Designing high-speed CNC-operations

A Kh Nurkenov, V I Guzeev, P G Mazein and I P Deryabin
South Ural State University, 76 Lenin prospect, Chelyabinsk, Russia
E-mail: nurkenovak@susu.ru

Abstract. The research considers the technique of cycle's parameters calculation for high-speed operations on CNC machines. The methods of calculating the technological limits are developed to ensure the accuracy and surface quality requirements with regard to technological capabilities of the grinding's equipment and tools. It was determined that the performance of the designed cycle directly depends on the technological system stiffness and number of cycle steps depends on the stiffness of the technological system. The technique is invariant and works either when all the limits exist or some of them. Consequently, the calculation of limits will be performed in dependence on the design environment for each specific machining conditions.

1. Introduction
The aim of the chapter is researching and improvement High-Speed CNC-machine cycle design methodology. In this case in factory area always have few problems like:
1. Quality of High-Speed CNC-machine cycle depend on operator and engineer qualification.
2. Productivity of High-Speed CNC-machine cycle depend on tools manual book for cutting modes from tools developer.
3. Adaptive and learning mode for High-Speed CNC-machine use only same little discreet area from few researching work.

For solutions this few problems authors addressed the following issues: High-Speed CNC-machine system stiffness; cycle's parameters calculation for high-speed operations on CNC machines; application method in manufacturing area (factory parts using)

2. Stiffness researching for technological system of High-Speed CNC-machine
Plunge grinding cycle may be designed on the basis of the rigidity of the machine tool’s technological system, determined in tests. Cycles are designed by the proposed method, and an algorithm is formulated for the design of the individual stages within the grinding cycle.

Grinding is the main finishing method. The productivity of grinding depends on the parameters of the grinding cycle. Historically, the design of grinding cycles has passed through the following stages: design on the basis of production experience [1–3]; design on the basis of standard data [4]; and design by simulation on the basis of the experimental and calculated parameters of the machine tool’s technological system. The design methods involve calculation of model parameters of the machine tool’s technological system and determination of the stages in the grinding process prior to machining. In turn, the capabilities of current numerically controlled machine tools permit efficient machining at the level of smart control of the technological system [5]. The cycle is designed on the basis of the dynamic rigidity of the machine tool’s technological system, which differs from the static rigidity and
depends on the machining conditions of the specific part [6]. Thus, we need to optimize the design of the grinding cycle on the basis of the actual dynamic rigidity of the technological system.

The corresponding optimization procedure is as follows:

1. A set of diameters is formed by recording the signal with an active monitoring instrument when the part to be machined (the blank) is turned without radial supply of the grinding wheel. On the basis of the results, the initial wobble \( \delta \) of the blank is estimated and taken into account in subsequent design of the grinding cycle.

2. A set of diameters of the blank is formed by means of the active monitoring instrument as a result of preliminary removal of part of the margin (e.g., figure 1). Where measurements by the active monitoring instrument (AMI): \( S_{\text{rad}} \), radial supply of the grinding wheel, mm/rev; \( V_k \), cutting speed, m/s; \( V_{az} \), azimuthal speed of the blank, m/s; \( Y \), elastic displacement in the technological system, mm; \( D_{\text{max}} \), \( D_{\text{min}} \), maximum and minimum recorded diameters of the blank, mm; \( P_{\text{ac}} \), actual allowance removed, mm; \( P_{\text{ca}} \), calculated allowance, mm; \( D_1 \), \( D_2 \), specified and actual diameters, mm; \( \delta \), Range between \( D_{\text{max}} \) and \( D_{\text{min}} \), mm.

![Figure 1. Measurements by the active monitoring instrument.](image)

3. On the basis of the results, the actual margin \( P_{\text{ac}} \) (allowance) is compared with the calculated margin \( P_{\text{ca}} \). The difference between the calculated margin \( A_{\text{ca}} \) and the actual margin \( P_{\text{ac}} \) determines the elastic strain \( Y \) in the machine tool’s technological system.

4. The radial component \( P_y \) of the cutting force, N [7].

5. In result we may calculate the rigidity of the technological system, N/m [8]

Thus, in the design of the grinding cycle, the specified initial information consists of the actual rigidity of the technological system and the error (wobble) of the blank, which is determined on the basis of test removal of some of the margin. In specifying the cutting conditions for each stage of the grinding cycle, we must take account of constraints in terms of the maximum cutting speed; the power of the primary drive; the crumbling of the grinding wheel; and the product quality.

In the roughing phase of the cycle, most of the margin is removed from the blank. With increase in supply of the grinding chuck, the scorching depth increases. Therefore, the following options are possible in the design of the grinding cycle.

1. Grinding of the margin with a supply that prevents scorching.
2. Grinding of the margin with a supply that permits scorching.
Thus, the first approach ensures the required product quality but reduces the productivity. The second approach results in a quicker process but a finishing stage is then required to remove the defect layer. In the present case, the infeed supply of the grinding chuck is adopted as the control factor. Therefore, the second option entails control of the scorching depth $h$.

On the basis of the set of possible grinding cycles, we calculate the technological constraints [7]. Finally, we select the optimal cycle, meeting the design requirements in the minimum machining time. Considering the initial working conditions as the technological limits allows refinement of radial feed when designing high-speed operation. The high-speed operations include CNC cylindrical plunge grinding. Cutting speed can be as high as 150-200 m/s when using the special grinding wheels. It is also necessary to take into account the requirements for accuracy, workpiece surface condition, and machine's capabilities. To satisfy the requirements, the paper suggests considering a number of limitations on the grinding wheel radial feed when designing a grinding sequence [10-20].

3. The effect of the rigidity of the process system on the performance of high-speed operation

To assess the effect of the rigidity of the technological system on the performance of high-speed operation, calculations were made in the design module of high-speed operations on CNC machines for intervals of rigidity from $1.6\cdot10^6$ to $6\cdot10^6$ H/m. The results obtained are presented in Figure 2. It can be seen from the figure that an increase in the rigidity of the technological system directly correlates with a decrease in processing time (see figure 2a). However, the processing performance, in case the nominal value is taken as the maximum estimated cycle time of 55.6 s as 100%, shows regression with respect to the previous reduction from 134 to 109% (see figure 2b).

![Figure 2](image2.png)

**Figure 2.** Graph of the processing time on the rigidity of the technological system:
  a) dependence "stiffness - time"; b) dependence "stiffness - performance".

If we take into account the rigidity of the technological system stiffness as a complex parameter machine-workpiece-tool, then determining the effect of each element of the system on processing performance will allow you to discretely rank the importance of these elements of the system. Therefore, to estimate the effect of the workability parameter of the workpiece under constant processing conditions, design grinding cycles are also formed (see table 1, figure 3).
Figure 3. Graph of processing time from a group of machinability:

(a) the dependence of the “material handling group - time”; (b) the dependence of the "machinability group of the material - performance".

Table 1. Groups machinability.

| Group number | Stress intensity, \(10^7, \text{H/m}^2\) | Grades of materials                              |
|--------------|-------------------------------------------|--------------------------------------------------|
|              | \(\sigma_i\)                              | (representatives of the group)                    |
| 1            | 214                                       | 18XHBA, XBT, 30XГСНА, 30ГТТ, У10, 35ХМ, 40ХС, 65Г, 5ХНС |
| 2            | 189                                       | 20, 12ХН3А, 20XН3А, ШXIX 15, 18X2Н4BA, 38X2IOА, ВЧ50-1 |
| 3            | 222                                       | 12X13, 20X13, 12X4, 12X18, X17H2, 12X18Г10Т, XH35ВТ |
| 4            | 254                                       | XH77ТЮ, X20H80Т3, XH56ВМТЮ, ВТЛ, ВТ1-2, ВТ5, ВТ16    |
| 5            | 292                                       | P18, P12, P6M3, P6M5                               |
| 6            | 274                                       | P9, P18Ф2, P14Ф4, P9Ф4, P9К5, P18K5Ф2, P9М4К8, P6М5К5 |
| 7            | 231                                       | СЧ12-28, СЧ18-36, СЧ38-60, КЧ30-6, КЧ37-12, КЧ56-4, АЧ-1, АЧ-3, АКЧ-1, АКЧ-2, БР.ОЦ10-2, БР.ОС5-25 |

It can be seen from the figure that an increase in stress intensity in accordance with the group of machinability of a material directly correlates with a decrease in processing time (see Fig. 3a). At the same time, the processing performance, in case the nominal value is taken as the maximum estimated cycle time of 32.4 s as 100%, shows the fluctuation of the processing cycle performance relative to the previous reduction from 114 to 104% (see Fig. 3b). What shows the trend of increasing processing performance with increasing stress intensity in accordance with the group of workability of materials.

4. Conclusion
The methods of calculating the technological limits are developed to ensure the accuracy and surface quality requirements with regard to technological capabilities of the equipment and tools. The technique is invariant and works either when all the limits exist or some of them. Consequently, the calculation of limits will be performed in dependence on the design environment for each specific machining conditions. On the basis research, we conclude the following:

1. If the grinding cycle is designed on the basis of test estimates of the technological system’s rigidity, the probabilistic aspects of machining may be taken into account.
2. The proposed design method permits optimization of the grinding conditions in the light of the calculated and technological constraints, with minimum cycle duration.
3. In design on the basis of the dynamic model of the forces between the wheel and the blank, the course of the technological process may be assessed. This provides a flexible instrument for the creation of a set of plunge grinding technologies for standard parts.
4. In the final stage of the grinding cycle, machining may be based on control of the tension in the technological system if the remaining margin is very small.
5. It is possible to draw a conclusion on the correlation of the technological rigidity, the group of machinability and the productivity of the processing.

The use of tools for optimization and automation of calculations allows you to move to the digitalization of high-speed processing with the possibility of its binding to the digital twin of the product. Based on this, it becomes possible, using the developed methodology and its implementation in the processing cycle calculation module, to formulate recommendations for designing high-speed operations. That shows the relevance of the solutions proposed above, both at the stage of technological preparation of production and at the stage of optimization of the parameters of the digital twin of the product/technology.

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