ISSN 1068-3666, Journal of Friction and Wear, 2019, Vol. 40, No. 5, pp. 376–383. © Allerton Press, Inc., 2019.
Russian Text © The Author(s), 2019, published in Trenie i Iznos, 2019, Vol. 40, No. 5, pp. 493–503.

Running-in Procedures and Performance Tests for Tribosystems

V. A. Vojtov[a], *, **A. Sh. Biekirov**[a], **A. V. Voitov**[a], **and B. M. Tsymbal**[b]

[a]*Kharkiv Petro Vasylenko National Technical University of Agriculture, Kharkiv, 61002 Ukraine*
[b]*National University of Civil Defence of Ukraine, Kharkiv, 61023 Ukraine*
**e-mail: vavoitovva@gmail.com*

Received September 9, 2018; revised July 9, 2019; accepted July 9, 2019

Abstract—This paper presents theoretical and experimental studies that validate the structure of a program on the running-in of tribosystems, which consists of two modes. The maximum load below the seizure threshold is set in the first mode with the minimum sliding velocity. This mode is called the adaptation of the tribosystem to external conditions. The minimum load and maximum sliding velocity are set in the second mode. The transient characteristics are obtained for the tribosystem running-in, establishing the relationship between the tribosystem design, rational loading conditions, running-in time and running-in wear. The practical significance of the work is the minimization of the running-in time and wear for the running-in period.

Keywords: tribosystem, running-in, running-in procedure, adaptation of the tribosystem, learning ability, tribosystems, running-in wear

DOI: 10.3103/S1068366619050192

INTRODUCTION

The running-in of tribosystems is the final process stage of manufacturing and, at the same time, the initial stage of machine operation. Running-in forms the base surface layers of a tribosystem, providing the future maximum lifetime operation and minimum friction losses. The results of research by many scientists suggest that the completion of the running-in process is not only reduced to the formation of the optimal roughness of the mating surfaces in the tribosystem, but includes thermal, diffusion, and strain physical, and chemical phenomena that occur in the friction zone in the presence of lubricating media and the environment. Therefore, reducing the running-in process time and improving the efficiency will significantly increase the lifetime of machinery, which will have economic benefits.

The fundamental work devoted to the running-in processes is arguably [1]. This work presented a system-oriented approach and comprehensive studies of the running-in processes, on the basis of which a conclusion was drawn on the execution of a seizure threshold running-in process. In subsequent works [2], the authors performed an analysis of various types of running-in processes and noted that the step-load running-in method is the most widespread. At the same time, the authors concluded that the most effective method is seizure threshold running-in. The authors of [3] concluded that the effectiveness of running-in requires the application of three modes. The first one occurs at the microgeometric level for smoothing and cutting the microroughness of the friction surfaces. In the second mode, the wear rate decreases, the friction surfaces become stronger, and the friction loss becomes smaller. The third and final mode is characterized by the stabilization of the wear rate, friction loss, and temperature. A transition from one mode to another is carried out by changing the load and sliding velocity.

Based on a large amount of experimental work, the author of [4, 5] determined the effectiveness of step-load running-in. It was established that each load step is characterized by the highest surface interaction intensity and the dominant plastic strain. As running-in effects of various natures occur, the stress–strain state of the surface is transformed into elastoplastic and then into elastic strain, as the least energy consuming mode. In [6], antifriction material features of friction joints were tested for running-in depending on the changing external load. The author established that effective running-in is possible if the friction joint operation runs in the mode of steady-state mixed friction. It was shown that the governing parameter of the external action is the normal load and, to a lesser extent, the sliding velocity.

Summing up the analysis of the works devoted to running-in modes, it may be concluded that the novelty of this study is a methodological approach to obtaining theoretical dependences of changes in the wear rate, friction coefficient, and running-in time, which will allow validation and development of an effective running-in program for various tribosystem designs.

The purpose of the work was the validation and development of a running-in program for various tribosystem designs and its performance testing.

MATERIALS AND METHODS

The subject of research in this work is a system analysis and comprehensive studies of the running-in processes of various tribosystems.

To simulate the running-in process, the following laboratory tribosystem for a UMT-1 friction machine was chosen: steel 40X (a moving triboelement, internal friction of the material structure $\delta_m = 2644$) + bronze alloy $CuA_{19}Fe_3$ (the fixed triboelement $\delta_f = 3494$). The mutual overlapping coefficient $C_{mo} = 0.5$ and the shape coefficient $C_{sh} = 12.5\ m^{-1}$. The lubricating medium was M-10G2k motor oil and the tribological properties $E_y = 3.6 \times 10^{14}\ J/m^3$. The thermal conductivity of steel $a_m = 1.27 \times 10^{-5}\ m^2/s$, the thermal conductivity of bronze $a_f = 2.1 \times 10^{-5}\ m^2/s$, the roughness of the friction surfaces, $R_a = 0.2\ \mu m$.

Experimental studies were carried out on the UMT-1 friction machine; the tribosystem was steel 40X + bronze alloy $CuA_{19}Fe_3$. The tribosystem parameters and the lubricating medium were the same as those used in the simulation. During the experiment, values of the friction moment were recorded every 100 seconds, which were converted into a friction coefficient, as well as values of the acoustic emission power, whose value determined the wear rate [7, 8].

The running-in time was determined by stabilizing the wear rate and the friction coefficient with respect to the steady-state value. The experimental results of each of the programs were repeated 3 times, with the calculation of the Cochran test values to confirm the repeatability of the results from test to test.

VALIDATION OF THE STRUCTURE OF THE TRIBOSYSTEM RUNNING-IN PROGRAM

Based on the analysis of works, we let the running-in be the tribosystem transition from a non-equilibrium thermodynamically unstable state to a steady equilibrium state, which stabilizes such parameters as the wear rate and friction coefficient, as well as the temperature and roughness of friction surfaces. This transition is associated with the formation of a special, dissipative triboelement surface layers structure as a result of self-organization. The task of creating such conditions is solved in two stages.

At the first stage, a tribosystem design is selected (friction areas and the related volumes of friction areas), as well as triboelement materials (rheological properties of the structures of materials and their thermal conductivity) and the tribological properties of the lubricating medium. The first stage is carried out in the process of tribosystem design does not change in the process of running-in and operation.

The second stage involves the selection of a running-in program, which may contain several modes. The purpose of the modes is determined by the value of the tribosystem Q-factor, which determines the load magnitude and sliding velocity in the running-in process [9].

The second-stage process is characterized by successive conversion of the mechanical energy of friction into internal energy, primarily thermal energy dissipating into the environment due to the thermal conductivity of the materials, as well as the energy of structural changes in the surface and subsurface layers of the triboelement materials.

If the mechanical energy (pumping energy) value exceeds the threshold value, which is determined by the Q-factor value of the tribosystem [9], a loss of tribosystem stability may occur, that is, scoring or seizure of the triboelement friction surfaces.

The analysis of the works devoted to tribosystem running-in indicates that the minimum running-in time is provided in the seizure threshold mode, when the pumping energy is approximately 90% of the scoring or seizure energy.

The pumping energy or power that is delivered to the tribosystem W can be determined by the expression:

$$W = Nv_{sl} = \mathrm{N}\frac{\mathrm{m}}{\mathrm{s}} = \mathrm{W}, \quad (1)$$

where N is the load, N, and v_{sl} is the sliding velocity, m/s.

Therefore, the first running-in program component is the fulfillment of the condition $W = \text{const}$. In this case, the value of W should not exceed 90% of the pumping energy, which will lead to a charge on the tribosystem friction surfaces.

The second program component is the control of the running-in process by changing the magnitude of the load N and the sliding velocity v_{sl} inversely (providing $W = \text{const}$).

The basis for the validation of the tribosystem running-in modes is the fulfillment of the following conditions:

(A) the minimum completion time of the transient process, t_{tr} min;

(B) the minimum value of the wear rate in the steady state, that is, after the completion of running-in, $I_{st} \rightarrow \min$;

(C) the minimum value of the friction coefficient after the completion of running-in, $f_{st} \rightarrow \min$.

(D) the minimum amount of the running-in wear, which can be expressed as $U \rightarrow \min$.

The beginning of the running-in process is accompanied by severe deformation of the roughness of the

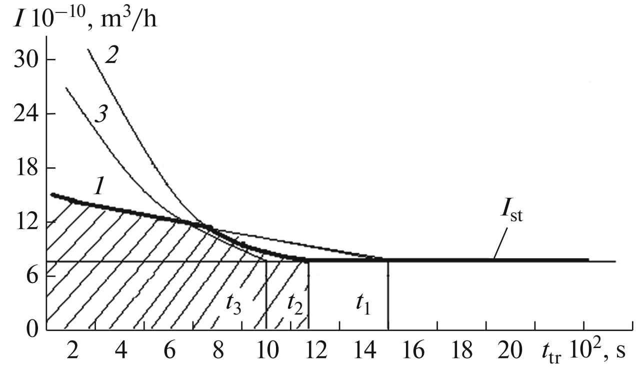

Fig. 1. The transient running-in wear rate characteristics of the steel 40X + bronze alloy CuA19Fe3 tribosystem.

friction surface and the formation of the equilibrium roughness. Due to the fact that the structure of the friction surface does not change instantly, but with a certain inertia the tribosystem may lose stability, resulting in scoring.

To reduce the sensitivity of the tribosystem to scoring, it is necessary to reduce the criterion K_1. One of the effective ways to reduce K_1 is to decrease the sliding velocity; this follows from the conclusions of [9].

Along with the development of the equilibrium roughness of the friction surface, there is a running process of the surface layers restructuring with the formation of oxide films and secondary structures, which is evaluated by a running-in criterion K_2. One of the ways to increase the running-in criterion is to decrease the sliding velocity, this follows from the conclusions of [9].

According to the performed validation based on the conclusions of [9], let us write the first running-in program mode as:

$$N = \max, \quad v_{sl} = \min, \text{ when } W = \text{const}. \tag{2}$$

Upon this, the minimum value of the sliding velocity is chosen in such a way as to provide the optimal values of the wear rate d_I and the friction coefficient d_f damping decrements of [9].

After the formation of the friction surface equilibrium roughness, a transition to the second running-in mode is required. The purpose of the second mode is to reduce the inertia of transient processes in the surface layers, i.e., to complete the formation of the surface layers structure (increase in hardness and the formation of secondary structures and oxide films) in a minimum amount of time. According to [9] one of the ways to reduce the inertia criteria of tribosystems, that is, time constants, is to increase the sliding velocity.

Based on the presented validation, let us write the second mode of the running-in program as:

$$N = \min, \quad v_{sl} = \max, \text{ when } W = \text{const}. \tag{3}$$

In this case, the maximum sliding velocity value is selected from the condition that provides the optimal values of the damping decrements d_I and d_f [9].

The completion time of the first program mode, as well as the second mode, is determined by the simulation results, whose technique was described in [9]. In this case, the following values are determined: the maximum handover of the running-in wear rate I_{max} and friction coefficient f_{max}; the steady-state wear rate I_{st} value and the friction coefficient f_{st} after the running-in completion; the running-in time t_{tr} in terms of the wear rate, friction coefficient, and running-in linear wear U.

RUNNING-IN SIMULATION ACCORDING TO VARIOUS PROGRAMS

Let us select the operational load mode for the tribosystem. According to formula (1), the power that is delivered to the tribosystem is equal to:

$$W_{oper} = N v_{sl} = 1040 \times 0.5 = 520 \text{ W}. \tag{4}$$

Let this mode be the third operation mode after the completion of running-in.

Let us write the first running-in mode according to formula (2) as:

$$W_1 = 2600 \times 0.2 = 520 \text{ W}. \tag{5}$$

The second running-in mode according to formula (3) is:

$$W_2 = 650 \times 0.8 = 520 \text{ W}. \tag{6}$$

As follows from expressions (4)–(6), the equality $W =$ const holds for all three modes.

The transient characteristics of the running-in process of the steel 40X + bronze alloy $CuA_{19}Fe_3$ tribosystem in terms of the wear rate parameter are presented in Fig. 1, and in terms of the friction coefficient, in Fig. 2. The curve number indicates the mode number and the times t_1, t_2, and t_3 are the running-in times for each mode.

Running-in wear rates U_1, U_2, and U_3 are defined as the areas under the corresponding curve according to the formula:

$$U = \sum_{i=1}^{n} \frac{I_i t_i}{F_{fr}} = \text{m}, \tag{7}$$

where n is the number of domain partitions under the curve into rectangular uniform sections; I_i is the wear rate per section, m^3/h; t_i is the operating time per section equal to 100 s; and F_{fr} is the total friction area of the moving and fixed triboelements, 0.00045 m^2.

An analysis of the transition curves in Fig. 1 indicates that the maximum wear per running-in $U_2 =$ 1.199 μm occurs when the second mode is applied: $N =$ 650 N; $v_{sl} =$ 0.8 m/s; in this case the running-in

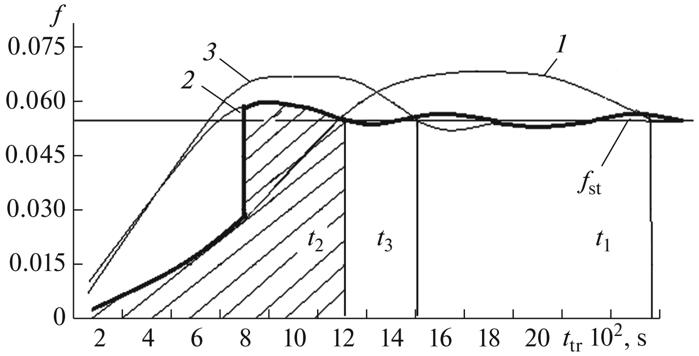

Fig. 2. The running-in friction coefficient transient characteristics of the steel 40X + bronze alloy CuA19Fe3 tribosystem.

time has an average value of the three modes equal to $t_2 = 1100$ s.

The running-in wear in the first mode is $U_1 = 0.988$ μm, and $t_1 = 1400$ s. The running-in wear in the third mode is $U_3 = 0.905$ μm, $t_3 = 900$ s.

An analysis of the transient friction coefficient curves in Fig. 2 indicates that the minimum deviation from the steady-state value and the minimum running-in time is characteristic of the second mode, $t_2 = 1100$ s.

The transient process in terms of the friction coefficient in the first mode, that is, $N = 2600$ N; $v_{sl} = 0.2$ m/s, has the longest running-in time of $t_1 = 2400$ s and the largest deviation $f_{max} = 0.068$ from the steady-state value $f_{st} = 0.054$.

A joint analysis of the running-in modes (Fig. 1 and Fig. 2) allows validation of the tribosystem running-in program under the following conditions: $U \to \min$, $t_{tr} \to \min$. According to Fig. 1 the running-in should be started in the first mode: $N = 2600$ N; $v_{sl} = 0.2$ m/s. Upon reaching the time $t_{tr} = 700$ s, when curves *1* and *2* cross each other, it is necessary to switch to the second mode: $N = 650$ N; $v_{sl} = 0.8$ m/s. Transient performance of this program is highlighted in Fig. 1 in bold. The total running-in wear (shaded area under the bold curve) will be $U = 0.840$ μm and the running-in time will be $t = 1100$ s.

The damping decrement values for the wear rate in the first mode are $d_I = 0.62$, and in the second mode, $d_I = 0.98$. This indicates that slight fluctuations are present at the beginning of the process and there are no fluctuations at the end; this follows from the conclusions of [9].

The damping decrement values for the friction coefficient in the first mode are $d_f = 0.52$, and in the second mode, $d_f = 0.64$. This indicates that the running-in process in terms of the friction coefficient occurs with fluctuations, whose values damp by the end of the running-in.

The analysis of the curves in Fig. 1 indicates that a more sustainable program is a transition from mode 1 into mode 2. In this case, $t_{tr} = 900$ s. However, this will significantly increase the running-in time in terms of the friction coefficient to 1400 s, Fig. 2.

The running-in according to the program means that the first mode (the running-in time is 700 s) is followed by the second mode, let us call it the first program, which will complete the transient process to stabilize the friction coefficient in 1100 s. This program is shown in Fig. 2 in bold. The area under the shaded curve characterizes the friction loss. In this case, the running-in times of the wear rate stabilization and the friction coefficient coincide and are equal to $t_{tr} = 1100$ s.

The running-in of the tribosystem according to mode 1 followed by mode 3 will significantly increase the running-in time in terms of the friction coefficient to $t_3 = 1400$ s.

The validated running-in program based on the simulation results will be confirmed experimentally at a later stage.

For comparison, let us consider a reverse running-in program (the second program), where the loading modes are applied in the reverse order.

(A) The second mode: $N = 650$ N; $v_{sl} = 0.8$ m/s.

(B) The first mode: $N = 2600$ N; $v_{sl} = 0.2$ m/s.

The simulation results of the transient processes in the steel 40X + bronze alloy $CuA_{19}Fe_3$ tribosystem are presented in Figs. 3 and 4.

An analysis of the curves in Fig. 3 indicates that the beginning of running-in in the second mode, shown in curve 2, followed by the transition to the intersection with curve *1* (to the first mode) will lead to the greatest running-in wear $U = 1.560$ μm, and a running-in time of 1.400 s. The friction coefficient stabilization running-in time under this program, shown in Fig. 4, will be $t = 2400$ s. This running-in program is shown in Figs. 3 and 4 with the bold dotted line.

Based on the simulation results, it can be concluded that the running-in program mode 2 → mode 1 is not sustainable, because it leads to the maximum

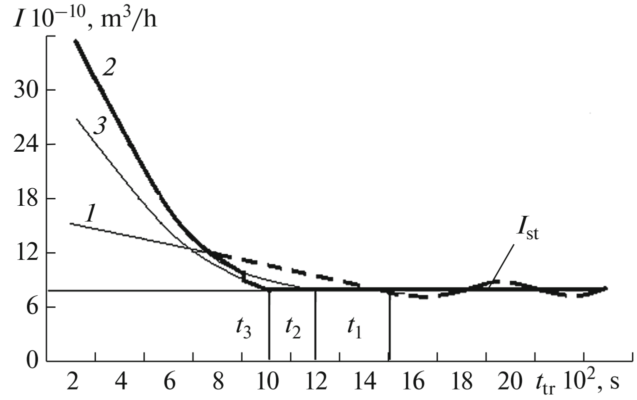

Fig. 3. The running-in wear rate transient characteristics of the steel 40X + bronze alloy CuA19Fe3 tribosystem for the reverse program.

running-in wear $U = 1.560$ µm and the maximum running-in time $t = 2400$ s.

The damping decrement values for the transient processes in mode 2 are $d_I = 0.98$, $d_f = 0.64$. This indicates the absence of wear rate unevenness and slight fluctuations of the friction coefficient.

When switching from the second mode to the first, the damping decrement values are equal to $d_I = 0.62$, $d_f = 0.52$. This indicates the unevenness in the transient processes, both in terms of the wear rate and friction coefficient.

A more sustainable program for the considered transition characteristics is the following sequence of modes: mode 2 → mode 3. This program (the third program) is shown in Figs. 3 and 4 with a bold solid line.

The running-in wear under this program will be $U = 1.083$ µm, with the running-in time $t = 900$ s, and the friction coefficient stabilization running-in time $t = 1400$ s.

Based on the simulation results, it can be concluded that of the three considered running-in programs for the steel 40X + bronze alloy $\text{CuA}_{19}\text{Fe}_3$ tribosystem the first program is the most effective: mode 1 → mode 2, and then switching to mode 3, the operation mode. As noted above, with this sequence, the running-in wear will have the minimum value $U = 0.840$ µm, and the wear rate stabilization time and the friction coefficient $t = 1100$ s.

RESEARCH AND DISCUSSION

A comparison of the simulation and experimental results for the 40X steel + bronze alloy $\text{CuA}_{19}\text{Fe}_3$ tribosystem for the first program is presented in Table 1.

An analysis of the results presented in Table 1 indicates that the running-in wear rate simulation error does not exceed $e_I = 10.5\%$ and the friction coefficient error is $e_f = 10.0\%$. The running-in time simulation error is $e_t = 8.3\%$.

At the beginning of the running-in process (in the first mode according to Table 1), there are fluctuations in both the wear rate and the friction coefficient. At the end of the running-in process (in the second mode), there are no fluctuations in the wear rate parameter, but they remain in the friction coefficient. These experimental facts agree with the simulation results.

A comparison of the simulation and experimental results for a similar tribosystem in the second (reverse) running-in program is presented in Table 2.

An analysis of the simulation and experimental results indicates that in the second program the simulation error increases. For the wear rate it is equal to $e_I = 12.9\%$, for the friction coefficient it is $e_f = 14.4\%$. At the same time, a significant fluctuation in the running-in process is observed, both in terms of the wear rate parameter and in the friction coefficient parameter. The wear rate running-in time simulation error is $e_t = 12.5\%$ and the friction coefficient error is $e_t = 12.0\%$.

The experimental results confirm the conclusion obtained by the simulation that the second (reverse)

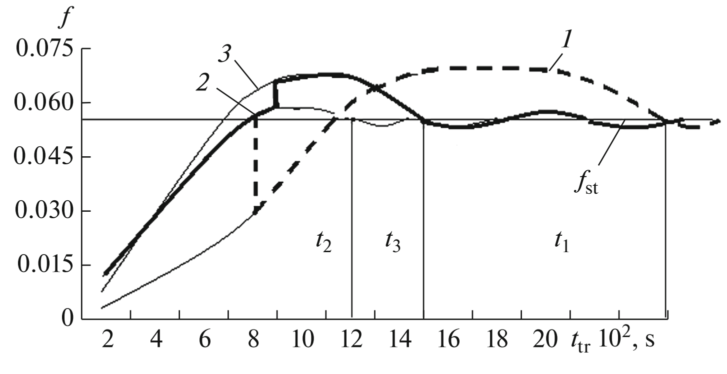

Fig. 4. The running-in friction coefficient transient characteristics of the steel 40X + bronze alloy CuA19Fe3 tribosystem for the reverse program.

Table 1. Comparison of the simulation and experimental results

Running-in time t, s	$I_{sim} \times 10^{-10}$, m^3/h	$I_{exp} \times 10^{-10}$, m^3/h (average value)	e_I, %	f_{sim}	f_{exp} (average value)	e_f, %
First mode $N = 2600$ N, $v_{sl} = 0.2$ m/s						
100	14.8	16.2	8.6	0.0011	0.0012	8.3
200	14.5	16.2	10.4	0.0042	0.0044	9.0
300	14.0	15.6	10.2	0.0088	0.0091	2.2
400	13.47	14.5	7.1	0.014	0.015	6.6
500	12.8	13.4	4.4	0.02	0.022	9.0
600	12.2	12.8	4.6	0.026	0.028	7.1
700	11.6	11.8	1.7	0.033	0.03	10.0
Second mode $N = 650$ N, $v_{sl} = 0.8$ m/s						
800	9.95	9.0	10.5	0.057	0.055	3.6
900	9.39	9.0	4.3	0.057	0.055	3.6
1000	9.06	8.8	2.9	0.055	0.052	5.7
1100	8.87	8.6	3.1	0.054	0.051	5.8
Steady-state friction parameters						
1200	8.87	8.6	3.1	0.054	0.051	5.8

Table 2. Comparison of the simulation and experiment results

Running-in time t, s	$I_{sim} \times 10^{-10}$, m^3/h	$I_{exp} \times 10^{-10}$, m^3/h (average value)	e_I, %	f_{sim}	f_{exp} (average value)	e_f, %
First mode $N = 650$ N, $v_{sl} = 0.8$ m/s						
100	38.2	43.0	11.1	0.0027	0.0029	6.8
200	30.6	34.0	10.0	0.023	0.025	8.0
300	23.7	27.0	12.2	0.037	0.042	11.9
400	18.4	21.0	12.3	0.048	0.054	11.1
500	14.8	17.0	12.9	0.054	0.06	10.0
600	12.4	13.0	4.6	0.057	0.064	10.9
700	10.88	10.0	8.8	0.057	0.062	8.0
Second mode $N = 2600$ N, $v_{sl} = 0.2$ m/s						
800	10.3	9.8	5.1	0.039	0.042	7.1
900	10.05	9.6	4.6	0.044	0.048	8.3
1000	10.0	9.4	6.3	0.049	0.053	7.5
1100	9.6	9.2	4.3	0.053	0.057	7.0
1200	9.2	9.0	2.2	0.057	0.06	5.0
1300	8.9	8.4	5.9	0.06	0.064	6.2
1400	8.84	8.6	2.7	0.062	0.066	6.0
1500	8.82	8.6	2.5	0.063	0.07	10.0
1600	8.8	8.6	2.3	0.064	0.072	12.1
1700	8.82	8.6	2.5	0.065	0.076	14.4
1800	8.84	8.6	2.8	0.065	0.072	9.7
1900	8.86	8.7	1.8	0.064	0.072	11.1
2000	8.88	9.0	1.3	0.064	0.072	12.1
2100	8.88	9.2	3.4	0.063	0.071	11.2
2200	8.86	9.3	4.7	0.062	0.068	8.8
2300	8.84	9.3	4.9	0.061	0.064	4.6
2400	8.82	9.2	4.1	0.06	0.062	3.2
2500	8.8	9.0	2.2	0.059	0.06	1.6
2600	8.8	9.0	2.2	0.059	0.062	4.8
2700	8.82	9.2	4.1	0.058	0.064	9.3
2800	8.84	9.3	4.9	0.056	0.066	13.6
Steady-state friction parameters						
2900	8.8	9.0	2.2	0.056	0.06	6.6

Table 3. Comparison of the simulation and experimental results

Running-in time t, s	$I_{\text{sim}} \times 10^{-10}$, m^3/h	$I_{\text{exp}} \times 10^{-10}$, m^3/h (average value)	e_I, %	f_{sim}	f_{exp} (average value)	e_f, %
Second mode $N = 650$ N, $v_{\text{sl}} = 0.8$ m/s						
100	38.2	42.0	9.0	0.0027	0.003	10.0
200	30.6	33.0	10.9	0.023	0.026	11.5
300	23.7	26.0	14.2	0.037	0.04	7.5
400	18.4	20.0	12.0	0.048	0.052	7.6
500	14.8	16.0	7.5	0.054	0.059	8.4
600	12.4	13.5	8.1	0.057	0.061	6.5
700	10.88	10.0	8.8	0.057	0.062	8.0
Second mode $N = 1040$ N, $v_{\text{sl}} = 0.5$ m/s						
800	9.19	9.0	2.1	0.061	0.063	3.1
900	8.65	8.5	1.7	0.061	0.063	3.1
1000	8.37	8.0	4.6	0.06	0.062	3.2
1100	8.27	8.0	3.3	0.059	0.06	1.6
1200	8.27	8.0	3.3	0.057	0.058	1.7
1300	8.32	8.0	4.0	0.056	0.057	1.7
1400	8.63	8.5	1.5	0.054	0.055	1.8
Steady-state friction parameters						
1500	8.65	8.5	1.7	0.054	0.055	1.8

running-in program, which begins with the second mode ($N = 650$ N; $v_{\text{sl}} = 0.8$ m/s) and the subsequent switching to the first mode ($N = 2600$ N; $v_{\text{sl}} = 0.2$ m/s) is not effective compared to the first program.

A comparison of the simulation and experimental results for a similar tribosystem in the third program are presented in Table 3.

The difference of this program from the previously presented ones is that the running-in is carried out with a step-like load increase to the operational value, subject to the condition $W = \text{const}$.

As follows from the results in Table 3, the wear rate simulation error is $e_I = 14.2\%$, and the friction coefficient error is $e_f = 11.5\%$. The running-in time simulation error does not exceed 8.0%.

The experimental studies established that at the beginning of the running-in process, there are no fluctuations in both the wear rate and the friction coefficient. After the transition from the second mode to the third one, only the friction coefficient fluctuations occur, which corresponds to the conclusions on the simulation results described above.

The experimental results confirmed the conclusions obtained by the mathematical simulation. The mathematical model that was developed in [9] makes it possible to validate the running-in modes for each specific tribosystem. The input parameters are as follows: geometric tribosystem dimensions, which are taken into account by the shape coefficient, C_{sh}; the combination of the materials of the moving and fixed triboelements, which is taken into account by the internal friction, δ_{m}, δ_{f}; the tribological properties of the lubricating medium, E_y; the initial roughness of the friction surfaces; load, N; sliding velocity, v_{sl}. Therefore, using simulation, an individual two-mode running-in program will be obtained for each tribosystem design.

CONCLUSIONS

Based on the theoretical and experimental studies, the structure of a two-mode tribosystem running-in program was developed and validated. In the first mode, the maximum load below the seizure threshold is set at the minimum sliding velocity. Due to the intense strain of the microasperities, this mode allows the formation of the equilibrium friction surface roughness and changes in the structure of thin surface layers. The first mode can be called the adaptation of the tribosystem to external conditions. In the second mode, the minimum load and maximum sliding velocity are set. This mode makes it possible to reduce the restructuring time of the surface layer and to complete the formation of secondary structures and oxide films. The second mode can be called the learning and training of the tribosystem.

The tribosystem running-in transient characteristics were obtained, which make it possible to establish the relationship between the tribosystem design, sustainable loading conditions, running-in time, and running-in wear. The practical significance of the work is the opportunity to minimize the running-in time and wear for the running-in period.

NOTATION

UMT-1	is the Universal friction machine
W	is pumping energy or power delivered to the tribosystem
N	is the load
$v_{\rm sl}$	is the sliding velocity
$t_{\rm tr}$	is the transient process completion time
$I_{\rm st}$	is the steady state wear rate
$I_{\max}$	is the maximum running-in wear rate value
$f_{\rm st}$	is the friction coefficient after the running-in
$f_{\rm st}$	is the maximum running-in friction coefficient value
U	is the running-in wear rate
d_I	is the damping decrement of the wear rate fluctuations
d_f	is the damping decrement of the friction coefficient
$\delta_{\rm m}$	is the internal friction of the moving triboelement material structure
$\delta_{\rm f}$	is the internal friction of the fixed triboelement material structure
$C_{\rm sh}$	is the shape coefficient of the tribosystem
$E_{\rm y}$	is the tribological properties of the lubricating medium
$a_{\rm f}$	is the thermal conductivity of the fixed triboelement material (bronze)
$a_{\rm m}$	is the thermal conductivity of the moving triboelement material (steel)
$R_{\rm a}$	is the friction surface roughness
$F_{\rm fr}$	is the total friction area of the moving and fixed triboelements
$I_{\rm sim}$	is the wear rate obtained from the simulation results
$I_{\rm exp}$	is the wear rate obtained by the experimental results
$f_{\rm sim}$	is the friction coefficient obtained from the simulation results
$f_{\rm exp}$	is the friction coefficient obtained from the experimental results
e_I	is the wear rate simulation error
e_f	is the friction coefficient simulation error
e_t	is the running-in time simulation error

REFERENCES

1. Karasik, I.I., *Prirabatyvaemost' materialov dlya podshipnikov skol'zheniya* (Workability of Materials for Sliding Bearings), Moscow: Nauka, 1978.
2. Genkin, V.A., Zharin, A.L., Fishbein, E.I., Shipitsa, N.A., and Terekhov, A.L., Material workability for friction joints, *Trenie Iznos*, 1989, vol. 10, no. 3, pp. 530–534.
3. Sergeichev, A.V. and Denisova, N.E., Workability of intricate engineering system from the viewpoint of reliability and wear, *Trenie Iznos*, 2004, vol. 25, no. 1, pp. 22–28.
4. Zelinskii, V.V., Isofriction running-in of sliding bearings of machines, Part 1, *Mashinostr. Bezop. Zhiznedeyatel'nosti*, 2009, no. 6, pp. 117–121.
5. Zelinskii, V.V., Isofriction running-in of sliding bearings of machines, Part 2, *Mashinostr. Bezop. Zhiznedeyatel'nosti*, 2011, no. 3, pp. 48–52.
6. Volchenkov, A.V., Study of antifriction materials of friction units for workability, *Sovrem. Probl. Nauki Obraz.*, 2014, no. 6. http://science-education.ru/ru/article/view?id=16065. Accessed August 5, 2018.
7. Sviridenko, A.I., et al., *Akusticheskie i elektricheskie metody v tribotekhnike* (Acoustic and Electrical Methods in Tribotechnics), Belyi, V.A., Ed., Moscow: Nauka i Tekhnika, 1987.
8. Baranov, V.M., et al., *Akusticheskaya emissiya pri trenii* (Acoustic Emission in Friction), Moscow: Energoatomizdat, 1998.
9. Vojtov, V.A. and Biekirov, A.Sh., The mathematical model of transitional processes in tribosystems and modeling results, *Probl. Tribol.*, 2018, no. 1, pp. 18–27.
10. Bershadskii, L.I., *Adaptivnost' i obuchaemost' tribosistem* (Adaptability and Learning of Tribosystems), Kiev: Znanie, 1987.