Bush chain friction depending on speed and influence of centrifugal effect

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Abstract. Evaluation of friction in chain drives is the first step in the process of reducing the friction. This paper presents the results of experimental evaluation of friction in a bush chain considering only the friction in the joints of the chain (pin-bush joints and chain-sprocket joints) and not the friction in bearings. Friction is presented as friction torque, measured for a basic chain drive with transmission ratio equal to one, depending on speed. The influence of the centrifugal effect on friction is also analysed.

1. Introduction

The importance of reducing friction in automobiles transmission is as high as possible in the context of the regulations imposed by the 20/20/20 goals from the Directive for Energy Efficiency of the European Union (2012/27/UE), imposing targets for year 2020, like: 20% reduction of CO2 emissions compared to 1990 levels and 20% reduction of final energy consumptions. In the same directions have been moved the goals of automotive industry for year 2020. American standards CAFE impose a one third reduction of fuel consumption, relative to year 2008. European Commission set a goal for 2021 of average CO_2 emissions of 95 grams CO_2 / km for the whole fleet produced in 2020.

One of the main applications for bush chains is in the timing system of combustion engines, where tensioning and speed reach some of the extreme values of the field of use. Reducing friction in timing chains is an important goal since, according to [1, 2, 3], the part of the fuel energy dedicated to overcome friction in the engine system is about 15% (7–18%) of total losses.

Very few experimental researches on chain friction have been published. A procedure for measuring losses in the timing chain and the loss in the guides of an engine, using equipment consisting in a full engine is presented in [3]. The contribution of chain friction and guide friction on the global timing system friction are only presented for one oil temperature and one value of rotational speed. Friction between chain and guide is subject of several papers referring to friction coefficients [4], friction contribution [5] or theoretical approaches [6].

At the Tribology Centre of Transylvania University of Brasov, a research on friction in chain drives, used for timing system of combustion engines, has been developed with the finance of Schaeffler Group. The procedure for measuring chain friction is presented in [7]. Friction losses are measured as friction torque depending on speed, tensioning and oil temperature.

A global friction torque in chain and bearings is measured in a first stage. In a second stage, the friction torque in bearings (sum of friction in input bearing box and output bearing box, at the same rotational speed and load) is measured in the same conditions [7]. Friction in chain results by extracting bearing friction from global friction.

$$T_{f\ chain} = T_{f\ chain+bearings} - T_{f\ bearings}. \quad (1)$$

In order to correctly evaluate the friction in the chain drive, all the influences must be considered. Since the tensioning force along the chain, also acting in the pin-bush joint, has great importance for the friction, the influence of the centrifugal effect on this force must be carefully studied.

The theoretical approach [8, 9] on the centrifugal effect on chain drives presents a component F_c, which is equilibrating the centrifugal force. The force F_c is creating a supplementary tensioning force on the whole length of the chain and, in the same time, it creates a release of the initial tensioning of the transmission. The value of F_c force is

$$F_c = \frac{m}{l} v^2, \quad (2)$$

where (m/l) is the mass of chain per unit of length and v is the linear speed of the chain.

A study of the influence of the stiffness of supports and chain on the effect of centrifugal force is presented in [10]. It shows that the force F_c divides in two components: one, with a value of $2\kappa_S F_c$, goes on release of the shafts; the second component, with a value of $\kappa_C F_c$ determines supplementary tensioning of the chain. The coefficients indicating how much of the F_c force goes to the chain tensioning (κ_C) and how much goes to the shafts releasing (κ_S) are [10]:

$$\kappa_C = \frac{c_C}{c_S + c_C}; \ \kappa_S = \frac{c_S}{c_S + c_C}, \quad (3)$$

where c_C, respectively c_S, are the stiffness of chain (2 parallel arms), respectively of the supports.

This paper presents the results of experimental evaluation of friction in a bush chain considering only the friction in the joints of the chain and not the friction in bearings. Friction is presented as friction torque, measured for a basic chain drive with transmission ratio equal to one, depending on speed. The influence of the centrifugal effect is also analysed.

2. Theoretical approach on chain friction

Horovitz [8] presents the calculus relation of the mechanical work loss by friction L_f in the case of one pin-bush joint, for entering or exiting a sprocket, along a pitch angle $\varphi = 2\pi/z$ rad

$$L_f = \frac{\mu \pi d_3 F}{z}, \quad (4)$$

where μ is the friction coefficient in joint, z is the number teeth of the sprocket, d_3 is the diameter of the pin and F is the force in joint. In order to calculate the friction losses as the friction torque for a basic chain drive (transmission ration equal to one), the sum of mechanical work losses, in the four pin-bush joints entering and exiting the two identical sprockets, must be divided by the pitch angle

$$T_f = \frac{2\mu \pi d_3 (F_1 + F_2)}{z} / \frac{2\pi}{z} = \mu d_3 F, \quad (5)$$

where F_1 and F_2 are the tensioning forces on the two arms of the chain and F is their sum. In the absence of the centrifugal effect and neglecting the weight of the chain, the force F is loading the supports. As it can be seen from equation (5), the friction torque should be depending only on the pin-bush friction coefficient, diameter of the pin and tensioning force.

3. Experimental results on bush chain friction

The tests have been developed on the chain rig described in [7], based on the procedures presented in the same reference. The subject of the test is a bush chain B8, with 8 mm pitch, 64 links working with identical 23 teeth sprockets. Tensioning is created by automatic enlarging the centre distance, ensuring a constant tensioning force F_0 of 1 kN. This is the force constantly loading the two bearing boxes. The transmission is vertical with transmission ratio equal to one.

Lubrication of the chain is made with two jets of oil oriented to the points of chain entering the two sprockets. 5W30 Castrol Edge synthetic oil is used with a controlled temperature of 90 °C. The measured kinematic viscosity at 90 °C is $27 \cdot 10^{-6}$ m^2/s, resulting a $23 \cdot 10^{-3}$ Pas dynamic viscosity.

Four identical chains have been tested in the same conditions, measuring friction torque for a series of values of rotational speed *n* {500, 1000, 1800, 3000, 5000} rpm. Each chain has been previously subject of running in for 50 hours. Friction in each chain results by extracting measured bearing friction from measured global friction. The diagram showing measured global friction for the first tested chain C1, measured friction in bearings and the resulted friction in the first tested chain C1 is presented in figure 1. The values of friction torque from figure 1 are presented as percentage of the minimum chain friction torque resulted for 1800 rpm (Tf% = $T_f \cdot 100/T_{f\,\text{chain 1800 rpm}}$).

Figure 2 presents the results for the tests on four identical B8 chains (C1, C2, C3 and C4) and an average of the measurements. The values of friction torque from figure 2 are presented as percentage of the minimum average chain friction torque resulted for 1800 rpm (Tf% = $T_f \cdot 100/T_{f\,\text{C\_avg 1800 rpm}}$).

The analyses of the results presented in figure 2 allow us to draw few conclusions:

- Even looking identical chains, there are differences in measured friction up to 20%;
- The trend of all the friction vs. rotational speed curves is the same;
- A comparison with the theoretical model shows that the influence of speed on chain friction may act on modification of friction coefficient and/or on chain tensioning;
- Instead of constant friction vs. speed, there is a friction change with maximum 35% at a 10 times increasing speed (from 500 to 5000 rpm);
- Friction tend to diminish with increasing rotational speed at small rotational speed; this could be explained by boundary or mixed friction in the joints, following Stribeck's curve;
- For high speed, friction tends to increase with increasing speed; this may partially be explain by the influence of increasing centrifugal effect.

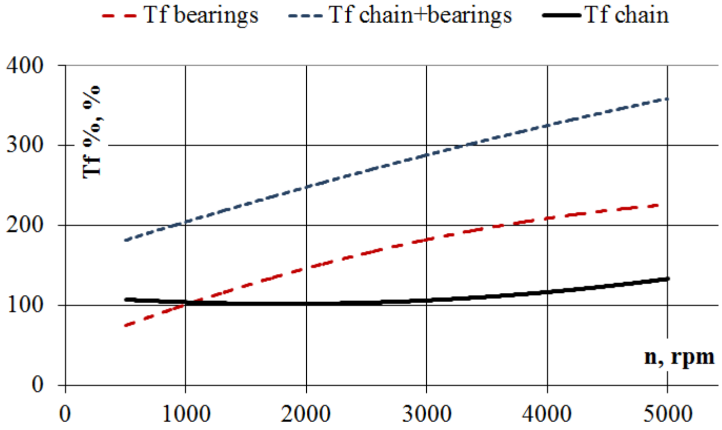

Figure 1. Global friction, bearing friction and resulted friction in chain C1.

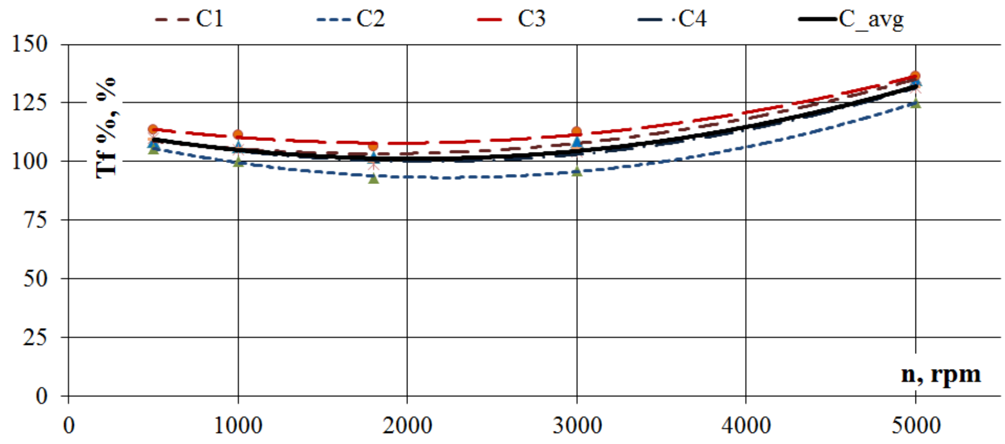

Figure 2. B8 chain friction depending on rotational speed.

4. Centrifugal effect on bush chain friction

All the tests have been made with constant F_0 tensioning force of 1 kN, with automatic control on tensioning.

Figure 3 presents three stages of loading the chain transmission:

- in the initial stage (figure 4, a), tensioning at rest, F_0 tensioning is acting on both support and the two arms of the chain together;
- if the two supports are blocked and chain is moving with linear speed v (figure 4, b), the component of the centrifugal force F_c (see equation (2)) is divided in order to release the supports and at the same time to supplementary tension the chain;
- in the case of our tests, with automatic tensioning, the load on the supports F_0 was all the time constant (figure 4, c), including the centrifugal effect; in this case the entire F_c component is supplementary tensioning the two arms of the chain.

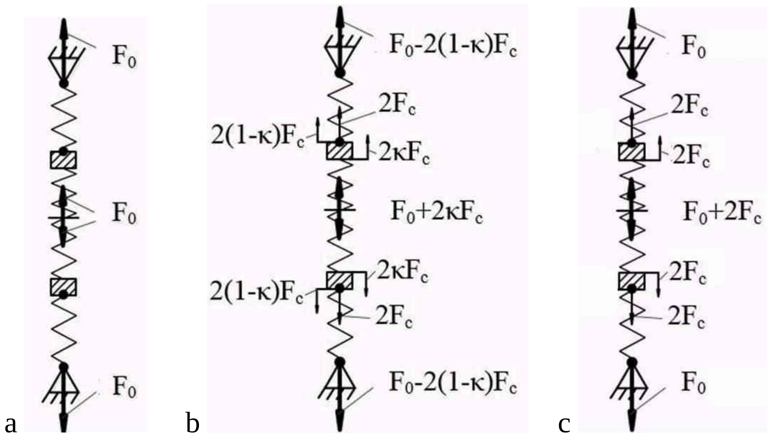

Figure 3. Forces on initial tensioning (a), repectively with centrifugal effect with blocked supports (b) and with automatic tensioning (c).

For a B8 bush chain (m/l = 0.3383 kg/m), figure 4 shows the change in chain tensioning with the increasing rotational speed, considering both arms of the chain $F = F_1 + F_2$.

Taking into account the measured value of friction torque at 1000 rpm rotational speed and considering the theoretical calculus relation for friction torque (equation (2)) with centrifugal influence on chain tensioning force F, and constant friction coefficient, figure 5 presents a comparison between this and the measured averaged friction torque. The differences may be explained by continuing decreasing friction coefficient up to 4000 rpm rotational speed and a small increase of friction coefficient at high rotational speed due to bad lubrication.

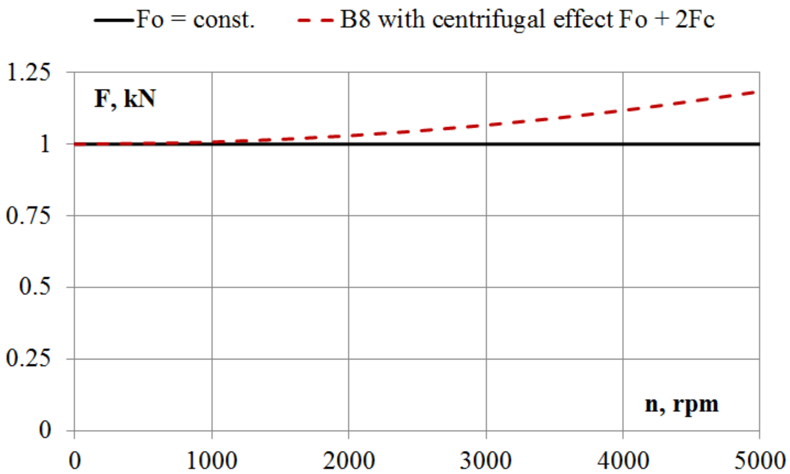

Figure 4. Chain tensioning with entire centrifugal effect.

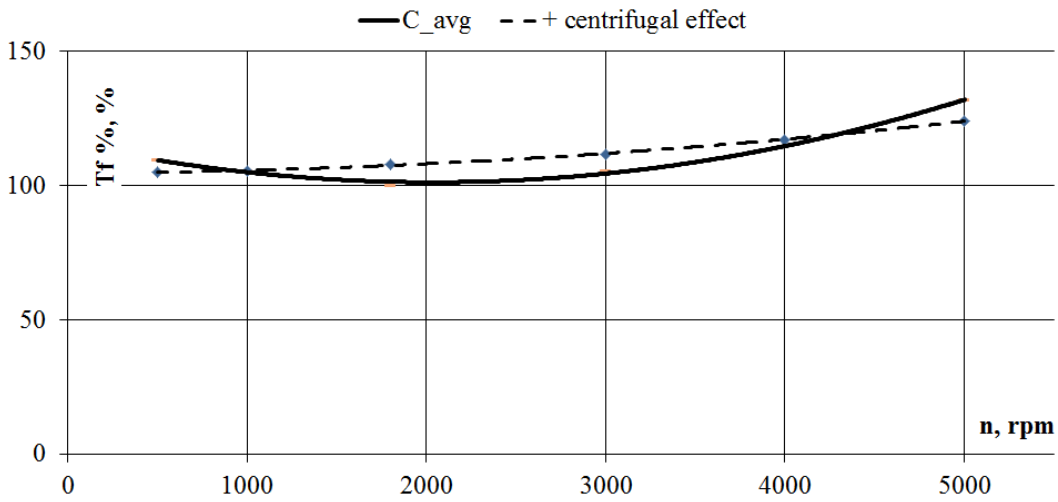

Figure 5. Comparison between experimental results and theoretical friction model with correction of centrifugal effect on tensioning.

5. Conclusion

Future research should focus on the influence of tensioning and lubrication on chain friction. Friction coefficients from the theoretical model should be evaluated. There is also needed an evaluation of other than pin-bush friction since sliding of the bush on the tooth of the sprocket has been clearly demonstrated.

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