DEVELOPMENTS IN MECHANICAL ENGINEERING
ISSN: 2300-3383 DOI: 10.37660/dme.2020.15.8.8 **15(8)2020**

The effect of temperature lag on the value of power-temperature correlation for frictional pair of conformal contact

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Abstract: The article presents a statistical analysis of electric power supplied to the friction node and temperatures of that node. The paper examines the dependence of the temperature lag of friction node of conformal contact on the amount of electric power consumption using the Pearson's method. To the a/m analysis R software was applied [1–3].

Key words: surface texture, surface layer, base oil, additives, electric power, temperature

1. Introduction

During the mating of elements of a given frictional pair there is a friction which is characterized by the loss of mechanical energy. This energy undergoes a transformation or is diffused. During the transformation or diffusion of this energy the following occurs:

- there is work in the contact zone of mating elements;
- there is work of elastic, plastic deformation and adhesion work;
- transformation into heat, vibration, and the like.

Monitoring the amount of energy brought to the mating of kinematic pair and consequences of its transformation (temperature, among others) one can determine individual portions or relations between, for example:

- amount of power brought into the system and temperature of the frictional pair;
- the amount of power brought to the system and the quantity of vibrations;
- the amount of power brought to the system and performed work of plastic deformation;
- the amount of power brought to the system and wear in given conditions.

Heat is the main 'beneficiary' of the friction forces work. Therefore, it is very important to determine dependencies between the amount of power brought to the co-acting elements and temperature value of a given friction node.

2. Test conditions

The following set of input factors was adopted during these tests:

- average relative motion velocity V;
- type of lubricating composition (in this case it was a pure oil base SN-150).

The average velocity of relative motion during the tests amounted to 0.16 m/s. Samples with a counter sample were co-acting at the external load of 600 N, which – at the contact surface of samples with a counter sample of 300 mm^2 – corresponds to the theoretical pressure in the contact zone of 2.0 MPa.

Taking into account the material of samples and of a counter sample, the following hardness of samples was adopted: 40 HRC, and for a counter sample: 60 HRC.

Constant factors in the tests included the construction material of samples, i.e. steel 102Cr6 (NC6). This steel is characterized by, inter alia, a small hardness spread after a heat treatment, therefore in order that hardness of samples be within a narrow range, this material was selected for testing. Samples were in the shape of a cube measuring 10×10×10 [mm].

It was assumed that the material of a counter sample and its hardness (H) remained unchanged. Therefore, these features of a counter sample were included into the constant factors. A counter sample was made of steel X210Cr12 (formerly NC11) quenched to the hardness of 60±2 HRC. The hardness of the counter sample was much greater than the hardness of samples in order that the process of wear and results of transformation of the surface layer be visible primarily on samples. The condition of the surface texture of the counter sample was periodically controlled – its texture did not show any significant symptoms of wear.

On the basis of preliminary tests the value of the path of friction L = 2000 [m] was adopted. For this value, when pure oil base SN-150 is used, there is a stabilization of tested factors (T temperature changes and surface texture titres).

Conditions of treatment of tested elements were also accepted as constant factors – grinded surface, work temperature (temperature in which the transformation of the surface layer took place) equal to the ambient temperature: +20°C.

Completed tests of a specified range were performed on the test rig shown in Fig. 1. Tested samples were fixed in three grooves made every 120° on the front of the sleeve fixing the samples. A reliable and uniform pressure of co-acting elements was obtained with the use of a spring [4, 5].

Tests were conducted for SN-150 pure oil base.

Thermocouples of K type, designed for the temperature measurement were placed in an oil chamber in the distance of 5 mm from co-acting elements (Fig. 2).

P-T correlations were calculated using the Pearson's method. It was assumed at the same time that obtained results have a normal distribution.

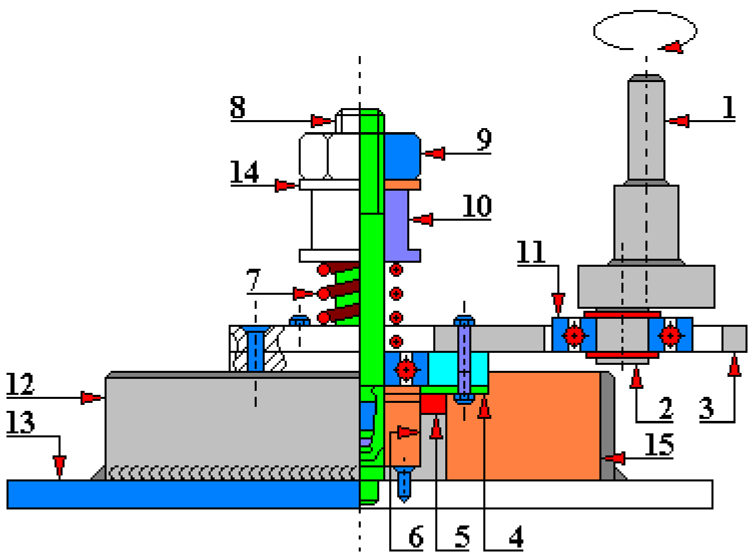


Fig. 1. Structural form of the test rig: 1 – eccentric handle; 2 – eccentric; 3 – lever; 4 – counter sample; 5 – tested samples; 6 – samples stabilizing bush; 7 – spring; 8 – central screw; 9 – nut; 10 – distance bush; 11 – single-row ball bearing; 12 – pipe jacket; 13 – steel plate of the base; 14 – washer; 15 – tested lubricating compound [own study]

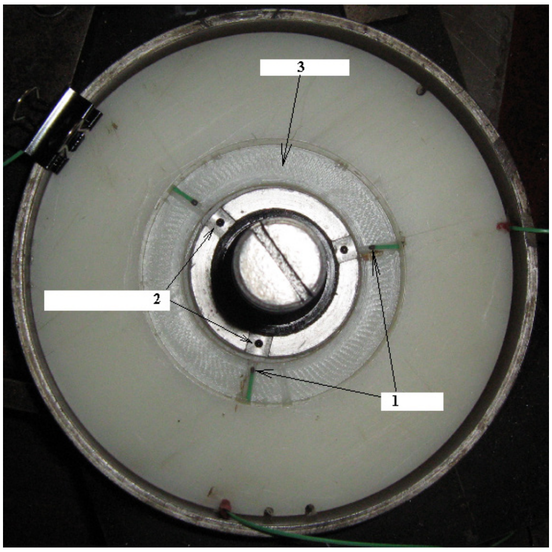


Fig. 2. Distribution of thermocouples in an oil chamber:
1 – thermocouples; 2 – place of fixing samples; 3 – oil chamber [own study]

3. Test results

During these tests it was observed, on the basis of obtained measurement, results, that the temperature lag T (system response) in relation to power P (input signal) is 1 minute. Below presented is a fragment of importing data into R software (Table 1). The first 15 results can be viewed. Column V1 comprises data pertaining to the value of electric power consumption P [kW], and column V2 comprises temperatures read T [°C], while column V3 comprises the path of friction [m]. On the basis of this fragment it is evident that after the first minute from the moment of supplying power P, thermocouples have not noted any temperature variations. Only in the second minute of work the oil temperature has undergone a change from 18.187°C to 19.102°C. Based on this, it was accepted that a response lag (here variations of temperature T) against a set signal (here – electric power P) for this concrete case amounts to one minute. Therefore, calculations of P-T correlation were conducted for temperature values shifted by one minute against a set value of power P and for measurements not shifted in time to compare them.

Measured values of power consumption P [kW] and temperature variations T [°C] of frictional pair are presented jointly in Fig. 3. The diagram of the power consumption P is produced as a mean of 3×12000 second measurements of power for which average minute values were defined. And temperatures were measured every 1 minute on the path of friction L = 2000 meters. Thus, 9×200 minute measurements of temperature were made, and its values were averaged. For the data so prepared, a graph of power and temperature course was generated in R software (Fig. 4), box plots (Fig. 6) and correlation courses (Fig. 5). In Tab. 2 presented list of statistical parameters for P-T correlation.

Table 1. Fragment of importing data into R software:
V1 – electric power consumption P [kW]; V2 – temperature T [°C];
V3 – path of friction [m] [own study]

No.	V1	V2	V3
1	0.000	18.187	0 START
2	3.303	18.187	10
3	3.476	19.102	20
4	3.424	19.657	30
5	3.579	20.503	40
6	3.431	20.526	50
7	3.458	20.868	60
8	3.386	21.091	70
9	3.546	21.451	80
10	3.508	21.678	90
11	3.519	21.753	100
12	3.396	22.510	110
13	3.435	22.345	120
14	3.411	22.538	130
15	3.429	22.689	140

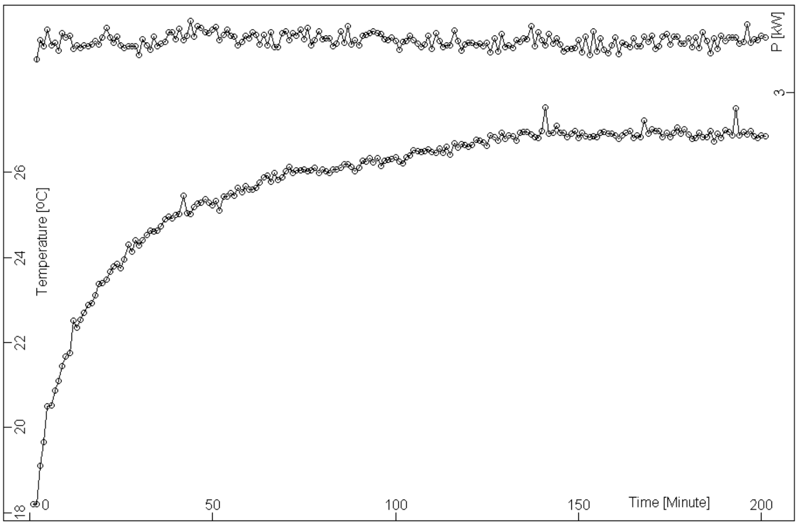


Fig. 3. The course of variations in the electric power consumption P and variations of temperature T in the oil chamber; path of friction L = 2000 m, relative motion velocity v = 0.16 m/sec, 100% SN-150 pure oil base [own study]

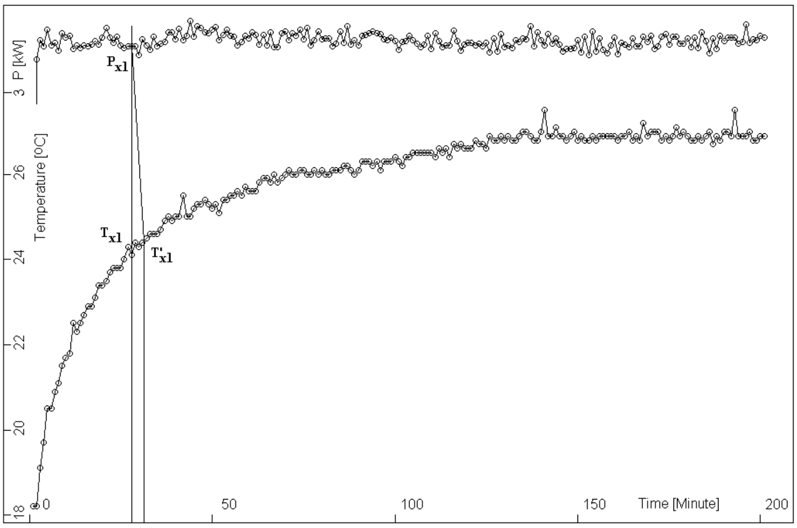


Fig. 4. Presentation of the response lag (variations of temperature T) relative to a set signal (supply of electric power P) for the tribological system: P_{x1} – set power in time ×1; T_{x1} – read temperature in time ×1; T'_{x1} – change of temperature after supplying power P_{x1} (temperature change lag caused by inertia/inertance of the system) [own study]

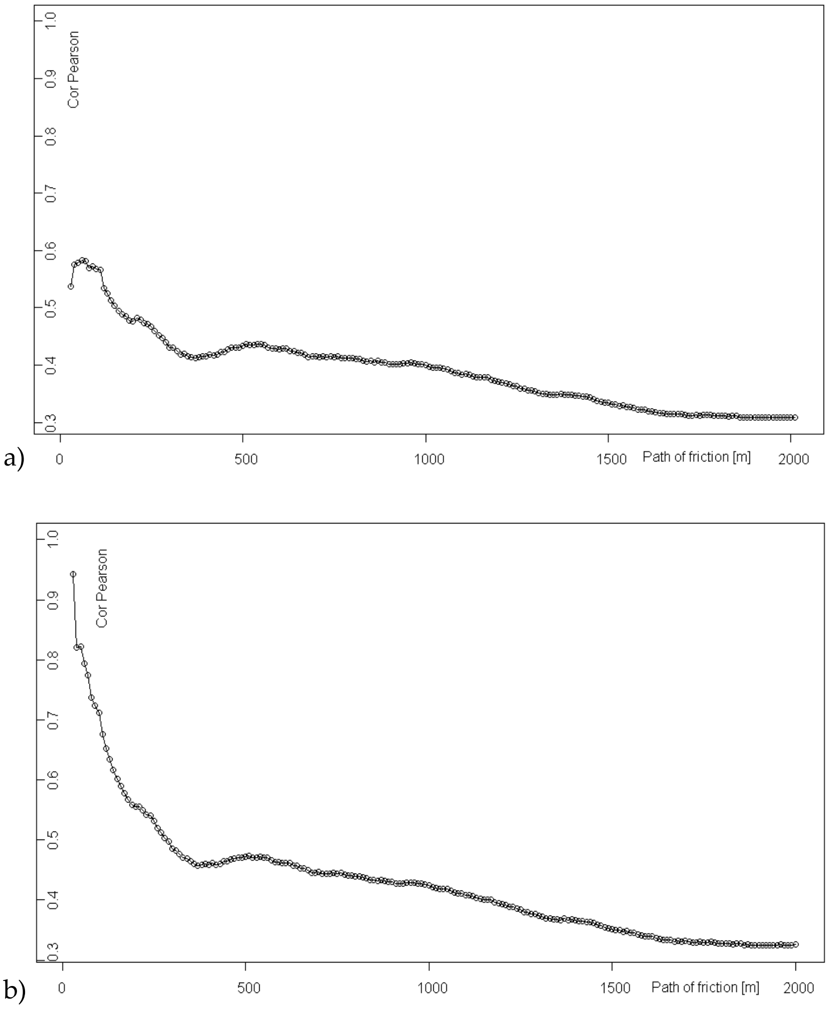
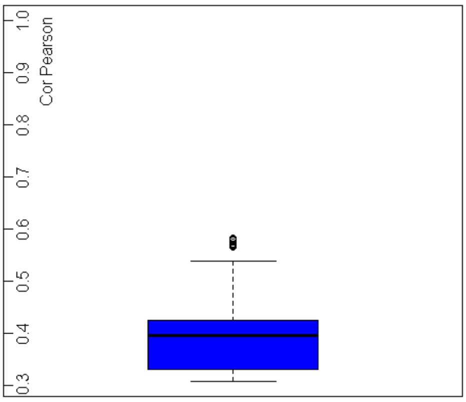
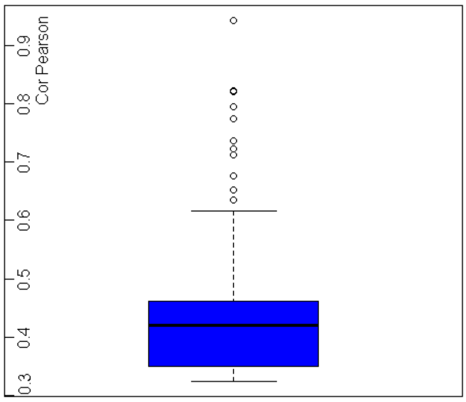


Fig. 5. The result of P-T correlation determined with the Pearson's method; 100% SN-150 (pure oil base), path of friction L = 2000 m, relative motion velocity v = 0.16 m/sec
a) without a time shift; b) with a time shift of 1 minute [own study]



a)



b)

Fig. 6. A box plot generated in R software concerning the P-T correlation (power-temperature) determined using the Pearson's method; 100% SN-150 (pure oil base), path of friction L=2000 m, relative motion velocity v = 0.16 m/sec:
a) without a temperature shift; b) temperature shift by 1 minute [own study]

Table 2. List of statistical parameters for P-T correlation. A relative motion velocity v = 0.16 m/sec, path of friction L = 2000 m, 100% SN-150 (pure oil base)
Min – minimum value; 1stQu. – first quartile; Median – median; 3rdQu. – third quartile; Max – maximum value; s – standard deviation; Mean – arithmetic mean [own study]

	Min	**1stQu.**	**Median**	**3rdQu.**	**Max**	**s**	**Mean**
Cor Pearson (without a shift)	0.308	0.332	0.396	0.423	0.583	0.066	0.390
Cor Pearson (with a shift)	0.324	0.351	0.421	0.462	0.943	0.104	0.429

4. Summary

Based on the obtained results one may conclude that:

- P-T correlation is reduced on the path of friction;
- it is generally small (apart from the initial work period);
- the inertia of the system has an impact on the value of P-T correlation, especially in the initial period of work of co-acting elements;

- for the temperature values shifted by 1 minute greater values of P-T correlation were obtained than for temperature values not shifted (mean values of correlation are respectively 0.429 and 0.390);
- in the terminal period of work (after 2000 m path of friction) obtained were similar values of P-T correlation for values of shifted temperatures and not shifted ones (respectively 0.324 and 0.308).

The cause of small P-T correlation obtained should probably be viewed in the construction of the tribological test rig used. This test rig is characterized by an oscillatory work cycle, which may constitute a source of disturbances of dependencies between power and temperature, especially at the moment of temperature stabilization.

Literature

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