Profile Gear Grinding Temperature Reduction and Equalization
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Abstract. The profile gear grinding modes definition technique is developed to provide the uniform residual temperatures after heating and subsequent cooling which predetermine uniform thermal deformations on periphery of a cogwheel when grinding. The initial basis for this is a possibility to determine the gear grinding temperature both on the heating and cooling stages and, besides, it may be also a choice of the operation cycle structure with and without the working stroke omission. In the interval of the profile gear grinding modes, two variants of the gear grinding working cycle structure with reciprocating displacement of the grinding wheel are considered using the simulation method with an omission and without one of the working stroke. Certain combinations of mode parameters are found in the range of their possible values at which the combination of heating and cooling leads to the lowest residual surface temperature both during and after working stroke.

Keywords: profile gear grinding, gear grinding temperature, heating stage, cooling stage, cycle structure, working stroke, temperature.

1 Introduction

Typically grinding modes are selected according to reference statistical tables [1]. The choice of them is not substantiated by any criterion, for example, a criterion of the absence of grinding burns, a criterion of the grinding wheel life, a criterion for uniform heating of the machining cogwheel on its periphery, etc.

It is known the method of determining the modes of profile grinding in the three successive stages of this operation according to the system-wide principle of stage theory for any technical process. These stages are rough, semifinish, and finish ones and each of them depends on grinding temperature [2]. A peculiarity of the third grinding stage is the need to equalize the temperature heating along the periphery of a cogwheel. There is a rule that at the finishing stage, the infeed value should be such that it would be possible to grind all the cogwheel teeth without dressing the profile grinding wheel [3]. This is due to the fact that after the dressing, the grinding wheel changes its cutting capacity and the position line of the cutting edge. The infeed value at the finishing stage is reduced as the grinding stock for this stage decreases, and at the last grinding working stroke it is not recommended to apply the infeed values less than 0.010...0.015 mm [2]. However, these data are also not substantiated by any objective criterion and are more likely to be the result of practice.

In the paper [4] the three staged structure of the gear grinding operation is analyzed and consists of rough, semifinish and finish stages. Moreover, modes for each stage are selected based on the parameters of the specific material removal rate in mm³/(s·mm) and the specific material removal in mm³/mm. However, these are formal indicators which are not related, for example, to the grinding temperature and the grinding wheel wear.

The purpose of the paper is to improve the method of determining the grinding modes on the last finish (third) stage of the machining cycle by establishing a connection between formal indicators mentioned and the grinding temperature.

2 Research Methodology

2.1 Initial equations

One of the requirements for the finish (third) stage of machining is to ensure a uniform heating of a cogwheel by eliminating the heat accumulation on the periphery of the cogwheel. Thus, the criterion for optimizing the grinding operation at this stage may be the temperature of the grinding as one of the reasons that determine the...
cogwheel heat content. The temperature field at the heating stage is described by a mathematical dependence, which is a solution of a one-dimensional differential equation of heat conductivity. To determine the temperature \( T_H(x, \tau_H) \) at the heating stage, we can use the equation [5]

\[
T_H(x, \tau_H) = \frac{2q}{\lambda} \sqrt{\frac{\alpha t_H}{\pi}} \text{erfc} \left( \frac{x}{2\sqrt{\alpha t_H}} \right) + T_0, \quad (1)
\]

in which by denoting \( \frac{x}{2\sqrt{\alpha t_H}} = \xi \), we remind the well-known relations

\[
\text{ierfc} \xi = \left[ \frac{1}{\sqrt{\pi}} \exp(-\xi^2) - \xi \text{erfc} \xi \right]; \quad \text{erfc} \xi = 1 - \text{erf} \xi; \\
\text{erf} \xi = \frac{2}{\sqrt{\pi}} \int_0^\xi \exp(-u^2) \, du.
\]

In the formula (1) \( q \) is the heat flux density (W/m²), \( a \) stands for the temperature conductivity (m²/s), \( \lambda \) for the heat conductivity (W/(m·K)), \( x \) for the dimensional coordinate along the depth of the surface layer (m), \( \tau_H = 2h_H/V_f \) for the maximum dimensional heating time at the heating stage (s), \( V_f \) for the velocity of the source in the direction of the \( z \) axis (axial feed or velocity of the part, m/s), \( h_H \) for the maximum value of the provisional value \( h \) (\( 0 \leq h \leq h_H \)) at the heating stage, that is, the actual half-width of the real heat source (m), \( T_0 \) is the initial temperature of the machining workpiece (room temperature, constant value).

The density of the heat flux \( q \) is obtained by averaging the instantaneous value of this parameter \( q(r_x) \), and taking into account for each point of the involute profile with an instant radius vector [6]

\[
q(r_x) = e_c \varphi \frac{dQ}{dS_c} = \frac{P}{V_f S_c} \varphi \frac{V_f t_{n(r_x)}}{D t_{f(r_x)}}, \quad (2)
\]

where \( e_c \) and \( Q \) are the specific grinding energy and material removal rate (in J/mm³ and mm³/s), \( S_c \) stands for the contact area (m²), \( P \) for the grinding power (W), \( S_c \) for the cross-section area in the grinding wheel movement direction (m²), \( \psi \) for the share of heat into the workpiece, \( t_{n(r_x)} \) and \( t_{f(r_x)} \) are the normal and vertical depths of cutting at an involute profile separate point (m), \( D \) is the instant diameter of the grinding wheel in the considered cross-section of its profile (m).

To determine the temperature at the cooling stage, which follows immediately after heating, with the initial conditions obtained during the heating stage, the following equation can be used [5]:

\[
T_C(x, t_C) = \int_0^\infty \frac{1}{2\sqrt{\pi a t_c}} \left\{ \exp \left( \frac{-(x-x')^2}{4a t_c} \right) + \exp \left( \frac{-(x+x')^2}{4a t_c} \right) \right\} \text{erfc} \left( \frac{x + x'}{2\sqrt{a t_c}} \right) \left[ f(x') \, dx' \right] + \]

\[
-A \exp \left( a t_c A^2 + A(x + x') \right) \text{erfc} \left( \frac{x + x'}{2\sqrt{a t_c}} \right) - A \exp \left( a t_c A^2 + A(x - x') \right) \text{erfc} \left( \frac{x - x'}{2\sqrt{a t_c}} \right) \left[ f(x') \, dx' \right] + \]

\[
+ aA \int_0^{t_c} \exp \left( -\frac{x^2}{4a(t_c - \tau_x)} \right) \left[ \varphi(\tau_x) t_c \right] d\tau_x,
\]

in which

\[
f(x') = \frac{2q}{\lambda} \sqrt{\frac{\alpha t_H}{\pi}} \left[ \frac{1}{\sqrt{\pi}} \exp \left( -\frac{x'^2}{4\alpha t_H} \right) - \frac{x'}{2\sqrt{\alpha t_H}} \text{erfc} \left( \frac{x'}{2\sqrt{\alpha t_H}} \right) \right] + T_0,
\]

where \( \tau_H = 2h_H/V_f \) stands for the maximum heating time at the heating stage (s), \( t_C \) for cooling time (s); \( A = \frac{\alpha h}{\lambda} \) for the reduced heat transfer coefficient, \( \alpha_h \) for heat transfer coefficient (W/(m²·K)), \( \varphi(\tau_C) \) for the starting temperature of the lubricant (°C), which can vary over the cooling time interval \( \tau_C \), and \( 0 \leq \tau_C \leq t_C \).
2.2 Technique for decision making

Thus, with a known type and a method of supplying the lubricoolant, for controlling the temperature at the cooling time interval it is possible to control the convection coefficient, the magnitude of the output temperature of the lubricoolant, and the grinding modes, that is, to regulate the vertical cutting depth and the axial feed. Moreover, the value of affects the maximum heating temperature as well as the value of which determines the time of heating and cooling, which affects both on the and the achieved temperature level at the end of the cooling stage in the “heating-cooling” cycle on each working stroke. Thus, under otherwise identical conditions (cutting speed, grinding wheel characteristics, lubricoolant kind, etc.), the control and optimization parameters may include elements of cutting modes: and .

The cooling time is counted from the heating interval end. The task is to determine such mode parameters and , under which the heating stage with the surface temperature (Figure 1, line 1) will be changed by a cooling stage at which the temperature will change in the required manner (Figure 1, line 2). The control is to choose the grinding modes and which will result in the absence of heat accumulation (Figure 1, line 2): , , and are necessary (completely cooled surface) and are necessary (not completely cooled surface) surface temperature dependence on time in the first, second and third working passes, respectively.

![Figure 1](image1.png)

With a local increase in the temperature of individual ground sections of the toothed surface, the temperature field is asymmetric in the symmetric body of the work-piece. This will lead to temperature ununiformed deformations of the heated sections, and, in consequence, to the cogwheel accuracy parameters deviations after the cogwheel cooling.

3 Results

3.1 Gear grinding with and without working stroke omission

There are two structures of the “heating-cooling” cycle: the up-and-down grinding without working stroke omission (Figure 2 a) and the only up grinding with the omission (Figure 2 b). In the cycle structure without working stroke omission the grinding wheel makes a working stroke with the length of ( is the width of the tooth rim, and are the grinding wheel approach and overtravel lengths), i.e. consistently passes the points 1-2-3 (up grinding), which are located in the beginning, middle and end of the length of the tooth rim (Figure 2 a). On the reverse working stroke, the grinding wheel makes reverse displacement (down grinding), i.e. consistently passes the points 3-2-1. In this case, the greatest amount of heating gets the point 3, because at this point, the cooling time is the smallest and is equal to

![Figure 2](image2.png)

Figure 2 - The grinding cycle structures, in which is a grinding wheel; IP, IS and WS are the initial position, single and working strokes respectively.

When repeating the “heating-cooling” cycle, the point 1 gets the greatest heating amount, because at this point, the cooling time is the smallest and is equal to
\[ t_2 = \frac{2l_1}{V_f}. \]  

In the structure of the cycle with the working stroke omission, the grinding wheel makes a working stroke \( l_1 + B + l_2 \) consistently passing the points 1-2-3 (up grinding), which belong to the beginning, middle and end of the tooth rim length (Figure 2 b). Before the reverse stroke the grinding wheel does not move radially to the cutting depth \( t_v \) that is this reverse stroke is idle and the grinding wheel makes idle stroke with the length of \( l_2 + B + l_1 \) (points 3-2-1 without heating) getting to the initial position. When repeating the “heating-cooling” cycle, heating at the up grinding receives the point 1, that is at this point, the cooling time is the smallest and is equal to

\[ t_3 = \frac{2l_1 + 2l_2 + 2B}{V_f}. \]  

### 3.2 Reduction and equalization of temperature

Assuming \( l_1 = l_2 = l \) for the structure with the working stroke omission we can see that cooling time according to formula (6) increases more than twice because the ratio of \( t_3/t_1 \) is equal to the \( t_3/t_2 \) and is \((2l+2B)/2l = 2 + B/l\).

Next, we introduce the following symbols for the surface temperature (i.e. \( x = 0 \)) for heating and cooling: \( T_H(0, \tau_H) = T_H \) and \( T_C(0, \tau_C) = T_C \), respectively. For both structures of the cycle the influence of the axial feed \( V_f \) and the vertical depth of cutting \( t_v \) on the heating time \( \tau_H \) and the heating temperature \( T_H \) by the formula (1) and the cooling temperature \( T_C \) by the formula (3) are established with the following initial data: \( x = 0 \) (on surface); \( \varepsilon_c = 50 \, J/mm^2; \psi = 0.8; \) profile angle \( \alpha = 20^\circ \) or \( \frac{\alpha \pi}{180^\circ} \) rad; \( D = 400 \, mm; \) \( a = 5.68 \times 10^{-6} \, m^2/s; \)
\( \lambda = 24 \, W/(m \cdot K); \) \( \alpha_H = 10 \times 10^3 \, W/(m^2 \cdot K); \)
\( \Lambda = \frac{\alpha_H}{\lambda} = 416.67 \, m^{-1}; \)
\( T_0 = 0 \, ^\circ C; \) \( \varphi(\tau_C) = 15 \, ^\circ C; \)
\( l_1 = l_2 = 7.86 \, mm; B = 24 \, mm. \) The axial feed \( V_f \) varies in the range of 500...7000 mm/min, and the vertical depth of grinding \( t_v \) takes the following fixed values: \( t_v = 0.015 \, mm \) (Tables 1, 2) and \( t_v = 0.074 \, mm \) (Tables 2, 4). With increasing \( V_f \) for \( t_v = \) const (Tables 1, 2) the heating time \( \tau_H \) decreases and the heating temperature \( T_H \) increases. With the increasing \( t_v \) at the same values for \( V_f \) (pairs of Tables 1, 2, as well as Tables 3, 4), the heating time \( \tau_H \) and heating temperature \( T_H \) increase.

For the cycle with the working stroke omission (Tables 3, 4) the heating time \( \tau_H \) and the heating temperature \( T_H \) did not change compared with the previous structure (without working stroke omission), therefore, \( \tau_H \) and \( T_H \) in Table 3 and Table 4 are not given. There are both cooling time \( t_C \) and cooling temperature \( T_C \) changing at \( t_v = 0.015 \, mm \) (Table 3) and \( t_v = 0.074 \, mm \) (Table 4). The reason for the difference between the parameters \( t_C \) and \( T_C \) in cycles with and without working stroke omission is the only one - the increase in cooling time \( t_C \) in the cycle structure with working stroke omission.

### Table 1 – Influence of the \( V_f, \tau_H, T_H, t_C, \) and \( T_C \) for the cycle structure without working stroke omission at \( t_v = 0.015 \, mm \)

<table>
<thead>
<tr>
<th>( V_f, , mm/min )</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>3500</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau_H, , s )</td>
<td>0.2939</td>
<td>0.1469</td>
<td>0.09798</td>
<td>0.07348</td>
<td>0.05879</td>
<td>0.04899</td>
<td>0.04199</td>
</tr>
<tr>
<td>( T_H, , ^\circ C )</td>
<td>42.42</td>
<td>59.99</td>
<td>73.47</td>
<td>84.84</td>
<td>94.86</td>
<td>103.91</td>
<td>112.24</td>
</tr>
<tr>
<td>( t_C, , s )</td>
<td>1.8868</td>
<td>0.9434</td>
<td>0.6289</td>
<td>0.4717</td>
<td>0.3774</td>
<td>0.3145</td>
<td>0.2695</td>
</tr>
<tr>
<td>( V_f, , mm/min )</td>
<td>4000</td>
<td>4500</td>
<td>5000</td>
<td>5500</td>
<td>6000</td>
<td>6500</td>
<td>7000</td>
</tr>
<tr>
<td>( \tau_H, , s )</td>
<td>0.03674</td>
<td>0.03266</td>
<td>0.02939</td>
<td>0.02672</td>
<td>0.02449</td>
<td>0.02261</td>
<td>0.021</td>
</tr>
<tr>
<td>( T_H, , ^\circ C )</td>
<td>119.986</td>
<td>127.268</td>
<td>134.143</td>
<td>140.696</td>
<td>146.956</td>
<td>152.957</td>
<td>158.731</td>
</tr>
<tr>
<td>( t_C, , s )</td>
<td>0.23585</td>
<td>0.20964</td>
<td>0.18868</td>
<td>0.17153</td>
<td>0.15723</td>
<td>0.14514</td>
<td>0.13477</td>
</tr>
</tbody>
</table>
Table 2 – Influence of \( V_f \) on \( \tau_H, T_H, t_C, T_C \) for cycle structure without working stroke omission at \( t_v = 0.074 \) mm

<table>
<thead>
<tr>
<th>( V_f ), mm/min</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>3500</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau_H ), c</td>
<td>0.65287</td>
<td>0.32644</td>
<td>0.21762</td>
<td>0.16322</td>
<td>0.13057</td>
<td>0.10881</td>
<td>0.09327</td>
</tr>
<tr>
<td>( T_H ), °C</td>
<td>140.428</td>
<td>198.595</td>
<td>243.228</td>
<td>280.856</td>
<td>314.006</td>
<td>343.977</td>
<td>371.537</td>
</tr>
<tr>
<td>( t_C ), c</td>
<td>1.88678</td>
<td>0.94339</td>
<td>0.62893</td>
<td>0.47177</td>
<td>0.37736</td>
<td>0.31446</td>
<td>0.29654</td>
</tr>
<tr>
<td>( T_C ), °C</td>
<td>18.61</td>
<td>26.35</td>
<td>33.541</td>
<td>40.264</td>
<td>46.604</td>
<td>52.618</td>
<td>58.348</td>
</tr>
<tr>
<td>( V_f ), mm/min</td>
<td>4000</td>
<td>4500</td>
<td>5000</td>
<td>5500</td>
<td>6000</td>
<td>6500</td>
<td>7000</td>
</tr>
</tbody>
</table>

Table 3 – Influence of \( V_f \) on \( t_C \) and \( T_C \) for the cycle structure with working stroke omission at \( t_v = 0.015 \) mm

<table>
<thead>
<tr>
<th>( V_f ), mm/min</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>3500</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_C ), c</td>
<td>9.53357</td>
<td>4.76678</td>
<td>3.17786</td>
<td>2.38339</td>
<td>1.90671</td>
<td>1.58893</td>
<td>1.36194</td>
</tr>
<tr>
<td>( V_f ), mm/min</td>
<td>4000</td>
<td>4500</td>
<td>5000</td>
<td>5500</td>
<td>6000</td>
<td>6500</td>
<td>7000</td>
</tr>
<tr>
<td>( t_C ), c</td>
<td>1.1917</td>
<td>1.05929</td>
<td>0.95336</td>
<td>0.86669</td>
<td>0.79446</td>
<td>0.73335</td>
<td>0.68097</td>
</tr>
<tr>
<td>( T_C ), °C</td>
<td>11.529</td>
<td>11.624</td>
<td>11.738</td>
<td>11.867</td>
<td>12.008</td>
<td>12.158</td>
<td>12.317</td>
</tr>
</tbody>
</table>

Table 4 – The same as Table 3 at \( t_v = 0.074 \) mm

<table>
<thead>
<tr>
<th>( V_f ), mm/min</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
<th>3500</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_C ), c</td>
<td>9.53357</td>
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<td>3.17786</td>
<td>2.38339</td>
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<td>1.58893</td>
<td>1.36194</td>
</tr>
<tr>
<td>( V_f ), mm/min</td>
<td>4000</td>
<td>4500</td>
<td>5000</td>
<td>5500</td>
<td>6000</td>
<td>6500</td>
<td>7000</td>
</tr>
<tr>
<td>( t_C ), c</td>
<td>1.1917</td>
<td>1.05929</td>
<td>0.95336</td>
<td>0.86669</td>
<td>0.79446</td>
<td>0.73335</td>
<td>0.68097</td>
</tr>
</tbody>
</table>

Let’s perform a comparison of the cooling temperatures for two grinding cycle structures at \( t_v = 0.015 \) mm (Fig. 3, a) and \( t_v = 0.074 \) mm (Fig. 3, b). There are three ways to achieve the lowest cooling temperature \( T_C = 11.6 \) °C for \( t_v = 0.015 \) mm (Fig. 3, a): 1) when grinding without working stroke omission with axial feed \( V_f = 0.5 \) m/min (point A), 2) when grinding with working stroke omission with axial feed \( V_f = 1.8308 \) m/min (point B), and 3) the latter at \( V_f = 4226.9 \) mm/min (point C).

There are two ways to achieve the lowest cooling temperature \( T_C = 18.6 \) °C for \( t_v = 0.074 \) mm (Figure 3 b) when grinding without working stroke omission with axial feed \( V_f = 0.5 \) m/min (point D); 2) when grinding with working stroke omission with an axial feed \( V_f = 2.6444 \) m/min (point E).

The time to machine by gear grinding both without and with working stroke omission can be determined by the following formulas, respectively

\[
T_M = \left( \frac{B + l_1 + l_2}{V_f} \frac{z_{\text{max}}}{t_v} + \frac{T_{IND}}{60} \right) z ; \quad (7)
\]

\[
T_D = \left( \frac{B + l_1 + l_2}{V_f} \frac{z_{\text{max}}}{t_v} + \frac{T_{IND}}{60} \right) z ; \quad (8)
\]

where \( B \) stands for the width of the tooth rim (\( B = 24 \) mm), \( z \) for the number of cogwheel teeth (\( z = 40 \)), \( l_1 = l_2 = 7.86 \) mm, \( z_{\text{max}} \) for the grinding stock for machining a cogwheel in the finish (third) stage (\( z_{\text{max}} = 0.1 \) mm), \( T_{IND} \) for the indexing time (cogwheel angular turning for one tooth), \( T_{IND} = 4 \) s.

To ensure the lowest cooling temperature \( T_C = 11.6 \) °C, the minimum time to machine is equal to 7.632 min (Table 5) which is obtained in the with working stroke omission cycle structure at \( t_v = 0.015 \) mm and \( V_f = 4226.9 \) mm / min.
To provide the cooling temperature $T_C = 18.6 \, ^\circ C$ (more than 11.6 °C), the minimum time to machine $T_M = 4.29 \, \text{min}$ (Table 5) is obtained in the cycle structure with working stroke omission at $t_e = 0.074 \, \text{mm}$ and $V_f = 2644.9 \, \text{mm/min}$. From these five variants (points A, B, C, D, and E in Figure 3) we choose the variant with the minimum value $T_C = 11.6 \, ^\circ C$ (points A, B, C), since the theoretical value is $T_C = 0$. It can be seen (Table 5) that the minimum time to machine $T_M = 7.632 \, \text{min}$ is obtained in the cycle structure with working stroke omission at $t_e = 0.015 \, \text{mm}$ and $V_f = 4226.9 \, \text{mm/min}$ ($T_C = 11.6 \, ^\circ C$).

Thus, the study of the gear grinding temperature models (1) and (3) both at the heating (1) and cooling (3) stages allowed to recommend the working stroke omission in the structure of this operation and to assign the appropriate gear grinding modes for the finish (third) gear grinding stage both for $t_e = 0.015 \, \text{mm}$ (points A, B, C in Figure 3) and $t_e = 0.074 \, \text{mm}$ (points D, E).

### 4 Conclusions

As the depth of gear grinding $t_e$ increases the maximum cooling temperature $T_C$ increases as well. In the gear grinding cycle structure with working stroke omission cooling time $t_C$ is greater than that without working stroke omission. As the axial feed $V_f$ increases the cooling temperature $T_C$ for the cycle structure with working stroke omission at $t_e = 0.015 \, \text{mm}$ and $t_e = 0.074 \, \text{mm}$ does not practically change, while for the cycle structure without working stroke omission the cooling temperature $T_C$ increases. The smallest cooling temperature $T_C$ is reached at $t_e = 0.015 \, \text{mm}$, so it is expedient to accept the minimum possible vertical depth of grinding $t_e$ on the finishing (third) gear grinding stage, for example, for the finishing stage we take $t_e = 0.015 \, \text{mm}$.

Moreover, in this stage, the axial feed $V_f$ is chosen not only from the condition of maximum productivity (maximum $V_f$), but also from the condition of surface roughness (in the interval of $V_f$ from 1830.8 to 4226.9 mm/min) and the smallest elastic deformation in the gear grinding system.
References

Зниження та вирівнювання температури профільного зубошліфування
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Анотація. Розроблено методику визначення режимів зубошліфування на третьому завершальному етапі профільного зубошліфування на верстаті з ЧПК, виходячи із забезпечення вирівнювання температури по периферії і найменшого нагрівання зубчастого колеса. Для цього використано формули для визначення температури зубошліфування на етапі нагрівання та охолодження оброблюваної поверхні. На етапі нагріву температурне поле поширюється по глибині поверхневого шару і зменшується в часі. У момент закінчення етапу нагріву, миттєве температурне поле, яке згасає по глибині поверхневого шару, є початковою умовою для визначення температури на етапі охолодження. Тому температура охолоджувальної поверхні залежить не тільки від регульованого часу охолодження, але також від миттєвого розподілу температури в поверхневому шарі, яке враховується як початкова умова при моделюванні на етапі охолодження. Знайдено оптимальні умови охолодження, в тому числі за рахунок пропусків робочих ходів, які реалізовані зубошліфуванням без установки глибини різання.

Ключові слова: профільне зубошліфування, температура зубошліфування, етап нагріву, етап охолодження, структура циклу, пропуск робочого ходу, вирівнювання температури.