ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XIV [2016] – Fascicule 3 [August]
ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1]Holger HOTA, [2]Imre KISS, [3]Botond-Pál GÁLFI, [4]Péter DANI, [5]Renata Ildikó SZÁVA

# EXPERIMENTAL INVESTIGATIONS AND PRELIMINARY NUMERICAL SIMULATION ON THE ROLLING FRICTION COEFFICIENT'S EVALUATION OF UNCOVERED STEEL PARTS

[1,3,4,5] University "Transylvania" of Brasov, ROMANIA
[2] University "Politehnica" Timişoara, Faculty of Engineering Hunedoara, ROMANIA

**ABSTRACT**: The authors, based on their preliminary researches and their original testing bench, performed several experimental investigations concerning on rolling friction coefficient's magnitude, as well as preliminary numerical simulation of the rolling phenomenon. Their main contribution consists of establishing the rolling friction coefficient's magnitude in the starting moment because in literature these values are not mentioned. In the next period, the authors intend obtaining useful database on the rolling friction coefficient's for different types of covered and uncovered tribo-couples.
**Keywords**: rolling friction coefficient, experimental investigation, numerical simulation, starting moment of the rolling phenomenon

## 1. THEORETICAL APPROACH

The literature underlines the importance of the rolling friction coefficient's magnitude in engineering [1; 2; 3; 9; 10; 11]. The authors, in their previous works, analysed the tribo-couples consisting in the dynamics of some cylindrical elements rolling on plane surfaces, mainly in order to evaluate the magnitude of the rolling friction coefficient in the starting moment of the rolling process.

It is well-known fact that the main parameters, having great influence over the rolling friction coefficient's magnitude, are:

- the elastic behaviours of the materials;
- the roughness of the conjugate bodies;
- the curvature and the deformability of the contact surfaces, as well as
- the magnitude of the applied load.

In figure 1, based on the references [8; 9; 10], are presented the correlations between: the applied vertical load Q, the horizontal force P, destined to overcome the rolling friction resistance's momentum $N \cdot s$, respectively the reaction force N, moved ahead in the rolling/moving direction with a small distance s, defined as the rolling friction coefficient.

From the Theory of Elasticity it is well-known, that due to the deformability of the conjugated surfaces (referring here mainly to the plane surface), the reaction force N (as the resultant of the infinitely small reactions in the contact zone) will be located in front of the direction of the applied vertical force with the small distance s.

The original testing bench of the authors, described in references [4; 5; 6; 7; 8; 12] and presented in Figure 2, is constituted roughly from the following main parts: the four rolling elements 6 (here: with cylindrical shape, having a dia. 12 mm and 50 mm length) are located between two very rigid external steel plates 2, respectively one other intermediate one 3, all of them having length 300 mm, width 70 mm, respectively thickness of 10 mm. Their initial relative positions are assured by means of two Aluminium plates 5, having 1.5 mm thick, which play the role of the cages.

All of the plates and rolling elements are manufactured from the same material (low-alloyed steel), having the same roughness and hardness.

This subassembly is positioned between the jaws of one universal (tensile and compression) testing machine; the applied compression force's magnitude ($F_1$) is monitored by means of an octagonal electric strain gauge force transducer 1.

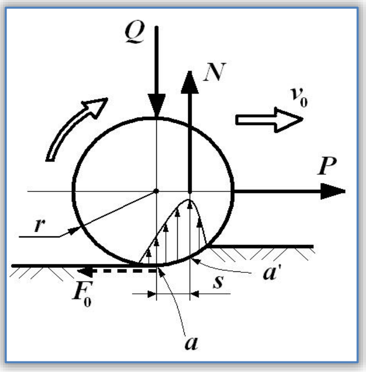


Figure 1: The phenomenon of the rolling friction and the definition of its coefficient [8; 9; 10]

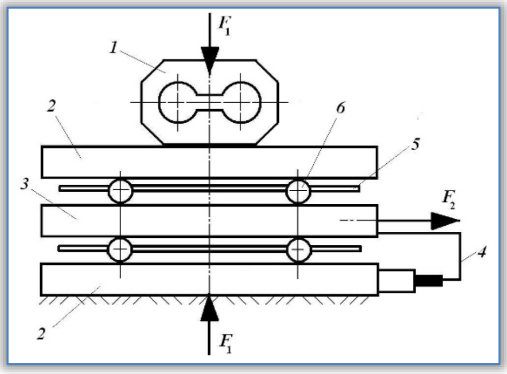


Figure 2: The original testing bench [4]

The monitoring of the horizontal force (denoted here with $F_2$ instead of P, from Figure 1, destined to overcome the rolling friction resistance's momentum $N \cdot s$) is assured by mean one other electric strain gauge force transducer, as well as the cyclical horizontal movement of the intermediate plate 3, having the same amplitudes of 57 mm in left and right direction with respect to its median position (representing approximately 1.5 times the circumference of the cylindrical elements 6) by mean of a special electronic device. This electronic device assures also the numbering of the performed cycles by this plate 3. The mentioned inductive transducer 4, shown in the same Figure 2, serves to monitor the starting moment of the rolling elements 6.

Based on the above-mentioned testing bench, the generalized analytical model (see Figure 3), by mean of the equilibrium of the intermediate plate and considering the identity of the friction conditions ($s'_1 = s_1 = s' = s$), offers finally the rolling friction coefficient's expression

$$s = \frac{2 \cdot r \cdot P}{(Q' + 2 \cdot G) + Q' + (Q' + Q_0 + 4 \cdot G) + (Q' + Q_0 + 2 \cdot G)} = \frac{P}{2 \cdot Q' + Q_0 + 4 \cdot G} \cdot r \, . \qquad (1)$$

In the generalized case different values for: the rolling friction coefficients ($S'$, $S_1'$, $S$, $S_1$); the acting loads on the cylinders ($Q_1$, $Q_2$, $Q_1'$, $Q_2'$) due to the applied vertical force Q'; the sliding friction forces ($S_1$, $S_2$, $S_1'$, $S_2'$), the corresponding rolling friction's momentums ($M_{f1}$, $M_{f2}$, $M_{f1}'$, $M_{f2}'$), and the normal reaction forces ($N_1$, $N_2$, $N_1'$, $N_2'$) were taken into consideration, as well as were accepted the same weight G for all of the rolling elements and $Q_0$ for the intermediate plate.

By neglecting the rolling elements weights G, respectively the weight $Q_0$ of the intermediate plate, one will obtain a very simply relation:

$$s = \frac{P}{Q'} \cdot \frac{r}{2} \, . \qquad (2)$$

Based on the fact that their magnitudes are: $Q_0 = 15.46N$; $Q_0$=15.46N; $G = 0.43N$; $Q'_{min} = 250N$, which in normal cases can be neglected in comparison of the applied vertical force Q' >250N.

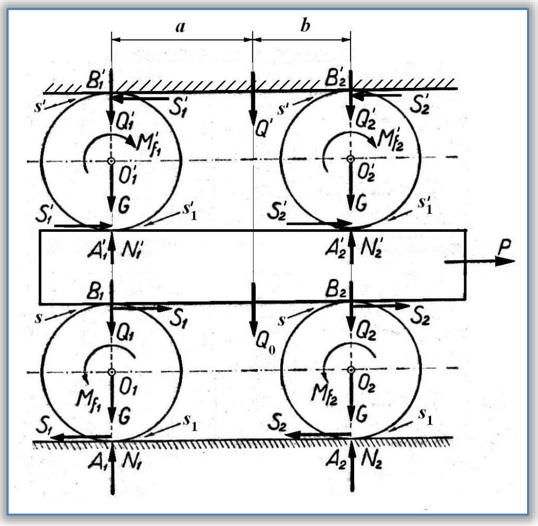


Figure 3: The generalized analytical model [8]

## 2.EXPERIMENTAL INVESTIGATIONS' RESULTS

In the experimental investigations were involved plates and cylindrical rolling elements manufactured from Romanian steel OLC 45, having 37, respectively 55 HRC hardness. They were combined into plates and rolling elements having the same hardness, as well as into others with different hardness. In the experimental strategy [8] the loading steps of 250N for the applied

vertical force $Q' \equiv F_V \equiv F_y$ [N], and a monitoring of the corresponding horizontal force $P \equiv F_H \equiv F_x$ [N] during the cyclical motion back and forth with a sampling rate of 250 samples/sec was foreseen (see Figure 4).
By calculus, taking into the consideration a nominal loading step of the vertical force and for the back and forth moving directions, the corresponding values of the rolling friction coefficients $s_1$, $s_2$ [mm] were obtained. As illustration, in Figure 5 are offered the corresponding curves $s_1$, $s_2$ with respect to the tribo-couples having 50 HRC, as well as their mean values $s$ (Figure 6).

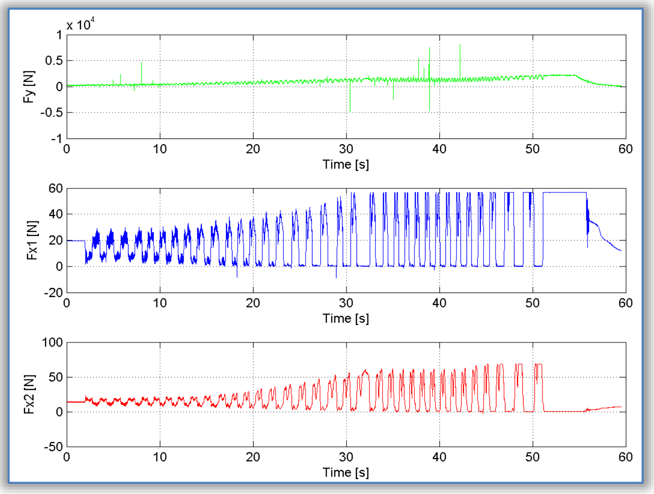


Figure 4: The sample of the data acquisition; $F_{x1}$, $F_{x2}$ [N] represent the horizontal forces in the back and forth moving directions of the intermediate plate [8]

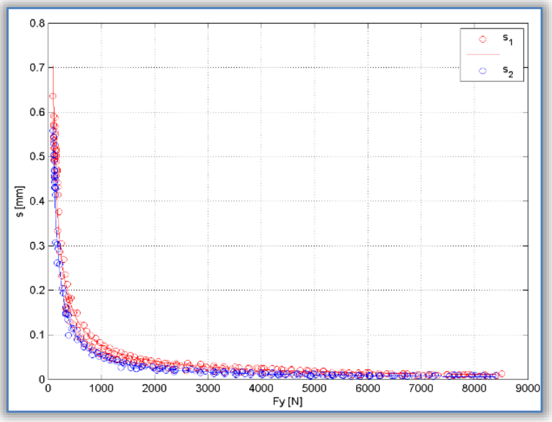


Figure 5: The individual values of the rolling friction coefficient, corresponding to the back $(s_1)$ and forth $(s_2)$ movements for the case of 50 HRC of the tribo-couples [8]

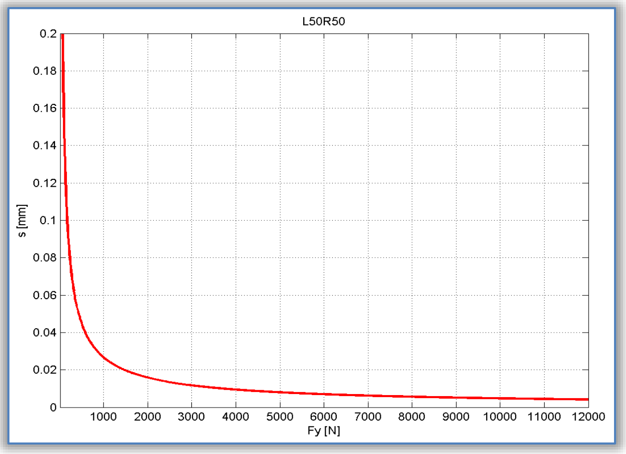


Figure 6: The mean values $(s)$ of the rolling friction coefficient, corresponding to the back and forth movements for the entire loading domain [8]

## 3. PRELIMINARY RESULTS ON NUMERICAL SIMULATION

In order to evaluate the stress-state of the rolling elements in the starting moment of the rolling phenomenon, the authors applied the LS-DYNA software, where the input data were the applied vertical and horizontal forces, as well as the corresponding rolling friction momentum, which includes the adequate/corresponding rolling friction coefficient.

The involved Finite Element was SOLID 164, obtaining finally 49711 nodes for the whole subassembly (external and intermediate plates, as well as for the four rolling elements).

As illustration, corresponding to the $F_y$ = 800 N, $F_x$ = 8.4 N and s = 0.0313048 mm, in Figure 7 is offered the equivalent von Mises stress-state of the rolling elements/cylinders.

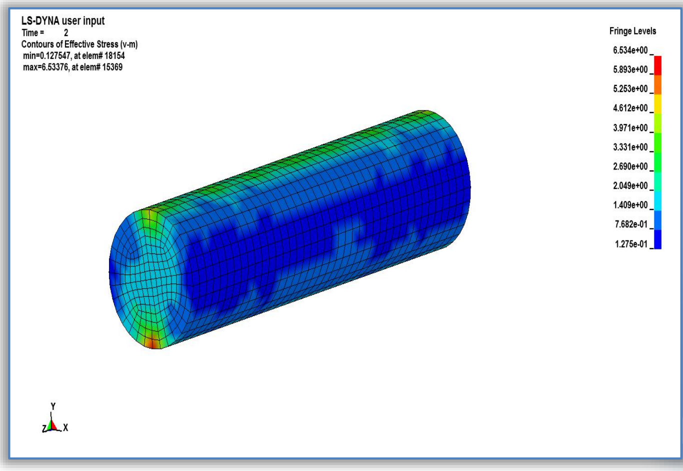


Figure 7: The equivalent von Mises stresses for the rolling element

## 4. CONCLUSION

The authors performed experimental investigations with their original testing bench in order to establish the rolling friction coefficient's law with respect to the applied vertical load and to the conjugate elements' hardness both in the starting moment of the rolling phenomenon and during the continuous rolling process.

One other goal of their researches was a preliminary numerical simulation of the stress-states, mainly in the rolling elements at the starting moment of the rolling phenomenon.

Based on the obtained laws, became possible to optimise the efficiency of the tribologic pairs from point of view of their energy balance.

The further goals of the authors consist in performing several, statistical acceptable tests for different kind of such tribologic pairs, widely applied in Romanian bearing industry and not only, as well as a more accurate numerical simulation of the contact zones between the rolling elements and plane surfaces.

## REFERENCES


[1.] Balekics, M., Tribologie – Frecarea, Cluj-Napoca, Editura Todesco, 2000.

[2.] Bobancu, Ş., Cozma, R., Tribologie, Frecare-Ungere-Uzare, Editura Universităţii Transilvania din Braşov, 1995.

[3.] Czichos, H, Tribologie Handbuch, Vieweg Verlag, Braunschweig/Wiesbaden, 1992.

[4.] Hota, H., Bobancu, Ş., Neagu, Ax., Gálfi, B., Száva, I., Testing device for the rolling friction coefficient evaluation, Surface Engineering INPO 2008, Czestochowa University, Wisla-Jawornik, Poland, 2-5 Dec., 2008. Published in „Inzineria Materialowa" PL ISSN: 0208-6247, INDEKS 36156, XXIX Year, nr. 6 (2008), pag. 1047-1049.

[5.] Hota, H., Bobancu, Ş., Száva, I., Experimental investigation of the rolling friction coefficient evaluation, Tehnonav, The 7th International Scientific Conference on Naval, Mechanical, Industrial, and Power Engineering, "Ovidius" University of Constanta, 20-22 May, 2010, Ovidius University Annuals, Scientific Journal, Mechanical Engineering Series, Vol. XII, TOM 1, 2010, Ovidius University Press, ISSN 1224-1776, pp. 199-202.

[6.] Hota, H., Bobancu, Ş., Gálfi, B., Száva, I., An efficient stand and some preliminary results on the rolling friction coefficient evaluation of the steel-steel elements, Acta Technica Napocensis of the Technical University of Cluj - Napoca, No. 53, Vol. II, Applied Mathematics and Mechanics, pp. 253-256, 2010.

[7.] Hota, H., Bobancu, Ş., Dani, P., Gálfi, B., Munteanu, I.R., Száva, I., New testing bench for the rolling friction coefficient's evaluation, vol. 4 (August), 2015 Acta Technica Corviniensis, - Bulletin of Engineering, e-ISSN: 2067 - 3809 (online), http://acta.fih.upt.ro

[8.] Hota, H., Ph.D thesis, Transylvania University of Brasov, Romania, 2015.

[9.] Johnson, K.L., Contact Mechanics, Cambridge University Press, 1985.

[10.] Pavelescu, D., Concepţii noi, calcul şi aplicaţii în frecarea şi uzarea solidelor deformabile, Bucureşti, Ed. Academiei, 1971.

[11.] Pavelescu, D., Muşat, M., Tudor, A., Tribologie, Bucureşti, Editura Didactică şi Pedagogică, 1977.

[12.] Hota, H., Oleksiuk, V., Pascu, A., Dani, P., Gálfi, B.P., Száva (Munteanu) I.R., Vlase S., Száva, I., Popa, G., Investigations on the rolling friction coefficient's evaluation of uncovered steel parts, MultiScience-XXX. microCAD, International Multidisciplinary Scientific Conference, University of Miskolc, Hungary, 21-22 April 2016


ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering