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INCREASE IN PRODUCTIVITY FOR PROFILE CNC GEAR GRINDING

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Annotation *The paper is devoted to solving an important scientific and technical problem of increasing the productivity of defect-free profile gear grinding on CNC machines on the basis of the development of information subsystems which allow adapting the elements of the technological system. For this purpose a question status analysis is performed as well as purpose and tasks of the study. Then a theoretical analysis of the profile grinding productivity on a CNC machine is given on the basis of both the gear grinding stock and specific material removal rate studying. A theorem about an equivalent rectangular profile which at the same depth of cut has the same cross-sectional area as an involute profile has is mentioned. Besides, experimental studies of the gear grinding system state parameters are carried out with the use of high-porous grinding wheels of sol-gel corundum, electrocorundum, monocorundum. Development of theoretical premises for determining the gear grinding modes and subsystems for automated designing, monitoring and grinding diagnosis were also considered.*

Keywords: *operation productivity profile gear grinding, grinding system, gear grinding modes, high-porous grinding wheel.*

In section "A question status analysis, purpose and tasks of the study" the significant amount of time spent on profile CNC gear grinding operation (from 40 up to 70%) is established. Therefore, the task of increasing the productivity of the gear grinding is actual one. Existing gear grinding methods technological possibilities are considered. It is established that the only two methods of gear grinding are the most used: discontinuous profile and continuous generating ones. The analysis of the methods of determining gear grinding stock, including ones when measuring it at the stage of adjustment of the CNC grinding machine is performed. It is established that the stock is a variable value along the periphery of the gear and is not considered as a totality of systematic and random components. That is why there is no appropriate theory for the stock determining which based on the deterministic and stochastic models that correspond to the specified components of the stock. In addition, these models could be used to withdraw the grinding wheel from the grinding gear to prevent the occurrence of thermal grinding defects. That's why with a limited number of grinding stock measurements the grinding temperature is one of the important factors which limit the productivity of the operation.

Two approaches to determining the temperature of grinding are known: phenomenological or temperature determination analytical method on the basis of the Fourier' differential heat conductivity equation solution and temperature field simulation on the basis of computer simulation by the finite element method. As a mathematical support of operation designing, monitoring and technological diagnosis subsystems for profiled grinding operations which are working in real time, the advantage has the first approach, because it requires less time to make a decision. The second approach is more labor intensive and can be used to justify the legality of the former. In this area, the analysis and classification of available analytical solutions that are adequate to thermal phenomena during tooth grinding is not carried out. These decisions should be similar to each other as for the initial and boundary conditions. There was no research on the continuity of these solutions as well as the establishment of continuity criteria and their ranges for conditions of profile grinding.

In analyzing mathematical models for determining the temperature field during grinding, a phenomenological approach to determining the grinding temperature for a three-, two-, and one-dimensional temperature field was used on the basis of a Fourier' differential heat conductivity equation. For subsystems of designing, monitoring and technological diagnostics of profile gear grinding it is necessary to find the conditions for the replacement of more complex solutions (two- and three-dimensional) of the thermophysical problem to a simpler (one-dimensional) without a significant loss of accuracy of temperature determination. To confirm the legality of these conditions, it is advisable to apply the simulation model with the help of appropriate computer programs. Besides it is necessary to describe the grinding temperature in a wide range of changes in the frequency and intensity of the heat flux pulses, ranging from the macrocycles of the reciprocating displacements of the grinding wheel to the microcycles of grinding with high porous wheels. Such an approach in the literature is not considered and of interest for choosing grinding modes by the temperature criterion and to substantiate the high porous wheel specifications for profile grinding with the aim of productivity increase.

A number of parameters are used to assess the grinding operation effectiveness at the stages of production and its preparation: Q_w in мм^3/s, Q'_w in мм^3/(s·мм), V_w in мм^3, V'_w in мм^3/мм. It is necessary to establish a connection between these parameters with the grinding temperature and the grinding wheel wear. Monitoring and gear grinding diagnosis systems analysis is made as like as information elements of the adaptive grinding technology on CNC machines, which allow to provide the final parameters of gears. On the basis of performed analysis, the aim and tasks of the scientific research are formulated.

In section "Theoretical analysis of the profile grinding productivity on a CNC machine", the methodology of scientific research is given, which includes three directions of the gear grinding system study, to wit: modeling, optimization and control. These directions characterize the investigating object as a system that has parameters: input, state, and output ones. On the basis of the theoretical-probabilistic and frequency approaches, methods of determining the gear grinding stock are developed and allow determining the stock maximum value along the gear periphery. It is established that according to the results of measurements, the stock for gear grinding contains a constant z_0 and variable Δz components. In accordance with the theoretical-probabilistic approach, the variable component Δz of the stock is considered, assuming the presence of a systematic periodic Δz_{sys} and random aperiodic component Δz_{ran} in it. The method of simulation of the stock on the basis of virtual instruments which form the signal containing the systematic and random components of the stock is proposed. The stochastic and deterministic-and-stochastic models of the stock are developed for determining the maximum stock value based on the results of its selective discrete measurements. The reduction in the number of measurements, which is the resource for increasing the productivity of the operation, must be substantiated and investigated through the two evaluation functions. The first of the functions is the sum of the squares of the differences in the readouts of the stock extreme values which is found by the limited and the maximum number of measurements. The second is the difference between the ordinal numbers of the maximum stock spaces, which are found for a limited and maximum number of measurements. The nomogram on the choice of the measurements number of the stock is developed at the CNC grinding machine adjustment stage. A number of common parameters are investigated to evaluate the process efficiency, to wit: Q_w, Q'_w, V_w, and V'_w. In the analysis of the profile grinding scheme, it can be found an analogy with the pattern of profile rectangular grinding on the amount of material removed per unit time Q_w. Consideration of this analogy allowed us to formulate and prove the theorem about an equivalent rectangular profile which at the same depth of cut t_{i+1} has the same cross-sectional area $S_{i+1} = W_{a(i+1)}\, t_{i+1}$, where $W_{a(i+1)}$ is the active profile width. A method for determining the active width $W_{a(i+1)}$ of an equivalent rectangular profile is developed. Besides the theoretical and experimental analysis made it possible to formulate and prove the stock alignment theorem, according to which the extreme values of the stock (minimum, maximum or difference between them, etc.) aligned to the left and to the right, do not depend on the location of the initial space (gap), from which the stock is measured on the two sides.

In section "Experimental studies of the gear grinding system state parameters", experimental studies of ordinary and high-porous grinding wheels are given. The influence of grinding modes on the grinding power and grinding specific energy as well as on the heat flow density with taking into account elastic deformations in surface grinding is established. In accordance with the accepted methodology of the active experiment on the analogue process (surface grinding), parameters which characterize the performance of ordinary and high-porous grinding wheels were determined. According to the results of this experiment, the advantage of high-porous wheels is determined by their performance characteristics compared with conventional wheels. Therefore, similar gear grinding wheels which are ordered and manufactured for the CNC machine Höfler RAPID 1250 are used. The actual gear grinding process with conventional and high-porous grinding wheels is experimentally tested and researched. It is established that with the same gear grinding modes, high-porous wheels (sol-gel corundum, electrocorundum, monocorundum) in comparison with the conventional electrocorundum wheels (without pores) provide better performances by the number of dressings, gear grinding power, the level of the acoustic emission signal.

The high-porous wheels surface topography was studied on the microscope УИМ-21 to confirm the possibility of the developed discontinuous grinding theory. The averaged dimensions of the grain cutting regions (l_1) and the pores (l_2) between them are found for the high-porous wheels having different specifications. The averaged parameters N (the number of cutting ledges on the wheel) and

s (the duty factor) are obtained for these wheels. It is established that these parameters correspond to the interval of reduced grinding temperatures in the obtained theoretical dependence.

In section "Development of theoretical premises for determining the gear grinding modes" it is made a study on the design of a gear grinding technological operation and a development of an appropriate automated design subsystem. To do this, an analysis of the gear grinding cycle structure on a CNC machine is performed. Elements of the cycle structure are the following: the number of stages and strokes in each of the stages, the sequence of gear spaces (gaps) machining, the sequence of measuring cycles, and the number of wheel dressings in each of the stages, etc. The automated grinding cycle includes the following steps: measuring the stock at the periphery of the gear, grinding itself, intermediate measurements of the gear parameters (length of the general norm, individual pitch deviation, total pitch deviation, radial runout, total profile deviation, tooth trace total deviation, etc.), intermediate grinding wheel dressing and gear output parameters final measurement. There are instant depths of gear grinding which determine the profile grinding temperature, namely are normal t_n and vertical t_v ones. Since in the gear grinding thermal phenomena study it is taken into account simultaneously both t_v and t_n, it is necessary to know their relation which allows to find one of these depths under the known other.

A method of calculating the instant values of the heat flux density and the temperature mean values of the profile grinding is developed, which allows determining the surface temperature in several sections of the grinding wheel involute profile by averaging the heat flux density instant calculated values over the area of these sections. It is developed a method to determine the gear grinding modes with the use of grinding specific material removal rate Q'_w which is predetermined on the rough, semi-finish, and finish stages of machining and which is related to the grinding temperature. An axial feed V_f is assigned as much as possible. Knowing the values of Q'_w and A_{spec} parameters which are determined at the stage of testing grinding wheels, it is calculated the temperature of T_H and compared with the fixed critical value of T_{KP}. If $T_H < T_{KP}$, then the defect-free depth of the grinding t_v is calculated from the equation of $Q'_w = t_v \cdot V_f$. In the opposite case, i.e. $T_H > T_{KP}$, the parameter value of Q'_w are reduced to a defect-free level.

It is established that in order to eliminate an accumulation of heat at the third stage of gear grinding with the known kind and method of lubricoolant feeding, it is possible to control the value of the heat transfer coefficient α_h, the value of the initial temperature of the lubricoolant $\varphi(\tau_C)$, gear grinding modes (t_v and V_f), and the use of idle working steps (without a set of grinding depth, i.e. $t_v = 0$).

In section "Development of subsystems of automated designing, monitoring and grinding diagnosis" the theoretical premises for the development of embedded designing, monitoring and grinding diagnosis systems as well as methods which take into account the individual features of gears during process control are presented. Designing, monitoring and technological diagnostics subsystems structural schemes are developed. In addition to the parameters Q'_w and V'_w it is proposed to use the specific grinding energy A_{spec} and grinding temperature T_H, since they determine the quality of the surface layer of ground parts and are used in the mathematical software of a developed subsystem of automated design.