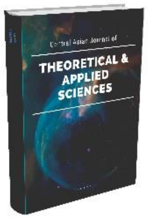

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Improving the Accuracy and Efficiency of the Production of Gears using Gas Vacuum Cementation with Gas Quenching under Pressure

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Abstract: *The article discusses effective methods of increasing the strength properties of steel gears of cylindrical and conical gears, mainly using methods of chemical-thermal treatment, gas cementation (nitrocementation) in controlled endothermic atmospheres with subsequent quenching in oil.*

Keywords: *Contact endurance of teeth, efficiency improvement, cementation (nitrocementation), gas vacuum cementation, quenching with gas under high pressure, nitriding, pitting.*

Gears are widely used in modern machines. There are power gears designed to transmit torque with a change in the frequency of rotation of the shafts, and kinematic gears that serve to transmit rotational motion between the shafts at relatively small torques.

Gears are widely used due to their versatility, high efficiency, the possibility of application in a wide range of speeds and capacities, compactness and reliability. To ensure these operational capabilities, high requirements are placed on the quality of the working surfaces of the gears. Their processing requires high qualification and special training of all employees. Processing of teeth and base holes is one of the most complex types of mechanical processing performed on specialized machines using expensive special tools.

The following types of gears are used in gears:

- cylindrical (straight-toothed, oblique-toothed, spiral and chevron);
- conical (straight-toothed, oblique-toothed and with a curved tooth);
- worm-like.

The hardness of the working surfaces. As a result of heat treatment, the surface hardness of the teeth of the cemented gears should be within the range of 45 ... 60 HP at the depth of the cementation layer 1.. .2 mm. When cyanizing, the hardness of the HP is 42...53, the layer depth should be within 0.5...0.8 mm.

The hardness of non-hardened surfaces is usually in the range of HB 180...270.

For the gear wheel in question:

- the landing hole is made according to the 7th quality;
- the accuracy of the form is not set;
- the accuracy of the relative position is limited by the value of the end runout of flat surfaces relative to the axis of the hole no more than 0.016 mm, as well as the value of the asymmetry of the keyway relative to the axis of the hole no more than 0.02 mm;
- surface roughness of the toothed crown Ra = 0.63 microns, holes and ends-1.6 microns. The toothed crown is tempered by HDPE to HP 45...50 to a depth of 1.... .2 mm.

Depending on the purpose, the transmitted loads and operating conditions, the material for the manufacture of gears is selected. At the same time, it is necessary to take into account such requirements for the material as: good machinability by cutting, the least warping during heat treatment, low cost.

In accordance with the main operational requirements, such as high strength, wear resistance, durability and taking into account technological requirements, structural steels are used for the production of gears: carbon (40, 45, 50), carbon with reduced hardenability (55PP), chromium (20X, 35X, 40X, 50X), chromium-nickel (12KHNZA, 12X2N4A, 2OHNZA, 20X2N4A, 20KHN, 40KHN), chromium-nickel with boron (20KHNR) and with molybdenum (20KHNM, 20KHN2M, 18KH2N4MA), chromium-manganese (18KHG), chromium-manganese with titanium (I8KHGT, 25KHGT, Z0KHGT), with nickel (I4KHGN, 19KHGN), with molybdenum and titanium (25XGM), chromium-molybdenum (20XM), chromium-manganese-nickel with titanium (15XGNTA, 15XGN2TA), with boron (20XGNR), with titanium and boron (20XGNTR), with molybdenum and titanium (25XGNMT), chromium-molybdenum-aluminum (Z8XMYA, 38X2MYA).

The main disadvantages of gears made of carbon steels are relatively low strength and large warping during heat treatment.

Alloy steels containing chromium, nickel, molybdenum and other alloying elements are used for the manufacture of high-load gears. Due to the low carbon content, the surface layer of gears made of alloy steels is subjected to cementation and nitrocementation, and from medium - carbon steels-nitriding. After chemical-thermal treatment, the gears made of these steels have higher wear resistance, impact strength and fatigue resistance.

The presence of residual internal compression stresses in the surface layers of the teeth with a depth of up to 0.02 mm also contributes to increasing the resistance of the tooth surfaces to wear under the influence of contact stresses.

The scope of application of various materials and chemical-thermal processes in the manufacture of gears, as well as the achieved contact endurance of the teeth in accordance with the ISO 6336 standard are shown in Fig. 1.

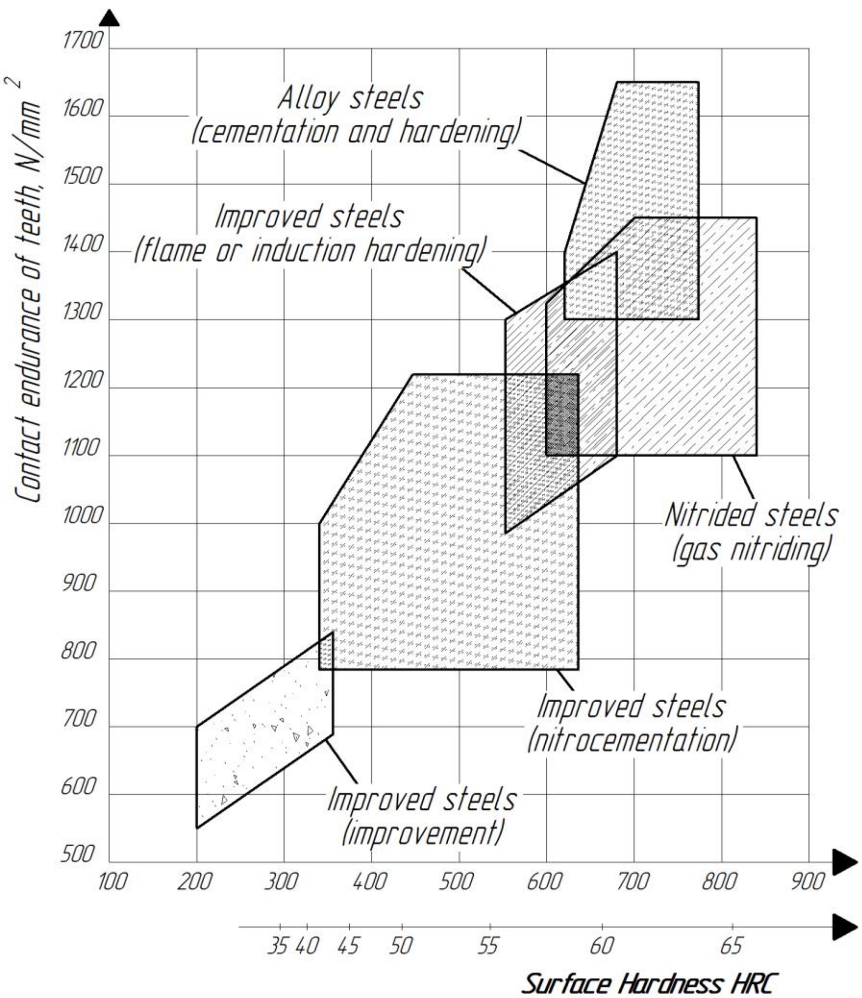

Fig.1 Contact endurance and hardness of the surface of the teeth of the wheels under various CTO methods

At the same time, not specific brands are indicated, but a wide range of steels included in the group, for example, alloyed, improved, nitrided and others. Each group covers a large number of steel grades, which differ significantly from each other in composition and properties. Of course, when determining the grade of steel and chemical-thermal treatment, the design features of gearing gears and their operating conditions should be taken into account.

It should be noted that for gears operating at high loads and circumferential speeds and having significant contact stresses, alloy steels are most often used after cementation (nitrocementation) and quenching, characterized by a contact endurance limit of the side surfaces of 1300 -1650 N/mm2 [1, 2].

Along with high contact strength, gears made of alloy steels after cementation (nitrocementation) and quenching also have high bending endurance in the range of 320-540 N/mm2 (Fig. 2).

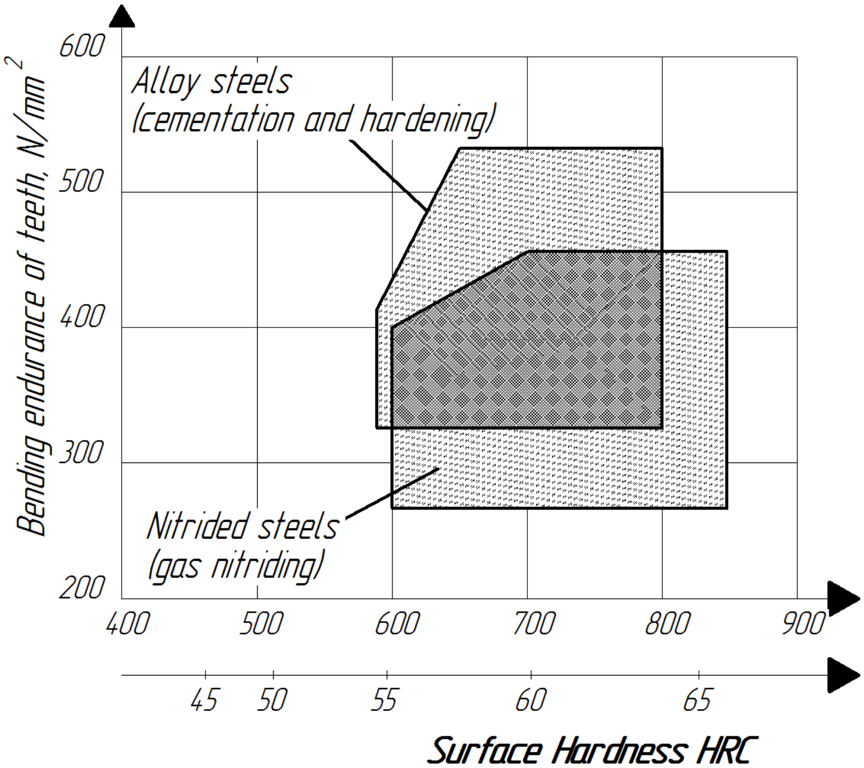

Fig.2 Bending endurance and surface hardness of wheel teeth under various CTO methods

The bending endurance of the teeth is characterized by the resistance of the gear engagement to fatigue breakdowns that occur at the base of the tooth. The force Fn, which reaches the maximum value when engaging in the area of the dividing line of the tooth and acts perpendicular to its surface, as well as the bending arm hf determine the stresses at the base of the tooth (Fig. 3). At the same time, the maximum possible radius of rounding rf at the base of the tooth and the thickness of the tooth leg along the chord Sf are crucial for achieving high bending strength under the action of the force Fn.

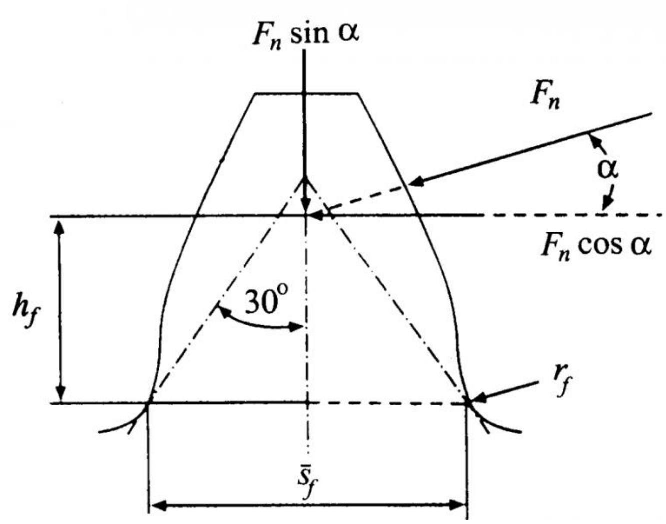

Fig.3 The scheme of determining the bending endurance at the base of the tooth

The technological process of manufacturing gears also has a great influence on the bending endurance of the teeth. The smooth coupling of the side surfaces of the teeth with their base at the maximum radius of rounding rf, which is obtained, for example, by simultaneously grinding the side surfaces and the bottom of the tooth cavity, can significantly increase the bending strength of the teeth.As a rule, gears after cementation have higher bending endurance indicators compared to gears after nitriding, while grinding the side surfaces of the teeth and the bottom of the cavity allows increasing the bending endurance of both cemented and nitrided gears.

The conducted studies allowed us to establish the main advantages of cementation and nitrocementation processes in comparison with nitriding:

1. A wide range of adjustment of the thickness of the hardened layer.
2. The possibility of carrying out CTO gears made of economically alloyed steels (low - and medium-alloyed).
3. High performance of CTO gears with the possibility of quenching after cooling or directly from the diffusion saturation temperature.
4. High indicators of bending and contact endurance of the teeth.

To obtain the necessary strength properties of steel gears of cylindrical and conical gears, gas cementation (nitrocementation) methods are mainly used in controlled endothermic atmospheres with subsequent quenching in oil [3]. At the same time, the CTO process is performed in automated pass-through and chamber units that have high productivity and provide a full processing cycle from heating to quenching. However, practice has shown that the use of such technology has a number of significant disadvantages:

- high consumption of the process atmosphere and high costs for its production;
- constant release of CO2 and CO into the environment due to incomplete combustion of the atmosphere after the completion of the process.
- oxidation of the working surfaces of the teeth of the wheels, which reduces the hardness of the surface of the teeth and their contact strength;
- high energy costs and labor intensity of equipment maintenance.

Along with the necessary hardening, cylindrical and conical gears with CTO receive significant volumetric deformation, the accuracy of the teeth is reduced by 1-2 degrees, respectively, according to GOST 1643-81 and GOST 1758-81. The basic and other responsible surfaces of gear blanks are also deformed: holes, cylindrical surfaces of shafts, ends, side surfaces of teeth and slots.

It is known that a large number of factors influence the deformation of gears during CTO, including: the design of the workpiece, the properties of the steel used, methods for obtaining forgings, pre-heat treatment, conditions for performing mechanical processing, etc. The decisive influence on the deformation is exerted by the unequal cooling intensity of different surfaces of the workpieces during quenching.

When quenching in oil, the workpiece heated during cementation is located in three different zones: convection, bubble and film boiling. This causes large temperature differences in the workpieces of the shaft type along the length, as well as inside the workpiece and on its surface. The different intensity of cooling of individual parts and surfaces of the workpiece during quenching in oil is the cause of significant deformations.

In this regard, gas vacuum cementation has recently been increasingly used. At the same time, the best results were achieved when using vacuum cementation in combination with subsequent quenching with gas (helium, nitrogen) under high pressure.

The great advantage of gas carburization at low pressure is the possibility of significantly increasing the productivity of the cementation process and reducing energy costs and the production cycle of gears.

The CTO of the cylindrical oblique gear wheel of the gearbox shown in Table 1 (mn = 4.0 mm, z = 37, β = 23°) with the achievement of a cementation layer thickness of 0.8 mm (0.35% C) showed that the method of vacuum cementation with subsequent quenching is more productive than gas by ≈18%.

Comparison of the performance of vacuum and gas cementation and subsequent hardening

Table 1.

Stages of the process	Vacuum installation	Gas installation
Loading	15 min	5 min
Heating up to 980°C	90 min	90 min
Cementation and diffusion	120 min	180 min
Reducing the temperature	45 min	60 min
Tempering	20 min	20 min
Discharge	5 min	5 min
Total time	295 min	360 min

In order to reduce the deformation of the curved teeth of the driving hypoid gear, it was decided to perform chemical-thermal treatment using a combination of vacuum cementation and gas quenching under pressure [6]. The driving hypoid gear of the shaft type made of low-carbon steel 25XGT had the following parameters: the number of teeth z = 11, the external circumferential module mte = 7.37 mm, the external height of the tooth he = 16 mm, the average angle of inclination on the surface of the depressions β = 45° 23', the hypoid displacement a = 36 mm, the normal pressure angle: on the working side (concave) of the tooth ap = 20° 15'; on the reverse side (convex) of the tooth ao = 24° 45' (Fig. 5).

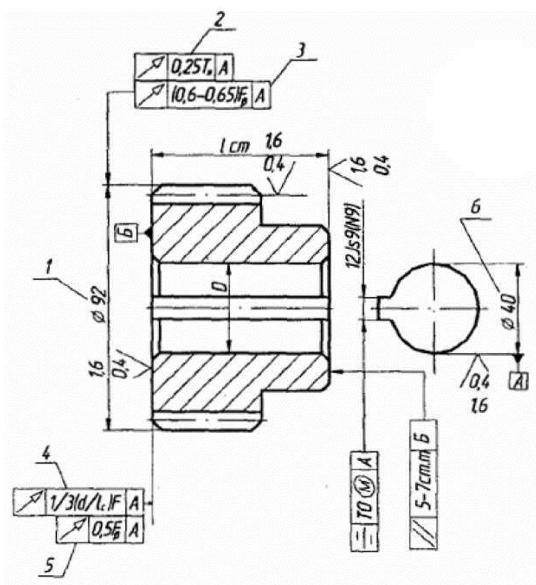

Fig. 5. A gear wheel with requirements for the accuracy of its manufacture.

The vacuum process of carburization began with the creation of a vacuum in the furnace of heating the workpiece to a high temperature of 980°C (possibly up to 1050°C) in an atmosphere without oxygen, in a nitrogen environment, which prevented the formation of harmful oxidation (Fig. 6).

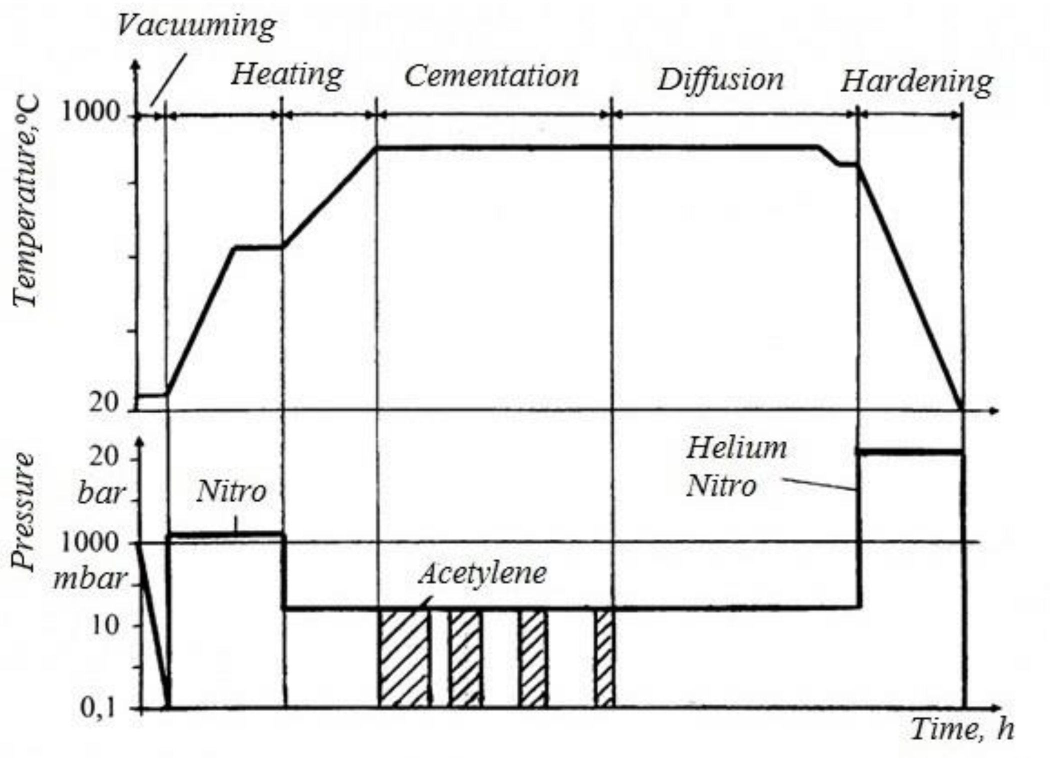

Fig.6 Scheme of vacuum cementation and gas quenching under pressure

Vacuum cementation was performed at low pressure in an acetylene medium (carbon content with ≈ 92%), which at high temperature has a significant dissociation rate. The high speed of carbon transfer to the surface of the workpiece of the driving hypoid gear has significantly reduced the time compared to atmospheric carburization and increased the productivity of the carburization process. To avoid the formation of carbides in the area of the tooth head, vacuum cementation was carried out by pulses by alternating short phases of carbon saturation and long phases of carbon diffusion into the surface layer of the workpiece.

Immediately after cementation, hypoid gears were fed into a quenching chamber providing high pressure (up to 2 MPa) of cooling gas (helium) with the possibility of regulating the feed rate (up to 25 m/s) and reversing the gas flow. The decisive advantage of quenching with gas under pressure compared to cooling into oil is the reduction of gear errors that occur during the phase transition. Heat exchange is carried out homogeneously, therefore, conditions arise to minimize the error in the size and shape of the teeth, as well as the base and auxiliary surfaces.

In existing industries, hypoid gears of the shaft type with curved teeth, after cementation (nitrocementation) and quenching in oil, the center holes are cleaned from traces of soot and burn, the radial runout of the base necks is controlled and adjusted when installed in the centers.

The high quality of gears is achieved with their systematic control throughout the entire manufacturing process. The most important surfaces of gears are the base surfaces and the gear ring. High requirements for the accuracy of geometric dimensions, the shape of parts and the roughness of surfaces determine the following types of technological control of gears:

- operational control, which is carried out by adjusters and workers directly at the workplace during the shift, after changing the tool and setting up the machine;
- interoperative selective control performed by employees of the OTC at specially designated control

posts, in the amount of 3...20% of the output of parts;

- final inspection performed by the employees of the OTC before sending the parts to the thermal workshop or for assembly.

The control of the main parameters of the gear teeth is carried out in measuring laboratories after changing the tool or setting up the machine. For each degree of accuracy of the gears, the norms of kinematic accuracy, smooth operation and contact of the teeth in the transmission, as well as tolerances for the lateral gap in the coupling are established. To control gears, the manufacturer can choose any combination of standards based on the operating conditions of the transmission, the required accuracy of measuring instruments, the dimensions of the gears.

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