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CALCULATION OF THE DURABILITY OF A CHEMICALLY-THERMALLY TREATMENTED GEAR WHEEL BY THE WEAR CRITERION

РАСЧЕТ ДОЛГОВЕЧНОСТИ ХИМИКО-ТЕРМИЧЕСКИ ОБРАБОТАННОГО ЗУБЧАТОГО КОЛЕСА ПО КРИТЕРИЮ ИЗНОСА

Abstract: The article studies the service life and durability of gears, which include a carburized wheel and a pinion subjected to ion nitriding, has a longer technical service life than a gear transmission consisting only of carburized parts. The durability of a nitrided gear, which is three times higher than that of a carburized one, is also considered. As a result, the study analyzed that, in addition to iron nitrides, special nitrides are formed in the near-surface layers with the participation of alloying elements of steel, in particular chromium and molybdenum.

Аннотация: В статье исследованы ресурс и долговечность зубчатых передач, включающих цементированное колесо и шестерню, подвергнутую ионному азотированию, которая имеет больший технический ресурс, чем зубчатая передача, состоящая только из цементированных деталей. Также рассмотрена долговечность азотированной шестерни, которая в три раза выше, чем цементированной. В результате исследования установлено, что, помимо нитридов железа, в приповерхностных слоях образуются специальные нитриды с участием легирующих элементов стали, в частности хрома и молибдена.

Annotatsiya: Maqolada ion nitridlashga uchragan karburizatsiyalangan g'ildirak va podshepnikni o'z ichiga olgan tishli g'ildiraklarning xizmat qilish muddati va mustahkamligi o'rganiladi, ular faqat karburizatsiyalangan qismlardan iborat tishli uzatmaga qaraganda uzoqroq texnik xizmat muddatiga ega. Nitridlangan tishli g'ildirakning mustahkamligi ham ko'rib chiqiladi, bu esa karburizatsiyalangan tishli g'ildiraknikidan uch baravar yuqori. Natijada, tadqiqotda temir nitridlaridan tashqari, po'latning qotishma elementlari, xususan, xrom va molibden ishtirokida sirtga yaqin qatlamlarda maxsus nitridlar hosil bo'lishi tahlil qilindi.

Key words: Gear wheels, operation, technical condition, wear, repair, capital, durability, resource, write-offs, statistical, assessments, probability, indicators, reliability, probability, analytical calculation.

Ключевые слова: Зубчатые колеса, эксплуатация, техническое состояние, износ, ремонт, капитальный, долговечность, ресурс, списания, статистический, оценки, вероятность, показатели, надежность, вероятность, аналитический расчет.

Kalit so'zlar: Tishli g'ildiraklar, ishlatish, texnik holat, termik purkash, ta'mirlash, kapital, chidamlilik, resurs, hisobdan chiqarishlar, statistik, baholashlar, ehtimollik, ko'rsatkichlar, ishonchlilik, ehtimollik, analitik hisoblash.

INTRODUCTION

One of the fundamental requirements for the operation of machines and other equipment is their failure-free operation up to the ultimate limit state in accordance with the technical operating conditions for a specified period of time. For many non-repairable components, particularly gears, the ultimate limit state coincides with failure and essentially determines the service life of the component.

An analysis of the methodology for selecting durability indicators shows that the most acceptable and simple selection method is a preliminary classification of the components, their operating conditions, and the consequences of failure. A fairly general classification of factors determining the selection of durability indicators has been proposed in [1, 2].

Since statistical definitions of indicators are obtained as a result of reliability tests, the statistical form of presenting the indicators is convenient for experimental reliability studies, and the probabilistic form is convenient for analytical calculations. The methodology for calculating reliability indicators is selected in accordance with GOST 27.301-95 "Reliability in Engineering. Reliability Calculation. Basic Provisions" [3, 4]. In our case, a probabilistic method for calculating typical machine parts according to the wear criterion is used, since gears are considered wearable items.

Main part

Analysis of gear damage reveals that premature failure is primarily due to processes occurring in the surface layers of the teeth. This is where the primary accumulation of various volumetric and structural defects occurs, contributing to intensive wear and the development of contact fatigue phenomena, which dramatically reduces the load-bearing capacity of the entire product. All of this must be carefully considered when determining the service life of components that experience various dynamic contact interactions during operation. Under such conditions, the use of steels and alloys with volumetric hardening alone cannot fully resolve the durability issue [5]. Improved gear performance can be achieved through various surface hardening methods, which not only increase the hardness of the near-surface layers but also generate residual compressive stresses within them.

It is known that for structural steels that can be improved, the greater the hardness, the higher the resistance to contact fatigue, and the ratio of the contact fatigue limit (σ_{-1}^{k}) with the number of loading cycles to the surface hardness is a constant: $\sigma_{-1}^{k} = k * HRC$, (1)

where is a coefficient depending on the hardness and the type of strengthening surface treatment.

For example, GOST 21354-87 for case-hardened (nitrocarburized) steels with surface hardness sets the contact fatigue limit at

Thus, the durability of friction pairs will be determined not only by the correct choice of component material, but also by the rational application of various technologies that increase surface hardness, such as thermochemical treatment. Thermochemical treatment, through diffusion saturation with various elements, can widely alter the chemical composition, structure, and properties of the surface layer.

To assess component wear during an experiment, a functional dependence of the failure-free operation probability of a wearing component on its operating time can be used. This dependence was derived from the gradual failure model proposed by A.S. Pronikov [6], whose main calculation parameter is wear rate.

Calculation using formula (3) is based on the assumption that the dependence of the component's surface wear on operating time, ignoring the running-in period, is linear and most accurately characterizes the resource distribution of components operating for long periods under steady-state wear conditions. An abrasive wear model was adopted as the calculation model, as this type of wear involves intense destruction of the friction surfaces of friction pairs due to microplastic deformations, microcutting, and other factors.

In order to estimate the wear rate of the contacting surfaces, a calculation of the contact parameters was performed. The value of the maximum pressure in the tooth contact zone can be obtained from G. Hertz's solution for the problem of contact between two cylinders with parallel axes [7]. If the radius of curvature of the lateral surface of one tooth is many times greater than that of the other, then the case of contact between a cylinder and a plane can be considered [8].

where is P_m the maximum Hertzian pressure, MPa;

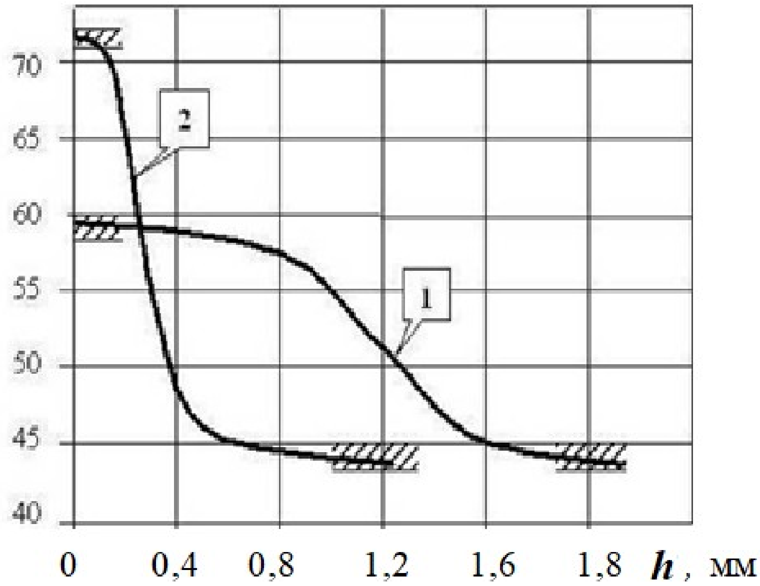
N_e is the specific normal load, N/m;

θ_t is the elastic constant for the contact case, m2/N;

$r_{пр}$ is the reduced radius of curvature, m.

In this study, to determine the effect of the hardness ratio of gear contact surfaces on wear resistance under contact loading, gears and pinions made of 34KhN1M steel with a module of mm, a tooth width of 25 mm, a pinion tooth count of 26, and a wheel tooth count of 42, with a center distance of 169.4 mm, were used.

Two thermochemical treatment methods were selected for these test pieces, each with its own technological characteristics and allowing for the production of hardened layers of varying hardness and thickness on the surface of the workpieces. In one case, the contact pair was subjected to carburization only, resulting in an effective diffusion layer thickness of 1-1.2 mm with a surface hardness of 1000 mm and a tooth core hardness of 1000 mm. In the other case, the gear was processed using the first method, and the pinion was nitrided in a glow discharge plasma. Ion nitriding was performed on pre-heat-treated parts using the same refinement regime as after carburization, which also allowed for a tooth core hardness of [unclear]. As a result of glow discharge plasma nitriding, the total diffusion layer thickness was 0.3-0.4 mm with a surface hardness of [unclear]. The hardness distribution across the hardened layer thickness of the gears studied is shown in Fig. 1.



Thickness of the hardened layer

Fig. 1. Hardness distribution across the thickness of the hardened layer: 1 - case-hardened gear; 2 - nitrided pinion.

The mechanical properties of 34KhN1M steel after volumetric strengthening heat treatment were studied on witness specimens under static tension at a temperature of 20°C. The average values of the ultimate tensile strength for both gears and pinions were MPa, and the relative elongation was 13-15%. For the calculations, the normal modulus of elasticity was assumed to be equal to MPa, and Poisson's ratio was 0.3 [8].

The experimental setup used was a rig consisting of a variable speed DC drive motor and two identical single-stage gearboxes, the shafts of which are connected to each other by means of cardan transmissions that close the power circuit, the kinematic diagram of which is given in [9]. The loading characteristics are shown in Fig. 2.

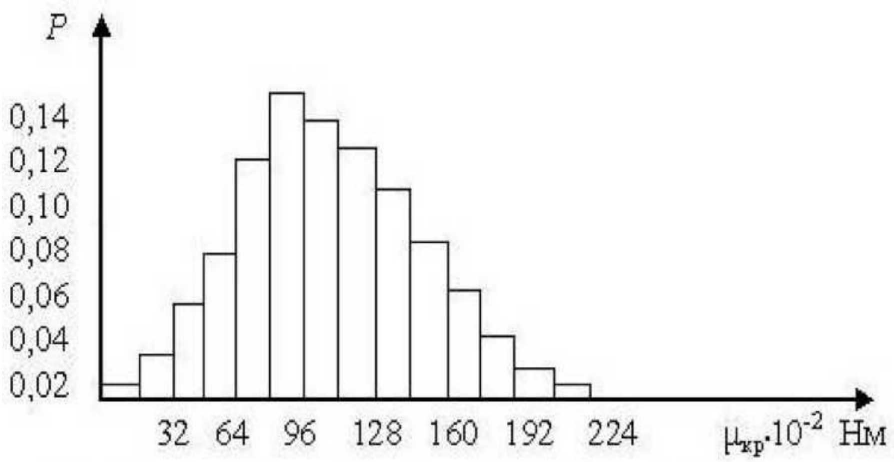


Fig. 2. Histogram of torque distribution on gear 1 and gear 2 at a gear rotation speed of 320 rpm

During the calculation, it was assumed that wear along the working profile of the tooth is practically uniform. This approach is due to the uniform pressing of the contacting surfaces during operation, which makes it possible to ignore changes in tooth geometry during wear given the relatively high hardness of the working surfaces of the wheels. For the calculation, we adopt the value of the specific normal load of 1.31 N/m, the value of the elastic constant of 9.1 m2/N, and the value of the reduced radius of curvature = 0.0345 m. Substituting these values into formula (4), we determine the average value of the maximum pressure = 364 MPa. [10].

The standard deviation of the pressure in the contact of the teeth ap can be determined from the dispersion of the torque on the gear, the value of which, in accordance with the torque distribution histogram, reaches 96 MPa (see Fig. 2). The contact area of the teeth is a rectangle of width . The half-width of the contact strip is determined according to Hertz's theory by the formula:

$$2b_H = 1{,}128\sqrt{\theta_\varepsilon r_{\text{пр}} N_e}$$

The calculation results yield a value of 2.2810-4 m.

The wear rate of contacting surfaces in the presence of abrasive particles in the lubricant depends on a number of factors characterizing the kinematic and geometric parameters of the interface, the mechanical properties of the friction surface materials and abrasive particles, as well as the properties of the lubricant and other factors. Common to all wear rate assessment methods is the use of coefficients determined empirically through laboratory testing on samples or from operating data from actual friction units.

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