Prediction of the "Screw-nut" gear life

Oleg Zhelezkov[1], *Evgeny* Martynov[2], *Maksim* Kharchenko[1,*], and *Roman* Dema

[1]Magnitogorsk state technical university named after G. I. Nosov, Magnitogorsk, Russia
[2]Starooskolsky branch of the Moscow Institute of Steel and Alloys, Stary Oskol, Russia

Abstract. A method has been developed for predicting the service life of a screw pair nut with a large thrust thread, which is based on the energy theory of wear. Based on the results of finite element modeling using the DEFORM-3D software package, the dependence of the change in normal pressures on the contact surface of the nut with the screw along the height of the thread projection was established. Using the SMTs-2 friction machine, a series of experiments was carried out and the coefficient of friction and the energy index of wear intensity were determined for bronze of the brand BrA9Zh3L, used in the manufacture of nuts for screw mechanisms with coarse threads. The calculation of the service life of the nut of the pressure device of the rolling stand of the hot rolling mill 2000 has been performed. The limit value of the number of revolutions of the screw is established, the excess of which leads to critical wear and destruction of the threads.

1 Introduction

Screw pairs of machines and mechanisms operate under conditions of intense abrasion of contact surfaces. Wear depends on many factors: the shape and dimensions of the contact surfaces, the forces acting on these surfaces, the thread profile, the speed of screwing, the roughness and hardness of the surfaces, temperature, the presence of lubricant, etc. The above factors act simultaneously, which significantly complicates the possibility of taking them into account when predicting the wear resistance and service life of friction pairs.

The developed technique for predicting the wear resistance of a screw pair nut is based on the energy theory of wear of solids [1-4], according to which the volumetric wear is directly proportional to the work of friction forces in the contact zone, i.e.

$$\Delta W = J_{\omega} \cdot A_{mp} \tag{1}$$

where J_{ω} (m3/J) – energy indicator of wear intensity, which is determined on the basis of experimental studies using special equipment (friction machines).

A method has been developed for predicting the wear resistance of a screw pair nut, which includes the following steps:

The parameters of the contact zone of the screw pair are determined: the profile and dimensions of the contact zone, the conditions for mutual movement, the mechanical properties of the nut and screw, the state of the surface (roughness and hardness), etc.

* Corresponding author: kharchenko.mv@bk.ru

2Using the methods of continuum mechanics, the interaction forces between the threads of the screw pair are determined when it is loaded with a working load (force F). In the cylindrical system of coordinate axes (r, z, φ), the forces acting on the nut turns are considered, and the dependence of the change in normal pressures q along the contact surface is established.

Based on the results of tests using a friction machine, the friction coefficient f and the wear intensity energy indicator are determined.

The work of friction forces for one complete revolution is determined. According to the found value of the work of the friction forces Amp, using dependence (1), the volumetric wear of the nut coil for one full revolution and the total volumetric wear occurring for n revolutions are determined

$$\Delta W_{\Sigma} = \Delta W * n \tag{2}$$

where n – number of complete turns.

The height of the worn layer in the zone of maximum wear is determined

$$h_{из} = \frac{\Delta W_{\Sigma}}{bL} \tag{3}$$

where b - is the width of the most worn layer;

L - is the length of the turn.

The reliability of the screw pair is evaluated

$$\psi = \frac{h}{h_{из}} \geq [\psi] \tag{4}$$

where ψ - is the safety factor;

h - is the initial height of the unworn layer in the zone of maximum contact pressures;

$[\psi]$ – allowable safety factor.

Using the above method, the prediction of the wear resistance of the nut of the screw pair used in the pressure device of the rolling stand of the hot rolling mill 2000 of PJSC "Magnitogorsk Metallurgical Plant" was carried out. Nut material bronze brand BrA9Zh3L. The thread of the screw pair is carried out in accordance with GOST 10177-82. The main dimensions of the nut thread: outer diameter D=600mm, inner diameter D1=564 mm, pitch p=24 mm, profile height H1=18 mm.

The greatest influence on the wear of the nut of the screw pair is exerted by the forces acting on the contact surface of the nut with the screw (contact pressure q). In well-known literary sources, information about the nature of the distribution of contact pressures in screw pairs is contradictory. Thus, in [5], the pressures on the contact surface are presented as a parabola with an extremum in the middle of the contact. In [6], it is assumed that the pressure between the nut and the screw is uniformly distributed over the contact surface. The above information about the nature of the distribution of contact pressures contradicts the pilot data presented in [7-9], according to which the contact pressure q between the nut and the screw is uneven and in the areas adjacent to the thread root, q has a maximum value.

The DEFORM-3D software package was used to simulate the process of interaction between the turns of the nut and the screw. In this case, the data stored in the software package for bronze were used as the nut material. The screw was considered as an absolutely rigid body. Based on the results of the performed calculations, the parameters of the stress-strain

state that occurs in the turns of the nut and, in particular, the normal pressures q on the contact surfaces of the turns of the nut with the turns of the screw, which are shown in Figure 1, are determined.

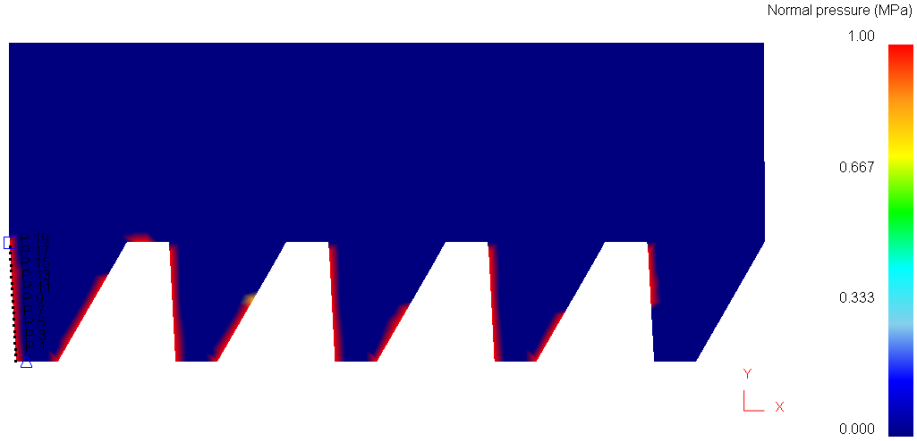
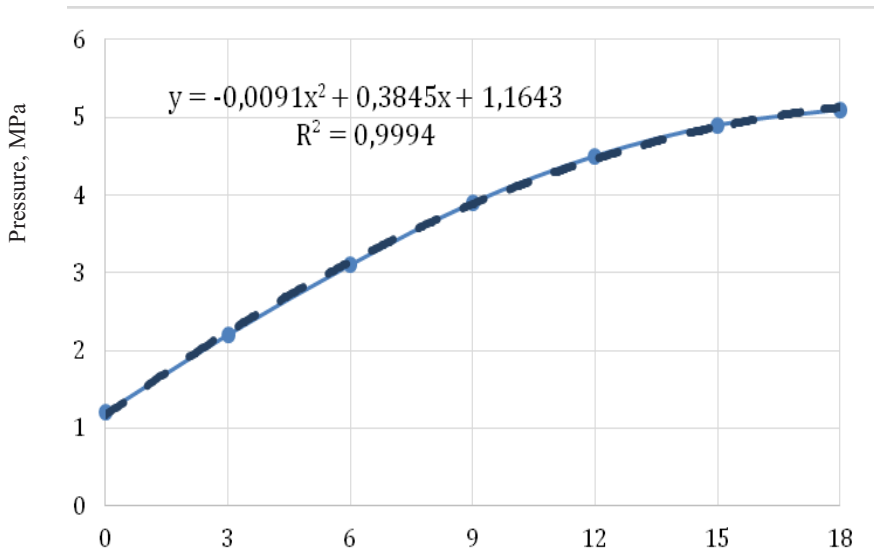


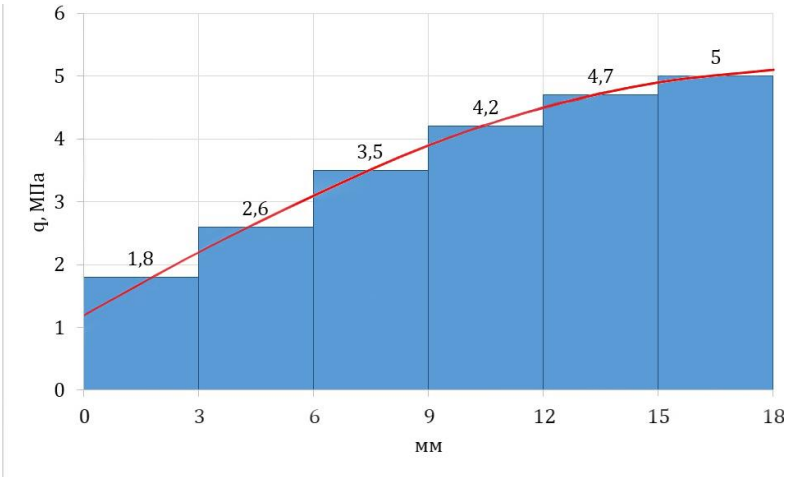
Fig. 1. Normal pressures q on the contact surface of the nut with the screw.

The obtained results of computer simulation made it possible to determine the patterns of change in contact pressures q along the height of the thread ledge. The calculation results in the form of a graph (a) and a histogram (b) are shown in Figure 2.

To describe the nature of the change in normal pressure on the contact surface, the polynomial q = a1x2 + a2x + a3 was used, where a1 = - 0.0091; a2= 0.3845; a3 = 1.1643 (determination coefficient R^2 = 0.9994).



(a)



Distance from the top of the protrusion, mm
(b)

Fig. 2. Change in normal pressures q on the contact surface of the nut with the screw: a - graph; b – histogram.

The friction coefficient f and the wear intensity energy index were determined on the basis of experimental studies that were carried out on a modernized friction machine model SMTs-2 [10]. The pads were made of bronze BrA9Zh3L. At the same time, two types of bronze blocks were made:

- pads with an outer surface obtained by fine turning;
- pads with an outer surface obtained by fine turning and burnishing with ultrasonic vibrations [11].

For the manufacture of the roller, steel grade 45 was used with the following mechanical properties: σv = 570 MPa, hardness 207 HB.

The average results of the experiments are presented in the table.

Table 1. The values of the friction coefficient f and the energy index of wear intensity.

Machining method	**Friction coefficient** f	**Energy index of wear intensity** J_w **(mm³/J)**
Fine turning	0,160	$4{,}46 \times 10^{-5}$
Fine turning and burnishing with ultrasonic testing	0,148	$4{,}13 \times 10^{-5}$

Analyzing the results of modeling the contact pressure along the height of the nut profile of the pressing device of the rolling stand (see Fig. 2), as well as the data presented in [9], we can conclude that the areas adjacent to the base of the thread profile ledge are subject to the greatest wear. Therefore, it is proposed to determine wear not over the entire contact surface, but only in areas where maximum contact pressures operate.

The scheme for calculating the height of the worn profile in the area of maximum wear is shown in Figure 3, where the dashed lines show the worn profile, and the hatched lines show the section of the area with maximum wear.

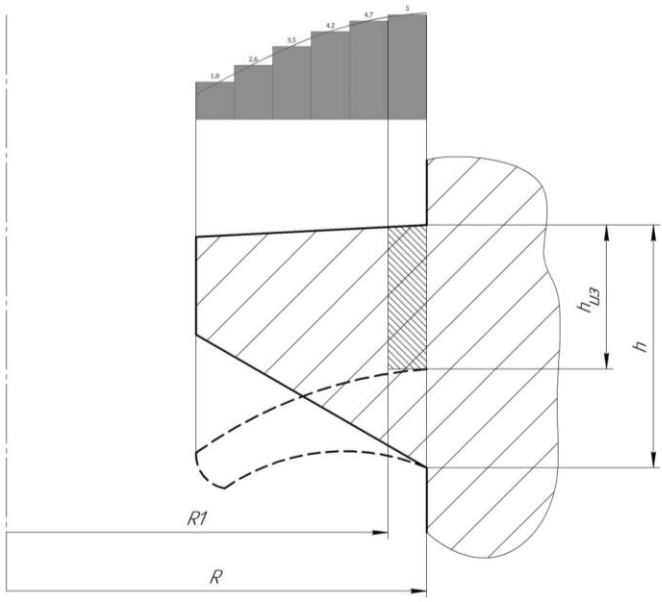


Fig. 3. To the calculation of the height of the worn profile in the area of maximum wear.

Assuming that the contact pressure in the area of maximum wear is constant (q = 5 MPa), the work of the friction forces in one complete revolution was determined

$$A_{fr} = 2\pi^2(R^2 - R_1^2)\left(\frac{R+R_1}{2}\right)qf \tag{5}$$

where R - is the outer radius of the most loaded contact surface;

R1 - inner radius of the most loaded contact surface.

Based on the found value of the work of the friction forces Afr, using dependence (1), the volumetric wear ΔW of one turn in the area with the maximum contact pressure per one complete revolution and the total volumetric wear of the most loaded contact surface occurring in n revolutions were determined

$$\Delta W_{\Sigma} = \Delta W * n \tag{6}$$

Maximum worn layer height:

$$h_w = \frac{\Delta W_{\Sigma}}{bL} \tag{7}$$

where b=(R - R1) is the width of the most worn layer;

$L = \pi(R + R_1)$ is the average length of the maximum worn layer.

After transformations (3), (4), (6) and (7), a dependence was obtained to determine the number of revolutions of the screw, above which there is a high probability of destruction of the nut

$$[n] = \frac{bLh}{\Delta W[\psi]} \tag{8}$$

The performed calculations showed that with an acceptable safety factor [ψ] = 2 in the case of using a nut made by fine turning, the screw should make no more than 149.5x104

revolutions, and for a nut finished by burnishing with the imposition of ultrasonic vibrations - no more than 161.5 x104 revolutions.

Conclusion

Based on the energy theory of wear, a method has been developed for predicting the service life of a screw pair nut with a large thrust thread. Normal pressures on the contact surface of the nut with the screw were determined by the finite element method using the DEFORM-3D software package. The resource of the nut is proposed to be estimated by the number of revolutions of the screw, if it is exceeded, the probability of thread destruction is high.

As a result of tests on a friction machine, the coefficient of friction and the energy indicator of wear intensity were determined.

Using the developed technique, the prediction of the service life of the nut used in the pressure device of the rolling stand of the hot rolling mill 2000 was made. The limiting number of screw revolutions is determined, above which the probability of thread destruction is high.

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