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THE EXPERIMENTAL TESTS ON THE FRICTION COEFFICIENT BETWEEN THE LEAVES OF THE MULTI-LEAF SPRING CONSIDERING A CONDITION OF THE FRICTION SURFACES

BADANIA EKSPERYMENTALNE WSPÓŁCZYNNIKA TARCIA POMIĘDZY PIÓRAMI RESORU WIELOPIÓROWEGO Z UWZGLĘDNIENIEM STANU POWIERZCHNI CIERNYCH*

In this study are presented the results of the simulation tests of the friction pairs occurring between the spring leaves while considering a condition of the mating surfaces and an impact of the velocity of their mutual dislocation on the values of the friction coefficients. It has been proposed a methodology in respect of a determination of the coefficients of the static and kinetic friction. Two kinds of the specimens have been prepared for the tests, which have been cut out from a spring leaf of the prototype spring – they have created the model friction pairs. The condition of the specimen surface and their selected mechanical properties have been evaluated. During the experimental tests have been considered: four sliding velocities, four variants of the surface conditions and two values of the normal load. The tests of the friction pairs have been performed at the laboratory stand for measuring the friction force. The results of the tests have been presented in a form of the time courses of friction force, graphs and tabular summaries of the friction coefficients. It has been conducted a comparative analysis of the results in order to determine an influence of the test results on the values of the determined friction coefficients. The proposed research conditions are approximate to the typical operating conditions of the road vehicles.

Keywords: *multi-leaf spring, laboratory tests, friction pairs, surface roughness, friction forces, static and kinetic friction coefficients.*

W pracy przedstawiono wyniki badań symulacyjnych węzłów tarcia występujących pomiędzy piórami resoru, z uwzględnieniem stanu powierzchni współpracujących oraz wpływu prędkości ich wzajemnego przemieszczania, na wartości współczynników tarcia. Zaproponowano metodykę wyznaczania współczynników statycznych i kinetycznych tarcia. Do badań przygotowano dwa rodzaje próbek, które wycięto z pióra resoru prototypowego - tworzyły one modelowe pary cierne. Oceniono stan powierzchni próbek i wybrane właściwości mechaniczne. W badaniach eksperymentalnych uwzględniono: cztery prędkości poślizgu, cztery warianty stanu powierzchni oraz dwie wartości obciążenia normalnego. Badania par ciernych wykonano na stanowisku laboratoryjnym do pomiaru siły tarcia. Wyniki badań przedstawiono w postaci przebiegów czasowych siły tarcia, wykresów i zestawień tabelarycznych współczynników tarcia. Wykonano analizę porównawczą wyników w celu określenia wpływu warunków badań, na wartości wyznaczonych współczynników tarcia. Zaproponowane warunki badań są zbliżone do typowych warunków eksploatacyjnych pojazdów drogowych.

Słowa kluczowe: *resor wielopiórowy, badania laboratoryjne, pary cierne, chropowatość powierzchni, siły tarcia, statyczny i kinetyczny współczynnik tarcia.*

1. Introduction

The spring is an elastic element of the suspension, which is responsible for transferring forces and torques between the vehicle wheels and its frame, reduces the impacts developed by the reactions of the ground that produce the effects on the riding vehicle and has an essential impact on the movement stabilisation and the ride comfort. The researches evidence that the friction in the spring significantly affects a dynamic stiffness and vehicle vibrations. As a result of the relative movement of the spring leaves in the spring is developed the friction, which may contribute to instability of the vehicle movement and the unfavourable increase of the inelastic friction in the suspension. It is noticeable, in particular, on the roads that feature the good road surfaces. The dynamic forces, generated by the road irregularities, can be too small to overcome the friction forces between the spring leaves. Then it is observed a phenomenon of the "spring interlock", which is disabled from the suspension operation, and the developed forces are transmitted from the road irregularities directly to from a wheel to the vehicle body. It leads to a deterioration of the ride comfort. In the study [14] have been researched the dynamic properties of the stiffness of the multi-leaf spring in terms of designing the structure with a particular attention to the ride comfort. The spring intended for a light-duty truck has constituted an object of the studies. A dependency between the friction, frequency and vibrations amplitude on the dynamic stiffness of the spring has been determined on the basis of

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** the experimental tests and the numerous numerical tests while using the finite elements method (FEM). The results of the conducted test have enabled to optimise a structure of the vehicle suspension in terms of the proper selection of the elastic and damping characteristics. As a result, the ride comfort has been significantly improved. According to [14] it has been found that the dynamic stiffness of the leaf spring changes as the frequency, amplitude and energy dissipated due to the friction are changed. In the study it has been evidenced that a decrease of the friction between the spring leaves of the spring is the most effective way to improve the dynamic stiffness of the multi-leaf spring. An operating status of the spring leaf surfaces, their susceptibility to wear is a subject of the researches presented in the study [8]. In the article it has been studied an influence of the residual stresses on the durability of the structural elements, while forecasting its wear. The residual stresses usually occur as a result of the surface processing, such as shot blasting or rolling. An objective of the experimental tests has consisted in determining an impact of friction and wear characteristic resulting from an interaction of the residual stresses for the sliding surfaces, in dry condition and a measurement of the interphase friction. The specimens for the tests are made from the SUP9 material intended for manufacturing the leaf springs. The residual stresses have been performed on the spring leaf surface due to shot blasting. The profiles of the residual stresses have been measured on the surface and under the surface using a method of X-ray diffraction. The sliding tests have been carried out under a different contact pressure for a specified sliding velocity of 0.035 m/s in order to determine the friction and wear characteristics of the leaf surfaces. The laboratory tests of the leaf springs have been performed on the strength testing machine. It has been obtained the load - displacement curves in a form of a hysteresis loop, which have constituted a basis for a determination of a friction force and a friction coefficient between the spring leaves. The friction coefficients, wear volumes and wear velocities for two conditions of the shot blasted surfaces and specimens, which have not been a subject of shot blasting. In this way, an influence of the residual stress on the tribological characteristic have been evaluated.

In the article [2] one has been proposed to evaluate a total force generated by the leaf spring as a composition of an elastic force and a dry friction force. It has been assumed a spring model, in which an influence of a velocity change of the relative values for the cutting forces of the spring leaves has not been considered. A hysteresis in this model is strongly non-linear. It has been demonstrated that an analysed model can be linked by a discretisation and a change of the parameters with a district time-varying model, which was proposed in 1980 by a team headed by Fancher. For the purposes of mapping a non-linear behaviour of the leaf spring, in the study [2] one has attempted to apply a classical spring model with a linear elastic force and a linear viscous friction force. It has been discussed a process of cross-validation these two non-linear models while considering a member of the elastic and dumping forces, originating from the dry friction and viscous friction. The non-linear model of the spring has been also tested during the experiments in the real heavy goods vehicle.

In the literature [4, 5, 9, 11] can be found the results of a computer simulation with a usage of the finite elements method for the different versions of the spring: beginning from a simple three-leaf spring and ending with the multi-object models [4, 9, 10]. This diversification makes that they are used at the different stages of the vehicle construction (modernization) process for an analysis of the physical phenomena that take place in the chosen elements, parts and assemblies and of the entire vehicle. They represent a different level of complexity and accuracy thus a labour input when developing them and required computational time

Article [11], in which the authors focus on the “multibody” approach and the finite elements method (FEM), in order to find a compromise between a computational accuracy and a computational velocity deserves a special attention. A research area includes an intended use of the vehicle, an evaluation of its operational dynamics within a scope of its handling and the ride comfort. In this article, an interesting variant of the multibody numerical model, as the multi-object model built in the LMS Virtual. Lab Motion [11] has been proposed. Each spring leaf of the spring is discretised in a form of the rigid bodies connected with the linear elastic beams. A contact is modelled as a simplified interaction between the balls, which has this advantage that is computationally efficient and it is suitable for this type of the applications, in which the contact areas are known a priori (leaf ends [5]).

Due to the wide use of the multi-leaf springs in the suspensions of the dependent suspension of the heavy-duty vehicles and trailers, a problem of their operational wear becomes very significant for the technical support facilities of the enterprises.

One of many reasons of the intensive wear of the leaf springs is the servicing negligence. In fig.1 is shown a typical case of the spring wear due to the corrosion (areas marked with the ellipses). The external environmental effects (water, dust, etc.) on the elastic elements causes their intensive operational wear. The generated corrosion products fill the apertures creating a distinctive notch between the mating spring leaves. The conditions of their mating are a subject of the change, and, in particular, the spring leaf curvatures and occur the further clearances between the spring leaves (change of the friction conditions) [3]. As a consequence of the variable dynamic loads, interacting with the vehicle suspension, fatigue strength of the spring changes radically and is durability decreases.

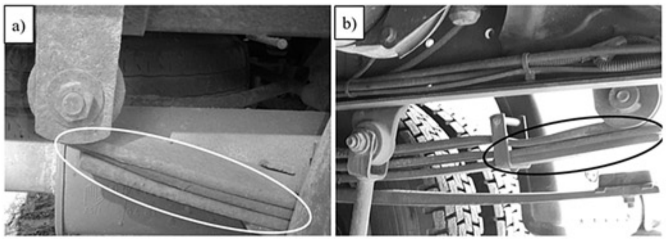


Fig. 1. The examples of the improper operational service of the elastic elements in the rear suspension of the vehicle: a) multi-leaf spring, b) double parabolic spring

The friction between the spring leaves has a great impact on the parameters of the vehicle suspension, and therefore on its operational characteristics. A possibility of considering the friction in the designing and diagnosing methods in respect of the spring is necessary to determine an operating condition of the suspension and the complete vehicle. The modern designing of the vehicle suspension requires a precise description of the friction phenomenon and an appropriate definition of the friction in a form of the different class of the models [4, 5, 9, 11]. For the purposes of the detailed defining of these models that map the friction phenomenon and changes of its interaction, it is necessary to know the static and kinematic friction coefficients. An answer to the question about an influence of the velocity of the mating leaf surfaces and an influence of the surface condition of the spring leaves on the values of the static and kinetic friction coefficients has not been found in the analyses papers, either. Due to the different friction cases, which occur between the spring leaves, an attempt to develop a complementary, consistent and universal model is a complex research problem.

In the study has been described a methodology of determining the friction coefficients in the research conditions similar to the typical operational conditions of the heavy-duty vehicles equipped with the metal multi-leaf springs. It has been conducted the comparative analysis of the simulation results and it has been determined an influence on the test conditions on the values of the determined friction coefficients.

2. Characteristic of the Test Object

2.1. Preparation of the Specimens and a Measurement of their Mechanical Properties

A basic objective of the experimental tests has consisted in the determination of the static and kinetic coefficients of the friction between the spring leaves for the typical for this element: structure condition of the surface layer and the chosen intermediate layers between the mating spring leaves. Therefore, the fragments of the spring leaf of the multi-leaf spring, intended for the rear suspension of the heavy-duty vehicle featuring the GVWR of 12 t have been used for the tests. In the programme of the laboratory tests have been foreseen two sets of the friction pairs comprising a specimen and a counter-specimen, which have been characterised by the different conditions of the friction surfaces. Four specimens have been cut out from the spring leaf:

- two specimens with the dimensions: 12 x 80 x 58 [mm];
- two counter specimens with the dimensions: 12 x 80 x 145 [mm].

Within the frames of the preparatory works in one set (friction pair) one has narrowed down only to its cleaning from the dust while remaining its surface layer in the existing condition (surface covered with a rust layer), but in the second friction pair, one has cleaned the surface layers, on which rust, pitting, cracks, etc. by grinding and smoothing. Then the friction pairs prepared like this have been used during the laboratory tests. The steel ingredients have been specified on the basis of the metallurgical certificate and it has been compared with PN-74/H-84032 standard (table 1).

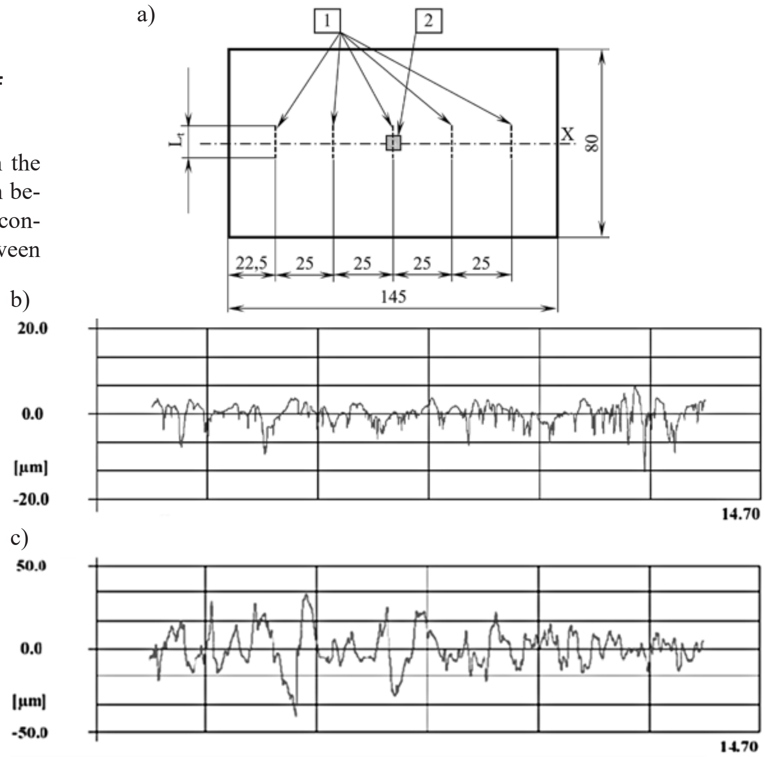


Fig. 2. Profilograms performed for the spring leaves: a) sites where the measurements have been carried out: 1 – location of the measurement sections, 2 – area, for which the 3D image of the micro-surface has been made, b) cleaned specimen, c) corroded specimen

Table 1. Chemical composition of steel 50HSA

Denotation		Proportion of elements in chemical composition [%]							
		C	Mn	Si	P	S	Cr	Ni	Cu
50HSA (by PN-74/H-84032)	min	0,45	0,3	0,8	-	-	0,9	-	-
	max	0,55	0,6	1,2	0,03	0,03	1,2	0,4	0,25
Test sample		0,46	0,38	0,88	0,013	0,01	0,93	0,19	0,15

While analysing the results contained in the table 1 it should be stated that the tested 50HSA spring steel meets, in terms of its chemical composition, the requirements comprised in the standard.

The mechanical properties of the steel have been evaluated using the specimens cut out from the spring leaf. The tests have been carried out pursuant to the PN-04310 standard on the strength testing machine, on which an elongation A_5, the percentage reduction of area Z and Young's modulus E of the steel have been determined. Furthermore, it has been determined hardness of the specimens with the Brinell hardness tester. The results of these tests are presented in the table 2.

Table 2. Selected mechanical properties of 50HSA steel

Denotation	R_m [MPa]	A_5 [%]	Z [%]	HB	E [MPa]
Value	1086	18,1	27,4	320	$2{,}03\cdot10^5$

A decrease in a tensile strength limit (R_m) by approx. 18% in respect of the value specified in the PN-74/H-84032 standard is worth noticing.

2.2. Evaluation of the Surface Condition of the Specimens

An evaluation of the surface condition of the friction pairs elements has been performed on the basis of a roughness measurement [6, 7, 13] at the laboratory stand equipped with a measurement instrument of the HOMMELL TESTER T1000 type. With regard to each specimen there have been performed the measurements have been carried out in the transverse direction in respect of a longitudinal axis x (fig. 2a) of the spring leaf (along its width) in the three (for the specimen) or five (for the counter-specimen) sites along its length.

A length of the measurement section has been assumed as L_t = 14.7 mm with a corresponding elementary section of L_c = 2.5 mm. A measuring head has moved with a velocity of 0.5 mm/s. The exemplary results of the measurements obtained for the specimens with two surface conditions are presented in a form of the profilograms (fig. 2b and c), performed in the regions of the geometrical centres of the specimen surfaces (intersection point of the longitudinal and horizontal axis of the specimen).

As a complement to the profilograms showed in fig. 2, table 3, there have been presented the basic parameters of the irregularities for the friction pair in the corroded and cleaned condition. They have been determined while using a smoothing filter compliant with the DIN 4777 standard.

The results presented in the table, constitute an arithmetic mean from five measurements. While analysing the results, contained in the table 3, it should be determined, that the maximum roughness heights (R_{max}), maximum ordinate values of the profile (R_z) and a total height of the profile (R_t) for the cleaned specimen are approx. one third (approx. 33%) of the values determined for the corroded specimen.

The selected results of the tests are shown in fig. 3. They constitute the 3D images of the tested micro-surfaces with a linear magnification 100x.

On these images, for the corroded specimen, a surface geometry is expressly shown. There are visible the sites where a layer of iron

Table 3. Selected parameters of surface roughness for the friction pair

Parameter [μm]	Specimen	
	corroded	cleaned
R_{max}	65,88	21,96
R_z	50,80	14,90
R_a	8,74	1,89
R_t	66,58	22,12
W_a	10,50	1,64

It is worth noticing a change in a waviness profile (W_a), which has decreased with regard to the cleaned specimen approx. 6.5 times in comparison with the corroded specimen (table 3). Moreover, the 3D images of the friction surfaces (fig. 2a, marking 2) have been made with a use of the optical microscope in the sites where roughness has been measured. For this purpose, the laboratory stand equipped with the measuring instrument of the KEYENCE VHX-1000 type has been used.

3. Experimental tests of the friction coefficient

3.1. Scope of the tests

The tests have been carried out at the laboratory stand for meas-

a)

b)

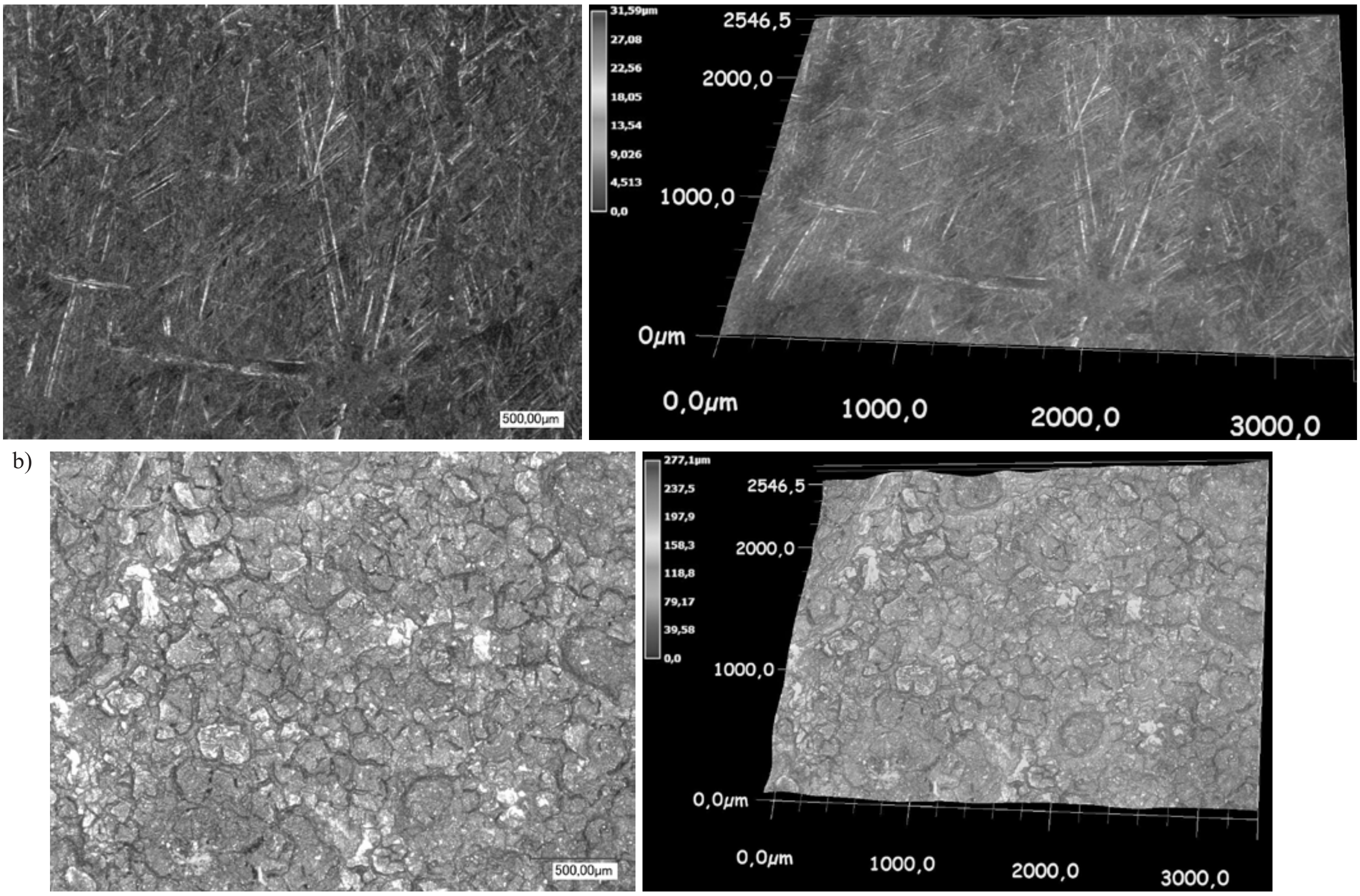


Fig. 3. The view of the specimen surface (linear magnification 100x) and the 3D images of the micro-surfaces: a) for the cleaned specimen – max. depth of the surface irregularities is of 37.6 μm, b) for the corroded specimen - max. depth of the surface irregularities is of 277.1 μm

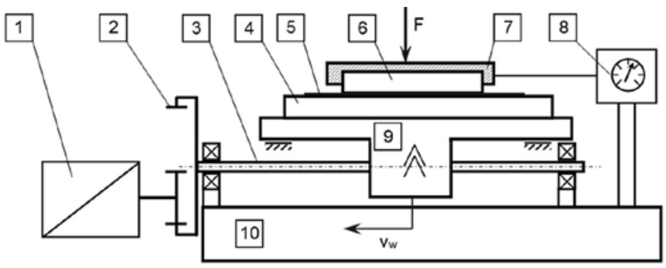


Fig. 4. The diagram of the measuring stand: 1 – motor, 2 – planetary reducer, 3 – screw propeller, 4 – specimen, 5 – intermediate layer (graphite grease or water), 6 – counter-specimen, 7 – handle, 8 – force indicator, 9 – sliding table, 10 – body

oxides is built-up [15], and the indentations and pitting between them. It will have an influence on obtaining the values of the friction coefficients [12]. The cracks visible on the surface of the cleaned surface are an effect of its former grinding.

uring the friction force (fig. 4), in the closed space, at the ambient temperature on the level of 22 ±0,10°C. The stand enables to obtain a relative movement of one element of the friction pair, assembled on the sliding table, in respect of the other one, maintained in the handle. The handle is connected through a force sensor, with the stand body. The sliding table is put into motion by a planetary reducer, powered by an electric motor. A change of the rotational velocity of the motor enables to change a sliding velocity of the friction pair elements. The constant sliding velocity is maintained in the course of a test. A change of the normal load (F) is realised by a change of a quantity of the weights featuring the known masses that exert pressure on the tested elements.

The experimental tests have been carried out for two types of the friction pairs. The first pair has been covered with a rust layer, but the second one has been cleaned prior to the test.

In respect of each pair, there have been changed both the load conditions, condition of the intermediate layer, and the sliding velocity. The tests have been performed for two loads, which are of

F = 58 and 107 N, respectively. The relative sliding velocity has been v_w = 0.0515; 0.111; 0.225 and 0,348 mm/s, respectively. These values result, first and foremost, from the possibilities offered by the test stand. Nevertheless, they are similar to the sliding velocity of the spring leaf ends at the typical operational conditions of the vehicles. In the case of the considered spring, at the maximum deflection (i.e. by 150 mm) a relative displacement of the longest spring leaves is of 3.49 mm, but of the shortest ones is of 0.866 mm. While deflecting with a frequency of 1 Hz, the maximum velocity values are of 10.9 and 2.72 mm/s, respectively. In the real operational conditions such large deflections (apart from the extreme situations) do not take place. If an average value of the spring deflection amplitude is assumed on the level of 20 mm, so with a frequency of 1 Hz a maximum velocity of the relative displacements of the spring leaves will be of 0.7 up to 2,9 mm/s, respectively for the shortest and the longest spring leaves.

At the first stage, the tests have been carried out for the dry surfaces. Them the friction surfaces of the corroded specimens have been moistened with water, and the cleaned specimens have been covered with a graphite grease layer. The surface conditions assumed for the tests result from these, which are found in the real operational conditions for the multi-leaf springs.

3.2. Results of the tests

In the course of the experimental tests, it has been recorded a value of the friction force between the specimen and the counter-specimen for each variant. A sampling period has been of Δt=0.02 s, and a quantity of the specimens n has been changed depending on the sliding velocity. For each variant, 3 up to 5 repetitions have been performed. In fig. 5 are presented the exemplary courses of the friction forces (three repetitions) obtained for the specimen covered with the rust for the dry surface condition at the determined sliding velocity. During the conducted trials, for most associations, it has been observed a great repeatability of the recorded results.

On the basis of the recorded courses, upon referring the friction force to the interacting normal load, a value of the static and kinetic friction coefficient has been determined. On the graphs (fig. 6) can be

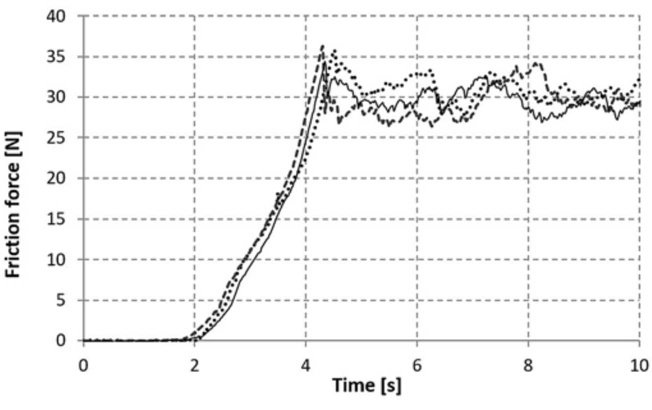


Fig. 5. The changes of a friction force as a function of time (three repetitions) at the determined sliding velocity obtained for the corroded specimen featuring the dry surface

observed three characteristic areas. In the first are, the friction force increases progressively, achieving its maximum value. In the second area, a transition from a condition of the sliding friction, and a value of the friction force decreases progressively. In the third area is noticed a stabilisation of the force value.

An issue of importance has constituted a determination of the borders of the particular areas. A border between I and II area corresponds to a moment, when it has been observed the maximum value of the coefficient. As a static coefficient has been assumed a maximum value observed prior to a beginning of the relative movement between the tested elements (i.e. on the border of the I and II area). The more complex issue has constituted a determination of the borders between II and III area (i.e. time $t_{III} = k \cdot \Delta t$, where k-times of sampling period (fig. 6)). It begins upon at the moment, upon which a coefficient of course variation has been lower than 10%. The coefficient of variation V has been calculated on the basis of a dependency (1):

$$V = \frac{\sigma}{\bar{\mu}} * 100\% \qquad (1)$$

where: $\bar{\mu}$ – average value in the range from k to n described by the formula (2):

$$\bar{\mu} = \frac{1}{(n-k)} \sum_{i=k}^{n} \mu_i \qquad (2)$$

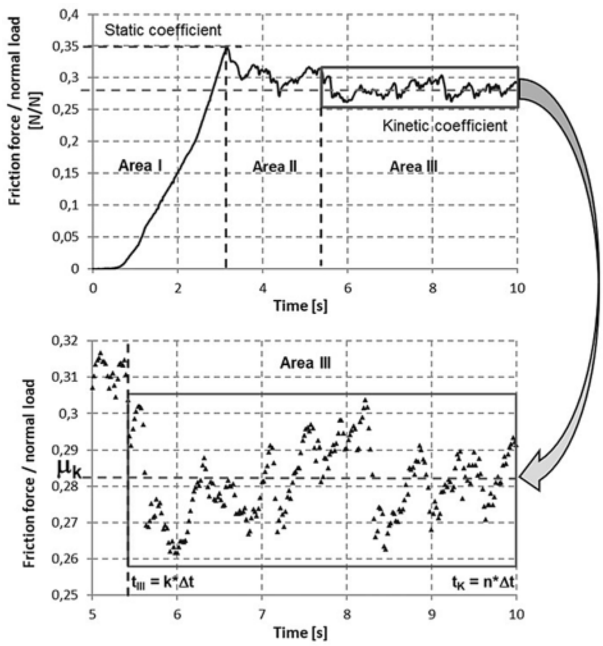
σ – standard deviation in the range from k to n, described by dependence (3):

$$\sigma = \sqrt{\frac{\sum_{i=k}^{n} (\mu_i - \bar{\mu})^2}{(n-k)}} \qquad (3)$$

μ_i – another value of the coefficient in area III.

A kinetic coefficient has been determined as an average value related to a fragment, for which a stabilization of the friction value has been observed (area III) ($\mu_k = \bar{\mu}$).

Fig. 6. Principle of a determination of the static and kinetic friction coefficients



Then, an arithmetic mean from the obtained results has been calculated in respect of a few repetitions (from 3 up to 5), for each test variant. The obtained test results have been summarized in a form of the graphs of the static and kinetic friction coefficient as a function of the normal load for the different sliding velocities (fig. 7 and fig. 8). It has been used a uniform scale in order to facilitate a comparison of the results presented in all graphs. Moreover, in table 4 and 5, the results of the friction coefficients (μ_s and μ_k), average values of the coefficients

($\mu_{s\text{-}sr}$ and $\mu_{k\text{-}sr}$), determined for a measuring series and corresponding with them values of the standard deviations ($\sigma_{\mu s}$ and $\sigma_{\mu k}$) have been summarised. While analysing the results for the cleaned surfaces it should be stated that there cannot be noticed a significant influence of the sliding velocity on the obtained values of the static and kinetic friction coefficient. The differences do not exceed even a few percent. For the dry surfaces, it is observed a slight (approx. 8%) increase of a value of the static friction coefficient. Covering the surface with the graphite grease decreases a value of the static and kinetic friction coefficient by approx. 7% in the case of a load of 58 N and even by 20% in the case of a load of 107 N. Furthermore, it causes a decrease in an influence of the normal load on a value of the friction coefficients.

The values of the static and kinetic friction coefficient for the dry surfaces covered with the rust are approx. 230-270% higher than for the clean surfaces, without any rust.

Moreover, it is observed a larger influence of the sliding velocity on the values of the friction coefficients. The differences between the maximum and minimum values of the coefficients are approx. of 20%. For the larger load, a decrease of the value of the friction coefficients has been observed. It is mainly caused by the surface smoothing and removing the corroded layer during the subsequent measuring series. It has been noticed that a larger load promotes a disintegration of the rust particles. It has been built-up in the indentations developing the distinctive intermediate layer. Moistening the specimen surface with water has resulted in a decrease of the friction coefficient value from 17 to 20%. Additionally, it has been observed that it has caused a slight decrease of the value of the standard deviation to the average value ratio (for the dry surfaces covered with the rust it is approx. of 12-13%, and for the moistened surface – approx. of 10-11%).

Table. 4. Values of friction coefficients for vertical load F = 58 N

Surface condition	Velocity [mm/s]	Static friction coefficients			Kinetic friction coefficients		
		μ_s	$\mu_{s\text{-}sr}$	$\sigma_{\mu s}$	μ_k	$\mu_{k\text{-}sr}$	$\sigma_{\mu k}$
Clean, dry	0,0515	0,130	0,135	0,0073	0,134	0,135	0,0051
	0,111	0,131			0,134		
	0,225	0,141			0,138		
	0,348	0,139			0,135		
Clean, covered with graphite grease	0,0515	0,135	0,125	0,0114	0,136	0,121	0,0127
	0,111	0,123			0,118		
	0,225	0,120			0,113		
	0,348	0,123			0,117		
Covered with rust, dry	0,0515	0,419	0,369	0,0486	0,348	0,315	0,0300
	0,111	0,385			0,323		
	0,225	0,338			0,298		
	0,348	0,335			0,291		
Covered with rust and moistened with water	0,0515	0,350	0,311	0,0343	0,301	0,270	0,0232
	0,111	0,297			0,261		
	0,225	0,280			0,254		
	0,348	0,315			0,263		

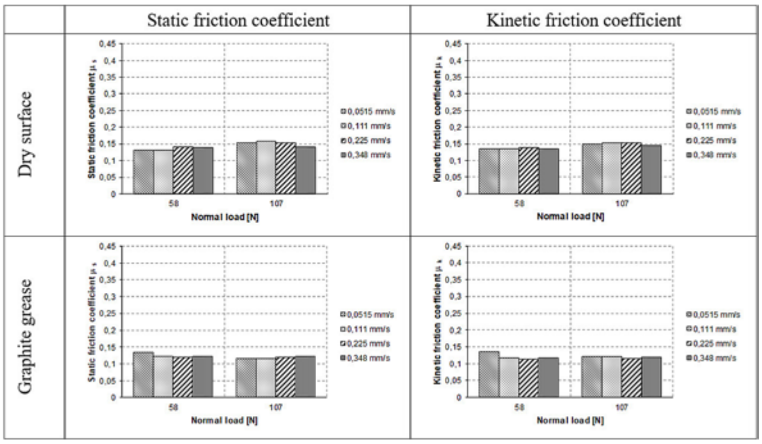


Fig. 7. Juxtaposition of static and kinetic friction coefficients for cleaned surfaces (Tab. 4 and 5)

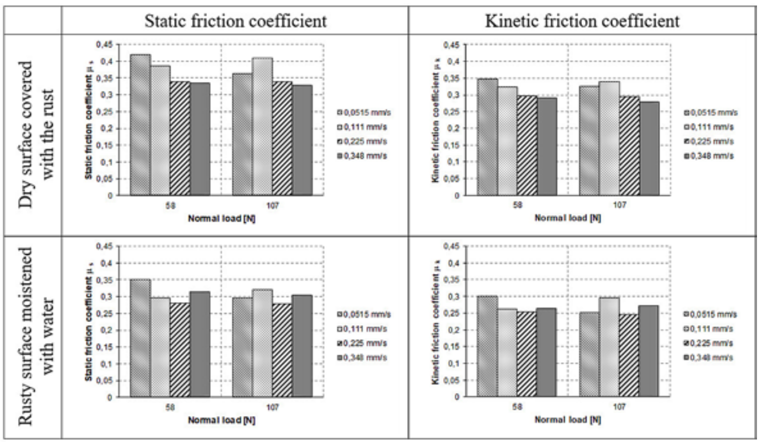


Fig. 8. Juxtaposition of static and kinetic friction coefficients for rusty surfaces (Tab. 4 and 5)

4. Conclusion

The selected results of the laboratory tests related to the friction coefficient values for the different surface condition of the spring leaves of the multi-leaf spring have been presented in the study. Due to a nature of its operating in the vehicle suspension, an existing friction significantly influences the spring static and dynamic characteristics of the spring (suspension). In the course of the vehicle operating takes place a removal of the grease layer from the mating surfaces of the spring leaves. A failure to provide a proper maintenance favours corrosion, which by changing the friction conditions results in a change of the spring elasticity and an increase of the dissipated energy. In the extreme cases it leads to a blockade of the spring leaves at the small amplitudes of the suspension deflections.

The spring leaf surfaces covered with the rust significantly change its operating conditions. It has an obvious impact on worsening the ride comfort, a change of the dynamic loads and a vibration frequency structure of the vehicle.

In the study, one has been considered four surface conditions: clean and dry, covered with the graphite grease (it is a desired condition), as well as covered with a layer of the rust and pitting, which has been moistened with water, at the subsequent stage. The carried-out tests of the surface roughness have visualised the significant differences related to all roughness parameters for the cleaned and corroded specimens. It has affected the results of the friction coefficient tests.

The obtained values of the static and kinetic friction coefficients for the cleaned specimens are similar to those presented in the literature [1].

While analysing the results for the cleaned surfaces it should be stated that there is no noticeable impact of the sliding velocity on the obtained values of the static and kinetic friction coefficients. These differences do not exceed even a

Table. 5. Values of friction coefficients for vertical load F = 107 N

Surface condition	Velocity [mm/s]	Static friction coefficients			Kinetic friction coefficients		
		μ_s	μ_{s-sr}	$\sigma_{\mu s}$	μ_k	μ_{k-sr}	$\sigma_{\mu k}$
Clean, dry	0,0515	0,154	0,151	0,0104	0,149	0,150	0,0080
	0,111	0,157			0,153		
	0,225	0,154			0,154		
	0,348	0,141			0,145		
Clean, covered with graphite grease	0,0515	0,116	0,119	0,0092	0,122	0,120	0,0092
	0,111	0,117			0,121		
	0,225	0,120			0,116		
	0,348	0,123			0,120		
Covered with rust, dry	0,0515	0,364	0,360	0,0438	0,326	0,310	0,0300
	0,111	0,409			0,339		
	0,225	0,339			0,296		
	0,348	0,328			0,278		
Covered with rust and moistened with water	0,0515	0,297	0,301	0,0315	0,251	0,266	0,0246
	0,111	0,321			0,296		
	0,225	0,279			0,246		
	0,348	0,305			0,271		

few percent. Introducing the graphite grease has resulted in a decrease of the friction coefficient values. It is particularly noticeable in the case of the larger load, for which the changes by approx. 20% have been determined.

The measurement of the static and kinetic friction coefficients has demonstrated the 230-270% increase of their values in comparison with the clean surfaces. In the course of the tests, one has observed smoothing of the surfaces – especially in the case of the larger load. Moistening the friction surfaces with water has caused developing a distinctive lubricant layer that has decreased the friction coefficients approx. by 15%.

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