Methods and main results of Tribo-Fatigue tests

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\textbf{Article info}

\textbf{Abstract}

The methods and machines for wear-fatigue tests developed in the framework of Tribo-Fatigue testing are described and are used for the experimental estimation of the mutual influences and joint effects of the processes of friction (including wear) and mechanical fatigue on the performance of materials and models of Tribo-Fatigue systems. A select number of the experimental results are presented, including unique results that allow the estimation of the regularities of the direct (influence of the conditions and processes of friction and wear upon the change in the fatigue strength characteristics) and back (influence of the cyclic stresses upon the change in friction and wear characteristics) Tribo-Fatigue effects.

\textbf{1. Introduction}

By now, experimental mechanics has become a basis for any strength and longevity analyses. It also plays another important role in that it reveals the regularities and specific features of the behaviour of materials under loads in various conditions, including alternating loading, friction, etc.

Tribo-Fatigue involves special methods for wear-fatigue tests used to estimate experimentally the mutual and joint influences of friction and mechanical fatigue processes on the efficiency of materials and models of Tribo-Fatigue systems with complex loading.

\textbf{2. Methods and machines for wear-fatigue tests}

The progress of Tribology motivated the creation of a special class of testing equipment–machines for friction and wear tests. In turn, the development of fatigue fracture mechanics resulted in the creation of another class of testing equipment–machines for fatigue tests.

According to the known data \cite{1-14}, the dimensions of the specimens for the tests on friction and wear range from 5 to 1000 mm, and tests with the unification of different loading types (e.g., tests with axial loading, bending, and torsion) have not been performed (see Fig. 1).

According to the known data for mechanical fatigue \cite{13-23}, the dimensions of the specimens for mechanical fatigue tests range from 3 to 500 mm, and tests with the unification of different loading types (e.g., tests with axial loading, bending, and torsion) have not been performed (see Fig. 2).

The progress of Tribo-Fatigue required the development of a new class of testing equipment–machines for wear-fatigue tests \cite{24-29}.

Fig. 3 exemplifies the principle of developing the methods for wear-fatigue tests when rotational bending is the main source of mechanical fatigue in the tests.

Rotational motion is the most common type of motion in modern machines \cite{22,23,25,29}; hence, the methods presented in Fig. 3 are of practical significance.

The central and most important feature of the methods for wear-fatigue tests is that they are all based on a single unified object–a 10 mm diameter shaft that can be tested with any loading pattern (see Fig. 4). This provides comparability of the data obtained from the tests of structural elements, friction pairs, and Tribo-Fatigue systems. Up until this point, researchers have not had such an opportunity. Traditional methods to test rolling and sliding friction have yielded non-comparable results because the dimensions of test objects differ, as a rule.

At the beginning of the 1990s, a special universal machine named after Sosnovskiy and Indman (hereinafter referred to as the SI machine) was designed with the intent of implementing the methods for wear-fatigue tests. To date, several modifications of the machine have been designed. Figs. 5 and 6 and Table 1 give information on its performance.
Most of the loading mechanisms in test machines use a load suspension. However, this mode of force excitation is unsatisfactory because stresses in the test objects cannot be varied during testing.

The modular SI machines have first been equipped with MP-100 mechanisms with a DC drive. The schematic diagram of the SI-O3 M machine equipped with these mechanisms is shown in Fig. 6. The supply voltage of the mechanisms is 24 V, and the consumption current can range up to 2 A. Despite the small power consumption, the mechanisms of this machine series yield a force of up to 1700 N, applied directly to the output rod.

The mechanisms are provided with limit switches that allow the extreme positions of the rod to be determined. An additional limit switch can be mounted at any intermediate (middle) position of the rod.

In this manner, the application of the mechatronics elements in the SI machines created the very real possibility for the automation of the loading process to follow any program.

The main characteristics of the SI machine are as follows.

1. The SI machine is universal in the sense that it allows one to implement fatigue, friction, and wear tests, as well as all the basic types of wear-fatigue tests (primarily, conditions with rotational motion).
2. While the SI machine is multipurpose, it is designed on a unified basis (case, drive, and moving mechanism) that provides its high efficiency.
3. The SI machine has no mechanical transmissions; this not only avoids power losses but also significantly reduces any test errors.
4. The rotational speed of the specimens is varied continuously within a wide range from 50 to 5000 r.p.m. When performing rolling tests, the slip degree can be set continuously up to 85%. Because the drive features a tracking loop, the required test regime is maintained with a high accuracy within a broad speed range.
5. Bending and contact loads are also varied continuously according to the associated law by means of universal electric mechanisms with a tracking loop. Cyclic stresses up to 700 MPa or higher and contact pressures up to 3500 MPa can be imposed. On the other hand, the minimum loads are so small that metal-polymer and polymer-polymer systems can be tested.

6. Contact loads can be prescribed and the friction process can be realised in the zone of either tensile or compressive bending stresses.

7. The SI machine is equipped with a modern PC-based measuring and controlling system. This allows the automation of the testing and data processing.

Since machine compliance and stroke input accuracy (especially for reciprocating sliding cases) play an important role in fatigue and wear testing the actual relative motion between contacting specimens could be significantly affected. This effect is considered in the work [30].

Fig. 2. Summary of the main test schemes for mechanical fatigue.
Fig. 3. Scheme for the formation of new test methods: MRF – mechano-rolling fatigue; MSF – mechano-sliding fatigue; FF – fretting fatigue.

Fig. 4. System to unify the methods of wear-fatigue tests (L.A. Sosnovskiy): 1 is the specimen, 2 is the specimen's fixture, 3 is the counterspecimen.

Fig. 5. SI-03 M machine (version SI-03Mo) for wear-fatigue tests of materials and models of Tribo-Fatigue systems.
3. Main results of wear-fatigue tests

Some of the new experimental results, including the most fundamental results, have been obtained with the use of the SI machine, both in Tribo-Fatigue and in traditional research fields such as Tribology and mechanical fatigue.

Known works [10, 31, 32] contain the curves for sliding fatigue in a test region limited by the maximum number of cycles, \(10^4\) cycles.

Fig. 7 shows the total sliding fatigue curve for the test pattern shown in Fig. 4d. For the first time, this curve is plotted over a wide longevity range: from \(\sim 10^3\) to \(\sim 10^8\) cycles. All tests are performed at the same frequency of 3000 r/min.

These results are obtained from a unique experiment that required more than two years of continuous tests, as the base longevity of \(10^8\) cycles was used. The average wear of a 100 µm polymer specimen was considered to be the limiting state of the friction pair [25].

Once the total sliding fatigue curve has been obtained, the corresponding wear resistance condition can be written; for example, it could be described by using one of its elements the high-cycle fatigue curve:

\[
\tau_W = f p_a \lesssim [\tau] = \tau_f / n_s
\]

where \(\tau_W\) is the specific friction force, \(p_a = F_a / A_a\), \(F_a\) is the friction force, \(A_a\) is the contact surface area, \(f\) is the friction coefficient, \(\tau_f = f(F_c/A_0)\) is the sliding fatigue limit found from the curve in Fig. 7, and \(n_s\) is the safety factor.

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**Table 1**

Technical characteristics of the SI machines.

<table>
<thead>
<tr>
<th>Description of indicators</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SI-01 machine</td>
</tr>
<tr>
<td>Basic friction pair</td>
<td>Cylinder – block</td>
</tr>
<tr>
<td>Diameter of the working portion of a specimen, mm</td>
<td>10</td>
</tr>
<tr>
<td>Dimensions of a counterspecimen, mm</td>
<td>(10 \times 10 \times 11.5)</td>
</tr>
<tr>
<td>Relubrication range</td>
<td>drop-feed lubrication</td>
</tr>
<tr>
<td>R.p.m. range of a specimen, min (^{-1})</td>
<td>–</td>
</tr>
<tr>
<td>R.p.m. range of a counterspecimen, min (^{-1})</td>
<td>70–700</td>
</tr>
<tr>
<td>Bending load range, N</td>
<td>10–500</td>
</tr>
<tr>
<td>Contact load range, N</td>
<td>2</td>
</tr>
<tr>
<td>Measuring error of load, %</td>
<td>(\pm 3)</td>
</tr>
<tr>
<td>Measurement range of total wear of a specimen and a counterspecimen, µm</td>
<td>10–2000</td>
</tr>
<tr>
<td>Measuring error of total wear of a specimen and a counterspecimen, %, no more than</td>
<td>(\pm 3)</td>
</tr>
<tr>
<td>Measurement range of friction torque, Nm</td>
<td>0.01–1.2</td>
</tr>
<tr>
<td>– in sliding friction</td>
<td>–</td>
</tr>
<tr>
<td>– in rolling friction</td>
<td>–</td>
</tr>
<tr>
<td>Measuring error of friction torque, %, no more than</td>
<td>3</td>
</tr>
<tr>
<td>Installed power of electric equipment, kW</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\(^a\) For SI-01-S: 1000–18,000 min \(^{-1}\).
in this case $A_{ij} < 1$. Then the scheme reflecting adequately the experimental data shown in Fig. 9 looks like it is shown in Fig. 9b.

Figs. 10 and 11 show the test results obtained from the SI machines. Four fatigue curves are plotted from the experimental data (see Fig. 10). The limiting state criterion in mechanical fatigue tests is the disintegration of a specimen into pieces, while the limiting state criterion in rolling fatigue tests is the critical density of pittings at the rolling surface. The limiting state in tests for mechano-rolling fatigue is determined by the damage and fracture criteria typical for mechanical and rolling fatigue tests.

The fatigue limits ($\sigma_{-1}, p_0, \sigma_{1p}, p_{0p}$), the slope parameters of the left branch of the fatigue curves ($m_p, m_{p0}, m_{p0p}, m_{p0r}$), and the abscissas of the inflection points of the fatigue curves ($N_{Ge}, N_{GeC}, N_{pGe}, N_{pGeC}$) are determined in all four cases (see Fig. 10). Note that $\sigma_{-1}$ is the limiting stress for the specimen undergoing cyclic bending with rotation. Under mechano-rolling fatigue, $\sigma_{1p}$ is the same limiting stress for a specimen being subjected to a contact pressure $p_0$. Similarly, $p_0$ is the limiting contact pressure for the friction pair under rolling fatigue. Lastly, in mechano-rolling fatigue, $p_{0p}$ is the same limiting contact pressure as considering the influence of stresses $\sigma_a$ due to bending.

The comparison of the fatigue curves $N(\sigma_a)$ and $N(\sigma_{w}, p_0 = \text{const})$ makes it possible to characterise the influence of the friction and wear processes on changes in the characteristics of the mechanical fatigue resistance under given test conditions. This influence is called the direct effect. In particular, the direct effect coefficient can be determined as follows:

$$K_d = \sigma_{-1p}/\sigma_{-1}.$$  

In fact, the coefficient $K_d$ is a tribological characteristic. Under the conditions of the tests, whose results are shown in Fig. 10, we obtain $K_d^{\max} = 256/165 = 1.55$.

The comparison of the fatigue curves $N(p_0)$ and $N(p_0, \sigma_a = \text{const})$ allows one to characterise the influence of the mechanical fatigue processes on changes in the characteristics of the friction and wear for a given test condition. This influence is called the back effect. The back effect coefficient can be determined as follows:

$$K_b = p_{0r}/p_0.$$  

In fact, the coefficient $K_b$ is a tribological characteristic. Under the conditions of the tests, whose results are shown in Fig. 10, we obtain $K_b^{\max} = 2.200/1.760 = 1.25$.

Considering that coefficients (1) and (2) characterise the direct and back effects in terms of the carrying capacity of a system, their similar coefficients

$$K_d = m_{p0}/m_{p}, \quad K_b = m_{p0r}/m_{p}$$

can define these effects in terms of the damage intensity because the slope parameters of the fatigue curves describe, in essence, the rate of change of the fatigue resistance in the number of loading cycles until the instant the limiting state is reached.

Table 2 contains the nomenclature and the numerical values of the basic characteristics that can be found from the fatigue curves plotted in Fig. 10.

Fig. 11 shows the first multi-criteria diagram of the limiting states of a Tribo-Fatigue system with mechano-rolling fatigue.

The analysis of the diagram ABCD (see Fig. 11) allows the following basic conclusions to be made:

1. The fatigue limit of a specimen can increase by a factor of up to 1.5 or 1.6, provided that rolling occurs simultaneously (the direct effect – portion AB).
2. The critical (limiting) pressure for rolling can increase by a factor of up to 1.20 or 1.25, if cyclic stresses are simultaneously imposed upon the specimen (the back effect – portion DC).
Fig. 10. Original experimental fatigue curves of unified objects (L.A. Sosnovskiy, A.V. Bogdanovich, S.A. Tyurin).

Fig. 11. First multi-criteria diagram of the limiting states of the Tribo-Fatigue steel 25X1T (roller)/steel 45 (shaft) system with mechano-rolling fatigue (L.A. Sosnovskiy, N.A. Makhutov, A.V. Bogdanovich, S.A. Tyurin).
Within the optimum contact pressure range \( p_0 = 400–1300 \text{ MPa} \), the rolling wear process leads to a significant rise of the system reliability in terms of fatigue resistance; for this reason, it would be detrimental to strive for wear-free friction in this case.

At cyclic loading under the optimum conditions \( \sigma_a \approx 50–100 \text{ MPa} \), tensile stresses are favourable because they promote a considerable rise in the system reliability in terms of rolling friction resistance.

The improvement of the characteristics of the limiting state \( \sigma_{-1} \), \( p_0 \) in wear-fatigue tests in comparison with those with rolling friction \( \sigma_a \) and mechanical fatigue \( \sigma_{-1} \) can be explained from a mechanics viewpoint by the following basic reasons:

- the summation of opposite-sign stresses (contact and bending stresses), which shifts the average stress of the cycle towards the negative values and, hence, reduces the maximum stress of the cycle;
- the surface plastic deformation hardening of the working portion of the specimen;
- the formation of favourable compressive residual stresses;
- the healing of initial fatigue cracks with elasto-plastic deformation at rolling friction.

### 4. Accelerated test methods

The multistage loading method is widely used for the accelerated assessment of the fundamental characteristic of the fatigue resistance of metallic materials – the fatigue limit. We apply this method to obtain a variety of specific characteristics of wear-fatigue damage under specific conditions.

Fig. 12 shows the comparison results of the tests of steel 45 for mechanical fatigue, a friction pair of steel 45 (shaft) and steel 25X1T (roller) for rolling fatigue, and a similar Tribo-Fatigue system of steel 45 (shaft) and steel 25X1T (roller) for mechano-rolling fatigue in the conditions of the direct and back effects.

Fig. 12 shows that the resistance of the comparison objects to wear-fatigue damage and fracture is substantially different in the level of limiting stresses, in longevity (i.e., the total number of loading cycles up to the occurrence of the limiting state), and in the number of loading steps that the object can withstand until reaching its limiting state.

Table 3 summarises the characteristics of the wear-fatigue damage, whose numerical values can be obtained from the test results using the multistage loading method. It also contains the formulae for their estimation.

### 5. Measurement and analysis of local damages during tests

The fact that any limiting state, especially in the contact zones, was always preceded by different factors that developed the local damage became common knowledge long ago [2]. From both a theoretical and practical viewpoint, it was clear that damages could be non-uniform (e.g., the wear of bearing inserts and crankshaft journals) and local (e.g., cavities, pitting, and thermal seizure zones). To address these concerns, experimental methods were developed and found wide use in the studies on local damages, usually after

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**Table 2**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Mechanical fatigue curve</th>
<th>Rolling fatigue curve</th>
<th>Mechano-rolling fatigue curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatigue limit, MPa</td>
<td>( \sigma_{-1} = 165 )</td>
<td>( p_f = 1760 )</td>
<td>( \sigma_{-1} = 256 )</td>
</tr>
<tr>
<td>Abscissa of the inflection point of the fatigue curve, cycles</td>
<td>( N_{\sigma_0} = 9 \times 10^6 )</td>
<td>( N_{p_0} = 2.6 \times 10^7 )</td>
<td>( N_{\sigma_0} = 5 \times 10^6 )</td>
</tr>
<tr>
<td>Fatigue curve slope parameter</td>
<td>( m_r = 7.5 )</td>
<td>( m_p = 14.5 )</td>
<td>( m_p = 11.6 )</td>
</tr>
</tbody>
</table>

**Fig. 12.** First comparison results of tests of different objects using the multistage loading method (L.A. Sosnovskiy, S.A. Tyurin, V.V. Komissarov).
Thus at the transition from 8 to 16 points the wear is measured in the local damages had reached some defined state. Among the experimental methods are the methods for measuring microhardness, optical metallography, X-ray analysis, electron microscopy, etc. However, the progress in this research field was hampered by the only, but very important, fact that there was no simple and effective method for studying the local damages at contact loading. Thus, the damage kinetics could not be reproduced in laboratory conditions, and the regularities of damage initiation and evolution could not be investigated experimentally.

In Tribo-Fatigue, a new simple and effective method of detecting, recording, and analyzing local damages in tests is proposed, developed, and implemented in SI machines. Its essence is illustrated in Fig. 13 for two main parameters of wear-fatigue damage – wear \( i \) in the sliding bearing/shaft systems and the convergence of the axes \( \delta_i \) in the roller/shaft systems (see Figs. 13 and 14).

The measurements can be performed using two methods – integral and discrete. The integral method implies the measurement of the value of \( t(\delta) \) per assigned time intervals. The main feature of the discrete method is the measurement of these values at eight points of the friction track in any loading cycle throughout the total test time.

The essence of the method is as follows. Eight points \((1), (2), \ldots, (8)\) are marked around the specimen circumference in the cross-section where the dangerous maximum cyclic stresses are imposed and friction (sliding or rolling) occurs (see Fig. 13). As each point passes the zone of contact between the specimen and counterspecimen, the local wear or the convergence of the axes is measured (see Fig. 14). It should be noted that if more than eight measurement points are taken the wear estimation accuracy is increased. Thus at the transition from 8 to 16 points the wear is measured using the base of 4 and 2 mm respectively.

Fig. 15 illustrates the typical measurement results of the steel 45/steel 45 system with mechano-sliding fatigue tests.

The obtained test results can be represented in two manners. The first representation is in the form of the kinetic curves of the local wear variance with time \( t \) (see Fig. 15 top). Each cross-section of these curves contains eight experimental points that are responsible for the wear variation over one cross-section of the specimen in a given loading cycle. Thus, eight realizations of the random process of local wear are obtained. The scatter band is bounded at the top and bottom by the solid lines. The variation of the average wear value is also shown. This average value can be identified with integral wear that is commonly measured. It is not difficult to see how strongly the local wear pattern differs quantitatively from the integral wear pattern. The second representation is made in the form of the circular diagrams of local wear obtained at specified instants in time that represent the corresponding sections of the local wear variance.
kinetic processes. The experimental points in the diagrams are connected with straight lines. It is quite obvious how strongly the pattern of real (locally measured) wear at the points of the specimen cross-section differs from that of the integral wear pattern in one revolution. Though loads remain unchanged in one revolution, the reactions of the metal surface layers in different local zones of the friction track appear to be substantially different because the mechanical and physical properties of these layers are also substantially different. Hence, as the fracture resistance of the local surface portions is different, the local wear over such portions is also different and, therefore, the anisotropy of the local material properties is studied by measuring local wear in model tests.

Special quantitative parameters of local damage (see Fig. 16) are introduced: the asymmetry coefficient (local damage degree for four specimen diameters)

$$R_a = \frac{1}{4} \sum_{i=1}^{4} \frac{r_{\text{min}}(i)}{r_{\text{max}}(i)},$$

where $r_{\text{min}}$ and $r_{\text{max}}$ are the minimum and maximum radii of the diameter of the dangerous cross-section of one specimen, and the irregularity coefficient (specimen cross-section averaged characteristic)

$$\eta_a = \frac{r_{\text{smallest}}}{r_{\text{greatest}}},$$

where $r_{\text{smallest}}$ and $r_{\text{greatest}}$ are the least and greatest radii, respectively, of the specimen during one revolution.

Fig. 17 shows the dependence of experimental $R_a$ and $\eta_a$ upon the magnitude of the cyclic stresses in the tests of the Tribo-Fatigue steel 45 / steel 23X1T system with mechano-rolling fatigue using the method of a step change in the bending load with the contact pressure $p_0 = 0.7p_f = \text{const}$. It can be seen that the irregularity degree of the local wear-fatigue damage grows with increasing cyclic stresses, whereas the coefficients $R_a$ and $\eta_a$ decrease.

Consider the depth of local damage $d_{\text{lim}}$ at a point on specimen surface to be the limiting state. Then, in fatigue tests, this value is reached at different points (in Fig. 18 they are shown by numbers 1–8) of the circumference of the dangerous section of the specimen at different times (i.e., different points have different longevity).

In Fig. 18 numbers 1, 2, ..., 8 represent the points around the rolling track perimeter that are obtained from the circular diagrams of the axes convergence and at which the limiting state ($d_{\text{lim}}$) is reached after $N$ cycles. The analysis of points 1, 2, ..., 8 shows that their positions on the plot are random. The dashed lines that bound their longevity scatter band, which increases with growing system longevity. This behaviour does not contradict the available statistical results from specimen mechanical fatigue tests: the longevity scatter increases as the load drops. However, in the considered case, the longevity scatter bands at each level of stress are determined from the test results for one friction pair.

The analysis of the curves presented in Fig. 18 leads us to conclude that the fracture resistances of the local zones on the surface of one specimen may vary substantially. In the conditions of this test, the longevity scatter can range from $2.5 \times 10^4$ to $8 \times 10^7$ cycles, i.e., can vary by a factor of 30.
The model tests of the friction pairs and the Tribo-Fatigue systems with different loading schemes have shown that local damages are the main contributor to a considerable decrease in longevity, which can be increased (or maintained) by using a complexity of measures to minimise local damages. These measures should be implemented at the design stage of a given unit and during the preproduction engineering.

6. Friction coefficient

Consider the problem of the influence of non-contact, bending-induced stresses upon the change in the rolling friction coefficient (a back effect in the Tribo-Fatigue framework) [34–38].

The Tribo-Fatigue steel 18X1T / steel 18X1T system was tested with mechano-rolling fatigue (see Fig. 4a) at two contact stress levels ($p_0 = 2000$ MPa and $p_0 = 3200$ MPa), which corresponds to the elastic and elasto-plastic deformation regions. For tensile stresses to be realised in the contact region, the bending load $Q$ is directed downwards; for compressive stresses, the bending load $Q$ is directed upwards (see Fig. 4a). In tests, the slip degree was held constant, equal to $\lambda = 3\%$.

The test results are represented in the form of the averaged rolling friction coefficient values (at different contact stress values $p_0$) as a function of the ratio $r_a/p_0$. Each point on the plot is calculated using 60 values of $f_r$, which provides sufficient accuracy for the obtained results.

From the data in Fig. 19, several conclusions can be drawn and are listed below.

In rolling fatigue tests, the values of the rolling friction coefficient $f_r$ remain invariable (see the dashed line) if $F_r = \text{const}$; this agrees with numerous known data. Depending on the contact stress level, the values of $f_r$ are 0.0626 at $p_0 = 2000$ MPa (elastic contact) and 0.0830 at $p_0 = 3200$ MPa (elasto-plastic contact), i.e., a transition from the elastic-plastic contact causes the rolling friction coefficient to grow by $\sim 20\%$ in test conditions.

In mechano-rolling fatigue tests (rolling friction + cyclic bending), the values of the friction parameter $f_{r_c}$ in the tension zone generally decrease.

On the other hand, in tests with mechano-rolling fatigue with friction in the compression zone, the $f_{r_c}$ values increase.
The plots in Fig. 19 can be approximated by a linear function of the form as proposed by two of the authors: L.A. Sosnovskiy and V.V. Komissarov.

\[
F_{\sigma} = f_r \left( 1 + \frac{k_{\sigma r}}{P_0} \right),
\]

where \( k_{\sigma r} \) is the dimensionless interaction parameter of damages due to contact and non-contact loads (contact and mechanical stresses).

In [39–41], a deformation approach is developed by one of the authors, S.S. Sherbakov. Following this approach, the predictive estimates show an acceptable degree of agreement with the experimental results both qualitatively (regularities) and quantitatively (numerical values).

Based on the above-described results and other experimental data (see, e.g., [34–41], the law of friction in the Tribo-Fatigue system is formulated by L.A. Sosnovskiy, S.S. Sherbakov and V.V. Komissarov: in the general case, the friction force is proportional both to contact and volume load if the volume load excites cyclic stresses.

Table 4

<table>
<thead>
<tr>
<th>Tribo-Fatigue system</th>
<th>( p_0 ), MPa</th>
<th>Friction parameter in the Tribo-Fatigue system ( \frac{\sigma_s}{\sigma_r} )</th>
<th>Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel18X1T/Steel18X1T</td>
<td>2000</td>
<td>0.060</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td>3200</td>
<td>0.076</td>
<td>0.077</td>
</tr>
</tbody>
</table>

7. Conclusion

Methods from Tribo-Fatigue tests are used for the experimental estimation of the mutual and joint influences of friction and mechanical fatigue processes on the efficiency of materials and models of Tribo-Fatigue systems of machines in different and complex conditions of loading. The Tribo-Fatigue test methods are a combination of mechanical fatigue and friction testing methods. Using this approach, it is also possible to use the designed wear-fatigue testing machines in more conventional tests, either on mechanical fatigue or on friction and wear alone.

A special advantage of the developed methods is that they can be used for different types of tests of the same object (test specimens). This permits the results of the tests performed in different conditions to be easily compared.

From the experiments, certain regularities are established: (a) the influence of cyclic stresses on the change in friction and wear strength characteristics and (b) the influence of contact stresses on the change in fatigue strength.

References


