We studied the contact fatigue resistance of case-hardened steel, using four-roller machines to imitate (at the surface of the rollers) friction conditions close to the actual working conditions of gear teeth [1]. The distribution of the sliding velocities over the circumference of rollers is shown in Fig. 1. The contact fatigue strength was measured by the working life under stresses of 18,000 or 24,000 kg/mm² according to the Hertz method.

The tests were divided into stages in each of which the sample was subjected to a certain stress under identical conditions. After each stage we measured the radial wear of the rolling surface every 30° of the circumference (with a vertical optimeter) and the microhardness 20 microns from the surface of friction. We also examined the working surface under magnifications of 10 and 100. The magnitude of the wear measured with the optimeter is the total crumbling out by wear and pitting. Also, we studied the variation of residual first-order stresses on the working surface during friction. Tangential residual stresses were determined by the generalized Davidenkov method [2, 3].

We investigated the influence of the structure and hardness on the contact fatigue strength of 18Kh2N4VA steel which, after case hardening, was heat treated as follows: 1) quenching in oil from 850°C and tempering at 140°C (HRC 54); 2) high temperature tempering at 650°C, quenching in oil from 800°C, and tempering at 140°C (HRC 59); 3) quenching from 800°C, cold treatment at −120°C, and tempering at 140°C (HRC 63). The thickness of the case-hardened layer was 1.7–1.9 mm.

The working surface of the roller was heat treated and then 0.3 mm of the radius was ground off so that the friction surface corresponded to the case-hardened layer containing the maximum amount of residual austenite.

Standard connected rollers of 20Kh2N4A steel were case hardened and heat treated to a hardness of HRC 60-61.

It is widely believed that the contact fatigue strength varies proportionally with the hardness of the material. The results we obtained show that the contact fatigue strength of case-hardened alloyed steel depends not so much on hardness as on the microhardness of the case-hardened layer, which varies with the amount of residual austenite and carbides resulting from the heat treatment conditions. Not only the amount of austenite but also its distribution plays an important role. As the result, the variation of the contact fatigue strength as a function of hardness is not uniform. Thus, treatment of 18Kh2N4VA steel at subzero temperature (heat treatment No. 3), which ensures a considerable increase in hardness as compared to heat treatments 1 and 2, does not increase the resistance to contact fatigue (Fig. 2).

X-ray and structural analyses of the case-hardened layer showed different amounts of residual austenite and a difference in the composition and the distribution of phases after the different heat treatments.

Heat treatment No. 2 induces uniform distribution of the structural components—hidden needle structure of martensite and small areas of austenite. These latter are so small that when the amount of austenite is 35% they cannot be seen under a magnification of 1000. The structure resulting from treatment at subzero temperatures induces a combination of needle martensite formed during quenching and hidden needle martensite formed during cooling to subzero temperature, i.e., the inherited structural heterogeneity peculiar to the case-hardened layer of highly alloyed steel (and due, apparently, to the concentrational heterogeneity) is preserved.

The microhardness of austenite which is not decomposed during treatment at subzero temperatures (H 640–680) is considerably higher than the hardness of the residual austenite before the treatment at subzero temperature (H 520).

X-ray analysis showed that the concentration of carbon in residual austenite after quenching is 1.2–1.3%.
Diffusionless transformation of a large amount (65-70%) of high-carbon austenite and of austenite alloyed with chromium and nickel is apparently responsible for the high microstresses produced during cooling to subzero temperature under conditions in which relaxation processes are difficult (this is also indicated by the considerable increase in the microhardness of residual austenite). The increase in the microhardness of the residual austenite decreases the resistance to rupture in steel treated at low temperature, which explains the ineffectiveness of treatments at very low temperatures for increasing the contact fatigue resistance of case hardened steel (similarly, the strength of untempered martensite in medium carbon steel is low). At the same time, the case hardened layer containing a considerable amount of austenite and, consequently, having a low hardness (HRC 54-56), has a high contact fatigue strength (Fig. 2a).

The investigation showed that the pre-pitting cracks appear earlier and develop faster on the case-hardened surface treated at very low temperature than on the surface not treated at subzero temperature. This phenomenon can be explained by the dynamics of the formation of pits, which is the result of two simultaneous processes: 1) cold working of the surface (smoothing and removal of the peaks of the protrusions left by mechanical treatment) with the formation of cracks under the influence of alternating stresses; 2) diffusionless transformation of a large amount of high-carbon austenite and of austenite alloyed with chromium and nickel under conditions in which relaxation processes are difficult, which increases the microhardness of residual austenite and decreases the resistance to rupture in steel treated at low temperature.