Influence of Speed and Geometry on Guide Friction Contribution in Global Power Loss of a Silent Chain Drive

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Abstract. The subject of the paper is the friction between a tooth chain and the guide. An experimental study is developed with the aim of determining how much is the contribution of chain-guide friction on the total friction in a basic tooth chain transmission. The measurements have been made on a chain friction rig, testing a basic silent chain transmission with transmission ratio equal to 1, with a controlled tensioning device. The following parameters can be adjusted and measured: rotational speed at the input shaft, tensioning force in the chain, position of the guide, temperature and pressure of the oil used for lubrication of chain and guide. Friction torque at the input shaft is a sum of friction torques coming from bearings, chain (pin-link, link-sprocket) and guide (guide-chain). It is measured for different rotational speed, tensioning force, temperature of oil, position of the guide (when the guide is present), with and without guide and separate in the bearings. The paper presents the resulted contribution of the guide in the power loss by friction, as percent of the power loss from friction in chain and guide together. Influence of speed, tensioning force and guide position is presented.

Keywords: Silent chain; guide friction; speed; tensioning.

1 Introduction

The research for diminishing the friction of automobile engine can generate a lot of benefits: reduced fuel and oil consumption; increased engine power output; reduction in harmful exhaust emissions; improved durability, reliability and engine life; reduced maintenance requirements and longer service intervals [1]. The part of the fuel energy consumed in friction can be divided into groups based on data from [1, 2, 3, 4]: 12–45% is needed to overcome the rolling friction in the tire–road contact, 30–35% are needed to overcome friction in the engine system, 7–18% to overcome friction in the transmission system, and 10–18% to overcome friction in the brakes.

Very few experimental results on chain drive friction have been published. A testing rig, procedure and experimental data on contribution of chain and guides on glob-

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al friction losses in the timing chain drive of an engine are presented in [5]. The testing rig is based on a full engine equipped in order to measure separate friction in camshaft, chain and the two guides. The results are showing the influences of tensioning and driven torque but not the influences of rotational speed and temperature. The geometry of the guides is not clear.

Theoretical approaches on the friction in chain drive system, needs values of friction coefficients in the links including the influence of different variables. Influence of speed, pressure and temperature, with and without lubrication, on the friction between chain plates and guide materials are presented in [6, 7], measurements being performed on a universal tribometer.

This paper presents experimental results on the contribution of guide friction on the global (chain + guide) friction of a basic chain drive (transmission ratio equal to 1). It shows the influences of rotational speed, tensioning and lubricating oil temperature on the contribution of guide friction on the global power losses.

The measurements are made on the friction chain rig presented in [8], with the diagram presented in figure 1. The rig allows to control and measure the rotational speed at input shaft, chain tensioning F and temperature of the lubrication oil used for chain and bearing boxes.

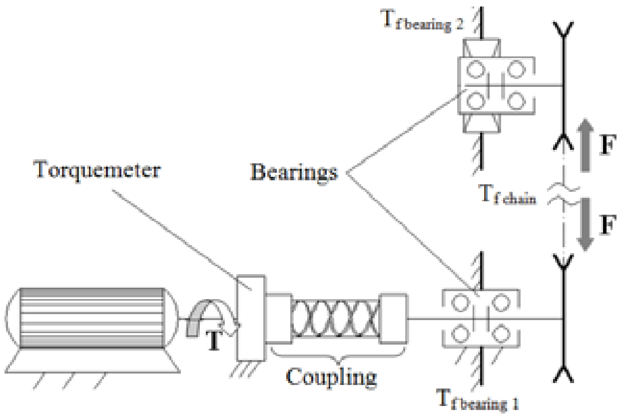


Fig. 1. Functional diagram of the chain friction rig

2 Equipment and guide friction device

In order to apply a controlled tensioning with a guide, the device presented in figure 2 is built, considering the particularities of the chain rig and the types of chains that will be tested.

The main components of the guide friction device are: 1 – base plate for attachment on the rig; 2 – assemble for adjustment of the pushing of the guide; 3 – lateral plate; 4 – tensioning spring; 5 – force sensors; 6 – guide attached on the lateral plate; 7 – articulated guide; 8 – plunger for pushing the guide; 9 – slider.

Figure 3 presents the chain rig equipped with the guide friction device.

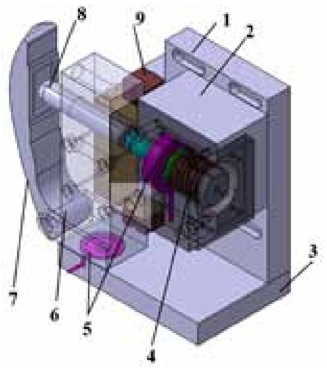


Fig. 2. Guide friction device

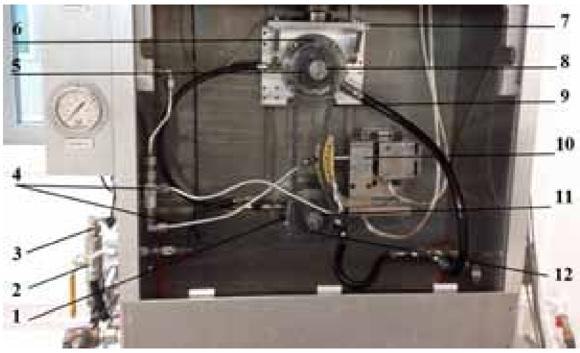


Fig. 3. Chain friction rig equipped with the guide friction device

The components of the chain friction rig equiped for guide friction measurements are: 1, 6 – input and output bearing boxes; 2, 3, 4 – oil circuit for bearings, chain and guide; 5, 12 – input and output sprockets; 7 – slider; 8, 11 – input and output shafts; 9 – chain; 10 – guide friction device.

3 Measurement procedure

3.1 Specifications

The tested chain is a silent chain with 100 links and 6.35 mm pitch. The two sprockets are identical (transmission ratio equal to 1) with 23 teeth. The centre distance of the chain drive (A) is approximately 300 mm.

The guide is made of PA66, circular shape with R_b = 200 mm radius. The guide is placed with a deviation f from the initial line of the chain. There are two positions (A and B) of the guide relative to the chain that have been tested, as presented in figure 4. The deviations in the two positions are: fA = 9.5 mm and fB = 16 mm.

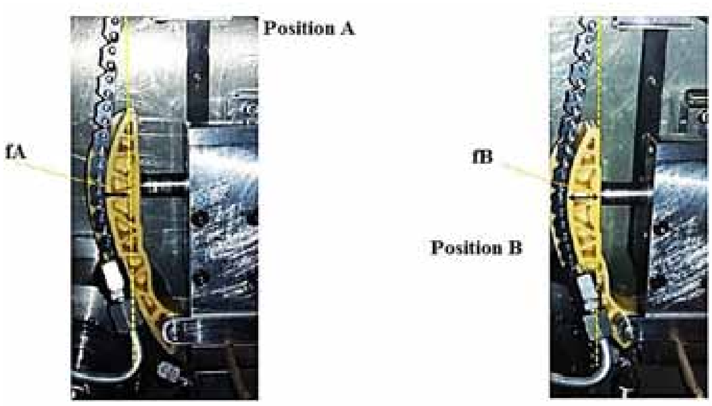


Fig. 4. Positions of guide relative to the chain

Corresponding to the positions of the guide relative to the initial line of the chain, the number of links n_z in contact with the guide are calculated based on the scheme from figure 5 and mathematical model from [9]. The position of the centre of guide, relative to the centres of the two sprockets is characterized by the ratio A1/A2 = 0.55 (see figure 5). The diagram from figure 6 presents the number of links in contact with the guide depending on the deviation f from the initial line of the chain, relative to the pitch p of the chain. The diagram is drawn for the known parameters of the chain drive presented before. The numbers of links in contact, for the two positions are: $n_{zA} = 5.1$ and $n_{zB} = 9.3$.

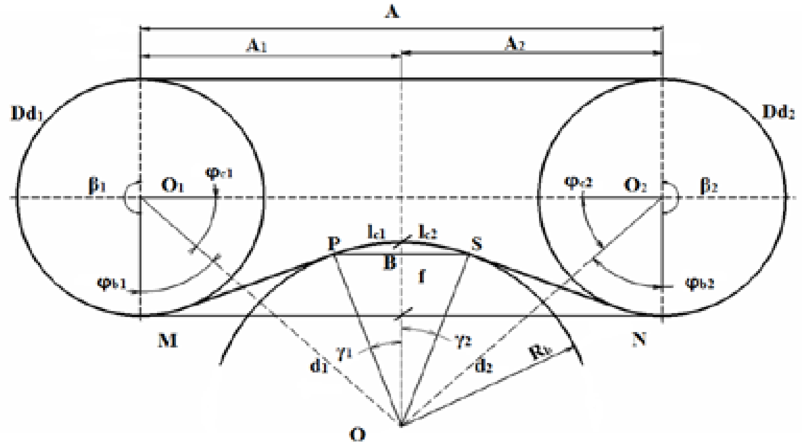


Fig. 5. Chain-guide geometry (Source: [9])

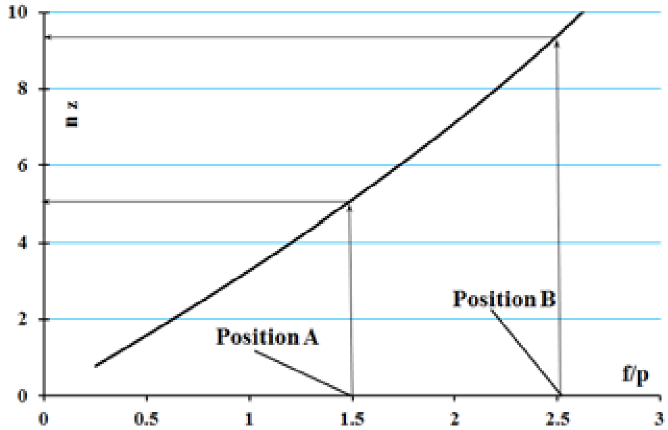


Fig. 6. Number of links n_z in contact with the guide depending on the ratio f/p

3.2 Preparation of rig and types of measurements

Measurements are performed for three separate structures of the rig, looking for separate results:

- Measurements of friction in bearings as input torque depending on speed and tensioning ($T_{fbearings} = T_{fbearing1} + T_{fbearing2}$). The measurements are made for the two bearing boxes mounted together, as presented in [10, 11];
- Measurements of friction in chain and bearings together (see figure 1) as input torque depending on speed and tensioning ($T_{fbearings+chain} = T_{fbearings} + T_{fchain}$), without the guide friction device. Friction in the chain [12] is calculated as $T_{fchain} = T_{fbearings+chain} - T_{fbearings}$;
- With the guide friction device, measurements of friction in chain, bearings and guide, together (see figure 1) as input torque depending on speed, tensioning and position of guide ($T_{fbearings+chain+guide} = T_{fbearings} + T_{fchain} + T_{fguide}$). Friction in the guide is calculated as $T_{fguide} = T_{fbearings+chain+guide} - T_{fbearings+chain}$.

3.3 Testing program

The testing program is consisted of steps of constant controlled parameters (rotational speed and tensioning force). The role of these steps is to stabilize the temperature distribution on all the elements of the rig and create the steady state conditions. The readings that count in evaluation of friction are only the one of the steady state period [10]. Friction torques ($T_{fbearings}$, $T_{fbearings+chain}$, $T_{fbearings+chain+guide}$) have been measured for:

- Rotational speed, n: 1000, 2200, 3000, 5000 rot/min;
- Tensioning force, F: 0.5, 1, 1.5 kN;
- Oil temperature for chain and guide lubrication, t: 90 °C.

· All the tests are repeated 3 times and an average of the results is considered.

Friction torque in bearings, chain and guide ($T_{fbearings+chain+guide}$) has been measured, also, for the two positions of the guide.

4 Results and discussion

By loading the chain with the tensioning force F, the force N pushing on the guide changes. The force N also depends on the position of the guide relative to the chain (see figure 4). Figure 7 presents the measured variation of the force N pushing on the guide depending on the tensioning force of the chain, for the two tested positions of the guide.

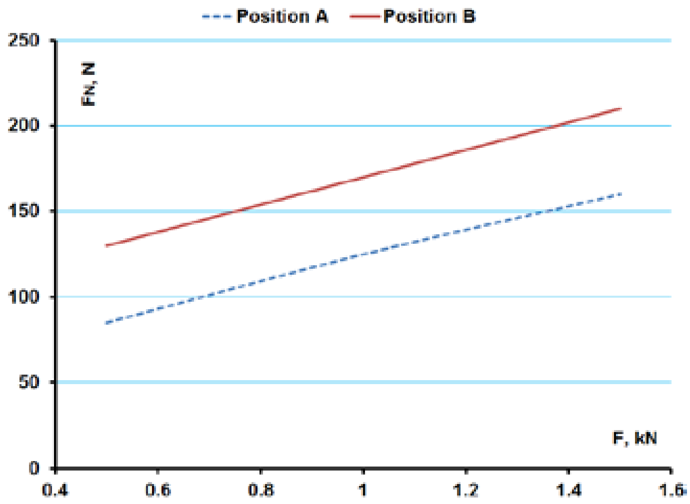
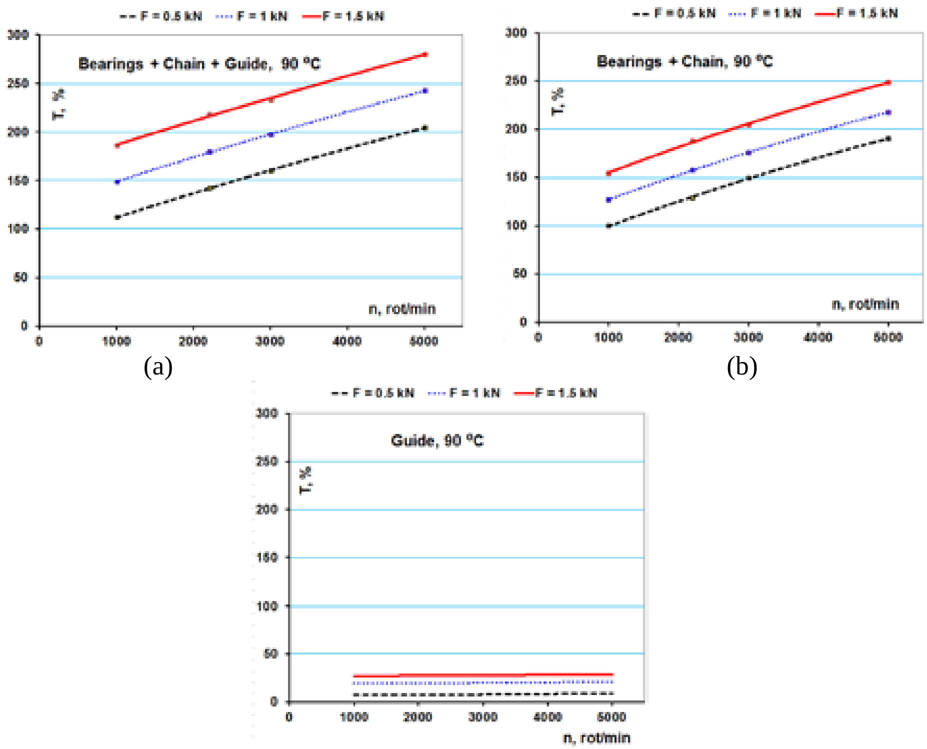


Fig. 7. Force pushing on guide depending on tensioning force on chain

Figure 8 presents the steps of determining the friction in guide as friction torque, for constant lubricating oil temperature of 90 °C. The values of friction torques, presented in figure 8, are calculated as percent of the friction torque from bearings and chain at 1000 rot/min rotational speed and 0.5 kN tensioning force (see figure 8, b). Guide friction (see figure 8, c) is obtained by subtracting friction in bearings and chain (see figure 8, b) from friction in bearings, chain and guide (see figure 8, a). It can be seen that friction in the guide is almost constant with rotational speed, at constant tensioning and it is a very small amount compared with global friction (bearings, chain and guide friction together).

In this case, the minimum guide friction contribution on the global (bearings, chain and guide) friction is approximately 6.5%, for maximum rotational speed (n = 5000 rot/min) and minimum tensioning force (F = 0.5 kN).



(c)

Fig. 8. Steps for determining friction torque in guide

The maximum guide friction contribution on the global (bearings, chain and guide) friction is approximately 14%, for minimum rotational speed (n = 1000 rot/min) and maximum tensioning force (F = 1.5 kN).

Friction in bearings will not be considered in the further analysis since chain and guide transmissions can work with different bearings depending on applications. Only guide friction and chain friction are compared in the following analyse.

Figure 9 presents friction in guide, measured as torque, in percent of the minimum torque value, obtained at n = 1000 rot/min and F = 0.5 kN, for position A of the guide. Guide friction is presented depending on rotational speed, for three steps of tensioning and for the two positions of the guide.

The diagram shows almost constant guide friction with rotational speed, in both cases of guide positions (A and B). This can be explained by the influence of centrifugal force which slightly increases the pushing of the guide.

For constant tensioning of the chain, guide position B determines bigger guide friction than guide position A. The bigger differences (approximately 50%) appear for lower tensioning and the difference reduces with increase of tensioning. For smaller rotational speed the differences are bigger.

The guide friction increases almost directly with the loading force. For guide position A, guide friction gets 270 – 295% higher, for 3 time increases of loading force. For guide position B, loading force influence is smaller and guide friction gets 210 – 220% higher, for 3 time increases of loading force.

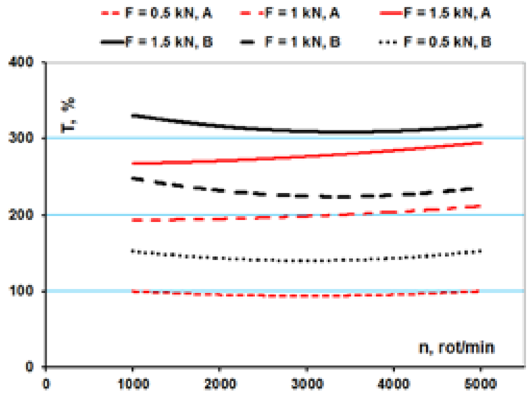


Fig. 9. Guide friction depending on rotational speed, for constant levels of tensioning force and guide position

Figure 10 presents the contribution of guide and chain friction on a chain transmission with guide, excluding bearing friction, for different rotational speed and three levels of loading force, for the two positions of the guide and for 90 °C oil temperature.

The influence of rotational speed on guide and chain friction contribution is very small, as seen in all the diagrams from figure 10.

For constant tensioning of the chain, guide position B determines bigger guide friction than guide position A. Since the chain friction is the same, the same differences seen in the diagram from figure 9 could be noticed. Guide friction contribution is about 50% bigger in case of position B, for F = 0.5 kN, 13-22% bigger for F = 1 kN and 10-24% bigger for F = 1.5 kN. The difference reduces with increase of rotational speed.

Guide friction contribution is decreasing with increase of loading force. In the case of guide position A, an increase of loading force from 0.5 kN to 1.5 kN determines a decrease of guide friction contribution from 30 – 31% to 25.5 – 26.5%. In the case of guide position B, an increase of loading force from 0.5 kN to 1.5 kN determines a decrease of guide friction contribution from 44 – 48% to 29 – 31.5%.

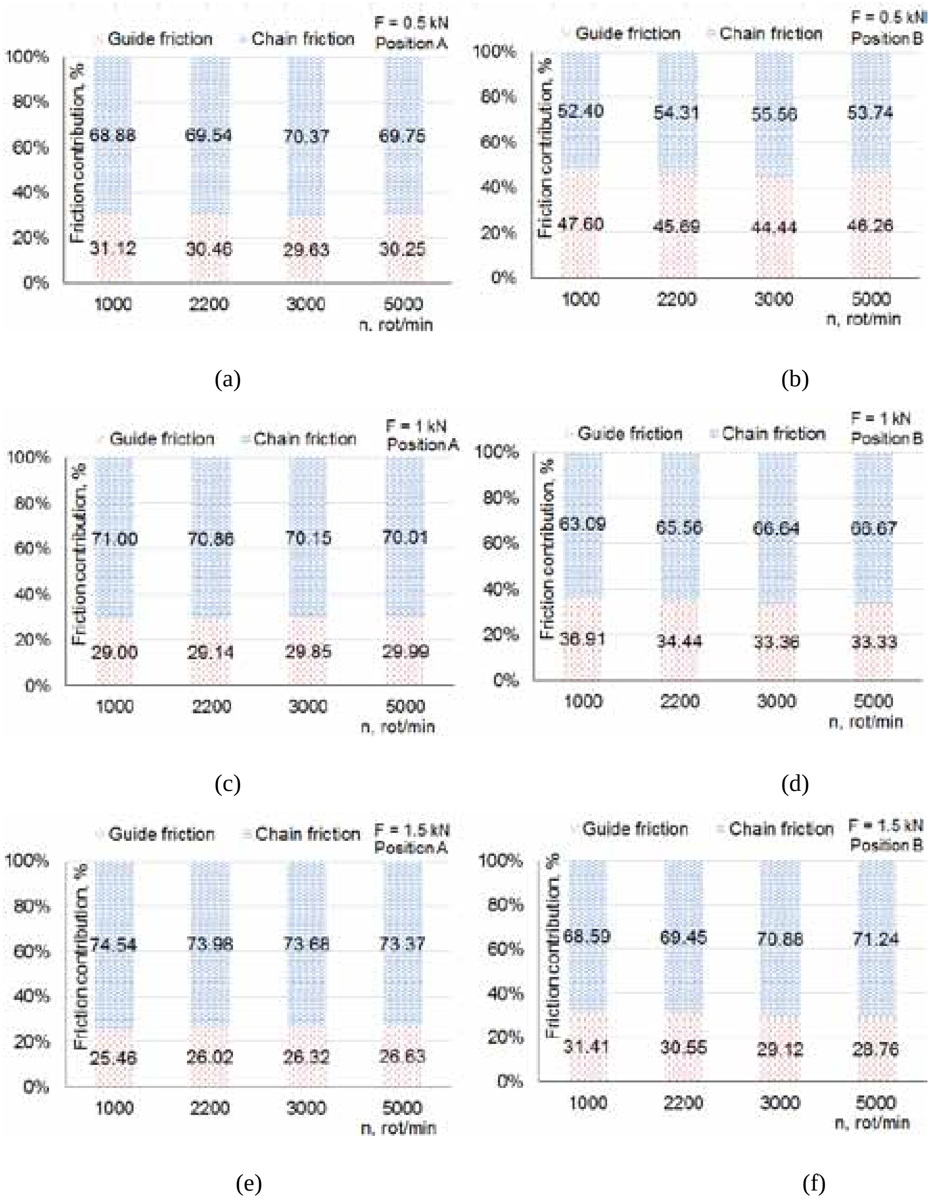


Fig. 10. Guide friction vs. chain friction contribution depending on rotational speed, for constant levels of tensioning force, for two positions of the guide, at 90 °C lubricating oil temperature

5 Conclusion

The results presented in this paper show that, even if the guide friction may be less than half of the chain friction, it is still an important aspect to be studied for diminishing power losses and improving mechanical efficiency of chain drives. Influences from rotational speed, guide position and loading, presented in this paper, are giving a good start for finding measures of improvement. Further research should focus on temperature influence, different chains and different guide materials.

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