Simulation of thermal fields using different types of wide burnishing

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Abstract: The article features simulation of heat build-up in the tool while treatment using different types wide burnishing. The understanding of conditions of heat build-up and heat distribution and the quantitative estimation on the finishing stages of part’s treatment is always challenging, because there is a possibility of negative and nonreciprocal effect onto the development of performance properties of treated parts. This issue gains particular importance during treatment, including burnishing using no means of lubrication.

Introduction
The understanding of conditions of heat build-up and heat distribution and the quantitative estimation on the finishing stages of part’s treatment is always critical, for minimization of negative and nonreciprocal effect of the heat onto the development of performance properties of treated parts, which is relevant for machining process, including wide burnishing. The reference literature does not provide analytical behavior for wide burnishing process, enabling temperature calculation in any area of machining of both the tool and the blank. The use of analytical methods enables us to get the generalized solution, relevant for simple shaped bodies (a plate, a cylinder, a ball) keeping some simplification in mind [1]. 2 and 3 dimensional tasks, however appears a difficulty integrating differential equation of thermal conductivity on unambiguous conditions, which corresponds to thermal processes in technological systems [2, 3]. This article features results of simulation. Two fundamental entries, affecting the overall image while wide burnishing: temperature of the tool and temperature by using different types of burnishing.

The heat distribution within the tool during wide burnishing, by self-positioning tool
The existing models for estimation of heat build-up while wide burnishing with feed (or “burnishing”) are not usable for wide burnishing owing to following features of wide burnishing: various type of integrity within these technologies – in tens of times more efforts by wide burnishing; absence of linear feed (only transverse direction); increased machining speed (machining cycle within 1-3 rotation of part); shapes of tools [4, 5, 6]. The authors have received details of dependence in order to estimate the contact surface temperature in the process of wide burnishing without use of cooling taking into account the thermo-physical characteristics of materials, speed of process, number of loading cycles and technical scheme of machining used, the use of which enables decrease of temperature.
As initial expression for heat distribution simulation onto the surface of the tool for wide burnishing let us use the known expression of isolated continuous source of \( q_{\text{max}} \) intensity, which is found within infinite body:

\[
\Theta(x,y,z,\tau) = \frac{q_{\text{max}}}{4\pi\lambda R} \left( 1 - \text{erf}\left[ \frac{R}{\sqrt{4\omega\tau}} \right] \right)
\]  

(1)

where \( R = \sqrt{(x_u - x)^2 + (y_u - y)^2 + (z_u - z)^2} \).

Considering the accepted shape of body (half-space), and taking into account the principle of source reflection, while transition to final expression let us multiply it by 2.

Since the source is decided to be found on the surface of the part, let us accept \( y_u = 0 \).

We should carry out integration of initial mathematical expression into necessary coordinates. We should bear in mind the shape and dimensions of thermal source, the heat-intensity distribution behavior on the contact surface, schematization of the part’s shape etc.

By integration on \( x_u \) and \( z_u \) axils on the contact surface, then we get information for case of equal distribution of heat-source density:

\[
\Theta(x,y,z,\tau) = \frac{q_{\text{max}}}{2\pi\lambda} T_2(x,y,z,\tau)
\]

(2)

\[
T_2(x,y,z,\tau) = \iint \frac{1 - \text{erf}\left[ \frac{(x_u - x)^2 + (z_u - z)^2 + y^2}{4\omega\tau} \right]}{\sqrt{(x_u - x) + (z_u - z) + y^2}} \cdot dx_u \cdot dz_u
\]

(3)

For normal one-direction distribution of heat-source, behavior (2), (3) is reconstituted in the following way:

\[
T'_2(x,y,z,\tau) = \iint \exp\left[ -k \left( \frac{2(x_u - l)}{l} \right)^2 \right] \times
\frac{1 - \text{erf}\left[ \frac{(x_u - x)^2 + (z_u - z)^2 + y^2}{4\omega\tau} \right]}{\sqrt{(x-x_u)^2 + (z-z_u)^2 + y^2}} \cdot dx_u \cdot dz_u
\]

(4)

**The temperature while using different technological types of wide burnishing**

Let use study the process of wide burnishing and its technological aspects from the point of view number and disposition of sources and heat sinks in the technological scheme.

When using the process of wide burnishing it’s possible to use different technological schemes of process (Figure 1):

1. Scheme A represents traditional process scheme of burnishing using single tool, effected by force \( P \).
2. Scheme B contains 3 and more tools, asymmetrically proportionally displaced on the on the part’s surface.
3. Scheme C contains 2, 4 and more tools, symmetrically and proportionally displaced.
4. Scheme D contains 2 and more tools, proportionally symmetrically/asymmetrically displaced.
The use of each scheme alternates in definite way the thermal pattern in the surface layers of treated material, consequently its physically-mechanical features [10].

With regard to above mentioned, we should consider, the by wide burnishing treatment same area of the surface might be effected by several loading cycles within several revolutions of the part or by use of several tool schemes [11].

![Figure 1. Basic technological schemes of wide burnishing process](image)

Let us reconstitute expression (2) and (3), with regard to mentioned factors. Regard to the number and displacement of the tools shall be effected through estimation of distance x and composition of temperatures of each tool. Taking into account, that estimation of temperature is carried out in coordinates relative to the tool (thermal source).

For Scheme B:

\[
\Theta_\Sigma(x, y, z) = \Theta(x, y, z) + \Theta\left(x + \frac{\pi D}{3}, y, z\right) + \Theta\left(x + \frac{2\pi D}{3}, y, z\right),
\]

(5)

Where \( \Theta_\Sigma(x, y, z) \) - temperature of single thermal source, calculated using one of the formulas (2), (3).

For Scheme C:

\[
\Theta_\Sigma(x, y, z) = \Theta(x, y, z) + \Theta\left(x + \frac{\pi D}{2c}, y, z\right),
\]

(6)

With the use of 4 tools, the dependence behavior attributes the following shape:
\[ \Theta_\Sigma(x, y, z) = \Theta(x, y, z) + \Theta\left(x + \frac{\pi D}{4}, y, z\right) + \Theta\left(x + \frac{\pi D}{2}, y, z\right) + \Theta\left(x + \frac{3\pi D}{4}, y, z\right), \]  
(7)

For Scheme D:

\[ \Theta_\Sigma(x, y, z) = \Theta(x, y, z) + \Theta_i(x + l, y, z) + \Theta_i(x + l_n, y, z) \]  
(8)

Where \( l_n \) – is distance of part’s circle periphery to the specific tool.

The consideration of several loading cycles is done through accumulation of heat from each loading cycle:

\[ \Theta_\Sigma N(x, y, z) = \Theta_\Sigma(x, y, z) + \Theta_\Sigma z(x + \pi D, y, z) + \cdots + \Theta_\Sigma N(x + \pi D(n - 1), y, z) \]  
(9)

Results and Discussion

Below is the image of results of estimation on above formula (Figure 2-4).

The thermal distribution by width of indentor shows, that the level of temperature is proportional by width of treated surface, which leads to equability of physical-mechanical features of the final surface layer. It's also visible that character of distribution barely depends of speed of burnishing, which enables us to use wider range of speed of burnishing to choose the needed temperature (Figure 2).

The results of estimation depending on burnishing speed of treated material are shown. The analysis of estimation results shows, that the temperature on the surface layer of the part by use of technological scheme of single tool burnishing increasing not significantly (Figure 3).

The use of multi-tool scheme, does not significantly affect the level of temperature of part’s surface, however enables us to reduce lead-time of wide burnishing process, increasing the performance. The main effect onto the features of the surface layers would be done caused by maximum temperature level in contact area directly next to indentor, where the basic physical-mechanical processes take place during burnishing (Figure 4).

It has been established that, despite of the differences of technological conditions of burnishing by cylindrical indentor and wide self-positioning tool the maximum temperature of contact area in both cases is on the same level, averagely, does not exceed limit of 300 °C.

Figure 2. Temperature distribution by width of burnishing: a) steel 40; b) cast iron; \( \theta = \Theta(z)/\Theta_{\text{max}} \) – relative temperature in dimensionless form
Figure 3. Dependence of average temperature on contact area by wide burnishing on speed

- a) - steel 40; b) - cast iron; 1 - P=40 N/mm; 2 - P=56 N/mm; 3 - 80 N/mm
Conclusion

1. We have established dependencies necessary to define contact temperature in the process of wide burnishing without cooling with regard to thermo-physical characteristics, speed of process, quantity of loading cycles and technological scheme used, the use of which enables us to minimize the heating.

2. The temperature significantly depends on speed and force of burnishing: together with increase of speed and pressure onto the surface of the part the average temperature of contact area by
wide burnishing may increase up to 8 – 9 times. But even in the most intense loading conditions the temperature of contact surface does not exceed 400 °C by wide burnishing of steel 40 and 450 °C – by treatment of high-tensile cast iron 75-50-03.

3. It has been established that, despite of the difference of technological conditions of wide burnishing by indentor and wide self-positioning tool the maximum heating temperature of contact area in both cases is on the same level, averagely, not exceeding limit of 300 °C.

4. The heat pattern of wide burnishing enables us to develop technological limitations to treatment process from the point of view of two factors. First point is, in order to prevent possible negative structurally-phase transformations in the surface layer of burnished part with the following lowering of its quality and operational reliability. And the second point is, in order to reduce tool-ware rate, especially using no lubrication.

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