Unbalances formation of the textured wheel at preparation to grinding process

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Abstract. The entrance factors of grinding processes of materials, affecting dynamic activity of a technological system, define exit indicators of processes: operation productivity, geometrical and physic-mechanical indicators of quality of the processed blanket, etc. One of such dominating factors is unbalance of quickly rotating grinding wheel, which role continuously increases in connection with a current trend of increase of cutting speed. Formation of the main vector of unbalances of the textured grinding wheel during his preparation to work is analysed. The mathematical model of unbalances, caused by errors of production of abrasive cutting elements, their assembly with the metal case, installation of the tool on a spindle, and also by uneven removal of abrasive material in the course of its first editing, is developed. On the basis of the established mathematical model the numerical values of unbalances of the textured grinding tool are defined and the recommendations, providing values of the main vector of the imbalances, regulated by the standard, are developed. The results of researches are necessary for high-quality design of the textured grinding wheels, intended for grinding of responsible surfaces.

1. Introduction
Modern grinding processes are carried out at high cutting speeds (50-80 m/s), therefore even small unbalanced mass in the tool causes the significant centrifugal force, which has negative impact on all exit indicators of machining. Grinding by standard wheels with the continuous cutting surface is investigated in detail. Are studied: a trajectory of abrasive grain, a formation of processed surface [1-4], a grinding stability [5], a self-organize of cutting surface of wheel [6], unbalances of wheels, an influence of unbalances on the vibration level of a technological system [7], ways of coolant giving in a cutting zone [8, 9] etc. The textured grinding wheels [10–13], discretization technology of abrasive wheels by laser beam and hydro abrasive jet of high pressure [14], technology of flat peripheral and flat face grinding [15–17], a shaping of discrete abrasive segments are developed [18]. Recently the area of a research of the textured wheels is directed also to the processes of a combined grinding [19, 20]. However, due attention was not given to formation and reduction of unbalances of the textured grinding wheels, what leads to reduction of technological capabilities of this progressive tool.

2. Unbalances of the textured tool, created by errors at production and assembly of abrasive segments in the case
The textured grinding wheel consists of the metal case 1 (Fig. 1, a), into which grooves abrasive segments 2 are inserted. Abrasive segments are pressed, therefore they have admissions of the sizes,
which determine tool unbalances. The sizes of the metal case also have admissions, but they are 10 times less in comparison with abrasive segments, therefore when determining unbalances of the textured tool, we do not consider errors of production of metal case. At preparation of the textured wheel for work its unbalances are forming at assembly of segments with the case, installation of wheel on a spindle, and also at uneven removal of abrasive material during the first editing of segments.

The unbalances, created by errors of production of abrasive segments, are defined as multiplication of coordinates of the mass centers of elementary figures, from which the segment consists, on their mass. The elementary unbalance, arising at installation of abrasive segment in the metal case, is determined by a formula:

\[ D_i = \gamma B_i F_i \sqrt{x_{0i}^2 + y_{0i}^2} \],

where \( \gamma \) – a density of abrasive material; \( B_i \), \( F_i \) – respectively height and cross-sectional area of \( i \)-segment; \( x_{0i} \), \( y_{0i} \) – coordinates of the masses center of \( i \)-segment in the \( XO_iY \) system (Fig. 1, a).

After installation in the case of all abrasive segments the unbalance of the textured wheel is equal:

\[ D_{st} = \sum_{i=2}^{i=n} D_i = \sum_{i=2}^{i=n} \sqrt{\left(\sum_{i=2}^{i=n} x_k^2\right)^2 + \left(\sum_{i=2}^{i=n} y_k^2\right)^2} \],

where \( \sum_{i=2}^{i=n} D_i \) – the geometrical sum of elementary unbalances, created by abrasive segments; \( n \) – number of abrasive segments in the textured wheel; \( x_k, y_k \) – projections to axes X and Y of the unbalances, which arose after installation of segments in the case.

The maximum of \( D_{st} \) arises, when the abrasive segments with the largest sizes, are located in one half of the case, and segments with the smallest sizes – in the second half.

3. The unbalances of spindle knot, caused by installation of the textured wheel on a spindle and by uneven removal of an abrasive material of segments

After installation of textured wheel on a spindle there is an unbalance, caused by a gap between a case hole and spindle. Unbalance is determined by a formula:

\[ D_{st1} = \frac{M}{2\pi} (T_1 + T_2 + u) \cdot e \],

where \( M \) – the mass of the textured wheel; \( |e| = 0.5(T_1 + T_2 + u) \) – the eccentricity of textured wheel on a spindle; \( T_1, T_2 \) – respectively an diameter admission of the case hole and a basic surface of spindle; \( u \) – a wear of case hole and a basic surface of spindle.
After fixing on a spindle the segments are edited. Removal of abrasive material at the editing is carried out unevenly: from one segment less abrasive material is removed (Fig. 1, a, curvilinear triangle $abc$), and from another – more (curvilinear trapezoid $mnop$). After editing the wheel has an interrupted cutting surface $3$. In spindle knot is formed an unbalance, which is equal:

$$D_{pr} = \sum_{k=1}^{k_{out}} D_k = \gamma \sum_{k=1}^{k_{out}} F_k B_k \vec{r}_k = \gamma (\sum_{k=1}^{k_{out}} F_k B_k \vec{e}_k \cdot \vec{i} + \sum_{k=1}^{k_{out}} F_k B_k \mu_k \cdot \vec{j}),$$

where $\vec{r}_k = \vec{e}_k \cdot \vec{i} + \mu_k \cdot \vec{j}$, $(k = 1; 2; \ldots n)$ – radius-vector of the mass center of a removed part of $k$-segment; $i$, $j$ – single vectors; $\vec{e}_k, \mu_k$ – coordinates of the mass center of a removed part.

The main vector of unbalances, arising owing to errors of production of the textured grinding wheel, its installation on a spindle of the machine tool, and uneven removal of abrasive material, is determined by formula (Fig. 1, b):

$$\vec{D}_{st} = \vec{D}_{st1} + M \cdot \vec{e} + \vec{D}_{pr}.$$

The value of the main vector of imbalances of spindle knot is defined by design of vectors $\vec{D}_{st1}, M \cdot \vec{e}, \vec{D}_{pr}$ on axes X and Y and their geometrical addition.

4. The spindle unbalances, caused by installation on it a standard wheel and uneven removal of abrasive material at first editing

The initial unbalance of a standard wheel is limited by [21]. After installation of wheel on a spindle there is an unbalance $M_c \cdot \vec{e}_c$ ($M_c$ – the mass of a wheel, $\vec{e}_c$ – the eccentricity, equal to a half of the maximum diameter gap between the central hole of a wheel and a base surface of a spindle). After first editing there is an unbalance, which is determined by a formula (Fig. 1, b):

$$D_{pr}^e = m_{sn} \cdot x_{sn} = \gamma F_{sn} B \cdot x_{sn},$$

where $m_{sn}, x_{sn}, F_{sn}$ – respectively the mass, coordinate on axis X of the masses center and a cross-sectional area of the abrasive material, removed at the first editing; $B$ – wheel height of a standard wheel.

The cross-sectional area of the removed abrasive material is equal:

$$F_{sn} = \pi R^2 - \pi \left( R - e_c \right)^2 = \pi e_c \left( 2R - e_c \right),$$

where $R$ – the radius of the peripheral cutting surface of a standard wheel before editing.

Coordinate $x_{sn}$ of the mass center of cross section of the removed abrasive material is equal:

$$x_{sn} = \frac{e_c R^2}{R^2 - \left( R - e_c \right)^2} = \frac{R^2}{2R - e_c}.$$

Ordinate $y_{sn} = 0$ in view of symmetry of the removed material to axis X (Fig. 1, b).

The unbalance of spindle knot, caused by installation on a spindle of the machine tool and the first editing of a standard wheel, is determined by a formula:

$$D_{st}^e = D_{st} + M_c \cdot \vec{e}_c + m_{sn} \cdot x_{sn}.$$

5. The comparative analysis of unbalances of the standard and textured grinding wheels

On the basis of dependences (1)–(9) and data of [21] the calculations of unbalances of standard and textured grinding wheels for various diameters of the cutting surface, number of abrasive segments, length $a_1$ of a texture, length $b_1$ of the cutting surface of segment (Fig. 1, a), and also for various admissions on the segment sizes and sizes of standard tool are executed. At segments production with broad admissions (1.5–6.0) mm the main vector of unbalances of the textured grinding wheel (Fig. 2,
a, curves 1, 2) is more, than of standard wheel (Fig. 2, a, curves 3, 4), what is inadmissible. Curve 3 corresponds to unbalance class \( r = 4 \) of standard wheel, curve 4 – to unbalance class \( r = 2 \) [21].

**Figure 2.** The main vector of unbalances of the textured and standard grinding wheel as diameter of cutting surface at admissions (1.5–6.0) mm (a) and (0.3–0.7) mm (b) on segments sizes.

At sizes admissions of segments up to (0.3–0.7) mm the unbalances of the textured wheel (Fig. 2, b, curve 2) are always less, than of the standard grinding wheel (Fig. 2, b, curve 1). Calculations by use (1)–(9) showed, that for approximate equality of unbalances of the compared tools it is necessary to appoint the next admissions \( \Delta T \) of the segments sizes: (0–50) mm – \( \Delta T \leq 0.2 \text{ mm} \); (50–100) mm – \( \Delta T \leq 0.3 \text{ mm} \); (100–150) mm – \( \Delta T \leq 0.45 \text{ mm} \); (150–250) mm – \( \Delta T \leq 0.70 \text{ mm} \). The specified admissions are wide, therefore segments production will not cause difficulties.

Increase in number \( n \) of segments in the textured wheel and of relation \( b_{1}/a_{1} \) (Fig. 1, a) for diameters \( D \leq 50 \text{ mm} \) almost does not cause increase in unbalances (Fig. 3, a, b, lines 1 and 2), and in the range of diameters (400–500) mm this influence significantly increases (Fig. 3, a, b, lines 3–5).

**Figure 3.** Influence of segments number and the relation \( b_{1}/a_{1} \) on unbalances of the textured wheel.

At reduction of unbalances of the textured wheels with diameters \( D \leq 500 \text{ mm} \) the quantity of abrasive segments should be limited to value \( n \leq 20 \), and the relation \( b_{1}/a_{1} \leq 4 \) (Fig. 1, a). The specified recommendations provide the unbalances of the textured grinding wheels, limited by standard [21], and the received results of researches are necessary for their high-quality design.

6. Conclusion

1. To unbalances of textured wheels due attention was not paid, what reduce technological capabilities of this progressive grinding tools.

2. The mathematical model of unbalances, including the unbalances, caused by errors of production of abrasive segments, by segments assembly with the metal case, by installation of a textured grinding wheel on machine tool and by uneven removal of abrasive material at the first editing of segments, is developed. This mathematical model is necessary for high-quality design of the textured wheels, intended for grinding of responsible surfaces.
3. For diameters up to 500 mm are recommended the number of abrasive segments \( n \leq 20 \), the relation \( b_i / a_i \leq 4 \) (Fig. 1, a), the admissions \( \tau_d \) for the segments sizes: (0–50) mm – \( \tau_d \leq 0.2 \) mm; (50–100) mm – \( \tau_d \leq 0.3 \) mm; (100–150) mm – \( \tau_d \leq 0.45 \) mm; (150–250) – \( \tau_d \leq 0.70 \) mm. These recommendations provide the unbalances of the textured grinding wheels, limited by standard [21].

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