

APARATURA

BADAWCZA I DYDAKTYCZNA

Proposed research method of agricultural machinery brakes friction materials

ELIZA BORAWSKA, ANDRZEJ BORAWSKI
BIAŁYSTOK UNIVERSITY OF TECHNOLOGY

Keywords: mechanical engineering, agricultural machinery, brakes, Ball-Cratering, Taguchi method

ABSTRACT:

The dynamic development of the automotive industry has had its impact on vehicles used for work in fields, too. The vehicles move with increasingly higher speeds and are becoming heavier as well. Consequently, they need new efficient braking systems to stop them. This in turn requires numerous tests aimed at optimising the composition of brake shoes. Various methods are used in tests and, ideally, the tests would be performed on a real-life object. However, it is seldom possible. Laboratory tests strive at simulating the object of research but usually they can be merely an imitation of the real thing. A lot of scientists are currently working on simulation research whose main advantage is low cost and practically unlimited possibilities of altering its conditions.

This article presents a new research method which applies Ball-Cratering contact. In order to plan the experiment properly Taguchi method of process optimisation was used. To verify the correctness of the method, preliminary tests were conducted in which the values of friction coefficient and abrasive wear coefficient were calculated.

Propozycja metody badawczej materiałów ciernych stosowanych w hamulcach maszyn przemysłu rolniczego

Słowa kluczowe: inżynieria mechaniczna, maszyny rolnicze, hamulce, Ball-Cratering, metoda Taguchi

STRESZCZENIE:

Dynamiczny rozwój przemysłu motoryzacyjnego dotknął również pojazdy wykorzystywane w pracach polowych. Poruszają się one z coraz to większymi prędkościami, charakteryzują się też większymi masami. Ich zatrzymanie wymaga więc stosowania nowych, bardziej wydajnych hamulców. To z kolei wymusza prowadzenie licznych badań mających na celu optymalizację składu okładzin ciernych. Do badań wykorzystuje się różne metody. Najkorzystniej jest, jeżeli wykonuje się badania na obiekcie rzeczywistym. Jednak mało kiedy jest to możliwe. W badaniach laboratoryjnych próbuje się jak najlepiej odzwierciedlić obiekt badań, jednak stanowiska badawcze zapewniają jedynie pewne przybliżenie. Wielu naukowców zajmuje się obecnie badaniami symulacyjnymi. Ich główną zaletą jest niski koszt oraz praktycznie nieograniczona możliwość wariacji warunków badań.

Niniejsza praca ma na celu zaproponowanie nowej metody badawczej wykorzystującej kontakt Ball-Cratering. Do odpowiedniego zaplanowania eksperymentu zaproponowano metodę optymalizacji procesów Taguchi. W celu zweryfikowania prawidłowości proponowanej metody wykonano przykładowe badania. Wyznaczono w nich wartości współczynnika tarcia oraz współczynnika szybkości zużycia ściernego.

1. INTRODUCTION

Industrial development and increasingly utilised new materials, characterised by improved properties, have translated into a far more intensive development of the agricultural industry [1]. Trends in agriculture reveal that the number of large farms is constantly growing. As a result, specialised equipment able to perform work in the field quickly and accurately has become indispensable. Agricultural equipment producers are trying to meet this demand. Many concerns have designed and started producing tractors with a speed capacity up to 60 km/h [2, 3]. Given the total weight of such a vehicle, the drag coefficient and its purpose, one must admit it is an impressive achievement. However, we should bear in mind that there occur emergencies on roads and in fields which require the vehicle to be stopped immediately. Therefore, agricultural machinery has to be equipped with suitable and effective braking systems [4, 5].

Friction brakes for all axes in a vehicle or a set of vehicles are the most frequently applied device [6]. The brake torque is generated as a result of cooperation between a friction pair. Kinetic energy of the motion is converted into thermal energy. The latter is released both into the at-

mosphere and the nearest situated suspension components. The effectiveness of the process is affected by the friction coefficient of the working components of the braking system, which in turn depends on the materials applied. On average, the mixture used in the production of abrasive linings consists of 15-20 components [7]. A non-homogenous composition of the abrasive material makes the determination of its properties harder. This article elaborates on research methodology which will enable scientists to achieve equivocal and repeatable results.

2. METHODOLOGY

Scientific research is a difficult task, since it requires vast knowledge and experience. Analysis of knowledge states may also prove useful, as it can prevent scientists from making a lot of errors [8, 9]. Nevertheless, the achieved results are not always of a satisfying quality. It is necessary to take certain details into consideration, including the choice of an appropriate stand or proper planning of the experiment. Another thing to bear in mind is the accuracy of the measurement which may sometimes prove erroneous [10].

2.1 The choice of a test stand

A lot of test stands available on the market help determine, for example, the friction coefficient. Pin-On-Disc, which ensures line contact, is the most frequently used stand in abrasive material research. This stand is the best reflection of disc brakes. Agricultural vehicles use drum brakes mainly, so applying a stand ensuring surface contact would be more appropriate. However, such tribotesters are rather rare. T-11 tribometer owned by Białystok University of Technology was used in the experiment (Fig. 1). The type of contact (the so-called Ball-Cratering) does not fully reflect the real conditions in brakes but, as proved further in the paper and in previous publications [11, 12], a properly designed experiment with a suitable number of repetitions ensures high quality results.



Figure 1 Ball-Cratering tester (source: authors' own)

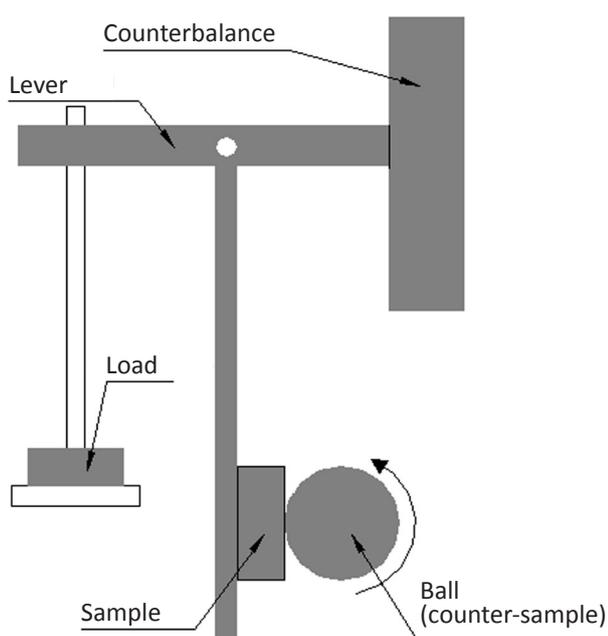


Figure 2 Scheme of research system of the tester

The sample installed in the holder should have a cylindrical shape (Fig. 2). During the test the sample cooperates with the counter-sample (the ball) placed in the engine handle. Thanks to a properly balanced lever, the load put on a scale pan ensures that the sample and the counter-sample press their surfaces together in an appropriate way. The stand facilitates a direct measurement of a friction force, which makes it possible to determine the friction coefficient – the most important property of an abrasive. It is also possible to add a lubricant or a wear-accelerating agent to the abrasive node. The stand may also be modified by adding more than one ball [13-15].

2.2 Planning the experiment

Proper planning of the experiment considerably shortens the research time, while, at the same time, maintaining high quality results [16]. However, the suggested method is not about shortening the time considerably, but about high quality of results and their good repeatability. Taguchi method of process optimisation, commonly applied in this type of research, was used for this purpose [17, 18].

The first step in planning should be the preparation of an orthogonal array. An experiment has three entry parameters: load, sliding distance and ball rotational speed. In compliance with the principles of the method, each of these parameters may have three values. Thus, the array will be a 9×3 matrix. In order to choose the values of parameters properly, preliminary tests should be conducted. In the analysed example, it turned out that the load values suggested in the standard [19] were too low. As a consequence, it was decided to adopt 1 N, 2 N and 3 N instead of 0.2 N, 0.4 N and 0.6 N, respectively. The final array is shown in Table 1. One can see in the table, that nine preliminary tests should be conducted and it is recommended for each test to be repeated at least three times. The achieved results will be used to determine the parameters for proper tests.

Table 1 An orthogonal array for preliminary tests (source: authors' own)

Number of preliminary test	Load P [N]	Sliding distance S [m]	Rotational speed of counter-sample n [rpm]
1	1	50	38
2	1	100	80
3	1	150	150
4	2	50	80
5	2	100	150
6	2	150	38
7	3	50	50
8	3	100	150
9	3	150	80

ETA function, which defines the signal-to-interference coefficient, can be calculated while conducting preliminary tests and measuring the size of craters in the samples. The function should have the highest value possible, so “the more, the better” criterion was adopted. According to the criterion the function equation is as follows:

$$\eta(y_i) = 10 \lg_{10} \left(\frac{1}{m} \sum_{i=1}^m y_i^2 \right) \quad (1)$$

where: m – the number of measurements (in this case $m = 3$), y_i – the result of the preliminary tests. The results obtained in preliminary tests should be used in the equation. Sample tests determined a function depicted in Figure 3.

Entry parameters for the experiment should be selected after an analysis of the graphs. The parameters are as follows: load $N = 1$ N, sliding distance: $S = 150$ m, ball rotational speed: $n = 80$ rpm.

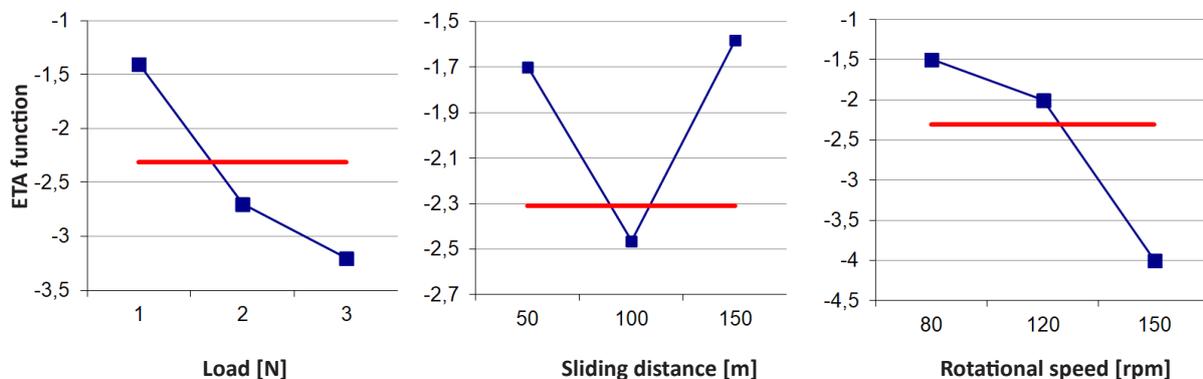


Figure 3 ETA function in sample tests

2.3 Analysis of the test results

Craters formed in the samples and values of friction force measured at a frequency programmed in the stand are an immediate result of the test. The diameter of the formed crater can be measured on two planes (Fig. 4) and then a mean value should be calculated:

$$b = \frac{b1+b2}{2} \quad (2)$$

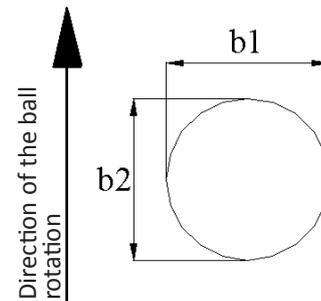


Figure 4 Measurement of craters

This makes it possible to calculate the volume of the used material:

$$V = \pi \frac{b^4}{64R} \quad (3)$$

where: R – the ball’s radius and the abrasive wear rate coefficient (K_c). Archard equation, which is also applied for dry friction, should be used:

$$K_c = \pi \frac{b^4}{64RSN} \quad (4)$$

where: S – sliding distance, N – load. Friction force values measured during the test can be divided into two groups: running-in and proper test (Fig. 5).

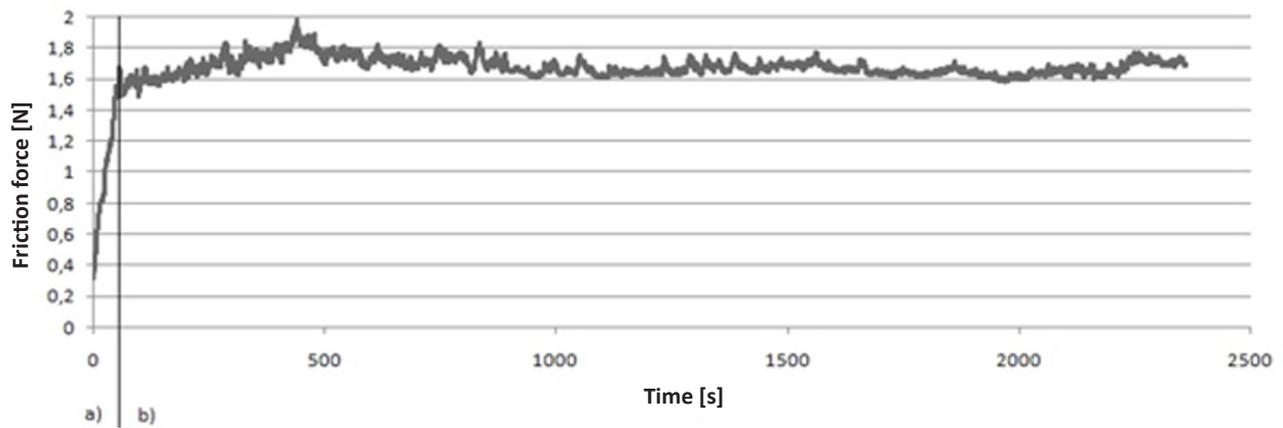


Figure 5 Sample measurement of friction force: a – running-in, b – proper measurement

While analysing the results, one should take into consideration the period when the value of friction force was steady. The running-in period should be skipped in the analysis. Then the value of friction coefficient can be determined while calculating the mean and applying Artos and Coulomb's law of friction:

$$\mu = \frac{\bar{F}}{N} \quad (5)$$

where: \bar{F} – mean value of the measured friction force. The abovementioned calculations should be made for each test individually, with (2) – (5) equations.

3. RESULTS OF SAMPLE TESTS

The method described above was tested. Abrasive linings in a tractor popular in Poland were used as a tested object. Cylindrical samples with a 1"-diameter and 10 mm high were cut out from the linings. Ten samples were prepared and the tests were repeated three times for each sample, which resulted in 30 trials in total. Figure 6 depicts a sample crater formed as a result of friction.



Figure 6 A microscope photo of one of the craters formed during the tests

It can be noticed that due to the application of a non-homogenous material, the crater has an irregular borderline. Measurements of b1 and b2 size were always made for the furthest points. The mean value of the tested association and the abrasive wear rate coefficient were determined with (4) and (5) equations. The values of standard deviation for both parameters were calculated using the following dependence:

$$SD = \sqrt{\frac{\sum_{i=1}^m (y_i - \bar{y})^2}{m-1}} \quad (6)$$

Table 2 shows the results.

Table 2 Results of sample tests

	Friction coefficient	Abrasive wear rate coefficient [10 ⁻¹³ m ³ N ⁻¹ m ⁻¹]
Mean value	0.41	1.458
Standard deviation	±0.016	±0.031

4. SUMMARY AND CONCLUSIONS

This paper suggests using Ball-Cratering method in the research on abrasive linings in brakes of agricultural machinery. It has been stated that:

- a proper design of the experiment requires preliminary tests facilitating a preliminary selection of the ranges of parameters in the experiment;
- appropriate values of parameters during the proper experiment can be successfully determined with Taguchi method of process optimisation;
- the difference between the contact in a real friction pair and the one used in the experiment can be compensated with appropriate planning and a suitable number of repetitions.

Affiliation

Research funded by Proper Work number MB/WM/4/2017, as part of subsidies for the devel-

opment of young scientists from the Ministry of Science and Higher Education Fund.

REFERENCES

- [1] Yang S., Dai S., A Glimpse at the Development and Application of Aluminium Alloys in Aviation Industry, *Materials Review*, 2005, 2, 68-72.
- [2] Kiniorska I., Wrońska-Kiczor J., Factors Affecting Sustainable Development of Agriculture and Rural Areas in the Świętokrzyskie Voivodship, *Barometr Regionalny*, 2015, 13 (1), 41-46.
- [3] Mellor J. W., *Agricultural Development and Economic Transformation*, Palgrave Studies in Agricultural Economics and Food Policy, Springer, Switzerland, 2015.
- [4] Yevtushenko A. A., Grzes P., 3D FE model of frictional heating and wear with a mutual influence of the sliding velocity and temperature in a disc brake, *International Communications in Heat and Mass Transfer*, 2015, 62, 37-44.
- [5] El-Tayeb N. S. M., Liew K. W., On the dry and wet sliding performance of potentially new frictional brake pad materials for automotive industry, *Wear*, 2009, 266, 275-287.
- [6] Kamiński Z., Experimental and numerical studies of mechanical subsystem for simulation of agricultural trailer air braking systems, *International Journal of Heavy Vehicle Systems*, 2013, 20 (4), 289-311.
- [7] Borawski A., Empirical research on the influence of friction material copper content on its tribological properties, *Proceedings of 24th International Conference "MECHANIKA 2019"*, 17 May 2019, Kaunas.
- [8] Puławski G., Szpica D., The modelling of operation of the compression ignition engine powered with diesel fuel with LPG admixture, *Mechanika*, 2015, 21 (6), 501-506.
- [9] Mieczkowski G., Optimization and prediction of durability and utility features of three-layer piezoelectric transducers, *Mechanika*, 2018, 24 (3), 335-342.
- [10] Szpica D., Modelling of the operation of a Dual Mass Flywheel (DMF) for different engine-related distortions, *Mathematical and Computer Modelling of Dynamical Systems*, 2018, 24 (6), 643-660.
- [11] Borawski A., Suggested research method for testing selected tribological properties of friction components in vehicle braking systems, *Acta Mechanica et Automatica*, 2016, 10 (3), 223-226.
- [12] Yevtushenko A. A., Borawski A., Воздействие периода эксплуатационных избранных трибологических свойства тормозных колодок, *Journal of Friction and Wear*, submitted for publication.
- [13] Allsopp D. N., Trezona R. I., Hutchings I. M., The effects of ball surface condition in the micro-scale abrasive wear test, *Tribology Letters*, 1998, 5 (4), 259-264.
- [14] Cozza R. C., Influence of the normal force, abrasive slurry concentration and abrasive wear modes on the coefficient of friction in ball-cratering wear tests, *Tribology International*, 2014, 70, 52-62.
- [15] Fildes J. M., Mayers S. J., Kilaparti R., Schleppe E., Improved ball crater micro-abrasion test based on a ball on three disc configuration, *Wear*, 2012, 274-275, 414-422.
- [16] Polański Z., *Planowanie doświadczeń w technice*, PWN, Warszawa 1984.
- [17] Osuch-Słomka E., Ruta R., Słomka Z., The use of a modern method of designing experiments in ball-cratering abrasive wear testing, *Journal of Engineering Tribology*, 2013, 227, 1177-1187.
- [18] Stoycheva S., Marchese D., Paulb C., Padoan S., Juhmani A., Linkov I., Multi-criteria decision analysis framework for sustainable manufacturing in automotive industry, *Journal of Cleaner Production*, 2018, 187, 257-272.
- [19] PN-EN 1071-6:2008 Advanced technical ceramics – Methods of test for ceramic coatings – Part 6: Determination of the abrasion resistance of coatings by a micro-abrasion wear test.