DEFORMATION OF CASE HARDENED CYLINDRICAL GEARS DURING HEAT TREATMENT

V. P. Ponomarev

Case hardened gears for heavily loaded transmissions are subjected to a complex heat treatment. The structural changes resulting from heat treatment lead to warping.

The type of deformation of gears depends on their shape and size and also on the type of heat treatment.

At our plant, the gears are divided into five groups according to their shapes: I) crown gears; II) gears of complex and asymmetrical shapes with low rigidity; III) massive rigid gears; IV) gears with long hubs and hollow-toothed shafts; V) solid-toothed shafts. Each group undergoes the same type of deformation and warping. Gears of each group were subjected to case hardening at 930°C to a depth of 1.6-1.9 mm in a solid carburizer for 31.5 h and in a gas carburizer for 14 h and then subjected to the following heat treatments:

<table>
<thead>
<tr>
<th>Treatment No.</th>
<th>Heat Treatment</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Normalization at 890°C (heated 1 h and 45 min and cooled 3 h), tempering at 650°C (heated 7 h and cooled 2 h), quenching in oil from 810°C (heated 1 h and 15 min), and tempering at 160°C for 4.5 h.</td>
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<tr>
<td>2</td>
<td>Tempering at 600°C for 9 h, quenching from 800°C in oil (1 h and 15 min), tempering at 160°C for 4.5 h.</td>
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<tr>
<td>3</td>
<td>Normalization using high-frequency heating at 950°C (heated 3 min and cooled 1 h), tempering in alkaline at 600°C (heated 3 h and cooled 1 h), quenching by steps (880 and 200°C) by heating in salts with supercooling in alkaline for 1 h, and tempering in alkaline at 160°C for 4.5 h.</td>
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<tr>
<td>4</td>
<td>Normalization using high-frequency heating at 950°C (heated 3 min and cooled 1 h), tempering at 600°C, quenching by steps (800 and 180°C) in oil (1 h and 10 min), and tempering at 160°C for 4.5 h.</td>
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<tr>
<td>5</td>
<td>Tempering at 500°C in NaOH for 3 h, quenching by steps (820 and 200°C) in salts (50% NaCl + 50% KCl), supercooling in a mixture of 63% KOH + 37% NaOH for 1 h, and tempering in alkaline for 1.5 h at 160°C.</td>
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<tr>
<td>6</td>
<td>Normalization at 900°C (heating in 50% NaCl + 50% KCl for 5 h), tempering at 600°C in NaOH for 3 h, quenching by steps (820 and 200°C) in salts (50% NaCl + 50% KCl), supercooling in a mixture of 63% KOH + 37% NaOH for 1 h, and tempering in alkaline at 1.5 h at 160°C.</td>
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We studied deformation of gears made of 20Kh2N4A steel and other Cr-Ni steels.

The use of mathematical statistics to analyze the precision of the gears is possible if the law of distribution of errors of the parameters determining the precision of the gears is known. Therefore, we determined the distribution of different parameters for all the gears (50 to 270 in each batch) with moduluses of 5, 5.5, 7, 8, and 9 mm with 9-61 teeth by the method described in [1]. We studied the two most widely used series of parameters (GOST 1643-56). The first series of parameters is the variation of the common normal $A_0L$ to the distance between the centers $A_0a$ during one revolution and $A_0a$ for one tooth: the error in the direction of the tooth is $A_B$. The second series is the radial play of crown gears $l_0$ and $A_0L$, the error in the profile $A_f$ and the limit deviation of the main pitch $A_t$, $A_B$. 

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Fig. 1. Variation of the length of the common normal after heat treatment I as a function of the shape of the gear made of 20Kh2N4A steel. 1) Gear of group I, \( m = 9 \text{ mm}, z = 18 \); 2) gears of group II, \( m = 9 \text{ mm}, z = 24 \); 3) gears of group III, \( m = 9 \text{ mm}, z = 20 \); 4) gears of group IV, \( m = 7 \text{ mm}, z = 30 \); 5) gears of group V, \( m = 9 \text{ mm}, z = 9 \).

Fig. 2. Variation of the length of the common normal for 20Kh2N4A steel gears of different shapes heat treated by condition I. The notations are the same as in Fig. 1.

Fig. 3. Influence of the different types of heat treatment on the length of the common normal of crown gears of 20Kh2N4A steel (\( m = 9 \text{ mm}, z = 18 \), group I). 1) After cutting the teeth; 2) after heat treatment 1; 3) after heat treatment 3; 4) after heat treatment 1; 5) after heat treatment 2; 6) after heat treatment 4; 7) after heat treatment 3.

We drew distribution curves for all these errors and calculated the eccentricity and the modulus of the difference according to the laws of normal distribution. The correspondence between the actual distribution and the theoretical one was checked by using the Kolmogorov criterion \( P(\lambda) \).

For most of the parameters investigated, the parameter \( P(\lambda) \) satisfied the normal distribution law. The shapes of the curves of the distribution of errors of separate parameters are close to the theoretical curves of normal distribution calculated for each parameter.

These errors in the parameters of gears (with the exception of the deviation of the main pitch and the length of the common normal) are positive magnitudes. The distribution curves of these magnitudes are close to the curves of normal distribution because in most cases the mean arithmetic error \( \bar{x} \) is larger than the mean square deviation \( \sigma \), i.e., the condition \( \bar{x} > 3\sigma \) is satisfied. The characteristics of the law of normal distribution are \( \bar{x} \) and \( \sigma \), and therefore we used these characteristics to determine the precision of the finish of the teeth. In cases where \( \bar{x} < 3\sigma \), we calculated the actual mean arithmetic values.

The acceptable errors were determined by the following equations:

For magnitudes with positive and negative deviations:

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\delta = \pm 3\sigma,
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