Improvement of the quality of designed cylindrical grinding cycle with traverse feeding based on the use of digital twin options

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Abstract. In practice of automated mechanical adjustment of cutting conditions for internal grinding operations at the CNC Machine, is carried out on many of control parameters (ccutting regimes, characteristics and geometric parameters of the wheels, etc.) and absence of effective methods of treatment and design of cycles (a normative reference, methods - engineering techniques and Automated Design Systems). All this leads to the fact that cycles for CNC machines are selected the same as for manually processing of a number of workpieces in a single cycle. In order to meet the accuracy requirements and quality design optimized for manually initially cycles, which have low regime's parameters. Therefore, the cycles obtained by the method of selection are not high-performance and they do not provide minimal processing time. This article discusses the use of a digital twin, which performs virtual testing for a specified grinding cycle, on the possibility of spoilage appearance at some combination of variable technological factors to improve the quality and reliability of control programs for CNC machines. Virtual testing of the digital twin is carried out by modelling the process of allowance removal for the whole processing cycle of the workpiece batch with different variables of technological factors, changing in the specified ranges of variation.

1 Introduction

To improve the quality, reliability and preparation of control programs for CNC machines, we proposed to use a digital twin (DT), which performs virtual test of a given grinding operation cycle on the possibility of defective products appearance during production with some combination of technological factors. Virtual testing of digital twin (DT) is carried out by modeling the allowance removal which was formed in the course of grinding process throughout the cycle parts batch processing at various combinations of the variable technological processes and factors.

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According to the results of a review of virtual modelling after each test, a forecast about accuracy of the treatment applied and the quality of the treated surface at the end of the grinding cycle is made. If simulation results give spoilage (for example, the processing accuracy), then the values of the variable factors giving spoilage are fixed.

Values of variable technological factors leading to the appearance of the spoilage are specified in the DT report based on the simulation results. When the value of any quality indicator is outside its allowable range, the cycle of feed must be corrected considering the identified conditions of the spoilage appearance.

For the designing of optimal grinding cycle, using estimation of an optimal cycle path for radial feed change, a dynamic programming method (DPM) is proposed. The same method is applied to a classic transportation problem which has a path network with intermediate stations and that needs optimal transport movement trajectory to be found.

The methodology of synthesis application of a digital twin technology and the DPM technology at the stage of preparation of control programs for CNC machines allows guaranteeing the maximal grinding process efficiency at variable treatment conditions that may change within specified limits.

2 State of the question and degree of scientific study of the question in this field

Designing theory of the optimal grinding cycle for CNC machines is reviewed in many works, for example Malkin, S., Guo, C. [1], Cahill, M.J., Bechtold, M.J., Fess, E., Wolfs, F.L., Bechtold, R. [2], Lur'e, G.B. [3], Dong, S., Danai, K., Malkin, S., Deshunukh, A. [4], Amitay, G., Malkin, S., Koren, Y. [5], Phan, A.M., Summers, M.P., Parmigiani, J.P. [6], Pereverzev, P.P., Akintseva, A.V. [7-8] and others.

However, none of these works review improving the design quality of the optimal grinding cycles considering their stability under variable processing conditions, existing in the real cylindrical grinding operations on CNC machines.

Therefore, we can conclude that, despite the numerous studies and enormous effort in theoretical and practical basis in the design of optimal cycles of cylindrical grinding, the problem of the optimal grinding cycles designing is not solved until now. Solution of this problem could provide the maximum performance operation and stability of meeting the drawing requirements (accuracy and quality) under any, even unfavourable, combinations of the variable grinding conditions.

3 Synthesis of digital twin DT and dynamic programming technologies for grinding cycle testing to check the resistance to variable technological factors

Treatment of workpieces batch during cylindrical grinding operations, executed on CNC machine, is performed with automated cycle of radial feed change, specified in control programming.

Grinding cycle parameters are constant at any variable condition of workpieces batch treatment: abrasive wheel grains blunting, allowance fluctuation, fluctuation of initial radial workpiece runout, grinding wheel wearing process and cutting speed decrease, variable rigidity of a technological system in different sections of a treated surface, fluctuations of physical and mechanical properties of workpiece material, fluctuations of grinding wheel characteristics, inaccuracy of active control device, wheel stability between truing.

Each variable parameter changes in a certain variation range which can be defined with three values: minimal, average and maximal.

During workpieces batch treatment any combination of variable factors values is possible. The number of variable factors combinations - even when each factor has three values - might reach several hundred.

However, a grinding cycle remains unchanged at any aggregate combination of variable factors that stipulates the fluctuation of treatment accuracy and other quality parameters of a grinded surface.

At the same time, during the optimal grinding cycle designing the path check for processing limits is held in case of determined conditions of grinding without considering grinding conditions changes at different values of variable technological factors.

Due to the fact that the number of various combinations of variable factors is beyond count, it is impossible to check the limits of the objective function in the entire array of variable factors combinations. The reason of that is an inadmissible amount of time needed for optimization that will be implied for optimal grinding cycle designing along with excessive complication of cycle optimization system.

For that reason, an optimal grinding cycle, which is designed on the basis of averaged determined conditions of grinding cycle, has relatively low reliability and resistance to the influence of variable technological factors on treatment accuracy and provision of other quality parameters.

Therefore, the method for optimal grinding cycle that is described above does not consider unforeseen situations related to unstable conditions of grinding, abrasive wheel grains blunting, allowance or initial radial runout fluctuations of the workpiece, etc. that leads to spoilage during processing.

For the design of the optimal grinding cycle, resistant to the aggregate impact of various variables technological factors, a synthesis of the grinding cycle diagnostics system for the resistance and optimal cycle designing system is needed.

Approach to developing a diagnostic system for the stability analysis of the grinding cycle for the combined effect of the constantly changing variables, arising while processing a batch of parts, the concept of «digital twin» (DT) is applied.

According to this concept, a system model DT is designed. DT, based on virtual testing of the grinding cycle intended for:

1) prevention of spoilage and its reasons in the process of cylindrical grinding;

2) increase the reliability and resistance of the grinding cycle to the aggregate influence of variable factors;

3) providing full automation of the design for control program at the stage of calculation and programming of cutting conditions;

4) forecasting the fluctuation of the accuracy, roughness, HRC hardness of the treated surface after processing a batch of parts;

5) fixing of variable factors array leading to the conditions of each spoilage appearance;

6) formation the array of the objective function limits with variable grinding conditions for the optimization cycle system;

7) automatic transfer of array of the objective function limits with variable grinding conditions to the optimization cycle system;

8) automatic loading of the tested cycle into the diagnostic system;

9) automatic completion of the grinding cycle diagnostics;

The developed system «DT-CicleStab» provides synthesis of the diagnostic and optimization systems according to the following algorithm (Fig. 1):

– the first version of the optimal grinding cycle is designed on the basis of the average constant grinding conditions with verification of restrictions under these conditions;

– the optimal grinding cycle is transferred to the system of the cycle diagnosis;

– combinations array of variable factors are generated;

– diagnosis of the optimum grinding cycle is performed for all variants specified of combinations array of the variable factors;

– during diagnostics, an optimal cycle is tested by using a grinding process modeling during the entire treatment cycle with hundreds of options of various variables technological factors combinations (formed in step 3 of the algorithm), that change within specified ranges of their variability. After each testing calculated values of treatment accuracy, HRC surface roughness and other specified quality parameters are evaluated;

– all types of spoilage and the conditions of its appearance are revealed. If there is no spoilage, then follow the point 9 of the algorithm;

– formation of the additional restrictions array on the basis of the revealed conditions of the spoilage appearance;

– transfer additional restrictions of the objective function to the system of the optimal grinding cycle designing;

– optimization of the grinding cycle with additional array of the objective function restrictions. Follow the point 2 of the algorithm;

– forming report and documentation for designing an optimal grinding cycle;

– transfer data for the optimal grinding cycle to the designing system of the control program for the CNC machine.

Thus, a system for designing of optimal cycles with improved reliability and resistance to variable grinding conditions has been developed.

3 Conclusion

1) Developed methodology for designing of optimal grinding cycles, resistant to variable treatment conditions, is based on a wide-range analytical model of allowance removal and synthesis of the system of optimal grinding cycle with diagnostic system of resistance and reliability of a grinding cycle at variable conditions of workpieces batch treatment.

2) The practical result of the optimization is the increase of a level of automation designing of control software for CNC machines that allows to calculate the optimal values for radial feed at all steps of a cycle, optimal distribution of removed allowance at the steps of a cycle that would guarantee the minimal main time of a grinding cycle and lower the risks of execution of specified requirements to accuracy and quality of the treated surface.

3) The obtained model of allowance removal is a wide-range in terms of variability of technological factors. The model has an analytical character due to the fact that it was obtained on the basis of mathematical interrelation between a radius size of a treated surface and actual feeds with analytical model of cutting force, elaborated on the basis of fundamental mechanics conformity of cutting process and the theory of plastic deformation of metal in a cutting area and which makes a connection with major technological factors, which are:

– physical and mechanical properties of a grinded metal (stress intensity);

– geometrical parameters of the contact area of a wheel and a workpiece (actual speed of feed, diameters of a workpiece and a wheel, rotational speed of a workpiece, width of a workpiece treated area);

– elastic properties of the technological system (elastic deformation and compliance of the technological system);

– characteristic of a grinding wheel and the grade of wheel grains blunting.

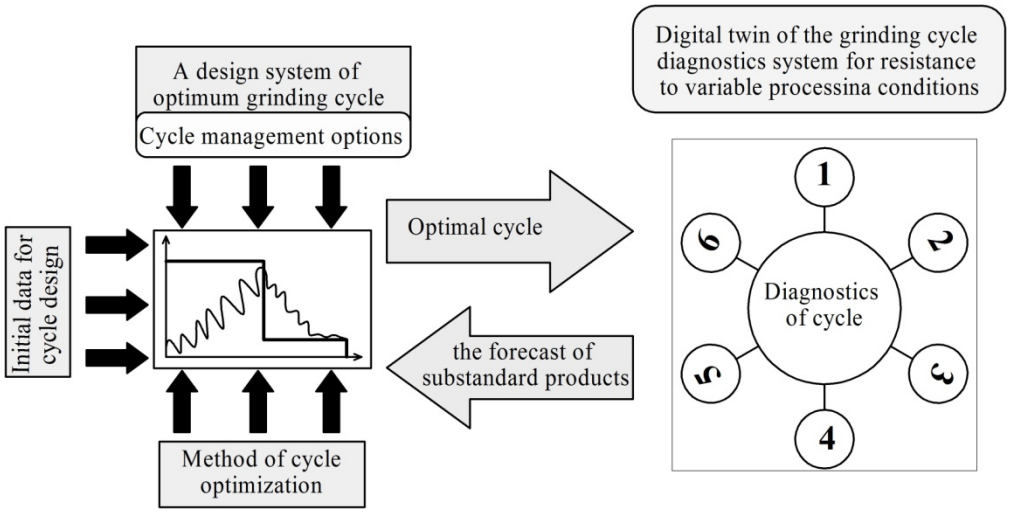

Fig. 1. Scheme of interaction of the cycle optimization system with digital twin (DT) to testing cycle: 1 – prevention of substandard products which do not meet quality requirements; 2 – improving the reliability of the grinding cycle; 3 – prediction of accuracy and quality of processing; 4 – formation of constraints in variable conditions; 5 – specification and generation of variable grinding conditions; 6 – cycle testing.

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