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# Low-temperature cementation – perspective technology of hardening of toothed parts

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**Abstract.** The structure, properties and geometrical accuracy of gear wheels after chemical heat treatment which cementation was carried out at 930°C and 870°C are investigated. Advantage of low-temperature cementation of toothed parts in size of a radial runout, fluctuation of a side clearance, ovality of an internal opening and the area of a spot of contact between teeth of the strengthened gear wheels is shown. Influence of structure of the endothermic atmosphere on mechanical properties and intensity of saturation by carbon steel 15HGN2TA and 20HGNMTA is investigated. It is established that increase in content of hydrogen from 20% to 40% in the endoatmosphere increases saturation speed carbon steel by 10 – 34%, excludes their hydrogen saturation and keeps indicators of mechanical properties of the cemented parts. The technology of chemical heat treatment of toothed parts including cementation at 870°C in the endothermic atmosphere containing 40% of hydrogen in the structure is developed and recommended for application.

## 1. Introduction.

The problem of increase in firmness of gear details in operation is considered one of most "ageless". Many experts solve it by application high-strength steel or due to use of the effective strengthening technologies. And in those and other cases indispensable condition is stability as on the accuracy of all geometrical parameters of detail, and on mechanical-and-physical properties of material of product. The special attention is deserved by the gear details high-loaded in operation which during the work at the same time are exposed to wear and test static, impact, flexural, contact and cyclic loads [1-5].

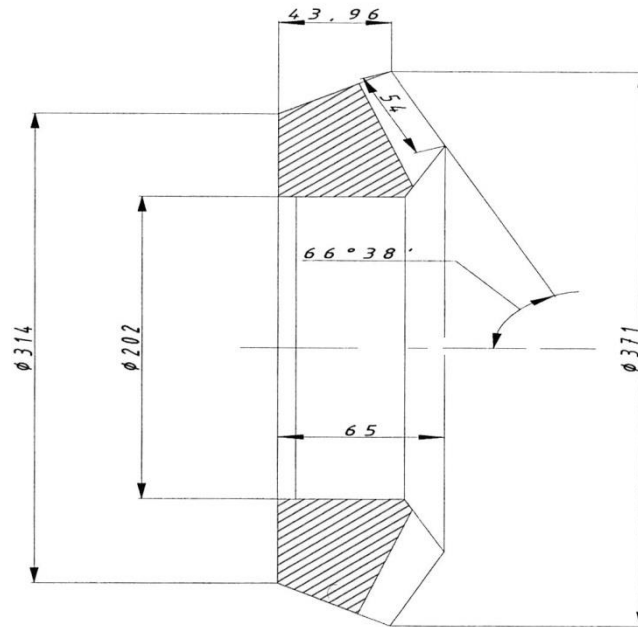
Results of experimental works and synthesis of production data show that in gear details it is inherent dispersion on macro – and to microgeometry, structure and mechanical-and-physical properties [4-7]. Receiving cases on the strengthened details of "spotty" cementation [8] are frequent that undoubtedly reduces the steel resilience to cyclic and other types of loadings. It is possible to achieve stabilization at the required level on deformation and buckling of details at high complex of mechanical and special properties of hardware due to development and implementation of innovative technologies in machine-building production. Considering that the center of collapse of details is in most cases observed on surface [5,9-10], the paramount value has to be given to blanket.

The work purpose – research and realization of the hidden reserves in technologies of steel redistribution at the machine-building enterprises directed to increase in accuracy of the geometrical sizes of gear details and stabilization at the high level of strength and plastic properties of hardware.



## 2. Methods of probe and results of work.

One of ways of complete solution of objective is the choice and justification of temperature of cementation of details. For confirmation of this hypothesis in work influence of technology of chemical heat treatment on structure, properties and geometrical accuracy of the conducted pinion gears (fig. 1) made of steel 20HGNMTA is investigated.



**Figure 1:** Form and the sizes of the conducted pinion gear from steel 20HGNMTA

The Chemical Heat Treatment (CHT) was executed in units of «Holkroft» and «Ipsen» with use of the chamber mechanized furnaces for cementation. On units of «Ipsen» «The Karbo-Prof» program allowing to steer the carbon potential of the atmosphere on duration of process of cementation of details is used. After cementation of detail chill to 850°C, tempered in the MZM hot oil – 26, washed out and subjected to holiday at temperature 180-200°C. Later CHT on details controlled the hardness, microhardness, depth and microstructure of the strengthened layer and core. Applied microscopes to metalgraphic probes «Neofot – 21», «Epitip – 2» and «IM 7200» with the system of the analysis of panoramic images «Video the Test — M» and the «Thixomet PRO» software product.

Took distance from surface to zone with the microhardness of HV of 550 determined by microhardness tester of «Dyurimet» at loading (0.1 N) for the effective depth of the cemented layer. Content of chemical elements in steel was determined on AH-7529 and AH-7560 analyzers, the AFS-51 spectrograph with the specialized software of SBP and NEXT and spectrometer «Spektrolab M-12» (Germany). Hydrogen content in steel was estimated according to GOST 17745 – 90 on the RH device – 2 «Leco».

Control of geometrical parameters of the strengthened details was carried out in laboratory and working conditions with use of instrumentation and the specialized equipment. The form, arrangements and the area of spot of contact piece between teeth of pinion gears in gearing were registered on control – the inspection machine. Relative area of spot of contact piece was defined by the relation actual to the area of spot recommended by regulations.

For determination of ovality of bore the caliper of ShTsTs-2 and Mahr 16 EW (Germany) used. Nonflatness of butt, size of radial run-out and backlash variation were measured on the multiple-purpose center Mar Gear GMX-400 (Germany).

Results of comparative probes of geometrical accuracy of pinion gears after CHT, structure and properties of the case are given in table 1. At measuring control it is established that all details which

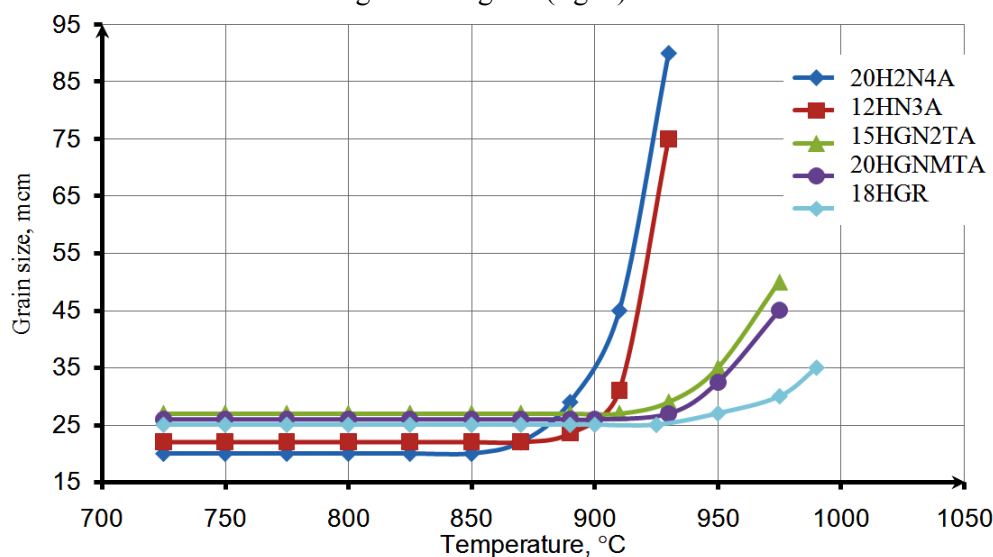
have undergone low-temperature cementation at CHT have undoubted advantage on stability of change of the analyzed dimensional indicators in comparison with details cemented on traditional technology – at temperature 930°C. Drop of temperature of cementation has allowed to reduce interval of dispersion of values on fluctuation of side clearance by 1.8 times, ovality of internal bore by 1.3 time, not planeness of butt by 2.0 times and the size of radial run-out by 3.5 times. Higher instability in dimensional parameters of details after cementation at temperature 930°C it is connected with disintegration of separate chemical compounds, austenite alloying with these elements and change of the grain building became which have impact on processes of phase and structural transformation when heating and cooling and, respectively, on change of volume and the sizes of hardware.

**Table 1:** Properties of the cemented\* gear steel 20HGNMTA details

Temperature (time) of cementation, °C	Thickness of the cemented layer, mm	Surface hardness, HV <sub>0,1</sub>	Microstructure of the cemented layer	Change of parameters of geometrical accuracy of details, mm				Relative area PC, %
				KBZ	EWO	NT	VRB	
930°C (13 hours)	1,3	762	M+A <sub>res</sub>	0,05 – 0,13	0,08 – 0,14	0,02 – 0,07	0,03 – 0,16	<u>58,86</u> 66,99
870°C (17,5 hours)	1,4	827	M+A <sub>res</sub>	0,05 – 0,09	0,02 – 0,06	0,01 – 0,03	0,04 – 0,07	<u>86,10</u> 81,69

Note: \* At cementation the gas atmosphere with the maintenance of 20% of H<sub>2</sub>, 20% with and 60% of N<sub>2</sub> is used. Designation: KBZ – backlash variation; EWO – ovality of internal bore; NT – notflatness of butt; PK- contact patch: in numerator on bent – in denominator on the convex party of teeth; VRB – size of radial run-out. M – martensite; A<sub>res</sub> – residual austenite.

In manufacturing techniques of the majority of details of cars from chromium-nickel steel including tappets of the hinge of the KAMAZ car, thermal methods of processing – hot plastic deformation are used, thermal and chemical heat treatment. Temperature of heating of metal at these stages of processing usually exceeds 900 °C. For example, heating under hot volume stamping makes 1220-1250 °C, and at heat treatment ~930 °C. At such temperatures of heating in steel type 20H2N4A, 12HN3A and similar low resilience to growth of grain (fig. 2) is observed.



**Figure 2:** Temperature dependence of growth of grain in steel

Chemical heat treatment in the specialized unit for chromium-nickel 1 steel (tab. 2, scheme 1) have not allowed to reach demanded (200 thousand cycles) the level of cyclic durability of details.

Periodic tests of 118 details strengthened on the specialized unit (tab. 2, scheme 1) have shown that their cyclic firmness to be ranging from 58 up to 118 thousand cycles. The characteristic type and the place of collapse of detail and also the macrostructure of surface of break are presented in figure 4. As a result of metalgraphic probes of details after collapse it is established that the hardness of surface was in limits of 57-60 HRC, and cores changed from 36 HRC to 45 HRC. Depth of the cemented layer fluctuated from 1.20 mm to 1.60 mm. In microstructure of the strengthened cemented layer presence of martensite (4-7ball), residual austenite and carbides (1-4ball) is revealed. Existence so-so – and coarse needled martensite testifies to the coarse-grained structure of steel [2].

It is established that the reason of the coarse-grained building in steel 20H2N4A, over crystallizable at 830 °C (scheme 1, tab. 2) is inheritance of large grain from cementation heating (920°C) and preservation of not broken up austenite at isothermal endurance (580±20 °C) before heating under training. It is shown that such condition of steel reduces the impact strength and indicators of strength of steel products (tab. 2 and tab. 3).

One of technology solutions on providing at the high level of properties of the cemented details from chromium-nickel steel application of low-temperature gas cementation. Despite reduction in the rate of diffusive saturation carbon, in such steel does not observe growth of grain at offered (870 °C) temperature that will not demand additional heat treatment on correction of the coarse-grained building. Chemical heat treatment of details on the offered technology (tab. 2, scheme 5) has provided the high level of properties of steel and its fine-grained building (fig. 3). It is necessary to notice that the general time of thermal treatment of steel (apart from tempering) on this technology is 22 hours instead of 20-23chas by traditionally known options in which the steel over crystallizable is provided (tab. 2, scheme 1 and 2).

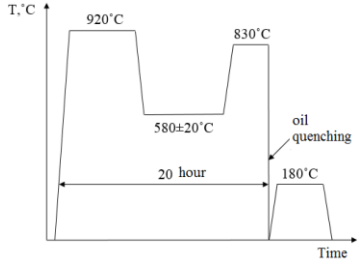
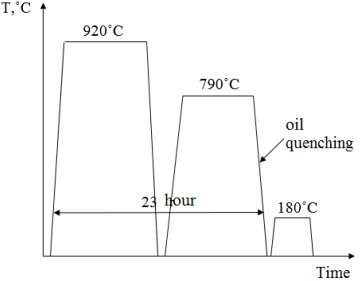
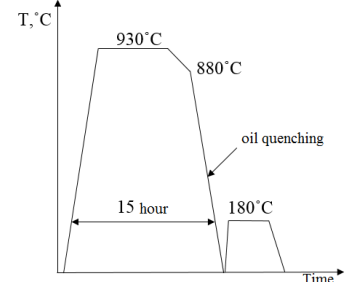
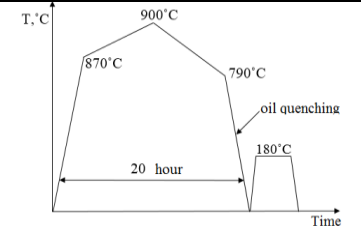
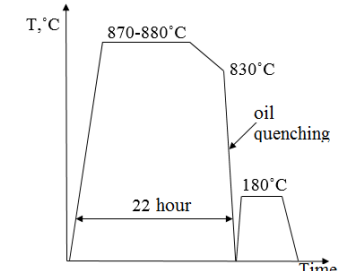
Many indicators of operational properties of gear details are connected with location, form and the area of spot of contact piece between teeth in gearing. The smoothness of gearing, noise level and size of contact tension depends on this criterion. The contact piece spot on teeth of pinion gears is normalized according to GOST 1643-81. It is revealed that CHT of pinion gears at cementation temperature 870°C allows to receive more favorable area and arrangement of spot of contact piece on teeth, than on teeth of the details which have undergone cementation at more high temperature.

On technical and economic indicators of drop of temperature of cementation can inevitably lead to increase in product cost. It is explained by reduction in the rate of saturation became carbon [12-13] and need of preservation on details of thickness of the strengthened layer. Therefore in thermal production are forced to increase duration of process of CHT.

The analysis of the CHT technologies used by various domestic and foreign enterprises demonstrate that at cementation in overwhelming number of cases the endothermic atmospheres as a part of which are present CO, H<sub>2</sub> and N<sub>2</sub> [11-13] are applied. Have essential difference of the atmosphere on the hydrogen content (20% and 40%) and nitrogen (60% and 40%). Not enough data on comparative characteristic of the endoatmospheres it is also impossible to give preference in information sources any of them. Therefore in work influence of hydrogen in such atmosphere on steel saturation speed by carbon and indicators of mechanical properties of the cemented products is estimated.

It is established that saturation speed carbon of details of various configuration and weight and made of steel 20HGNMTA, 15HGN2TA and 12HN3A at cementation with use in the endothermic atmosphere of 40% of hydrogen is higher, than when processing in the atmosphere from 20% of hydrogen. So, on steel 20HGNMTA the speed of saturation has increased from 0.073-0.090 mm/hour to 0.100-0.108 mm/hour, and on steel 12HN3A – from 0.087 to 0.108 mm/hour at temperature of the cementation of details corresponding 910°C in the mechanized furnaces of Holcroft. The know-how and statistical data have shown that due to change of content of hydrogen from 20 to 40% in the endothermic atmosphere the speed of saturation steel carbon increases by 10 – 34% (tab. 4).

**Table 2:** Structure and properties 20H2N4A after hardening of details according to various schemes CHT

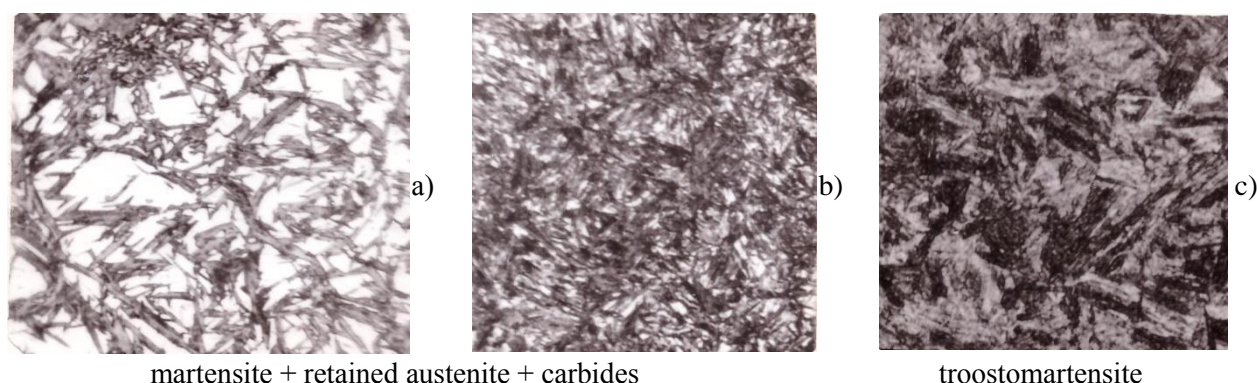
№	Scheme CHT and duration of process	Microstructure of the strengthened layer	Hardness $\frac{HRC_{surf.}}{HRC_{core}}$	Durability	
				$\frac{M_{dest.}}{M_{prop}}, \kappa N \cdot m$	N, thousand cycles
1		$M_{(5\delta)} + A_{res} + K$	$\frac{59}{43}$	$\frac{24,32}{17,18}$	90,6
2		$M_{(7\delta)} + A_{res} + K$	$\frac{55}{43}$	$\frac{24,79}{17,60}$	77,7
3		$M_{(6\delta)} + A_{res} + K$	$\frac{57}{42}$	$\frac{22,30}{15,90}$	66,6
4		$M_{(5\delta)} + A_{res} + K$	$\frac{58}{44}$	$\frac{25,12}{17,80}$	127,1
5		$M_{(3\delta)} + A_{res} + K$	$\frac{58}{42}$	$\frac{24,20}{18,40}$	314

Designations: M – martensite (point); A<sub>res</sub> – residual austenite; K – carbides; M<sub>dest</sub> – destroying moment; M<sub>pr</sub> – proportionality moment; N – number of cycles before collapse; HRC<sub>surf/core</sub> – hardness of surface (core).

**Table 3:** Properties of steel 20H2N4A after "false" cementation

Parameters of "false" cementation			
T, °C	Time, hour	Grain size, point	Impact elasticity (KCU), Dj/m <sup>2</sup>
870	20	8-11	4,15-5,04
890	20	7-11	3,50-4,94
910	15	6-9	-
920	14	5-9	1,2-1,7
930	15	4-7	1,1-1,7

Note: At each option about 15 samples are tested for impact elasticity.



**Figure 3:** Microstructure of the strengthened layer at distance of 0.3 mm (a) and 0.5 mm (b) from surface and microstructure of core (c) of details from steel 20H2N4A after CHT.  $\times 1000$ .

**Table 4:** Saturation speed carbon at cementation of details from variety of steel

Detail, material	Cementation time, h	Depth of layer, mm		Speed of saturation, mm/h	
		In the hollow	On the worker surfaces	In the hollow	On the worker surfaces
cylindrical gear, steel 20HGNMTA	14/17	$\frac{1,29 \pm 0,14}{1,20 \pm 0,16}$	$\frac{1,40 \pm 0,07}{1,25 \pm 0,15}$	0,092/0,070	0,100/0,073
gear, steel 20HGNMTA	14/17	$\frac{1,33 \pm 0,16}{1,28 \pm 0,13}$	$\frac{1,43 \pm 0,20}{1,29 \pm 0,13}$	0,095/0,076	0,102/0,082
the same	11/12	$\frac{1,22 \pm 0,18}{1,06 \pm 0,18}$	$\frac{1,30 \pm 0,16}{1,07 \pm 0,15}$	0,101/0,088	0,108/0,089
-//-	11/12	$\frac{1,18 \pm 0,13}{1,07 \pm 0,10}$	$\frac{1,26 \pm 0,13}{1,08 \pm 0,09}$	0,098/0,089	0,105/0,090
-//-	11/12	$\frac{1,22 \pm 0,12}{1,06 \pm 0,13}$	$\frac{1,29 \pm 0,12}{1,07 \pm 0,13}$	0,101/0,088	0,102/0,089
piston pin, steel 12HN3A	12/16,5	-	1,3/1,4	-	0,108/0,087

Note 1. In numerator sizes the corresponding cementations are specified in the atmosphere from 40% of hydrogen, in denominator - from 20%

2. Depth of layer corresponds to results of mathematical processing of 80 and more details

About negative impact of hydrogen in steel it is specified in many works of domestic and foreign scientists [14-16]. Therefore in work it was important to establish about possible hydrogen saturation of steel in the course of gas cementation in the water containing atmosphere.

To define how hydrogen content in the gas atmosphere affects the mechanical properties cemented steel, the samples which have undergone cementation in environments from 20 and 40% of hydrogen tempered in oil MZM– 16, washed out in KM-1 solution, released at 180°C within 120 minutes and then, those from them which on depth of the cemented layer differed no more than for 10%, were tested on torsion in accordance with GOST 3565-80. It is established that indicators of strength and the limit of proportionality cemented steel 15HGN2TA and 20HGNMTA in the atmosphere of the furnace practically do not depend on hydrogen content (tab. 5). At the same time, amount of hydrogen in processed steel also does not depend on its contents in the atmosphere: after processing in the atmosphere from 40% of hydrogen it is equal in steel 15HGN2TA to 1.25 ppm., from 20% of hydrogen – 1.41 ppm; in steel 20HGNMTA - 1,33 and 1,34 ppm respectively.

The fraktografichesky probes of breaks same cemented by steel it is established that in cementation zone the collapse displaced "fragile intergranular" and "visdisity calyceal". Quantity of fragile and visdisity components in break became identically in case of its processing in the gas atmosphere with 20 in 40% of hydrogen [17-18].

Thus, results of mechanical tests and fraktografichesky probes of breaks have shown that change of content of hydrogen in the endothermic atmosphere from 20 and 40% does not increase fragility investigated by steel.

**Table 5:** Mechanical properties of steel the endoatmospheres cemented in various structures

Steel	Depth of the cemented layer to HV550mm	Surface hardness HRC	Ultimate strength, MPa	Limit of proportionality, MPa
15HGN2TA	1,43/1,30	60/60	1450/1500	750/740
20HGNMTA	1,77/1,72	62/61	1440/1500	860/860

Note. In numerator sizes, the corresponding cementations are specified in the atmosphere from 20%, in denominator – from 40% of hydrogen.

As a result of complex probe of CHT technology of gear details it is revealed that drop of temperature of cementation with 930°C to 870°C allows to minimize change of the sizes of details after hardening, and application of the endothermic atmosphere from 40% of hydrogen instead of 20% will keep the capacity of thermal units in connection with bigger activity its sating ability.

### 3. Conclusions

1. Influence of temperature of cementation and structure of the endoatmosphere on geometrical accuracy is investigated, the speed of saturation there were carbon and properties of gear details after CHT. Advantage of cementation of gears is shown at 870°C.
2. Increase in content of hydrogen from 20% to 40% in the endothermic atmosphere increases steel saturation speed carbon by 10 – 34% and keeps indicators of mechanical properties of the cemented details at the high level.
3. It is recommended to apply cementation to gear details at 870°C with use of the endoatmosphere containing 40% of hydrogen.

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