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Determining the energy validity of the Kostetsky's hypothesis on the basis of models for relative motion velocity v = 0.08 m/sec

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Summary: The paper examines the dependence of the temperature of friction node of conformal contact on the amount of electric power consumption. It presents arguments confirming the validity of Kostetsky's energy hypothesis. R software was applied to the above-mentioned analysis.

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

1. Introduction

From an energetic point of view friction is a process in which mechanical energy (the work of forces maintaining bodies under friction in motion) is converted into other forms of energy. What are the proportions of the conversion of this energy into other forms of energy, and on what they depend – are the questions that have been bothering tribologists for many years. This paper presents arguments confirming the validity of Kostetsky's hypothesis [4–6]. R software was applied to the above-mentioned analysis [1–3, 7].

The energetic hypothesis of friction was first presented by Kuznetsov [8] who stated that all friction work is spent on formulating a new friction surface. He also tried to link the coefficient of friction with the effects of friction in the form of wear. This energetic hypothesis was further developed by Kostetsky [5], who, on the basis of the first law of thermodynamics, provided the following relationship as regards the energy balance in the area of friction. The work of external forces supplied to a given system of the mating friction pair is converted into the following components:

- heat given off at friction;
- work of shifting and sliding of the boundary layer;
- gain of the internal energy of the tribological system;
- surface energy gain;
- energy of external dispersion.

In addition, Kostetsky distinguishes – depending on certain friction parameters (to be precise on the amount of normal load and on sliding velocity) – the so-called normal friction and pathological friction. In his view, for a normal friction, almost the whole work of friction forces is converted into heat, and the main processes taking place in the contact zone are boundary layer slip and elastic deformation of friction work materials. And during a pathological friction there are phenomena such as ridging, tacking, push broaching, and major processes in the contact zone include:

- plastic deformation of the surface layer in a macro scale;
- molecular interaction;
- various mechanisms of destroying the macro-volume of the surface layer material.

According to Kostetsky, the amount of friction force during a pathological friction depends mainly on the structure of the material and condition of the rubbing surfaces.

2. Test conditions

Values which constitute the set of input factors were selected on the basis of gathered literature information and preliminary tests:

- average relative motion velocity v;
- type of lubricating compound.

The average velocity of relative motion amounted to: 0.08 m/sec. Samples with a counter-sample were mating at the external load of 600 N which – for the contact surface of samples with a counter-sample amounting to 300 mm^2 – corresponds to the theoretical pressure in the contact zone of 2.0 MPa.

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

Constant factors included the construction material of samples, i.e. steel 102Cr6 (NC6). This steel is characterized by, inter alia, a small hardness straggling after heat treatment, therefore, in order that the hardness of samples is within a narrow range, this material was selected for testing. Samples were in the shape of a cube measuring 10x10x10 [mm].

It was assumed that the material of a counter-sample and its hardness (H) remained unchanged during the tests. Thus, these features of samples were also 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 could be directed, and results of transformation of the surface layer could 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.

Conditions of treatment of tested elements were also accepted as constant factors – ground surface, friction face equal to L = 2000 m, pressure force of the counter-sample onto samples F = 600 N, work temperature (temperature in which the transformation of the surface layer took place) equal to the ambient temperature: 20°C.

Random, uncontrolled input factors – disturbances include inter alia:

- vibration resulting from deviations of structure elements of the test rig;
- contamination of the work environment;
- diversification of geometric surface structure of samples caused for example by the process of wear of tools during the treatment;
- variation of the pressure force resulting from the installation deviation of the spring deflection as well as progressive wear of samples;
- samples hardness straggling caused for example by heterogeneity of the samples material in its whole volume.

Tests were carried out on the rig presented in Fig. 1 and 2. Tested samples were fixed in three grooves every 120° on the face the bush stabilizing samples in order to ensure a reliable and uniform three-surface pressure of mating elements.

Tests were conducted for SN-150 pure oil base [8, 10]. Presentation of variations of temperature and power input – Fig. 3 and 4.

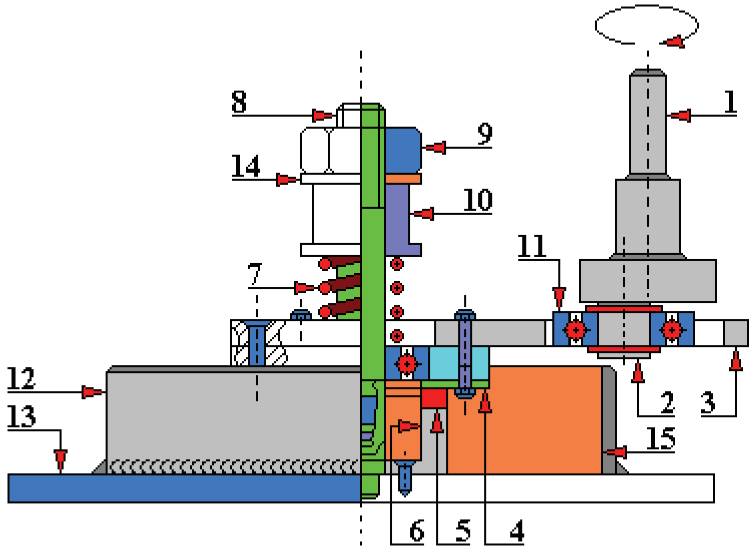

Fig. 1. Structural form of the test rig. 1 – eccentric handle; 2 – eccentric; 3 – lever, 4 – counter-sample; 5 – tested samples, 6 – samples stabilizing bush; 7 – spring; 8 – central screw; 9 – nut; 10 – distance bush; 11 – singe-row ball bearing; 12 – pipe jacket; 13 – steel plate of the base; 14 –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

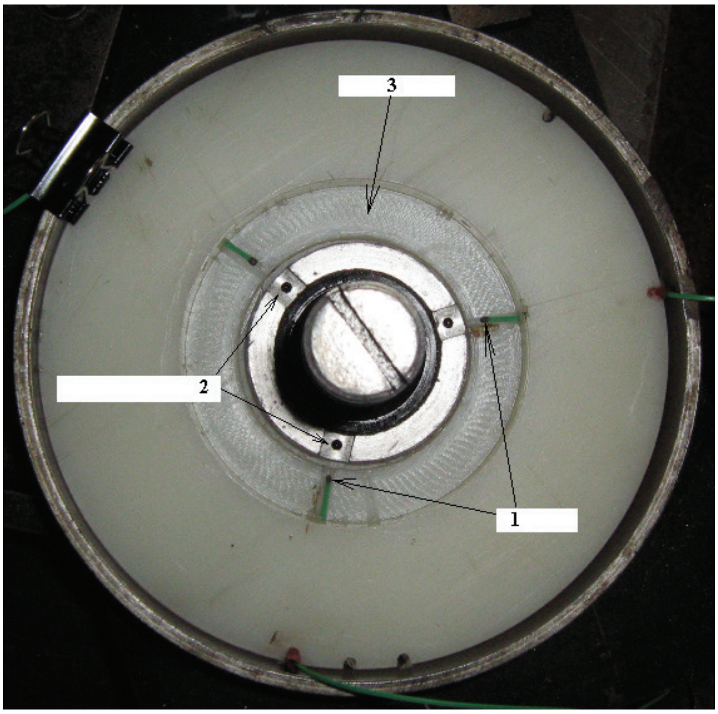

Fig. 2. Distribution of thermocouples in an oil chamber. 1 – thermocouples; 2 – place of fixing samples; 3 – oil chamber [own study]

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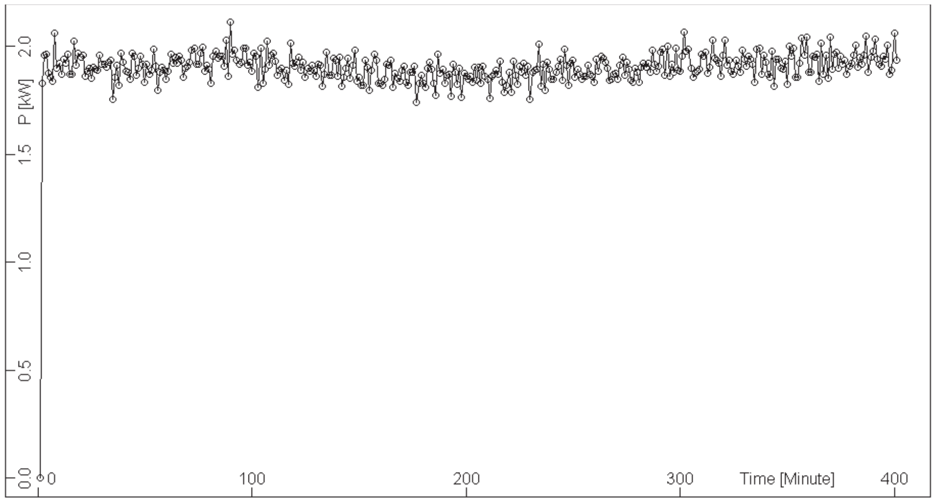

Fig. 3. A plot generated in R software referring to the power input for the 100% SN-150 (pure oil base). Relative motion velocity v = 0.08 m/sec; path of friction L = 2000 m; on the vertical axle – power consumption in [kW] [own study]

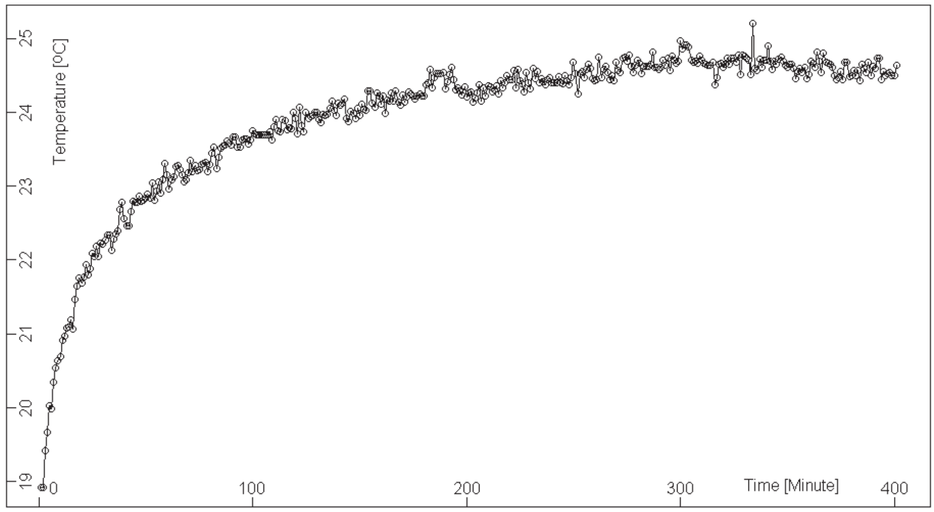

Fig. 4. Presentation of variations of temperature. 100% SN-150 (pure oil base). Relative motion velocity v = 0.08 m/sec; path of friction L = 2000 m [own study]

3. Tests results

Three polynomial models were built for the measured power consumption values P [kW] on the path of friction L = 2000 m:

- model No. 1 (power-friction path) – first order straight regression (Fig. 5);
- model No. 2 (power-friction path) – second-degree curvilinear regression (Fig. 6);
- model No. 3 (power-friction path) – third-degree curvilinear regression (Fig. 7).

Next, three polynomial models were also built for the measured temperature values T [°C] on the path of friction L = 2000 m:

- model No. 4 (temperature-friction path) – second curvilinear regression (Fig. 8);
- model No. 5 (temperature-friction path) – third-degree curvilinear regression (Fig. 9);
- model No. 6 (temperature-friction path) – fourth-degree curvilinear regression (Fig. 10).

After determining the values of model coefficients their diagnostics was performed in order to check the match of measured results.

One model best suited to the measured values P [kW] was selected from the set of models 1, 2 and 3. Similarly, one model best suited to the measured values T [°C] was selected from the set of models 4, 5 and 6.

Based on the description of fitting of above-mentioned models and organoleptic tests of these models' graphs, the following models were adopted as models adequate to the measured power and temperature values:

- for power P, model No. 2 determined by the equation:

$$y = 0.1678 \cdot x^2 + 0.2893 \cdot x + 1.9004$$

- for temperature T, model No. 5 determined by the equation:

$$y = 4.815 \cdot x^3 - 10.268 \cdot x^2 + 16.492 \cdot x + 23.931$$

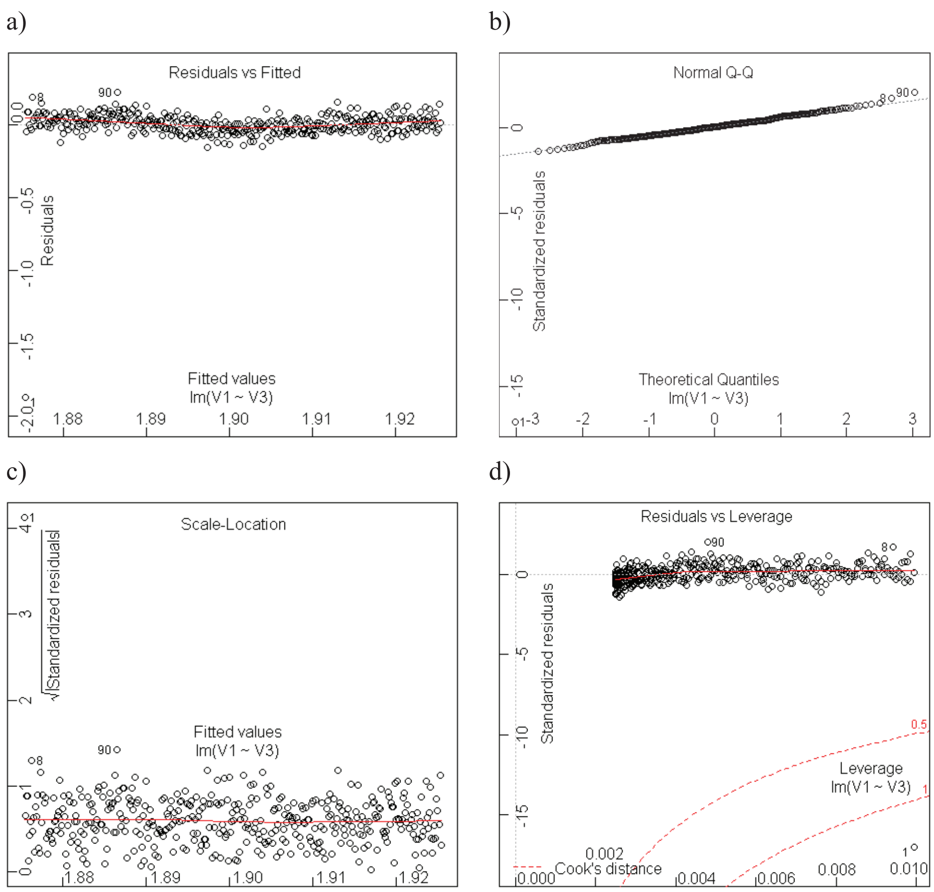

Fig. 5. Diagnostic graphs for model No. 1 (power-friction path, straight regression) [own study]

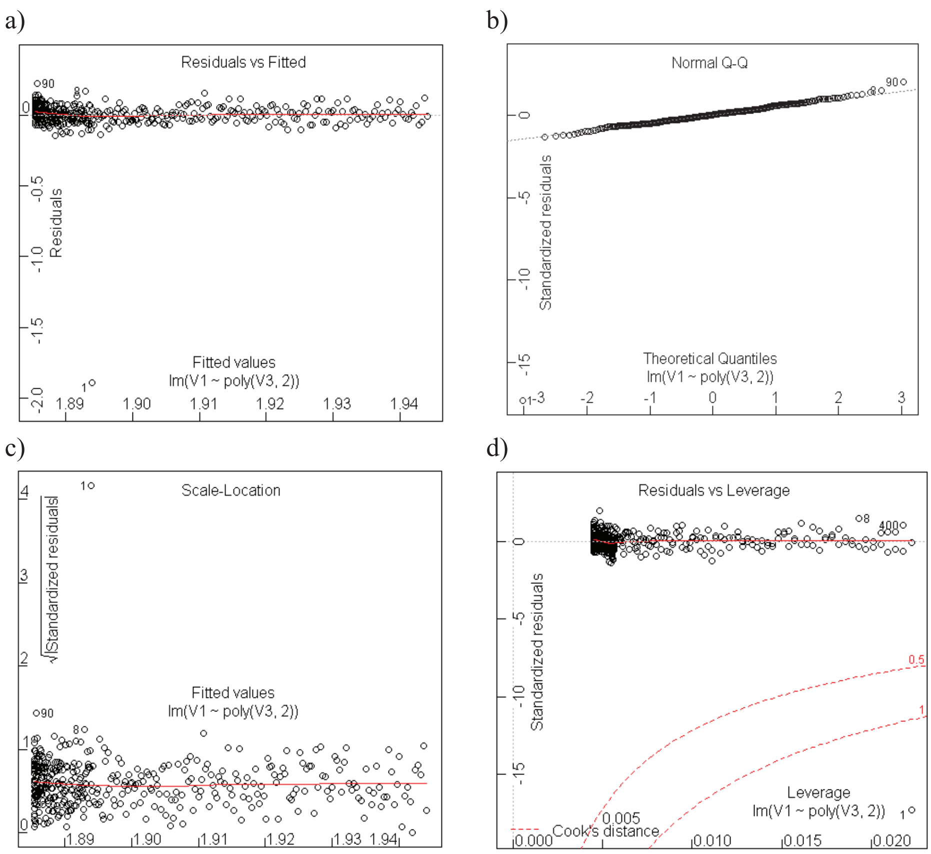

Fig. 6. Diagnostic graphs for model No. 2 (power-friction path, second degree curvilinear regression) [own study]

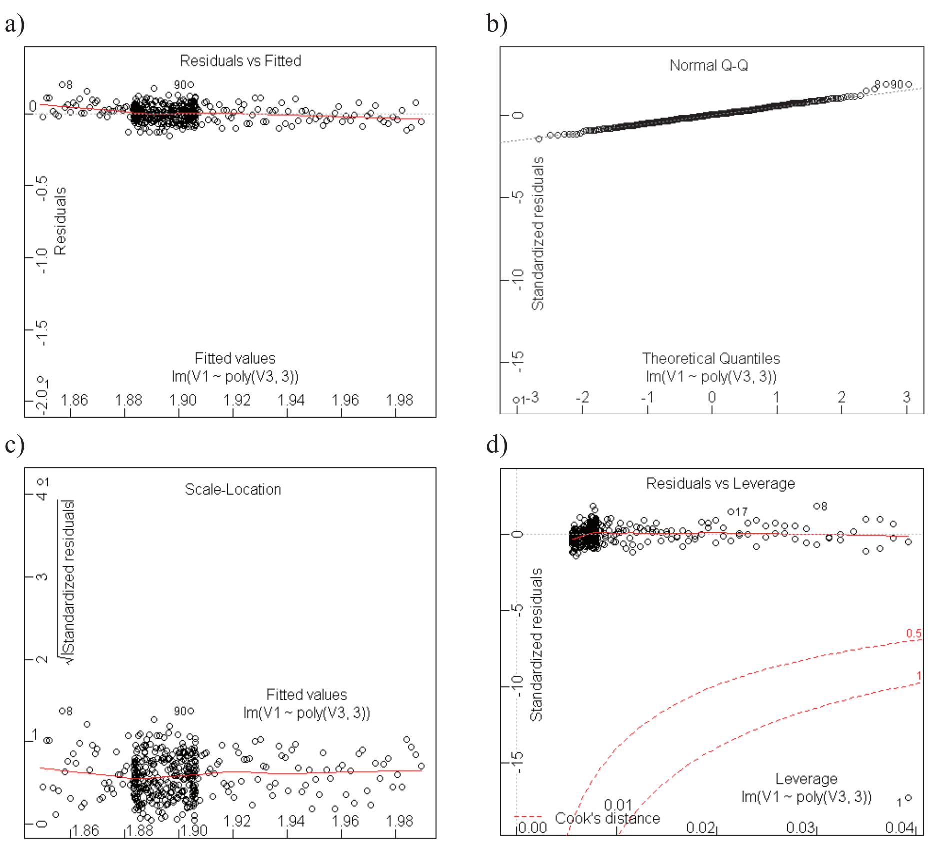

Fig. 7. Diagnostic graphs for model No. 3 (power-friction path, third degree curvilinear regression) [own study]

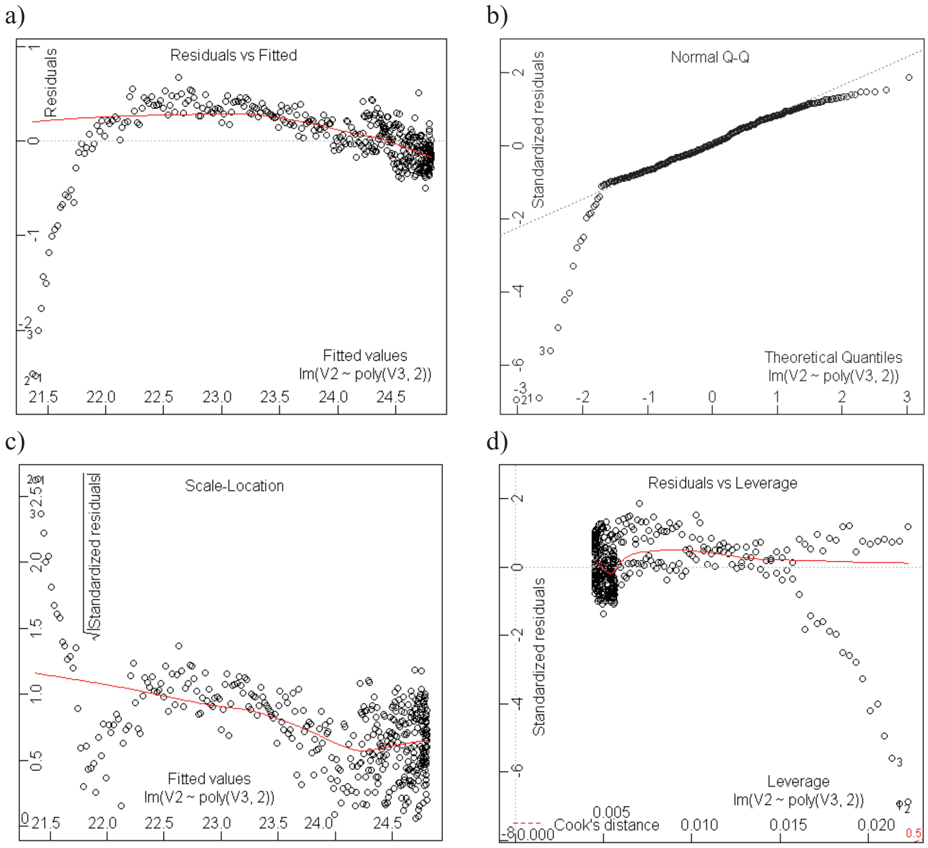

Fig. 8. Diagnostic graphs for model No. 4 (temperature-friction path, second degree curvilinear regression) [own study]

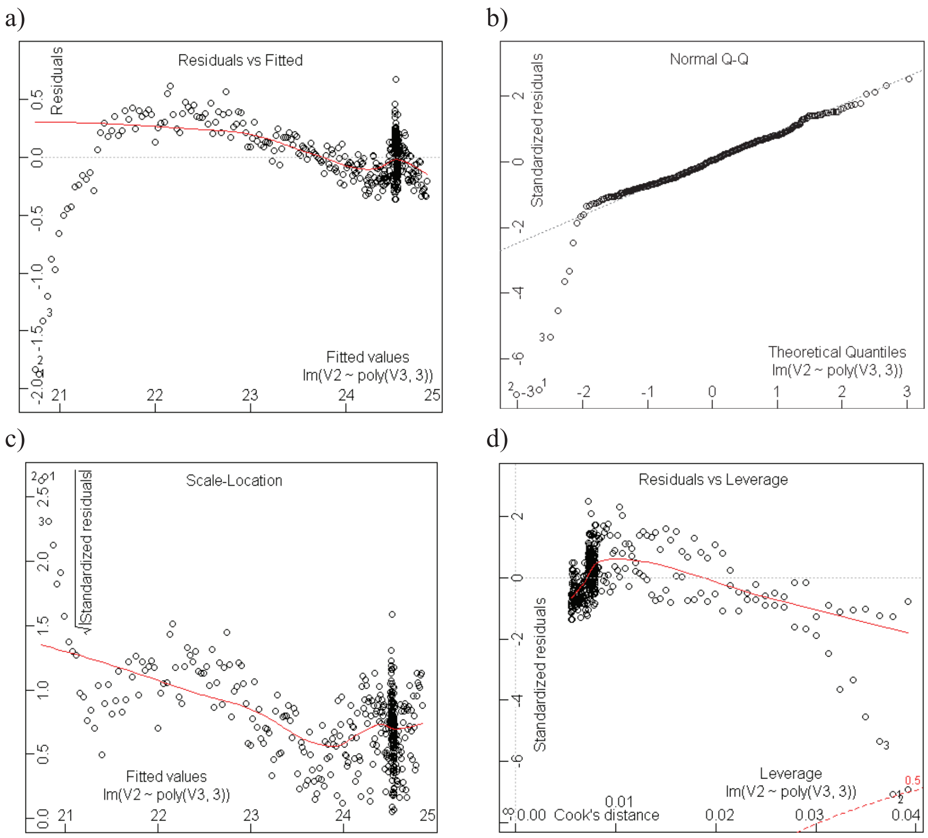

Fig. 9. Diagnostic graphs for model No. 5 (temperature-friction path, third degree curvilinear regression) [own study]

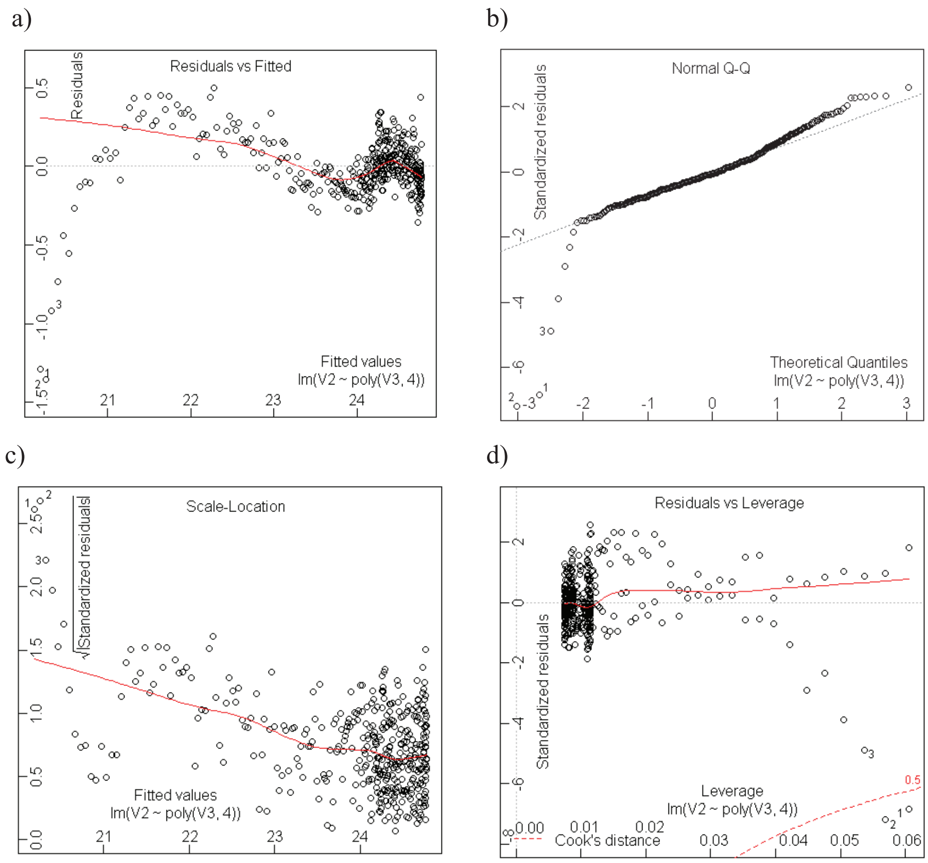

Fig. 10. Diagnostic graphs for model No. 6 (temperature-friction path, fourth degree curvilinear regression) [own study]

Then, in order to analyze a partial P-T correlation (Fig. 11-14), the path of friction L = 2000 m was divided into the following characteristic phases (Fig. 15):

- phase A (from zero to Pmax);
- phase B (from Pmax to L = 2000 m).

For model No. 2 power P reaches a maximum value Pmax = 1.934 kW for the path of friction L = 400÷535 m. In this range of path of friction the power maintains its maximum value.

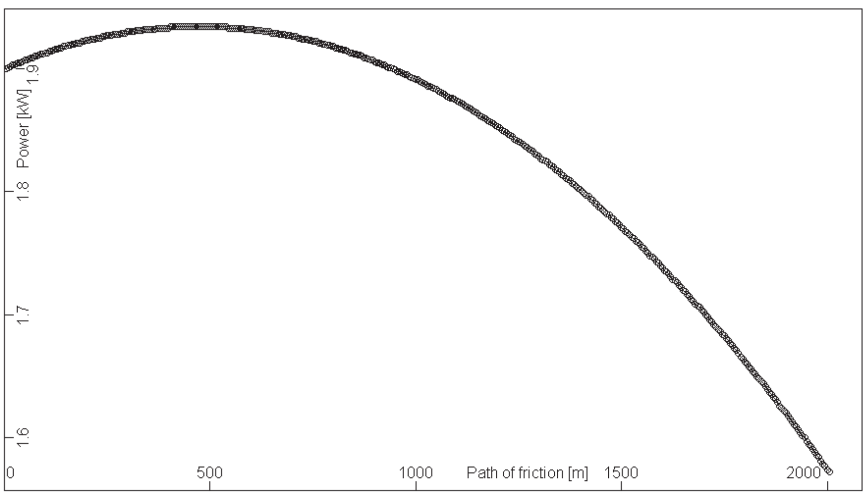

Fig. 11. Power P waveform on the path of friction L = 2000 m for model No. 2 [own study]

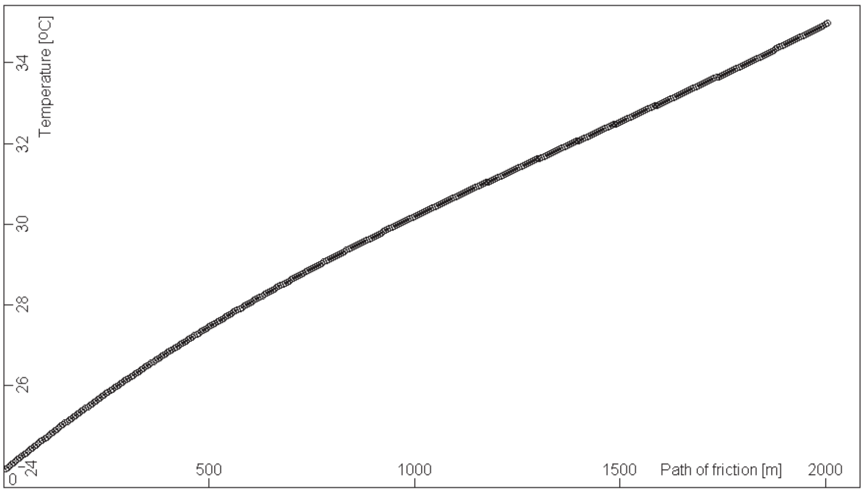

Fig. 12. Temperature T waveform on the path of friction L = 2000 m for model No. 5 [own study]

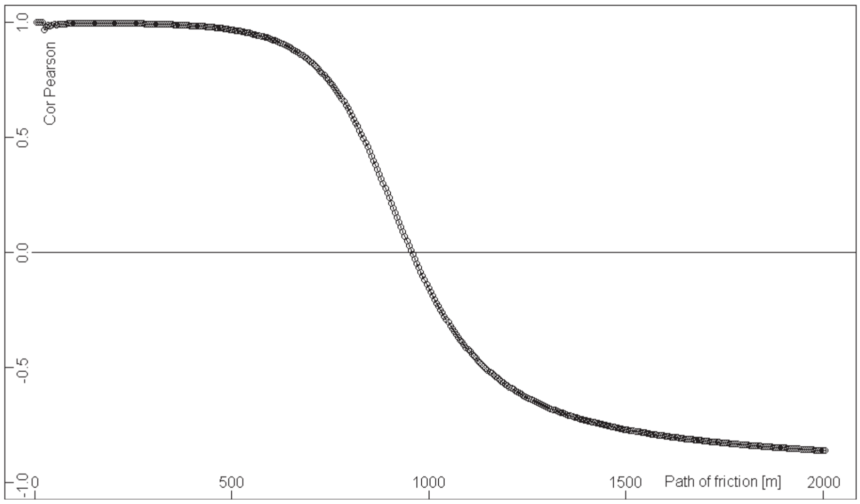

Fig. 13. Pearson's correlation process for adequate P-T models [own study]

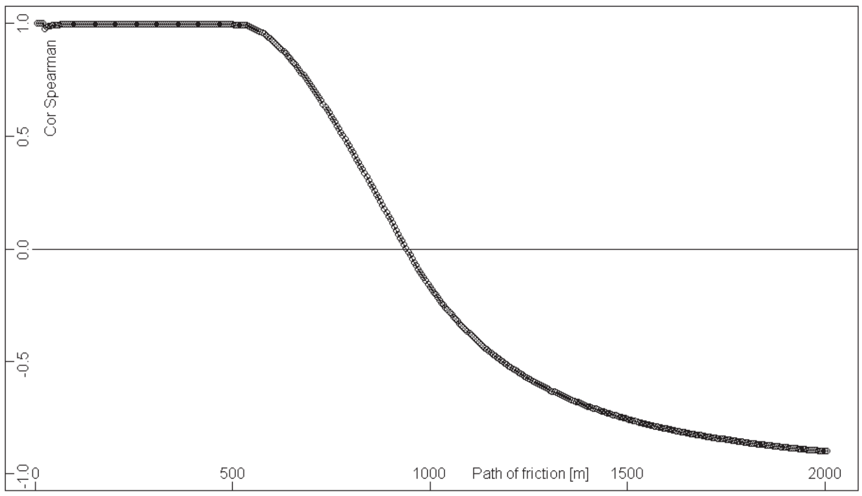

Fig. 14. Spearman's correlation process for adequate P-T models [own study]

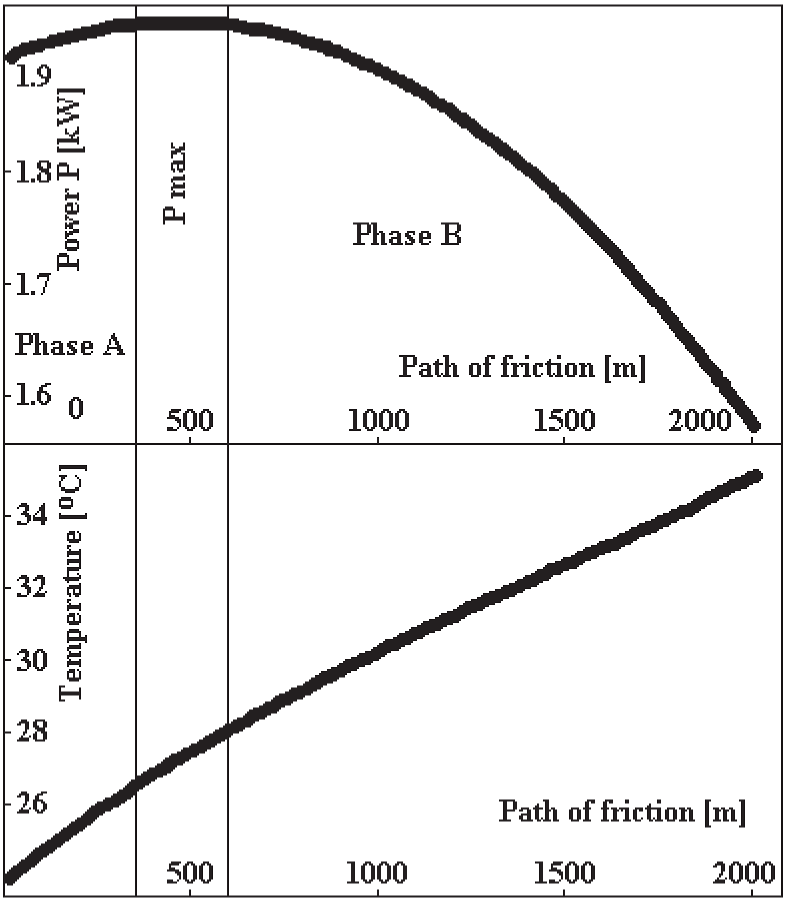

Fig. 15. Division of the path of friction L into two phases [own study]

For the above-mentioned, P-T correlations were recalculated only on these sections (Fig. 16-19).

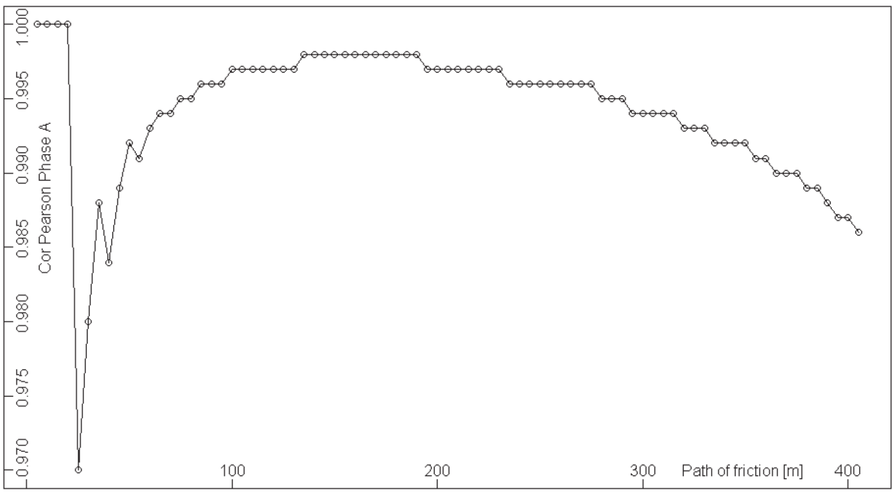

Fig. 16. The Pearson's correlation process for P-T models for phase A; path of friction L = 0÷400 m [own study]

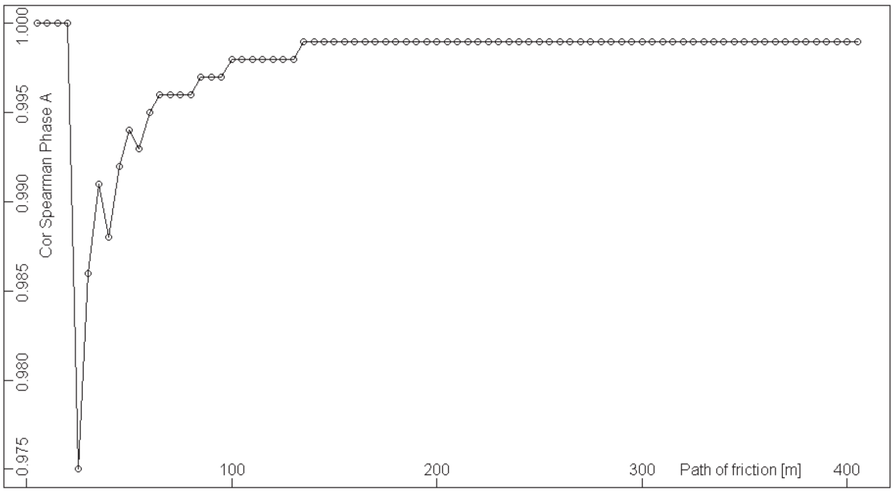

Fig. 17. The Spearman's correlation process for P-T models for phase A; path of friction L = 0÷400 m [own study]

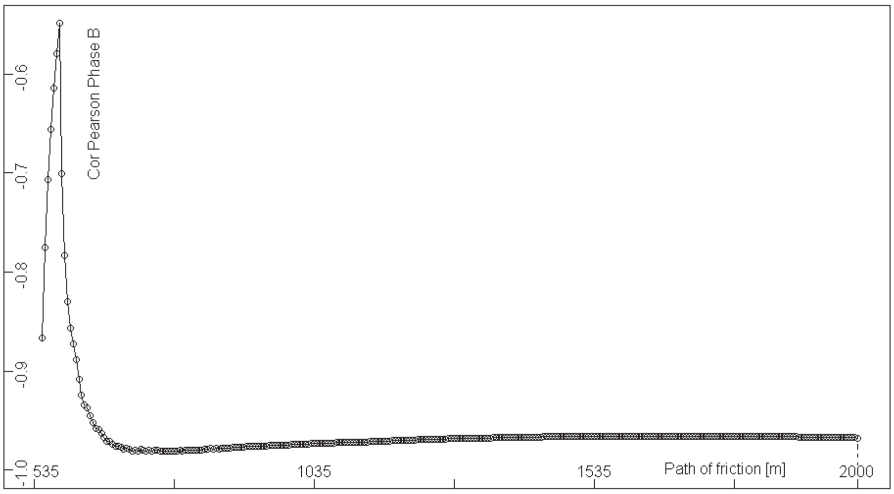

Fig. 18. The Pearson's correlation process for P-T modela for phase B; path of friction L = 535÷2000 m [own study]

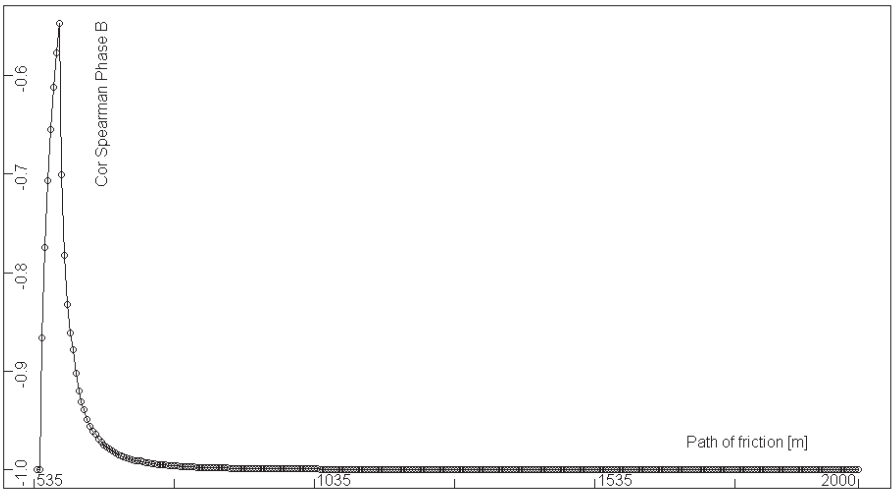

Fig. 19. The Spearman's correlation process for P-T models for phase B; path of friction L = 535÷2000 m [own study]

4. Sumary

- for phase A (when both parameters are rising) the P-T correlation is close to +1;
- for phase B (when one parameter decreases (P) and the other increases (T) the P-T correlation is close to -1.

Phase A means the stage of grinding in of the co-acting surfaces. The power supplied to the system is converted, among others, into the formation of the operational surface layer and into heat. The P-T correlation for this phase close to +1 indicates a functional relationship between these values.

Presented above results of the tests on models confirm the hypothesis made by Kostetsky who states that for normal (non-pathological) friction almost all work of friction forces is converted into heat, which is evidenced by a large correlation between the power supplied to the system and temperature.

Literature

[1] Biecek, P., „Analiza danych z programem R", Wydawnictwo Naukowe PWN, Warszawa 2013.
[2] Biecek, P., „Przewodnik po pakiecie R", Oficyna Wydawnicza Gis, Wrocław 2017.
[3] Gągolewski, M., „Programowanie w języku R", Wydawnictwo Naukowe PWN, Warszawa 2016.
[4] Gierzyńska, M., „Tarcie, zużycie i smarowanie w obróbce plastycznej metali", Wydawnictwo Naukowo Techniczne, Warszawa 1983.
[5] Kostetsky, W.I., "Trienije, smazka i iznos w maszinach", Kijew, *Tiechnika* (1970).
[6] Kragielski, I.B., Dobyczin, M.N., Kombałow, B.S., "Osnowy razczietow na trienije i iznos", Maszinostrojenieje, Moskwa 1977.
[7] Kulczycki, P., „Estymatory jądrowe w analizie systemowej", Wydawnictwa Naukowo-Techniczne", Warszawa 2005.
[8] Kuzniecow, W.D., „Fizika twierdowo tieła", t. IV, Tomsk, Krasnoje Znamia 1947.
[9] Mikołajczyk, J.R., „Maszyny tarciowe. Budowa, przeznaczenie", Wydawnictwo Państwowej Wyższej Szkoły Zawodowej w Pile, Piła 2018.
[10] Mikołajczyk, J.R., „Wpływ dodatków smarowych na transformację warstwy wierzchniej", Wydawnictwo Państwowej Wyższej Szkoły Zawodowej w Pile, Piła 2017.