SCIENTIFIC PROBLEMS
OF MACHINES
OPERATION
AND MAINTENANCE
3 (155) 2008

DEMOFILO MALDONADO*

The influence of dynamic properties of tribotesters on coefficient of friction

K e y w o r d s

Coefficient of friction, controlled inputs, vibration, tribotesters, scatter.

S ł o w a k l u c z o w e

Współczynnik tarcia, wejścia kontrolowane, drgania, testery tribologiczne, rozrzut wyników.

S u m m a r y

Reproducibility and repeatability are still problems to solve in tribological science, specifically in coefficient of friction and wear results obtained from tribotesters.

Is well know that there are controlled parameters in a tribosystem and many research has been done using those parameters to perform tribological tests, but is also know that there are uncontrolled parameters like vibrations that affect the reproducibility and repeatability of test results and the scatter of them, specially in coefficient of friction and wear.

The influence of dynamic properties of tribotesters characterized by vibration on coefficient of friction were investigated.

Correlation between controlled and uncontrolled inputs including vibration and tribological characteristics (coefficient of friction and wear) are presented in order to achieve better tribological test methods.

* University of Monterrey (UDEM), Mechanical Engineering Faculty, San Pedro Garza García, México.

Introduction

There are plenty of papers and reports that shown how different are the tribological test conditions in terms of standardization and scatter results of coefficient of friction and wear in dry conditions [1-7].

Despite of that, the existing literature [8, 9] about coefficient of friction values does not specify enough information in order to trust in the presented results.

We can observe that for a steel/steel couple the values of coefficient of friction are between 0.15 and 0.74 (static) and 0.09 and 0.57 (kinetic). Important characteristics like the standard test and controlled inputs are not observed

One of the important research is that up to now never was taking into account influence of dynamic characteristics of tribotesters on tribological processes.

Those results evidence a lack of control in the controlled parameters in order to achieve reproducibility and repeatability of coefficient friction results.

EXPERIMENTAL: Equipment

Tribotesters T-10 Vertical Position (ball-on-disk), T-10 Horizontal Position (ball-on-disk) and T-11 (ball-on-disk) worked out and produced in the Institute for Sustainable Technologies - National Research Institute (ITeE-PIB) were used changing inputs conditions like materials (disk and ring: steel or steel coated with CrN and balls: steel or ceramic Al_2O_3), humidity, load and speed. Acceleration of vibration parallel to the load was measured. (Figure 1 & 2).

The controlled inputs for these tests are:

Controlled Input	Characteristics
Humidity	35%, 50% and 80% controlled by automatic humidifiers
Load	5N, 10N and 15 N
Speed	0.1 m/s, 0.2 m/s and 0.3 m/s
Sliding distance	1,000 meters
Materials of the spatial configuration	For ball-on-disk: steel disk (AISI 52100) – steel ball (called s/s), steel disk (AISI 52100) – ceramic ball (Al_20_3) (called s/c) coated disk (CrN) – ceramic ball (Al_20_3) (called p/c) For block-on-ring: steel block (AISI 52100) and steel ring(AISI 52100) (called s/s) steel block (AISI 52100) and coated ring (CrN) (called p/s)
Sliding track radius	20 mm for T-11, and 18mm, 16.75mm and 16 mm for T-10
Ball Diameter	10 mm
Load direction	Vertical for T-10 and T-11 and Horizontal for T-10

High quality control of test measurement and procedure was performed in order to improve repeatability and reproducibility and obtain less scatter in coefficient of friction and wear results.

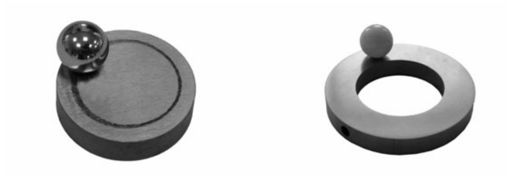

Fig. 1. Spatial configuration
Rys. 1. Konfiguracja przestrzenna

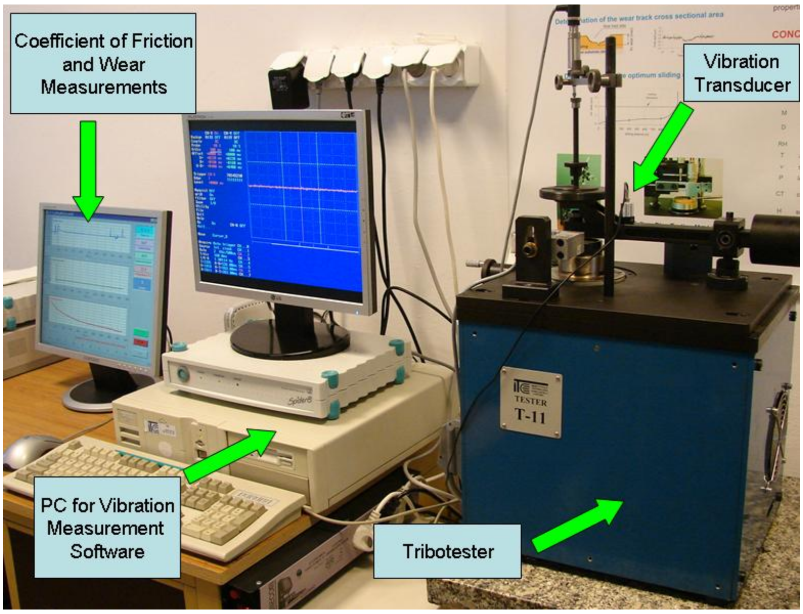

Fig. 2. Test facilities
Rys. 2. Stanowiska badawcze

Test method

All tests were performed according to standard ASTM G99-05 [10] and DIN-50324 [11].

The samples were cleaned with benzene in the ultra vibration cleaning machine for 5 minutes.

Three important groups of test were performed in this chronological order:

Group 1. Variation in controlled inputs with vibrations measurements.

Group 2. Variation in speed with fixed load and humidity, variation in load with fixed speed and humidity and finally variation in humidity with fixed load and speed, all with vibration measurements.

The complete set of test is shown in the table 1. Minimum three tests were performed until the values of wear and coefficient of friction are under Dixon´s Test levels; if not, two additional tests were performed. A profilometer was used to measure wear in disks.

Group 1 of test consists in:

a) For T-10 Horizontal, T-10 Vertical and T-11:

MATERIALS	Humidity (%)	Load (N)	Velocity (m/s)
steel disk and steel ball (s/s)	35	5	0,1
	50	10	0,2
	80	15	0,3
steel disk and ceramic ball (s/c)	35	10	0,3
	50	15	0,1
	80	5	0,2
coating disk and ceramic ball (p/c)	35	15	0,2
	50	5	0,3
	80	10	0,1

And finally the group 2 consists in variation in speed with fixed load and humidity, variation in load with fixed speed and humidity and finally variation in humidity with fixed load and speed, all with vibration measurements. Minimum three tests was performed until the values of coefficient of friction are under Dixon´s Test levels; if not, two additional tests were performed. See table 3.

Table 1. Set of test with variation in variation of speed with constant load and then variation in load with constant speed for group 2 of tests

Tabela 1. Zestawienie badań dla zmiennej prędkości przy stałym obciążeniu oraz zmiennego obciążenia przy stałej prędkości (grupa testów 2)

MATERIALS	Humidity (%)	Load (N)	Velocity (m/s)
coating disk and ceramic ball (p/c)	50	10	0,1
			0,2
			0,3
		5	0,2
		10	
		15	

For acceleration of vibration measurement a transducer was mounted parallel to the load, and perpendicular to the plane of the disk (Figure 3).

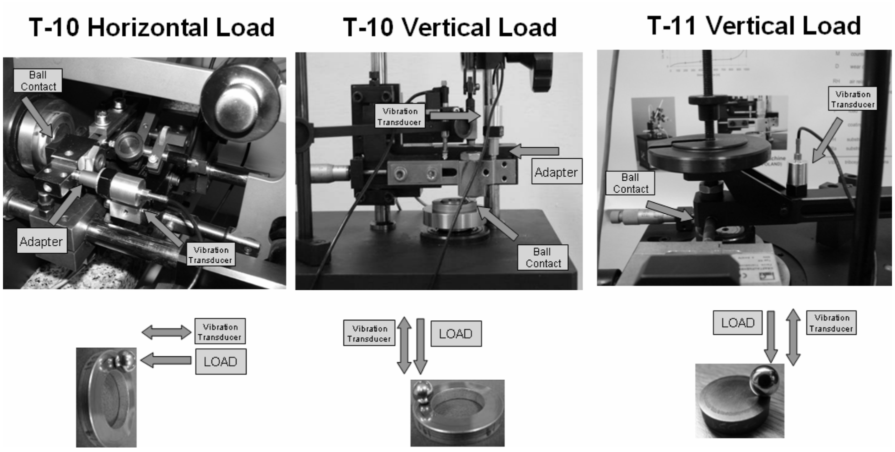

Fig. 3. Transducer position for vibration acceleration measurement
Rys. 3. Położenie przetwornika pomiaru przyśpieszeń drgań

For the calculations of the acceleration of vibration, we used the voltage peak to peak (Vp-p) as a amplitude. See figure 4.

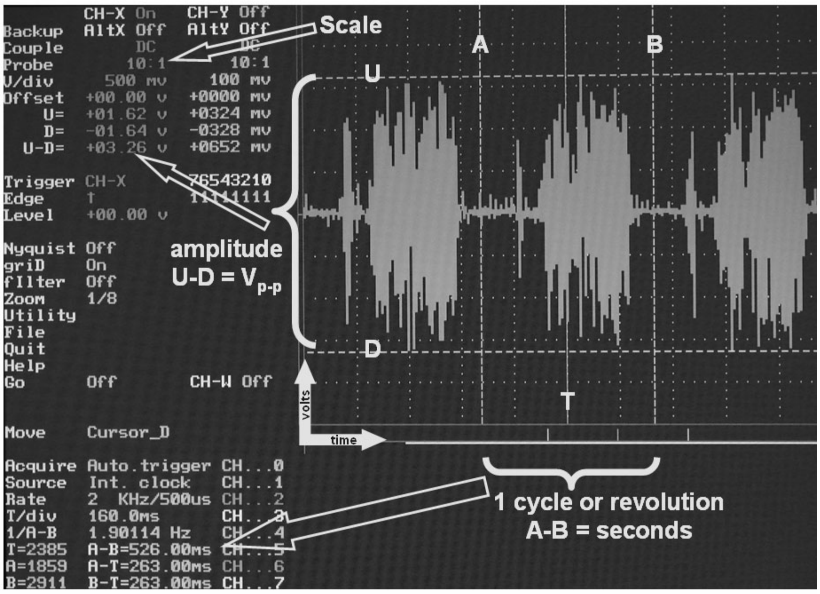

Fig. 4. Vibration measurement software screen
Rys. 4. Ekran programu przyśpieszeń drgań

The calculations to get the value of Ap-p (gravity), are:

Given data:
Sensitivity: 1.78 mv/ms^{-2}, gravity: 9.81 m/s^2

Measurement data:
Volt peak to peak = Vp-p (mV) = (U-D)
Probe = Scale, to fit on screen

Calculation:
Acceleration peak to peak ("Y" axe) = Ap-p
Ap-p = Vp-p / Sensitivity / Gravity / Scale

Example: Ap-p = 3260mv / 1.78 mv/ms^{-2} / 9.81 m/s^2 / 10 = 18.67 (g)

RESULTS: Influence of test equipment on the coefficient of friction values

The result of the acceleration of vibration is shown in the figure 5 (group 1). The highest values occur with high loads and speeds.

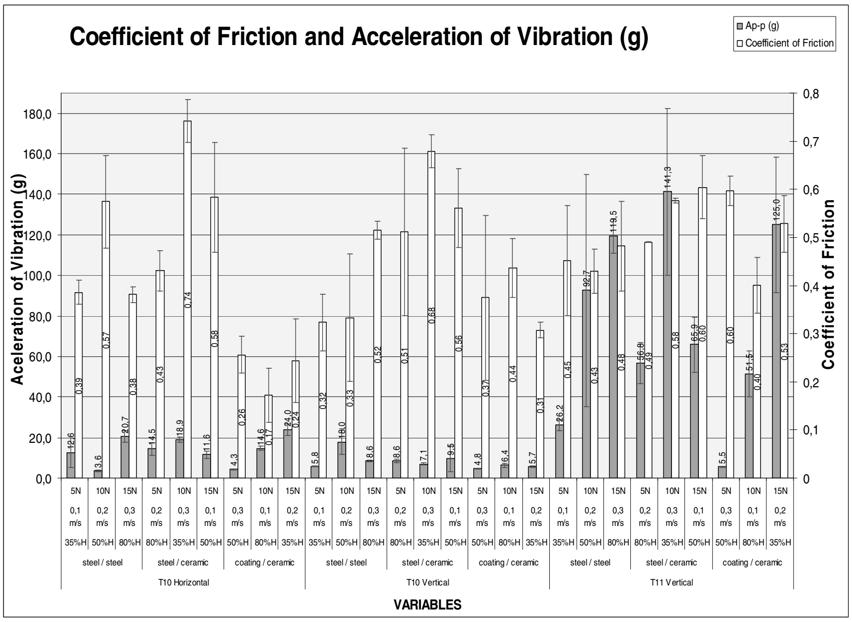

Fig. 5. Acceleration of vibration and coefficient of friction (results in all tribotesters, Group 1)
Rys. 5. Przyśpieszenie drgań i współczynnik tarcia (wyniki zebrane z różnych testerów, grupa testów 1)

From Figure 5, it's observed that the behavior of Acceleration of Vibration (mean values) and Coefficient of Friction (scatter) are the same in the tribotesters T-10H and T-11V.

Tribotester	Material Couple	Acceleration of Vibration (mean value) ▲= Increase the value ▼= decrease the value	Coefficient of Friction (scatter) ▲= Increase the value ▼= decrease the value
T-10 Horizontal	**Steel/Steel**	▲	▼
	Steel/Ceramic	▲	▼
	Coated/Ceramic	▲	▲
T-10 Vertical	Steel/Steel	▲	▲
	Steel/Ceramic	▼	▼
	Coated/Ceramic	▼	▼
T-11 Vertical	**Steel/Steel**	▲	▼
	Steel/Ceramic	▲	▼
	Coated/Ceramic	▲	▲

This could be explaining because in those tribotesters (T-10H and T-11V) there is no debris on the contact zone.

The Figures 6 and 7 shows the same tests (group 1) but now arranged by couple materials with **mean values** of acceleration of vibration and coefficient of friction.

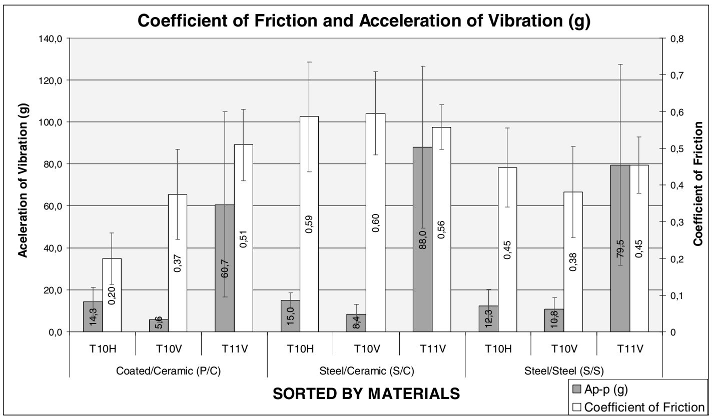

Fig. 6. Acceleration of vibration and coefficient of friction sorted by couple materials (Group 1)
Rys. 6. Przyśpieszenie drgań i współczynnik tarcia uporządkowany według materiałów (grupa testów 1)

The values of friction coefficient are bigger in the steel/ceramic couple materials and the values of the acceleration of vibration are bigger in the tribotesters T11-V in all cases, coincidently the values of coefficient of friction in those cases are the bigger values.

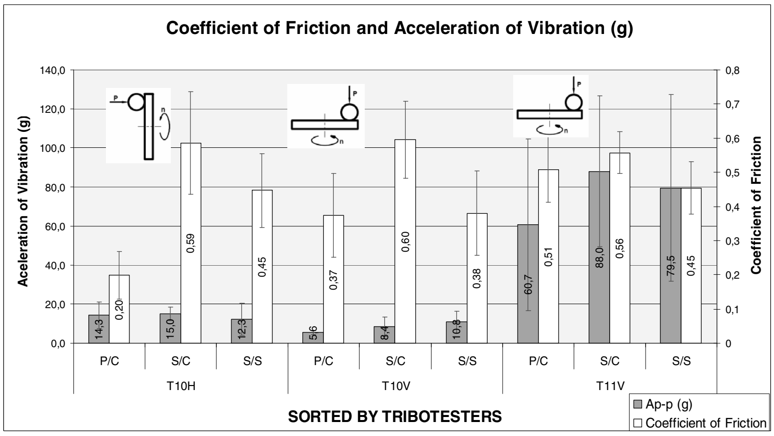

Fig. 7. Acceleration of vibration and coefficient of friction sorted by tribotesters (Group 1)
Rys. 7. Przyśpieszenie drgań i współczynnik tarcia uporządkowane według testerów (grupa testów 1)

In figure 7 it's shown bigger values of coefficient of friction in the T-11 vertical tribotester with the exception of the material couple steel/ceramic (0.56 vs. 0.60)

Regarding again Figure 6, the lowest acceleration of vibration (Ap-p = g) value and scatter appears in the T-10 vertical tribotester. As it is possible to see, for this tribotester one can state the clear dependence: increasing in value of vibrations causes increasing of coefficient of friction. Inside the T-10 vertical tribotester, the minimum values appear on the coating disk and ceramic ball.

Considering the previous observation, a group of test (group 2) was performed with the next controlled inputs (Figures 8 through 10).

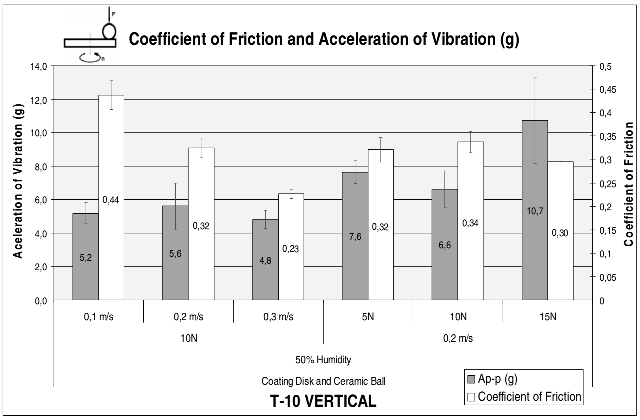

Fig. 8. Vibration acceleration measurements with constant load and variable speed and constant speed and variable load; fixed humidity in both cases (group 2)
Rys. 8. Wyniki pomiarów przyśpieszenia drgań dla stałego obciążenia i zmiennej prędkości oraz stałej prędkości i zmiennego obciążenia, stała wilgotność otaczającego powietrza w obu przypadkach (grupa testów 2)

In Figure 8, less and small scatter of mean value of coefficient of friction is observed when the speed is constant (0.30 to 0.34). The strong dependence of coefficient of friction and speed one can observe at the same load.

It's appears load has more influence in acceleration of vibration than speed and we must maintain the level of acceleration of vibration constant (between 4.8g y 5.6g) in order to have less scatter of coefficient of friction (from 0.23 to 0.44), only 0.21 of scatter.

Another example for prove the need of more controlled inputs is the case of coating disk and ceramic ball (Figure 9).

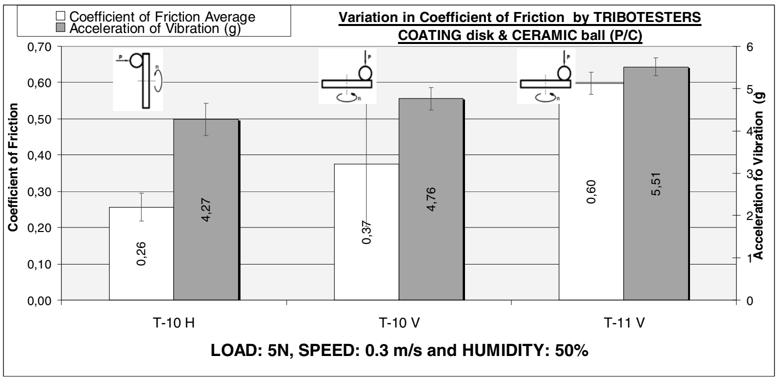

Fig. 9. Vibration acceleration measurements with constant parameters and different tribotesters
Rys. 9. Wyniki pomiarów przyśpieszenia drgań dla różnych testerów przy stałych warunkach pracy

In Figure 9, it's observed considerable difference in coefficient of friction (from 0.6 to 0.26) when the test is performed with the same materials, same load, same speed and humidity but with different spatial configuration and different tribotesters.

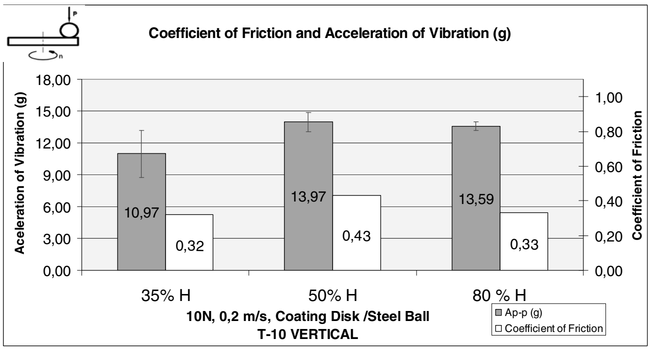

Fig. 10. Vibration acceleration measurements with variation in humidity and the rest of the parameters fixed (group 3)
Rys. 10. Wyniki pomiarów przyśpieszenia drgań dla różnych wilgotności przy stałych pozostałych parametrach

And finally only variation in humidity with the rest of the controlled inputs fixed (Figure 11).

In Figure 10 it's observed that lowest acceleration of vibration appears with less humidity percentage. (35%), and the scatter of Coefficient of friction is low (0.32 to 0.43), 0.11 only.

Summary and Conclusions

Summary

The tribotesters configuration has an influence in the coefficient of friction results, especially in the coating disk and ceramic ball pair

The tribotesters has an influence in the results of acceleration of vibration. The values of acceleration of vibration are much higher in the T-11 that the rest of the tribotesters.

Additional sources of vibration can be eliminated from a tribotesters with mechanical adjustment like in T-11 with the application of the safety nut and tighten the bolts on the load mechanism.

Higher scatter values of acceleration of vibration appears in the highest values of acceleration of vibration.

It is observed that the lowest coefficient of friction results and the lowest coefficient of friction scatter appears in the test performed on the T-10 Vertical position so, looks like there are a correlation between the acceleration of vibration and the coefficient of friction results and scatter.

The highest values of acceleration of vibration appear with higher loads or higher speeds or the combination of both.

It's appears load has more influence in acceleration of vibration than speed and we must maintain the level of acceleration of vibration constant in order to have less scatter of coefficient of friction in the coating disk-ceramic ball spatial configuration.

Lowest acceleration of vibration appears with less humidity percentage.

With good design of tribotesters and rigorous test procedures, it's possible to achieve lower scatter results.

Conclusions

On the base of the results one can state that:

Coefficient of friction value and the scatter of it depends on the speed, load and humidity of the surrounding air. These dependences are different for each type of used tribotesters (because of their different dynamic properties characterized by vibrations), as well on tested couple configuration (mainly since debris removed or not from friction zone).

The rules observed for each materials combination (influence of speed, load humidity on coefficient of friction for given type of testers and tested couple configuration) are different as well.

Talking into account results obtained one can state that quality of tribotesting experiments (repeatability and reproducibility) can be improved much more that it is usually reached if the test parameters: load, velocity, temperature, humidity as well dynamics properties of the tester (characterized by vibration) and spatial tested couple configuration are determined.

Acknowledges

Thanks to all the Tribology department of the Institute for Sustainable Technologies - National Research Institute (ITeE-PIB) for all your technical support, advices and facilities.

References

[1] Szczerek M.: *Metodologiczne Problemy Systematyzacji Eksperymentalnych Badań Tribologicznych*. ITeE-PIB. 1997,10.

[2] Huq M. Z., Celis J.P.: *Reproducibility of friction and wear results in ball-on-disc-unidirectional sliding tests of TiN-alumina pairings.* Wear 212, 2007, 151-159.

[3] Czichos H., Becker S., Lexow J.: *Multilaboratory Tribotesting: Results From The Versailles Advanced Materials and Standards Programme on Wear Test Methods.* Bundesanstalt für Materialprüfung, Under den Eichen 87, 1987.

[4] Czichos H., Becker S., Lexow J.:, *Internacional Multilaboratory Sliding Wear Tests with Ceramics and Steel,* BAM-Federal Institute for Materials Research and Testing, 1989.

[5] Chofu J.: *Comparison of tribological characteristics of sputtered MoS_2 films coated with different apparatus.* Wear 218, 1998, 110-118.

[6] Santner E.: *Wear Test Methods.* Vamas Bulletin 24, 2001, 23.

[7] Michalczewski R., Witold Piekoszewski W., Szczerek M.: *Effect of hard thin coatings on tribological characteristics of model tribosystems.* Tribologia 5, 2004, 171-180.

[8] http://hypertextbook.com/facts/2005/steel.shtml

[9] *Wear Control Handbook*, ASME. 1980, 38.

[10] ASTM G99-05: *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*.

[11] DIN 50324: *Prüfung von Reibung und Verschleiss. Modellversuche ber Festkorpergleitreibung* (Kugel-Scheibe-Prufsystem).

Manuscript received by Editorial Board, December 09, 2008

Wpływ właściwości dynamicznych testów tribologicznych na współczynnik tarcia

S t r e s z c z e n i e

Odtwarzalność i powtarzalność wyników badań tribologicznych są wciąż nierozwiązanym problemem, zwłaszcza w przypadku pomiarów współczynnika tarcia i zużycia z wykorzystaniem różnych testerów.

Jest powszechnie znane, że w systemie tribologicznym występuje wiele wejść kontrolowanych, w wielu badaniach zadaje się wejścia kontrolowane, wiadomo też, że istnieją również wejścia niekontrolowane, które wpływają na odtwarzalność i powtarzalność wyników badań oraz ich rozrzut.

W pracy zbadano wpływ dynamicznych właściwości testerów, ocenianych za pomocą pomiaru drgań, na współczynnik tarcia.

Zaprezentowano wyniki wskazujące na korelację pomiędzy wejściami kontrolowanymi i niekontrolowanymi, włączając drgania, na charakterystyki tribologiczne (współczynnik tarcia i zużycie), co pozwoli na poprawę istniejących metod badań tribologicznych.