Experimental study of double-sided face grinding machine tool

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Abstract. The work considers the methodology of experimental studies of double-sided face grinding machines on the criterion of heat stability. The proposed methodology includes: procedure of grinding process simulation; procedure of temperature measurement; procedure of determining the mutual angular position of the grinding wheels due to thermal deformations; procedure of machining error measurement. The described techniques allow you to fine-tune the machine under production conditions. Preliminary full-scale test of a double-sided face grinding machine showed that excess temperatures were distributed nonuniformly over the elements of the load-bearing structure of the machine tool when grinding an industrial batch of cylindrical rollers. When idling the end face of the spindle headstocks and bed had the highest excess temperature. When grinding the surface of the machine units, located in the immediate vicinity of the grinding zone, had the highest temperature. The experiments carried out confirmed the coordination of the nature of the change in excess temperatures at characteristic points and cutting coolant when simulating the grinding process on a machine with the corresponding experimental data obtained on a working machine.

1. Introduction
According to various estimates, the geometric error of the machined parts due to thermal deformation of the elements of machine load-bearing structure is not less than 50 % of the total machining errors [1-5]. Currently, there are two alternative points of view on the efficiency of thermal stability of machine tools [6]. In accordance with the first point of view, a detailed study of design solutions is carried out, based on the most detailed mathematical models, taking into account many factors and using complex mathematical models [7-11]. According to another point of view, the thermal stability of machine tools is effectively provided through the implementation of thermal error compensation technologies [12-14].

At the design stage for the machine tools of the face grinding group, the determination of temperature deformations is the most important. This allows the following: to assess the quality of structures according to the criterion of machining accuracy; give recommendations for improving temperature characteristics; choose the most rational design that meets the requirements for machining accuracy.

Currently, face grinding machines are used mainly in the bearing industry.

To a large extent, the performance indicators of bearings are determined by the accuracy of the manufacture of rolling elements. For cylindrical rollers, the ends that are machined on double-sided face grinding machines are of decisive importance.

The requirements for precision machining of the ends of cylindrical rollers are set by such indicators as: the accuracy of the size along the length the permissible error of the geometric shape (convexity of
the end face) and end-face runout. The improvement of the first indicator is mainly due to the improvement of the system of automatic adjustment of grinding wheels to a given size when grinding a batch of parts. Among the other two indicators, the main indicator, based on the functional purpose of the end surfaces (the end serves as the technological base for machining a cylindrical surface on a centerless grinding machine), is the face runout, which limits the deviation from the perpendicularity of the ends and the rolling surface. In this regard, the end-face runout of cylindrical rollers is accepted as the main characteristic of accuracy. Tolerances of end-face runout of cylindrical rollers is constantly rising. According to the current standard, the first and second degrees of machining accuracy are provided for a cylindrical roller with a diameter of 18 mm. Machining of parts on face grinding machines is associated with the release of a significant amount of heat, which has a noticeable effect on the machining accuracy [15, 16]. Since, as a result of thermal deformations, the relative position of the working ends of two abrasive wheels’ changes in space, it is possible, bringing their displacements to three coordinate axes, to consider the resulting machining error in each of the three directions. Linear displacements (along the Y-axis, figure 1) are compensated by the wear of the grinding wheels and the magnitude of their sub-adjustment during grinding. Deviations of the wheels in the XОY plane (along the direction of movement of the blanks) practically do not affect the quality of machining. The third direction of the thermal displacements of the grinding wheels is realized in the YОZ plane passing through the axis of the spindles perpendicular to the machine bed. The magnitude of these displacements is commensurate with the magnitude of the non-parallelism of the end faces of the grinding wheels. Therefore, they have a significant impact on the quality of machining and are also a criterion for assessing the quality of the machine tool design.

![Figure 1. The scheme of distribution of heat flows in double-sided face grinding machine: Q_e – the heat flow from the engine, Q_b – the heat flow from the bearing, Q_p – the heat flow from the pulleys, Q_c – part of the heat removed of the coolant from the cutting zone, Q_r – part of the heat removed by the rollers from the cutting zone, Q_m – part of the heat passing into the machine from the cutting zone, Q_Σ – heat in the cutting zone; C – coolant.](image)

A typical representative of the range of double-sided face grinding machines with horizontal spindles is the machine tool 3A343ADF2. This machine tool is designed for grinding bearings rollers, in which machining is carried out with increased grinding powers and, as a result, an increase in the machining
error during the machine tool operation. All the main machine units are unified with other representatives of this range of machine tools. This allowed the use of research results for all models of machines of this range.

In the development of experimental research methods it was necessary to solve the following technical problems:

- to evaluate the temperature change at the characteristic points of the machine and the temperature change of the coolant during operation of the machine tool;
- to measure the mutual angular position of the grinding wheels during machine operation.

To solve these problems, it is necessary to develop the following:

- the procedure of grinding process simulation;
- the procedure of temperature measurement;
- the procedure of determining the mutual angular position of the grinding wheels due to thermal deformations;
- the procedure of machining error measurement.

### 2. Methods and results

#### 2.1. The procedure of grinding process simulation

During the operation of the machine tool temperature deformation measurement is difficult. Therefore, researchers use a procedure of grinding process simulation. Grinding process simulation at a non-working machine should lead to similar heat generation for the working machine under load. In this case, the formed temperature field of the machine tool and the mutual angular position of the grinding wheels will be close to those that occur when the machine is under load.

Temperature mode of the machine tool is quite complicated and it is in a wide thermal and time ranges. The initial heating of the machine tool is provided by its heating from the electric motor and drive pulley, as well as the heat generated by the bearings. During grinding, the main heat load moves to the center of the machine, to the cutting zone, respectively, the thermal deformation of the machine tool changes not only its size, but also its direction.

The simulation of the commencement of operation was carried out when the machine tool is idling with the supply of coolant from the individual tank with the following characteristics:

- tank volume is 1.2 m³;
- heat-emitting surface area is 10 m²;
- heat transfer coefficient of the tank is 0.93 kW/m²°degree;
- coolant is located at three levels above each other;
- coolant is supplied to the grinding zone by centrifugal pump;
- pump capacity is 90 l/min;
- cleaning is carried out by a magnetic separator with a capacity equal to 0.2 m³/min.

3% aqueous solution of emulsol was used as coolant.

During the operation of the machine tool, the coolant is heated in the cutting zone. Therefore, the coolant heating system was designed to simulate the grinding process. For this purpose, the corresponding grinding power was simulated in an individual cooling tank using thermoelectric heaters. Thus, the heating of coolant heaters with a capacity of 18 kW corresponded to a working capacity of 12 kW. Coolant heating in the tank was carried out using heaters with a capacity of 18 and 6 kW. Such power values are typical for average grinding conditions of rollers with diameters of 18 and 12 mm.
2.2. The procedure of temperature measurement
Temperature measurements were carried out using copper-constantan thermocouples. The choice of the type of thermocouple was determined by the value of thermopower (electromoving force) of the thermocouple in the operating temperature range and the steepness of the characteristic, providing its sufficient sensitivity. A galvanometer was used as a recording equipment.

To reduce the measurement error, each thermocouple was calibrated with the instrument. The junction of each thermocouple was placed in a thermostat with cold water. As it was heating, the temperature measured using a mercury thermometer with measurement limits from 0 to 100 °C was recorded every 5°C. The galvanometer readings were recorded in parallel.

Temperature measurement was carried out at individual points of the machine tool. For this, the junction of each thermocouple was placed in a drilled hole (depth 0.5 wall thickness) on the surface of the machine tool, filled with oil. Cold ends of thermocouples were insulated with PVC (polyvinylchloride) tubes. The temperature was measured at the following points (figure 2):

- at the outer end faces of both headstocks (points 1, 2, 11 and 12);
- on the front sidewall of each headstock, near the fencing of the grinding zone (points 5, 6, 15 and 16);
- on the back sidewall of each headstock, near the fencing of the grinding zone (points 8, 9, 18 and 19);
- at the end faces of the bed, in its upper part (points 3 and 13);
- on the front and rear sidewalls of the bed, near the fence of the grinding zone (points 7, 17, 10 and 20);
- in the lower part on the bed, on its end faces and in the middle (points 4, 14 and 23);
- under the covers of the pulleys (points 21 and 22).

Figure 2. The layout of the control points of measurement temperatures (reducer and feed disc not showing).

A mercury thermometer (measuring range from 0 to 100°C) was used to measure the temperature of the coolant leaving the grinding zone and the ambient temperature. The readings were recorded every
0.5 hour during 7 hours of operation of the machine tool. The experiments were repeated up to three times to improve the reliability of the measurement results. According to the results of measurements, functional dependences of the type were determined

\[ \Delta T_e = f(\tau) \]  

where \( \Delta T_e = T_m - T_a \) – excessive temperature, degrees;
\( T_m \) – temperature measurement at the point, degrees;
\( T_a \) – ambient temperature, degrees;
\( \tau \) – operating time of the machine tool, hour.

2.3. The procedure of determining the mutual angular position of the grinding wheels due to thermal deformations

Analysis of the experimental data showed that only thermal displacements in the plane of YOZ had a significant impact on the accuracy of machining. This was due to the fact that the value of these displacements was commensurate with the magnitude of the non-parallelism of the end faces of the grinding wheels. Two conditions were taken into account in the development of the procedure. The first condition was that the measurement of the thermal displacements of the grinding wheels must be carried out during the rotation of the spindles. This was due to the high sensitivity of the machine structure to the inevitable changes in the temperature field. Since in comparison with the continuous operation of the machine, even a brief stop of the spindles led to a change in their spatial relationship. To implement the conditions, the principle of pneumatic stop was used, the design chart of which is shown in figure 3.

![Figure 3](image-url)

**Figure 3.** The design chart of the position measurement of the flanges of the spindles: 1 – bed, 2 – spindle headstock, 3 – feed reducer, 4 – lever, 5 – pneumatic nozzle, 6 – bellows sensor, \( d_w \) – diameter of the grinding wheel, \( d_f \) – diameter of the flange.

Lever 4 was fixed on the axis of the feed reducer. At the end of the lever, two pneumatic nozzles 5 were located each for its grinding wheel. The end faces of the spindle flanges served the measuring surfaces. This allowed to raise the accuracy of the reading compared to the data obtained at the end faces of the grinding wheels. Changing the position of the spindle flange relative to the feed plane was determined by two diametrically located points corresponding to the two positions of the lever 1.

The measurement was performed as follows. The lever was set to position I, and the spindle flange was fed to the nozzle until the arrow of the bellows sensor 6 occupied a certain position, taken for "0".
On the reference device of the machine, showing the value of the axial movement of the spindle quill, the initial value of "0" was also fixed. Then the measuring lever with the nozzle was transferred to position II by moving the spindle quill forward or backward, and the bellows sensor arrow was set to "0". The values of the spindle quill movements were reflected on the numerical control console, which indicated how much the position at point II differed from the position at point I, taken as zero. A similar measurement was carried out on the flange of the second spindle. The use of the pneumatic stop principle made it possible to measure the position of the spindle flanges without stopping them, since the measuring nozzle did not contact the rotating spindle.

The position of the spindle flanges was measured in parallel with the temperature measurement. During the first two hours, measurements were taken every 30 minutes, and then measurements were taken after each hour of operation of the machine tool.

The continuous operation time of the machine tool was 7 hours. Each experiment was repeated up to three times to improve the reliability of the results. The obtained deviations of the spindle flanges \( \Delta_e \) were recalculated on the diameter of the grinding wheel and the functional dependences were determined as

\[
\Delta_e = f(\tau)
\]

(2)

\[
\Delta_e = f(t_c)
\]

(3)

where \( \tau \) – machine tool operating time, hour.;

\( t_c \) – the temperature of the coolant at the outlet of the machine tool, degrees.

2.4. The procedure of machining error measurement

As the main characteristic of the machining accuracy, the axial run-out of the roller was adopted. Measurement of the axial run-out of the roller was carried out according to the following procedure: the roller was installed in a prism; with the help of a rubber roller, the machined roller was rotated and pressed against the stop at its axis; the tip of the measuring head was installed on the outer radius of the roller end face; the maximum difference between the readings of the head per revolution of the roller characterized its run-out (the price of division of the measuring head is 0.5 \( \mu m \)).

Taking into account the experience of using double-sided face grinding machines, abrasive wheels and the following conditions were selected:

- the coolant supply method was implemented by spraying through nozzles installed on top of the grinding wheels and through holes in the spindles;
- wear compensation of the grinding wheels was carried out in automatic mode, and the amount of compensation was 2 \( \mu m \);
- the machining modes were set as follows: the feed was regulated by a given capacity of 10000 PCS/hour, which corresponded to the feed rate of products equal to 5.3 m/min; the machining allowance was selected in the range of 0.05-0.07 mm; the speed of the grinding wheels was 900 rpm, this corresponded to the cutting speed at the periphery of the grinding wheel equal to 28 m/s;
- when setting up the machine tool, the mutual position of the grinding wheels was estimated in two planes as follows: in the vertical plane, the distance between the upper edges of the grinding wheels was 0.052 mm; in the horizontal plane, the distance between the edges of the grinding wheels at the entrance to the machining zone was 0.4 mm.

Grinding of cylindrical short rollers with a diameter of 18 mm was carried out on a double-sided face grinding machine 3A343ADF2.
Grinding roller end faces was performed after determining the rational modes and optimal setting of the machine tool. Three control batches of rollers of 3000 pieces each were machined.

Quality control of grinding was carried out according to the sample as follows: 5 machined rollers were selected for measurement every 10 minutes during the entire grinding time (3 hours of machine operation). The temperature of the characteristic points of the machine tool and the coolant temperature were measured simultaneously at the time of selection of rollers. Grinding power was evaluated according to the developed methods. Power measurements were carried out every 5 minutes of the machine. The results of power measurements showed that the grinding power ranged from 7 to 12 kW, and the idling power was 5.5 kW.

Processing of the results of grinding quality control showed that the dispersion of the length of the rollers ranged up to 11 microns; the convexity of the end faces did not exceed 3 microns; the roughness of the end faces (Ra) was in the range from 0.2 to 0.09 microns (this range corresponds to the required degree of accuracy of the rollers); burns were not fixed.

The results of grinding quality control by the parameter "axial run-out" are presented in figure 4 (I, II, III, IV are the degrees of accuracy). The figure shows that the I degree of accuracy of machining for the rollers was provided only in the first two hours of operation of the machine tool. The successive growth of thermal deformations led to a significant increase in machining errors. Starting from the third hour of continuous operation of the machine tool, the permissible second degree of accuracy of the roller was achieved only.

![Figure 4](image)

**Figure 4.** Change the accuracy of parts machining (axial run-out in time).

3. **Conclusions**

The proposed methods of experimental study of thermal behavior and machining errors of the double-sided face grinding machine allow to carry out the finishing of the machine tool in real production. Grinding of a batch of cylindrical rollers showed that excessive temperatures were distributed unevenly across the units of the machine tool at idle and during grinding. The end faces of the headstocks and the frame had the highest excess temperature when the machine tool is idling. When grinding, the surface of the machine components, located in close proximity to the grinding zone, had the greatest excess temperature as well. Behaviour of the change in the excessive temperatures of the characteristic points and coolant completely coincided with the experimental data obtained later in the simulation of the grinding process. This allowed us to consider the experimental data (excessive temperatures in characteristic points of the machine tool, excessive temperatures of coolant and angular displacement of
the grinding wheels) obtained by simulating the grinding process adequate to the data that take place under real conditions of the machine.

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