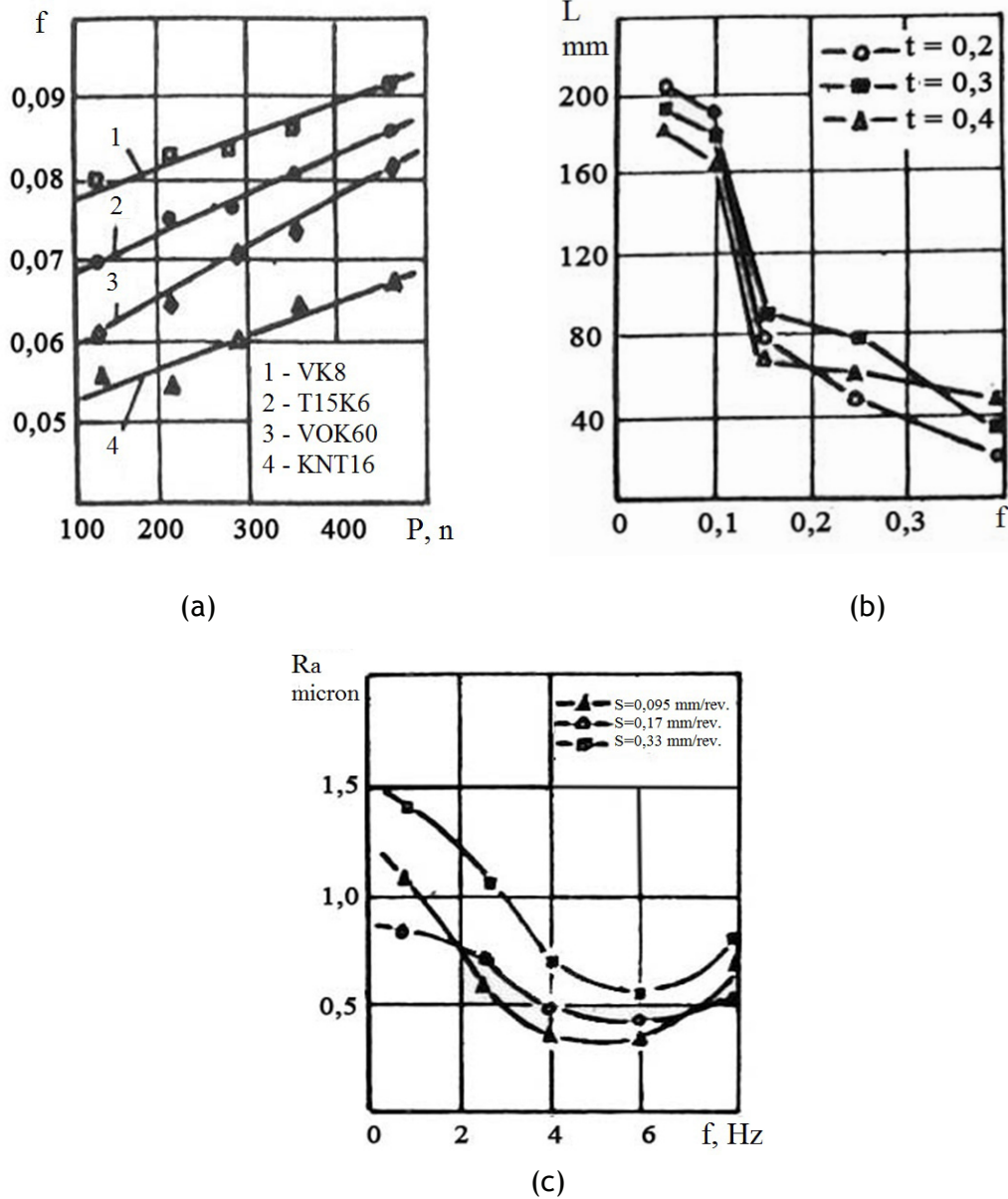


Figure 16. Effect produced by the energy-related characteristics of LTM on the surface parameters in chip breaking (a. Chip friction factor dependency, b. Chip length dependency, c. Surface roughness dependency).

Simultaneously, the dependencies of the length of the discharged chip L on the friction factor f have been discovered (Figure 16 b).

Increasing the friction factor up to the values of $f = 0.25-0.3$ decreases the length of the chip 2.5-5 times and ensures sustainable chip formation.

The study investigates the possibility to break the chip in the course of rotational turning with spindle oscillation in LTM-III. The expressions were obtained for calculating the alterations of thickness α_0 of the cutoff layer depending on the amplitude and phase frequency characteristics of LTM-III. Critical amplitude A/S_f and the area of sustain-

able chip formation have been determined theoretically for different ratios of the frequency of the workpiece rotation n and oscillation F under various modes of processing (V, S, t). Chip length and the workpiece surface roughness have been experimentally evaluated under changing oscillation parameters ($A/S_s, F_{osc}$) in LTM applying electrical and hydraulic, electrospark, mechanical and hydraulic controlling devices. The surface roughness (Figure 13 d), in the course of turning steel grade 20.40X.45 with LTM-III in oscillation mode, did not deteriorate ($R_a = 0.4-1.5$ micron); thereat, the amplitude value optimal from the perspectives of roughness has been established as $A/S_o = 4 \div 6$. Minimal chip length ($L = 20-25$ mm) has been obtained within the range of the oscillation parameters of $A/S_s = 3 \div 6, F = 6-8$ Hz. Accuracy (tolerance of the shape dimensions) of the workpiece was estimated applying the roundness charts that showed the out-of-roundness not exceeding 0.002 mm.

In LTM, the technical levitation devices (hydro-, gas-static) featuring low friction factor and high damping capacity create technological capabilities for implement fast and ultrafast workpiece processing.

LTM-III for fast wire brushing have also been developed and investigated within the range of the operation

modes as follows: $V = 2000 \div 6000$ m/min, $S_m = 100-1000$ mm/min, $t = 0.2 \div 1.0$ mm. The surface roughness obtained in the course of wire brushing steel grade 1X18H9T was 2-2.5 lower ($R = 0.5-1.25$ micron) as compared to the conventional TM; thereat, the optimum value of the density of the wire brush working surface in terms of roughness has been established within the range of $M = 62.5-87.5$ %. The wire brushing process models have been developed and used as the target functions for determining optimal structural and technological parameters of LTM to achieve the required quality of the processed surfaces.

In the course of investigating LTM, the possibilities for fast processing have been estimated based on the efficiency of the tools (Figure 17).

Thus, in the course of turning the silumin alloys to achieve the preset roughness criterion of $R_a \leq 0.16$ micron at $V = 12$ m/sec, $S = 0.05$ mm/rev, $t = 0.2$ mm the productivity was 3-4 times higher as compared to conventional TM.

From the perspectives of energy-related approach to secure the required surface quality, the study considered the possibility to apply the energy of LTM technological media to control the process of heat removal from

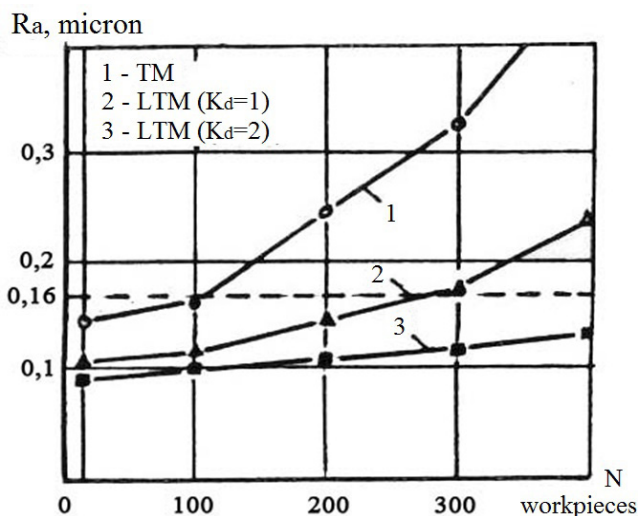


Figure 17. Estimated efficiency of LTM at fast turning of workpieces made of silumin alloys to preset roughness criterion $R_a \leq 0.16$.

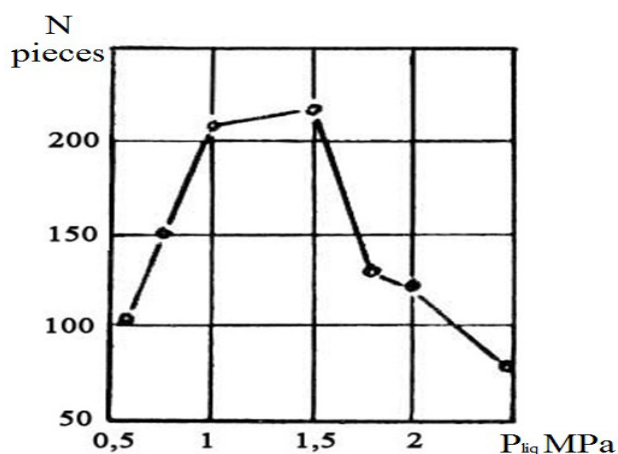


Figure 18. Effect produced by liquid pressure in headpiece of LTM -I on number of workpieces processed to preset roughness criterion $R_a \leq 0.63$ micron.

the processing area. The analysis has been carried out to investigate the effect produced by heat removal in LTM-I on the quality of the processed surface. Heat removal intensification due to the feeding the liquid coolant under pressure and with different thermal and physical properties can be estimated applying the heat emission factor α .

Heat emission factor α increases to 0.8-0.85 in the course of turning steel grade Y8, that occurs due to increasing the liquid pressure P_l in LTM-I headpiece to 0.5-2 MPa, reduces the cutting temperature and the roughness of the processed surface to the range of $R_a = 0.16-0.63$ micron. Optimal pressure $P_l = 1-1.5$ MPa (Figure 18) has been found at which the number of workpieces N processed with the preset roughness criterion of $R_a \leq 0.63$ micron was 2.1-3 times larger; thereat, the life of the cutting bits was 4-7 times longer.

The possibility to ensure the workpiece surface quality by feeding different lubricant-cooling agents to the processing area, including the agents modified with super dispersed powders (UDP) of diamond-graphite has been investigated. In the course of turning with LTM-I steel grade OXH3MΦA at cutting velocity of $V = 190 \text{ m/min}$, the comparison undertaken for six compositions of

lubricant-cooling agents showed that the minimum surface roughness value $R_a = 0.2$ micron was achieved when the lubricant-cooling agents with diamond UDP were fed. The temperature of such lubricant-cooling agents in the cutting area proved to be minimal along the cutting trajectory; the cutting process was run with minimum factor of chip shrinkage $\xi = 1.65$, and consequently, with minimal energy loss for this condition.

Implementing LTM-based technological methods, the possibility to control the dynamic processing error Δ that occurs due to the uneven flexibility of the technological system has been suggested and theoretically developed.

The experiments made it possible to establish the possibility of achieving near-zero unevenness of the technological system flexibility in the course of milling high-precision notches by way of stabilizing its value directly in the course of processing by optimizing rigidity j and damping h in hydrostatic supports of LTM-III.

Hodograph (2) of the milling cutter deflection vector (Figure 19) under optimal j and h assumes minimum value and rotation angle.

Simultaneously with controlling the process of the workpiece surface layer formation, the study also con-

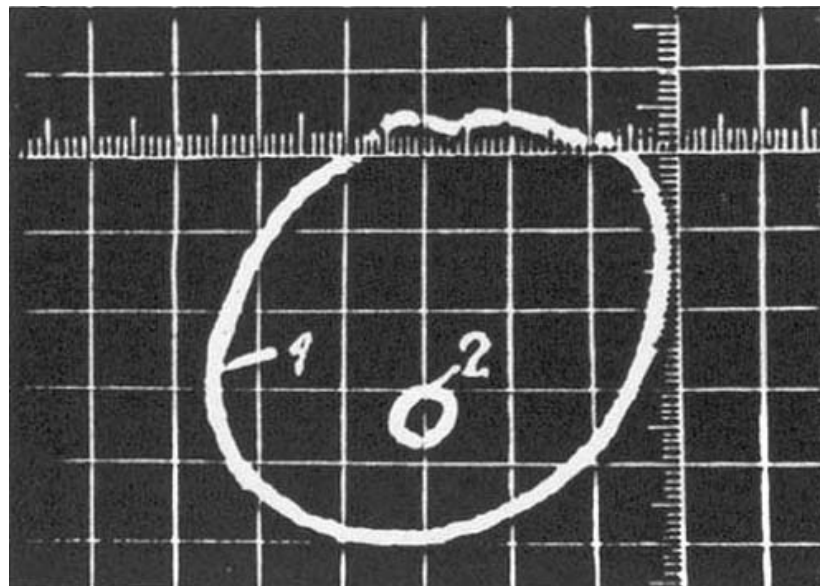


Figure 19. Hodograph of milling cutter deflection vector in notch milling (1 - TM, 2 - LTM).

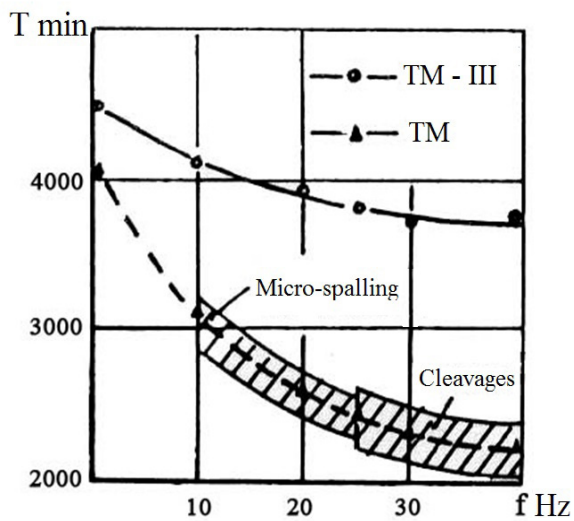


Figure 20. Dependency of service life of hard alloy T15K6 in turning steel grade IIIX15 on oscillation frequency of tool holder in LTM-III.

sidered the possibility to improve the functionality of the tools by applying levitation tool modules.

Within the framework of the experimental investigations, the vibroprotective properties of LTM have been evaluated. Figure 20 illustrates the dependencies of the service life of the rotary cutters employed by LTM-III and of those used in conventional TM on the frequency of the tool holder oscillation. The analysis shows that within the range of low oscillation frequency ($f \leq 10$ Hz) the principal wear mechanism is of abrasive mechanical nature and the service life with LTM-III is by 30-80 % better. With higher frequency (up to 40 Hz), the wear mechanism in LTM-III is almost the same; the service life is reduced just by 10-15 %, whereas with conventional TM the service life decreases by 75-180 %; there occur fatigue wear processes, small microspalling defects ($f = 10-25$ Hz) and cleavages ($f = 25-40$ Hz) at the cutting edge of the tool.

5. Conclusion

The experimental investigations presented in this study enable the conclusion that high efficiency and practicality of applying LTM for the purposes of technological quality assurance of the workpiece surface layer has been confirmed. Aggregated modular type levitation devices help do the following:

- Purposefully affect the process of forming the surface layer of the processed workpieces by controlling the characteristics of energy distribution in LTM;
- Make use of the complex effects and technological capabilities of technical levitation to control the parameters of the surface quality and to stabilize the parameters of mechanical processing;
- Narrow down the scatter of the surface quality parameters 2-3 times on average; improve the efficiency of processing by 15-30 % and improve the functionality of the tool by 30-50 %;
- Improve the quality of mechanical processing through the adaptive control of LTM based on stabilizing the energy-related characteristics and by introducing into the system the dynamic tension feedback mechanism using the changes in dynamic flexibility and in damping as regulative actions in LTM.

6. References

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