Experimental study on guide friction contribution in global power loss of a tooth chain transmission

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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 the contribution of chain-guide friction on the global friction of a basic tooth chain transmission. The measurements have been made on a chain friction rig, testing a basic tooth chain transmission with transmission ratio equal to 1, with a controlled tensioning device. The following parameters can be adjusted and measured: rotational speed, tensioning force in the chain, position of the guide, temperature and pressure of the oil used for lubrication. Friction torque at the input shaft is a sum of friction torques coming from bearings, chain and guide. The paper presents the contribution of the guide in the power loss by friction, as percent of the power loss from friction in chain and guide together. Influences of speed, tensioning force and oil temperature are presented.

1. Introduction
One of the first steps in the research for diminishing the friction of automobile engine is the correct evaluation of friction and the influences that really matter. 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, guide and bearings on global friction losses in the timing chain drive of an engine is presented in [5]. The testing rig is based on a full engine equipped in order to measure separate friction in bearings, chain and the two guides. The results are not showing the influences of tensioning, rotational speed and temperature.

Theoretical approaches on the friction in chain drive system, like [6], needs values of friction coefficients in the links. A correct evaluation of friction depends on the influence of different variables on friction coefficients. Influence of pressure, speed and temperature, with and without lubrication, on the friction between chain plates and guide materials are presented in [7, 8]. The conditions of testing are slightly different than in the real case. This paper presents only experimental results on friction in chain drives, which can be compared with results of theoretical approaches.

This paper is proposing a procedure for determination of the separate friction in the chain and in the guide of a basic chain transmission (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 (chain + guide) power losses.

The research developed at Transilvania University of Brasov is using the friction chain rig presented in [9] with the functional diagram from figure 1. It 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. The measured input torque (T) is a sum of the friction torques from: input bearing box $T_{fbearing1}$, output bearing box $T_{fbearing2}$ and from the chain $T_{fchain}$. Friction in the chain is calculated by subtracting the bearing boxes friction from the measured input torque [9]. The procedure for measuring bearing boxes friction is presented in [10] and the measured bearing boxes friction depending on speed, tensioning and oil temperature is presented in [11].

![Figure 1. Functional diagram of the chain friction rig.](image1)

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.

![Figure 2. Guide friction device.](image2)
The guide friction device consists of: 1 – main board for attachment on the rig; 2 – block containing the elements for adjustment and measure the pushing of the guide; 3 – base plate; 4 – tensioning spring; 5 – force sensors; 6 – guide link on the base plate; 7 – articulated guide; 8 – plunger for pushing the guide; 9 – translational bearing.

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

![Figure 3. Chain friction rig with guide friction device.](image)

The components of the chain friction rig equipped for guide friction measurements are: 1 – input bearing box; 2 – oil circuit for bearings lubrication; 3 – oil circuit for chain and guide lubrication; 4 – separate spraying oil circuits for chain and guide; 5 – output chain sprocket; 6 – output bearing box; 7 – slider, support of output bearing box; 8 – output shaft; 9 – chain; 10 – guide friction device; 11 – input shaft; 12 – input chain sprocket.

3. Measurement procedure

3.1. Testing parts and specifications

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

The guide is made of PA66, circular shape with radius of 200 mm in contact with the chain. The guide is placed so that the chain has a 9.5 mm deviation from the initial line.

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, tensioning and oil temperature ($T_{\text{bearing}} = T_{\text{bearing1}} + T_{\text{bearing2}}$). The measurements are made for the two bearing boxes mounted together, as presented in [9, 10].

- Measurements of friction in chain and bearings together (see figure 1) as input torque depending on speed, tensioning and oil temperature ($T_{\text{bearing+chain}} = T_{\text{bearing}} + T_{\text{chain}}$), without the guide friction device. Friction in the chain is calculated as $T_{\text{chain}} = T_{\text{bearing+chain}} - T_{\text{bearing}}$.

- Measurements of friction in chain, bearings and guide, together (see figure 1) as input torque depending on speed, tensioning and oil temperature ($T_{\text{bearing+chain+guide}} = T_{\text{bearing}} + T_{\text{chain}} + T_{\text{guide}}$), with the guide friction device. Friction in the guide is calculated as $T_{\text{guide}} = T_{\text{bearing+chain+guide}} - T_{\text{bearing+chain}}$. 
3.3. Testing program
The testing program is consisted of steps with constant controlled parameters (rotational speed, tensioning force and oil temperature). The first step is usually longer since it must check and adjust the oil temperature and also stabilize the temperature distribution on all the elements of the rig. The time for each step is minimum 250 seconds. The role of these steps is to stabilize the system and create the steady state conditions. The readings that count in evaluation of bearing friction are only the one of the steady state period [10].

Friction torques (\(T_{\text{bearing}}\), \(T_{\text{bearing+chain}}\), \(T_{\text{bearing+chain+guide}}\)) 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, \(t\): 40, 90 °C. All the tests are repeated 3 times and an average of the results is considered.

3.4. Oil measurements
The oil used in bearing lubrication is Castrol Edge 5W30 and the measured viscosity depending on temperature [10] is presented in figure 4, showing important decrease with increase of temperature, especially at lower temperatures.

![Figure 4. Kinematic viscosity versus temperature.](image)

4. Results and discussion
By loading the chain with the tensioning force \(F\), the force \(F_n\) pushing on the guide changes. Figure 5 presents the variation of the force pushing on the guide depending on the tensioning force of the chain.

![Figure 5. Force on guide depending on tensioning force on chain.](image)

Figure 6 presents the steps of determining the friction in guide as friction torque, for constant lubricating oil temperature of 40 °C. The values of friction torques, presented in figure 6, are calculated as percent of the friction torque from bearings and chain at 1000 rot/min rotational speed and \(F = 0.5\) kN tensioning force (see figure 6b). Guide friction (see figure 6c) is obtained by
subtracting friction in bearings and chain (see figure 6, b) from friction in bearings, chain and guide (see figure 6a). 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).

Figure 6. Steps for determining friction torque in guide: (a) sum of friction torque in bearings, chain and guide; (b) sum of friction torque in bearings and chain; (c) friction torque in the guide resulted as subtraction of (b) from (a).

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).

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 7 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. Guide friction is presented depending on rotational speed, for three steps of tensioning and for two values of lubricating oil temperature.

Both diagrams show a slightly increase of guide friction with rotational speed. This can be explained by the influence of centrifugal force which slightly increases the pushing of the guide.

The guide friction increases almost directly with the loading force. For smaller oil temperature (40 °C), guide friction increases with 220 – 230%, for 3 time increase of loading force. For higher oil...
temperature (90 °C), loading force influence is bigger and guide friction increases with 350 – 380% higher, for 3 time increase of loading force.

Figure 8 presents the contribution of guide and chain friction on a chain transmission with guide, excluding bearing friction, for different rotational speed and two levels of loading force, for 40 °C oil temperature.

Figure 7. Guide friction depending on rotational speed, for constant levels of tensioning force and for 40 °C (a) and 90 °C (b) oil temperature.

Figure 8. Guide friction vs. chain friction contribution depending on rotational speed at 40 °C lubricating oil temperature and for constant levels of tensioning force (a) F = 1kN and (b) F = 1.5 kN.

Figure 9 presents the contribution of guide and chain friction on a chain transmission with guide, excluding bearing friction, for different rotational speed and two levels of loading force, 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 figures 8 and 9.

Guide friction contribution is decreasing with increase of loading force. In the case of smaller temperature (40 °C), an increase of loading force from 1 kN to 1.5 kN determines a decrease of guide friction contribution from 30 – 32% to 27 – 28.5%. In the case of higher temperature (90 °C), for an increase of loading force from 1 kN to 1.5 kN determines a decrease of guide friction contribution from 29 – 30% to 25.5 – 26.5%.

Guide friction contribution is slightly decreasing with increasing temperature.
Figure 9. Guide friction vs. chain friction contribution depending on rotational speed at 90 °C lubricating oil temperature and for constant levels of tensioning force (a) F = 1 kN and (b) F = 1.5 kN.

5. Conclusion
The results presented in this paper show that, in the case of chain drives, even if the guide friction is only half of the chain friction, it is still an important aspect to be studied for diminishing power losses and improving mechanical efficiency. Influences from loading and lubrication, presented in this paper, are giving a good start for measures of improvement. Further research should focus on different chains, different geometry of the guide, different materials and different positions of the guide.

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