MultiScience - XXX. microCAD International Multidisciplinary Scientific Conference
University of Miskolc, Hungary, 21-22 April 2016, ISBN 978-963-358-113-1

INVESTIGATIONS ON THE ROLLING FRICTION COEFFICIENT'S EVALUATION OF UNCOVERED STEEL PARTS

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1. GENERAL ASPECTS

The importance of the rolling friction coefficient's magnitude is well-known in engineering. In this sense, between others, one can mention the cylindrical and conical rolling elements of the heavy-duty bearings, where this coefficient plays a very significant role.

In the literature [1; 2; 3; 9; 10; 11] the main elements are underlined which have a great influence over the rolling friction coefficient's magnitude, such as:

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

In Figure 1 the correlations are presented between: the applied vertical load *Q*, the horizontal force *P*, destined to overcome the rolling friction resistance's moment $N \cdot s$, respectively the reaction force *N*, moved ahead in the rolling/moving direction with a small distance s, defined as *the rolling friction coefficient.*

In this Figure 1, ***a*** represents the ideal/theoretical position of the reaction force *N*, considering un-deformable plane surface, and ***a'*** correspond to the real case of the deformable plane surface.

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 concentrated reaction force *N* (as the resultant of the infinitely small reactions in the contact zone) will be located in front of the applied vertical force *Q* with the small distance s.

The authors, in their previous works [4; 5; 6; 7; 8], presented both their original testing bench (Fig. 2), destined to evaluate the magnitude of the rolling friction coefficient in translation tribologic couples and some preliminary experimental

DOI: 10.26649/musci.2016.109

results on different pairs of materials (uncovered and covered steel parts, concerning plates and cylindrical rolling elements).

Briefly, this original testing bench has 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 a thickness of 1.5 *mm*, which play the role of the cages.

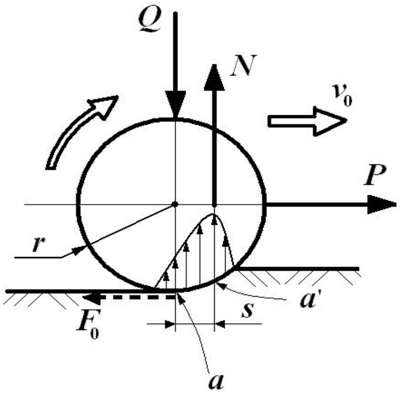

Fig.1
The phenomenon of the rolling friction and the definition of its coefficient [9]

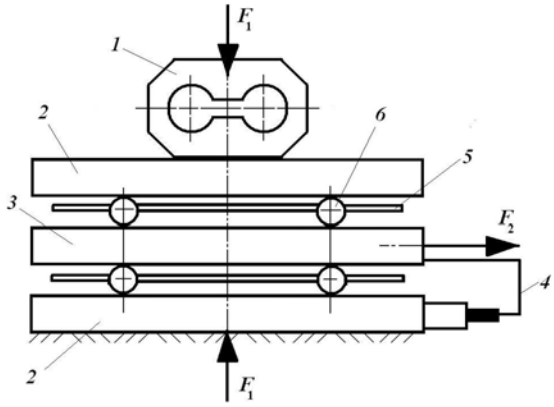

Fig. 2
The original testing bench [4]

All of the plates and rolling elements are manufactured from the same material (low-alloy 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***.

In order to monitor the horizontal force (here: F_2 instead of P, from Figure 1, destined to overcome the rolling friction resistance's moment $N \cdot s$), the authors have equipped the testing bench with another electric strain gauge force transducer.

They also conceived a special electronic device to assure 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.

Consequently, the rolling elements will perform a rolling of approximately 1.5 times of their circumference.

This electronic device offers also a 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***.

2. ANALYTICAL APPROACH OF THE PROBLEM

Based on the mentioned testing bench's main parts, the generalized analytical model is presented in Figure 3.

In this 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 frictional moments (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.

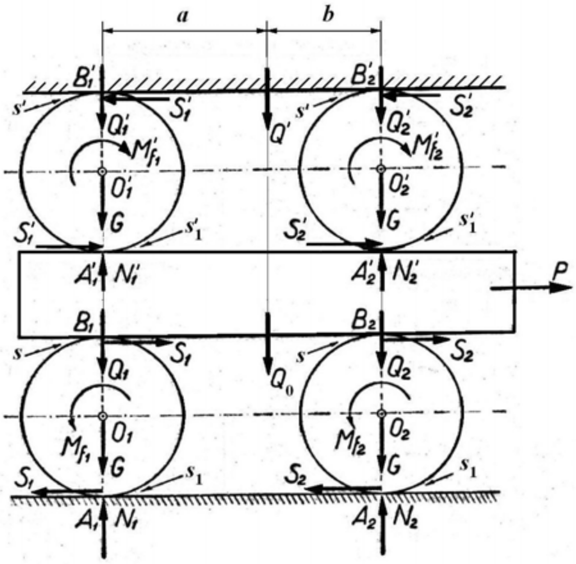

Fig. 3
The generalized analytical model [8]

One can accept the same weight G for all of the rolling elements, and Q_0 for the intermediate plate.

By equilibrium calculus of the intermediate plate, finally one can obtain:

$$s_1' \cdot (Q' + 2 \cdot G) + s' \cdot Q' + s_1 \cdot (Q' + Q_0 + 4 \cdot G) + s \cdot (Q' + Q_0 + 2 \cdot G) = 2 \cdot r \cdot P . \quad (1)$$

By accepting the identity of the friction conditions ($s_1' = s_1 = s' = s$), from relation (1), finally one will obtain the requested expression of the rolling friction coefficient:

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

In addition, by neglecting the weight G of each rolling element, and the weight Q_0 of the intermediate plate, one will obtain a very simple relation:

$$s = \frac{P}{Q'} \cdot \frac{r}{2}. \tag{3}$$

Of course, depending on the required accuracy, a part of these neglected weights can be taken into consideration in the calculus.

One has to mention the magnitudes of these weights: $Q_0 = 15.46\,N$; $G = 0.43\,N$, $Q'_{\min} = 250\,N$.

Consequently, in the usual cases the above-mentioned assumption is acceptable.

3. EXPERIMENTAL INVESTIGATIONS ON UNCOVERED STEEL ELEMENTS

The authors performed several experimental investigations regarding uncovered steel components (plates and cylindrical rolling elements), manufactured from Romanian steel OLC 45, having 37, or 55 *HRC* hardness (Rockwell Cone-based hardness). They were combined into plates and rolling elements (cylinders) having the same hardness, but also with others with different hardness. The plates' hardness is marked by ***L*** and the rolling elements' ones with ***R***; e.g.: *L*37*R*50 means plates having 37 *HRC* and rolling elements with 50 *HRC*.

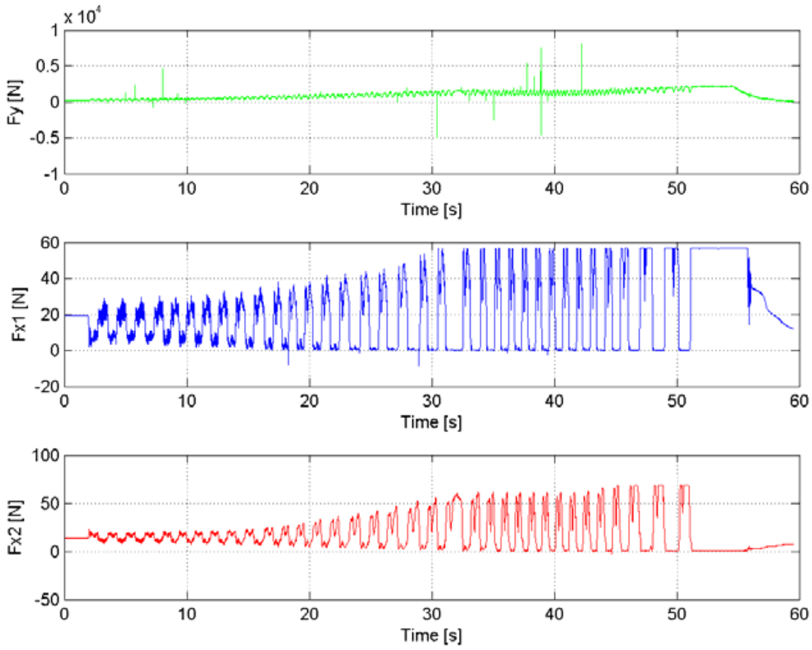

Fig. 4

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]

In the experimental strategy the loading steps of $250\,N$ 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* were used.

Based on reference [8], a sample of the data acquisition during the experiments is offered in Figure 4.

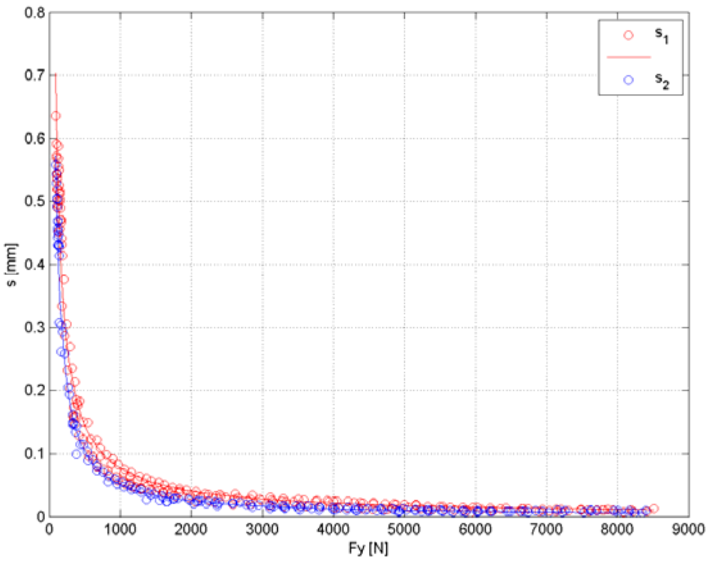

Fig. 5
The individual values of the rolling friction coefficient, for to the back and forth movements for the $L50R50$ case [8]

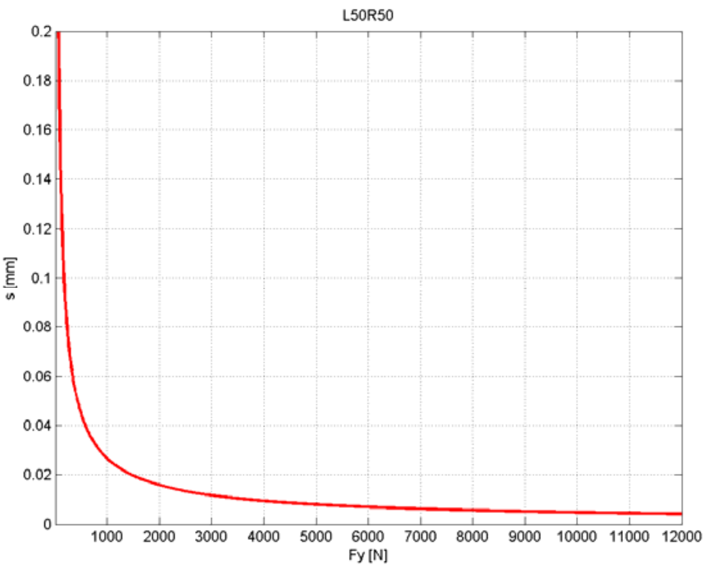

Fig. 6
The mean values of the rolling friction coefficient, corresponding to the back and forth movements for the $L50R50$ case [8]

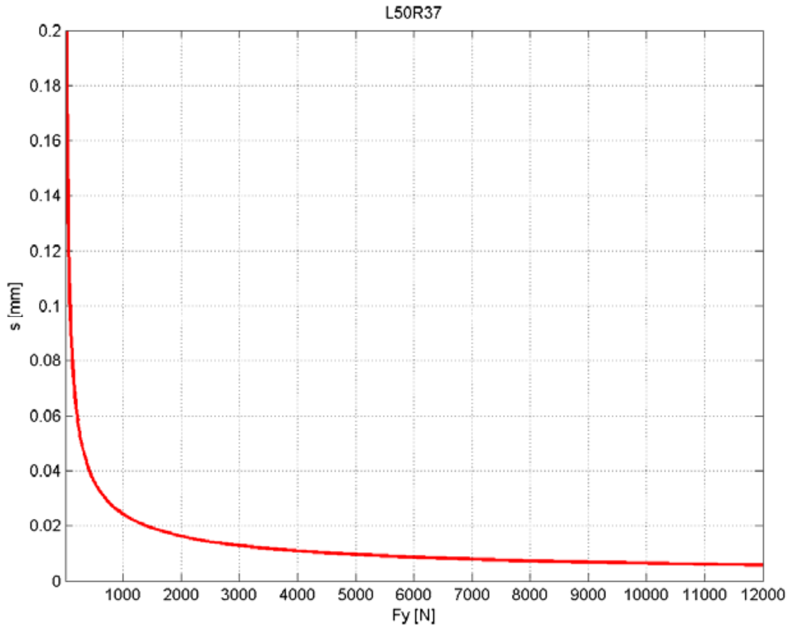

Fig. 7
The mean values of the rolling friction coefficient, corresponding to the back and forth movements for the *L*50*R*37 case [8]

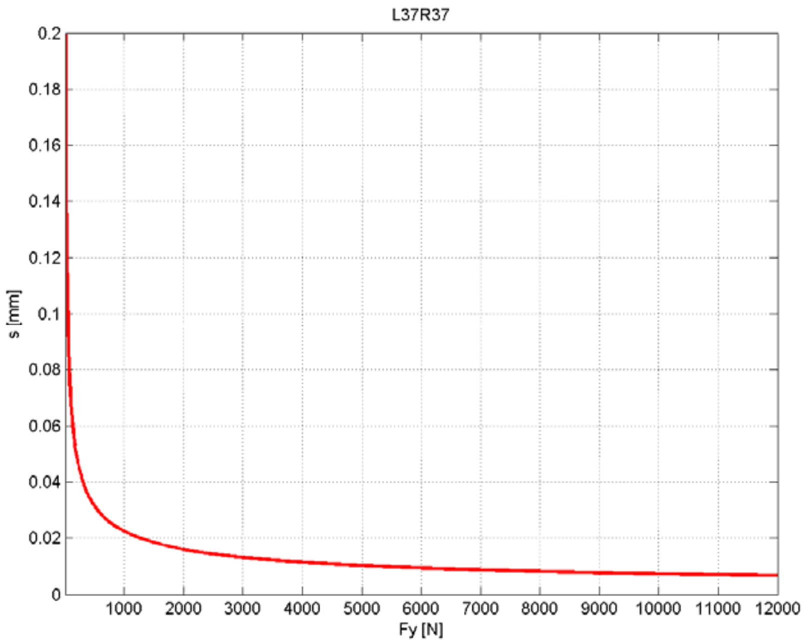

Fig. 8
The mean values of the rolling friction coefficient, corresponding to the back and forth movements for the *L*37*R*37 case [8]

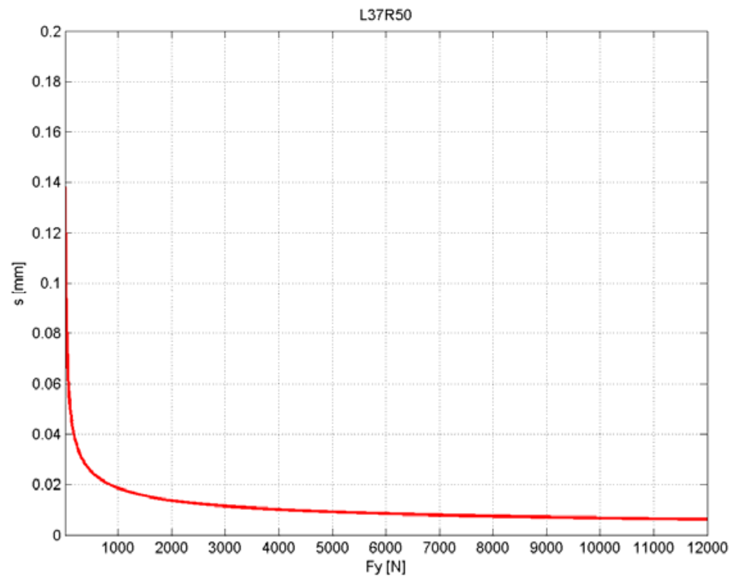

Fig. 9
The mean values of the rolling friction coefficient, corresponding to the back and forth movements for the L37R50 case [8]

By calculus, corresponding to a nominal loading step of the vertical force and for the back and forth moving directions, the related values of the rolling friction coefficients s_1 , s_2 $[mm]$ were obtained (see Figure 5 as illustration).

Based on these values/laws, it became possible to draw up the mean values and the corresponding mean laws for the rolling friction coefficients during the entire loading domain (see Figures 6, …, 9).

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.

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

A further goal of the authors consists of performing several, statistically acceptable tests for different kind of such tribologic pairs, widely applied in the Romanian bearing industry and even elsewhere.

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