EXPERIMENTAL STUDY OF FRICTION BETWEEN AN ALUMINUM PULLEY AND A RUBBER STRIP

Manolache-Rusu Ioan-Cozmin[1], Muscă Ilie[1], Glovnea Marilena[1], Varareanu Stroici Elena[1]

[1] *„Ştefan cel Mare" University of Suceava, 13 University Street, 720229, Suceava, Romania,*
cozmin.manolache@usm.ro

Abstract: Wide strips are widely used in industrial transport equipment for torque and rotation movements' transmission at important distances. This transmission mode involves the use of two or more pulley and a pre-tensioned elastic element - the strip. Although the operation of these transmissions depends exclusively on the friction between the pulley and the strip, the physical phenomenon that takes place is one more complex, which requires a good understanding. This paper aims to study the slipping angle and the friction coefficient between a wide rubber strip and an aluminum pulley. For the study of these transmission parameters three experimental static measurements were made. A good agreement between the experimental values of the friction coefficient and technical literature was found.

Keywords: *locking angle, slipping angle, transmission belts, wide band, friction coefficient*

1. Introduction

Belts transmissions are found in most areas of industry, being used to transfer the rotational movement and the torque from the engine shaft to the working machine. The operation principle of this transmission consists on a friction force occurrence at interface area between the belt and pulley. A particularity of this mechanical transmission with friction is that during operation, an elastic slip occurs between the belt and the pulley. This phenomenon leads to a different transmission ratio from the geometric one. Elastic belt slip occurs due to different stress values that appear in the two sides of the belt transmission during operation.

The use of these transmissions is widespread because it allows torque transmission at important distances between the axes and also ensuring protection against overloads. Also, the assembly of this type of transmission is made without special demands, and the production and maintenance costs are at low level.

The loading capacity of such transmissions is closely related to preloading degree of the elastic element, without exceeding the allowable tensile stress value of the strip.

This paper aims to study the friction phenomenon for wide rubber strip. This material commonly found in the production of mechanical transmissions, ensures high values of the friction coefficient and also a good wear resistance when wearing various textile yarns. Its use allows a better highlighting of the elastic slip phenomenon.

2. Theoretical elements

The performance of the wide belts transmissions are evaluated by a series of parameters like: transmitted power, transmission efficiency, strip peripheral speed, friction coefficient etc. Thus in wide belt transmissions efficiency value can reach up to 0.98% when for operation at low peripheral speeds and powers until 3 MW, [Gafițanu,2002]. The materials commonly used in the manufacture of these wide strips are leather, textiles, rubber, plastics or even steel. According to, [Chișiu,1981], the use of these materials ensures a friction coefficient between 0.45 and 0.8 on a range of peripheral speeds up to 50 m/s.

When fitting the belt over the pulley, between these bodies show`s up a contact zone. This contact area may have different values of the circle arc length described on the pulley. The estimation of the contact area length is made by referring to the center angle and it is called the wrapping angle (β). The wrapping angle may have two distinct areas, depending on the contact particularities between the pulley and the belt. Thus, it was found experimentally that the adherent contact area corresponds only to a certain part of the wrapping angle, [Kim,2011], called the blocking angle (β_b). The Eq. 1 reveals the angle difference that is called elastic slipping angle. (β_a).

$$\beta_a = \beta - \beta_b \qquad (1)$$

For the case when the transmission occurs in dynamic conditions, the law of tension evolution in the belt, [Lubarda, 2014], was established, as in the Eq. (2):

$$T = \rho v^2 + \left(T_1 - \rho v^2\right) \cdot e^{\mu\beta} \qquad (2)$$

where:

T – belt tension on the contact arc length;

T_1 – tension in the tight side;

ρ – wide rubber strip density;

v – wide strip peripheral speed;

μ – friction coefficient.

This study aims to determine in a stationary regime the value of the elastic slipping angle between a wide rubber strip and an aluminum pulley. In these circumstances, is not taking into account the effect of the centrifugal force. It is obtaining in this way a simplified form of the law of tension variation in the rubber band, as in the Eq. (3).

$$T = T_1 \cdot e^{\mu\beta} \qquad (3)$$

3. The experimental device

To carry out the measurements, an experimental device was used, that is shown in Fig. 1.

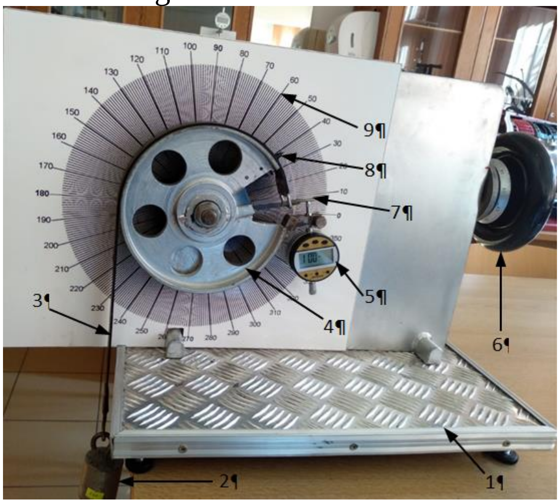

Figure 1 : *Components of the experimental device*

The main components of the device are: the frame (1), the known mass body used in loading (2), rubber wide strip (3), the pulley with cylindrical outer surface (4), digital dial comparator with 0.01 mm accuracy (5), graduated drum (6), elastic lamella (7) and the graduated front panel (9). In order to start measurements, the aluminum pulley is brought to its initial position, so that the indicator (8) indicates the value of 0 degrees on the front panel. In this way, the wrapping angle (β) of the belt over the pulley will be equal to 180 degrees. The rubber strip has two eyelets on the ends. When positioning it over the pulley, one ends must to keep in touch with the elastic lamella. At the opposite end of the strip the loading is performed by known mass body. One end of the elastic lamella is embedded in pulley body. The opposite end of the elastic lamella comes in contact with a digital dial comparator, which will indicate the deformation during the experiments. The digital dial comparator is mounted of a fixed support to the pulley body and positioned in such way that at deformation of the elastic lamella, the contact between these two elements remains firmly. At this point the digital dial comparator will be set to zero value.

4. Experiment presentation

To make measurements it is necessary to rotate the graduated drum in the direction of unfolding the strip off the pulley. The transmission of rotational motion from the graduated drum to the pulley shall be carried out by means of a worm gear. The transmission ratio of this gear, according to the constructive parameters, is 1/29.

The reading of the deformation values of the elastic lamella will take place every half turn of the graduated drum. This reading corresponds to an angle of approximately 6.21 degrees to the pulley. The working mode will be maintained throughout the measurements, except the case when the digital dial comparator displays first deformation value of the elastic lamella. In this case, an additional reading shall be performed in order to accurately express the value of the locking angle. From this moment the value of the wrapping angle is equal to the value of the slipping angle, and the friction force value drop under the value of loading force.

In order to determine the slipping angle and the friction coefficient between the wide rubber strip and the aluminum pulley, three uploads with different loads are made. Three bodies with known masses of 0.74 Kg, 2.08 Kg, and 5.4 Kg, were used in order to achieve three different loads. Wide rubber strip that was used has its own mass of 0.075 Kg.

A simplified loading scheme of the elastic lamella is shown in Fig. 2.

The loading scheme highlights that the elastic lamella is recessed at one end (point A), and at the opposite side the force F is applied, at a imposed distance of (a) from the other end (point C). It is noted that the place on the elastic lamella where the load is applied, namely (point B), differs from the place where the deformation is read with the digital dial comparator (Point C).

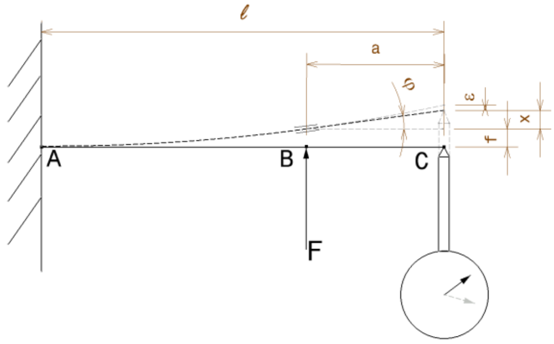

Figure 2 : *Loading scheme of the elastic lamella*

Therefore, the read value is affected by the error (ε). According to the loading scheme, the elastic lamella will deform with the value (f) to the point B and then with an additional value (x) to the Point C. The deformation of the lamella between force application point and the free end is a linear one, which depends only of the tilt angle value of the deformed medium fiber (φ). Mathematically the total value of this deformation at the measuring point can be expressed geometrically with:

$$f_{max} = f_B + |x| \tag{4}$$

The deformation corresponding to B point can be calculated with:

$$f_B = \frac{F}{E \times I_z} \times \left(\frac{a^3}{6} - \frac{l^2 \times a}{2} + \frac{l^3}{3} \right) \tag{5}$$

Also the (x) deformation value is given by loading geometry through the Eq. (6).

$$x = \operatorname{atan}\left[\frac{F}{E \times I_z} \times \left(\frac{a^2}{2} - \frac{l^2}{2} \right) \right] \tag{6}$$

where:

I_z – moment of axial inertia;

F – applied force;

E – Young's modulus.

A final measurement is made for the case when the lamella is in a horizontal position, and there is no contact between the wide strip and the pulley. This is the calibration measurement of the lamella, when the only force that still acts on her is the weight force. Based on this measurement, the elastic constant of the lamella is determined.

4. Results and conclusions

In Fig. 3 a comparison between experimental and theoretical results obtained when loading with mass of 0.74 Kg is presented.

It can be observed that the absolute error is less than the accuracy of the used digital dial comparator. For this reason we consider that the constructive version of the experimental device is well chosen.

The value of the slipping angle (βa) depending on the three load values can be observed in Fig. 4.

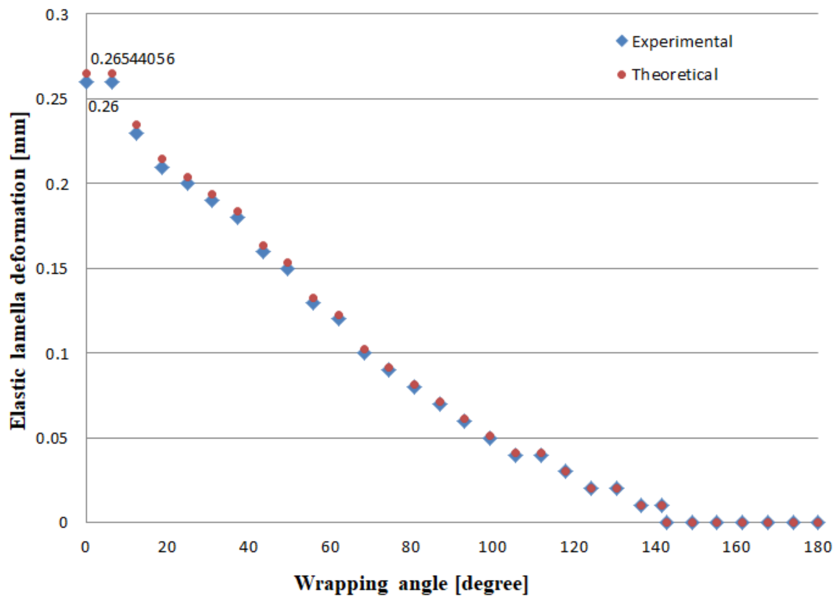

Figure 3 : *Theoretical and experimental deformation values of lamella when loading with mass of 0.74 Kg*

Here is specifying also the value of the frictional force at which the adherent contact area disappears. The locking angle shall be obtained by subtracting these individual values from the initial wrapping angle. It is noted an increase in the slipping angle with the loading.

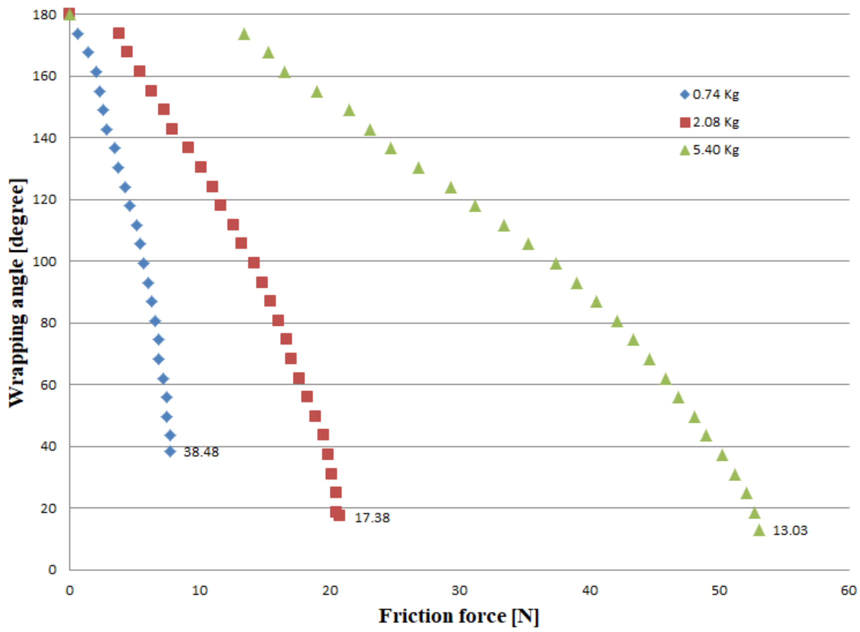

Figure 4 : *Evolution of the slipping angle with the load*

From the obtained values in the cases when loading with masses of 2.8 Kg or 5.4 Kg it can by noticed that the slipping angle has a slow increase at high loading values.

The experimental values obtained for the friction coefficient are plotted in Fig. 5.

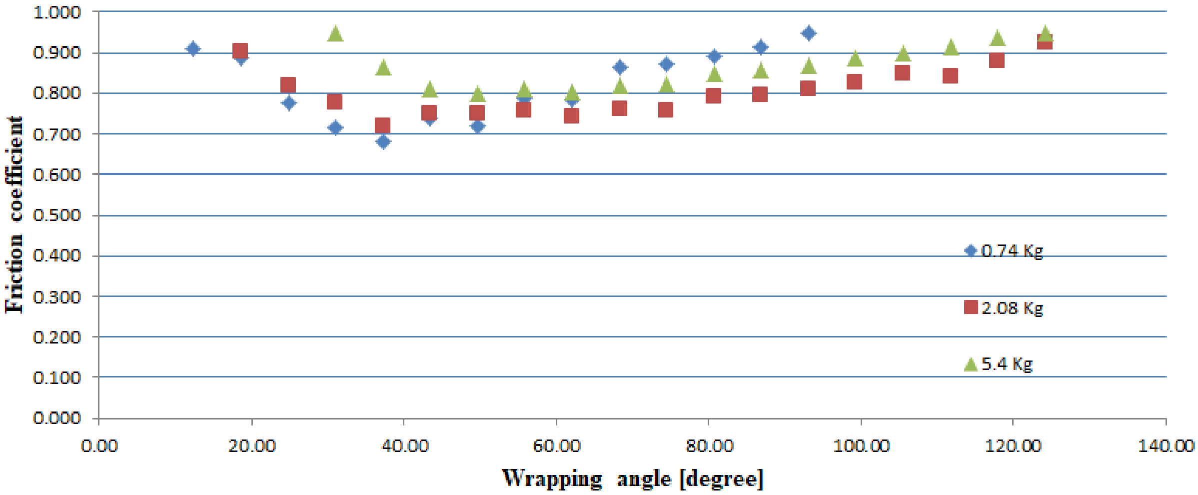

Figure 5 : *Friction coefficient dependence with wrapping angle*

This study shows that at the moment of the initial deformation of the elastic lamella, respectively just before wide rubber strip leaving the contact with the pulley, the values of the friction coefficient are higher. These values may be due to the static friction coefficient on the one hand, respectively to the slip-stick phenomenon that occurs in contact between rubber and aluminum.

It should be noted that the values obtained for the friction coefficient is around 0.8, comparable with those from the technical literature in the field, relating to the contact between the aluminum and rubber, [ADAMS, 2019].

References:

1. [Gafițanu,2002] Gafițanu, M., Bostan, I., et al *Organe de mașini*, Vol. 2, Editura Tehnică, București, 2002.

2. [Chișiu, 1981] Chișiu A.,Matieșan D., et al *Organe de mașini*, Editura Didactică și pedagogică, București, 1981.

3. [Kim,2011] Kim D., Leamy M. and Ferri A., *Dynamic Modeling and Stability Analysis of Flat Belt Drives Using an Elastic/Perfectly Plastic Friction Law*, Journal of Dynamic Systems, Measurement, and Control, ASME, 2011.

4. [Lubarda, 2014] Lubarda V., *Determination of the belt force before the gross slip*, Journal of Mechanism and Machine Theory, Vol. 83, pp. 31-37, 2015.

5. [ADAMS, 2019] MSC.ADAMS MSC. Software, *Material Contact Properties Table*, Available from http://atc.sjf.stuba.sk/files/mechanika_vms_ADAMS/Contact_Table.pdf