Centrifugal effect on shaft’s release of chain transmissions

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Abstract. The general conclusion from the literature on centrifugal effect on chain transmissions is that, a component \( F_c \), equilibrating the centrifugal force \( F_{cf} \), is loading the chain on all its length. The component \( F_c \) is creating a supplementary traction force in the chain and in the same time, it creates a release of the initial tensioning of the transmission. This research on centrifugal effect on the load of chain and belt transmissions has its base on the results that we obtained on measuring the tensioning of a chain drive. The results showed a difference to the theory previously presented. The stiffness of chain, supports and tensioning devices must be considered. The release of the shafts is measured and calculated for several chain transmissions and for different initial tensioning, using the same supports.

1. Introduction

One of the main applications for chain drives is in the timing system of combustion engines, where the running conditions could be considered extreme. The behaviour of the chain drive, under these conditions, must be very carefully analyzed and all the influences must be considered.

The literature [1, 2, 3] presents the theoretical approach on the centrifugal effect on chain drives. It considers that, for rigid chain, a component \( F_c \), balancing the centrifugal force \( F_{cf} \), is loading the chain on all its length and the value of this tensioning force is

\[
F_c = \frac{m}{l} \nu^2,
\]

where \((m/l)\) is the mass of the chain divided by its length (mass per unit of length) and \(\nu\) is the speed of the chain. As it is stated in the literature, the component \( F_c \) is creating a supplementary tensile force in the chain and in the same time, it creates a release of the initial tensioning of the transmission. The literature recommends to consider this effect only for high speed (8…10 m/s [1, 3], or minimum 5 m/s [2]).

The study of the literature revealed a paragraph in [1], with no other reference, presenting the influence of shafts and belt stiffness on the change of the initial tensioning of a permanent tensioned belt transmission. It states that the theory is only valid in the case of transmissions with constant centre distance and in the case of other tensioning systems the belt could be considered “absolutely rigid” and the theory previously presented should apply. The same reference [1] shows that the recommendations from standards for initial tensioning are sometimes opposite with the theory.

Our research on centrifugal effect on the load of chain transmissions has its base on the results that we obtained on measuring the tensioning of a chain drive. The results showed a difference to the theory previously presented. The stiffness of supports and tensioning devices [4, 5] must be considered.
Theoretical evaluation that we developed on the centrifugal effect on belts and chain transmissions, considering the influence of the stiffness of the components is presented in [6].

This paper presents the experimental research on centrifugal effect on shaft’s release of a chain transmission, with a comparison to the theoretical approach presented in [6].

2. Deformation and stiffness of the chain drive components

For a chain transmission with permanent tensioning, generated by elastic deformations of the components, performed by increasing the centre distance during mounting, figure 1 presents three distinct stages of the deformations:

- Stage I (see figure 1, a) presents the initial no tensioning phase when the centre distance is $A$;
- Stage II (see figure 1, b) corresponds to the initial tensioning of the transmission. The lower shaft $S_1$ is considered blocked and the upper shaft is displaced with a distance equal with the sum of the initial deformations of the components: $\delta_{0S1}$ and $\delta_{0S2}$ (deformations of the shafts 1 and 2) and $\delta_{0C}$ (deformation of the chain on both arms);
- Stage III (see figure 1, c) presents the deformations of the components coming from the centrifugal effect on the chain: releasing the supports, with $\delta_S$ and $\delta_{C2}$; supplementary tensioning of the chain, with $\delta_{C}$ supplementary enlargement.

The sum of releasing deformations of the two supports $\delta_S$ must be equal with the supplementary enlargement of the chain:

$$\delta_S = \delta_{S1} + \delta_{S2} = \delta_{C}. \quad (2)$$

![Figure 1. Stages of deformations of a chain transmission.](image)

The stiffness of the chain drive components has an important role in establishing the deformations of the components and the centrifugal effect on the loads of the chain transmission.

For the experiments on the centrifugal effect on shaft’s release of chain transmissions, we used the chain rig presented in figure 2 [7]. The torque is transmitted from the engine to the driving sprocket through a torquemeter. The chain is mounted between the driving sprocket from the lower bearings 1 and the driven sprocket from the upper bearings 2. The upper bearing box is assembled on a sliding carriage which allows vertical displacement of the driven sprocket, ensuring the tensioning force. A rotating nut attached to an electric engine controlling axial displacement of a screw accomplishes the self-adjusting tensioning control. The screw is connected to the upper bearing box sliding carriage by a force sensor. Testing rig devices and sensors control the input shaft rotational speed and the tensioning force.

There are two options for the control of chain tensioning:

- Automatic control – which permanently keeps the tensioning at a pre-set value. The rotating nut is acting in order to adjust the tensioning;
- Blocked – when the nut is blocked but the measurement of tensioning is on.

For our measurements we used the following pairs of chains and sprockets [8]:

- Bush chain with 8 mm pitch, B8, with 64 links, two sprockets with 23 teeth – each open arm of the chain has 20.5 links;
• Bush chain with 8 mm pitch, B8, with 110 links, two sprockets with 23 teeth – each open arm of the chain has 43.5 links;
• Bush chain with 8 mm pitch, B8, with 110 links, two sprockets with 28 teeth – each open arm of the chain has 41 links.

The stiffness of the chain \( c_C \) results from measuring its deformation depending on the load. The stiffness of the tested chains/sprockets depending on tensioning is presented in figure 3. The stiffness of B8, 64 links, 23 teeth is double the stiffness of B8, 110 links, 28 teeth. The stiffness of the chain is as smaller as the number of links is higher. As it can be seen, the stiffness increases with tensioning.

In order to determine the stiffness of the supports, several measurements and calculations have been performed.
Figure 4, a presents the case of measuring the deformation at the level of the sprocket on the output (upper) shaft, subject of tensioning with automatic tensioning (pulling up the screw attached to the upper bearing box). In this case the measured deformation $\delta_{S_1+S_2+C}$ is the sum of deformations of the lower and upper shafts and of the chain.

![Figure 4](image1.png)

**Figure 4.** Measurements of deformations depending on tensioning.

The calculated stiffness $c = \frac{dF}{d\delta}$ is the stiffness of the lower and upper shafts and of the chain together (springs mounted in series):

$$c_{S_1+S_2+C} = \frac{c_{S_1+S_2}c_C}{c_C + c_{S_1+S_2}}$$  \hspace{1cm} (3)

With known stiffness of the chain, the stiffness of the two shafts together results as

$$c_{S_1+S_2} = \frac{c_{S_1+S_2}c_C}{c_C - c_{S_1+S_2+C}}$$  \hspace{1cm} (4)

Figure 5 presents the calculated stiffness of the two shafts resulted from the measured stiffness of shafts and chain together and known stiffness of the B8 chain, 64 links, 23 teeth sprockets.

The stiffness of the tensioning system $c_{S_3}$ must also be considered in determining the stiffness of the supports, together with the stiffness of the two shafts. It is determined by measuring the deformation at the level of the sprocket on the output (upper) shaft (see figure 4, b), subject of tensioning by pulling down the upper bearing box with blocked nut. In this case the measured deformation is $\delta_{S_3}$ – the deformation of the tensioning system (screw, force sensor and plate attached to the upper bearing).

The total stiffness of the supports (tensioning system and the two shafts) results as

$$c_S = c_{S_1+S_2+S_3} = \frac{c_{S_1+S_2}c_{S_3}}{c_{S_1+S_2} + c_{S_3}}$$  \hspace{1cm} (5)

Figure 6 presents the calculated stiffness of the tensioning system, of the two shafts and the resulted total stiffness of the supports.
3. Centrifugal force component and shaft’s release force
As a result of the centrifugal effect on the chain passing a sprocket, a centrifugal force component $F_c$ should appear on each arm of the chain [6], calculated with equation (1).

Figure 7 presents the diagrams of the forces acting on the chain and the shafts, during stage II (initial tensioning – figure 4, a, see also figure 1, b) and stage III (initial tensioning + centrifugal effect – figure 4, b, see also figure 1, c).

In the initial tensioning stage, the $2F_0$ force is loading the two shafts and the chain ($F_0$ force on each arm of the chain).

The centrifugal force component $F_c$ resulted from the centrifugal effect must divide in order to perform in the same time [6]: enlargement of the chain with $\delta_c$ and releasing of the two shafts with deflection $\delta_S$. Part of the total component $2F_c$, with the value $2\kappa F_c$, creates a supplementary load on the chain elastic element and the rest $2(1-\kappa)F_c$ determines the releasing of the shafts.
The coefficients indicating how much of the $2F_c$ force goes to the chain tensioning ($\kappa_C$) and how much goes to the shafts releasing ($\kappa_S$) should be calculated with [6]

$$\kappa_C = \kappa = \frac{c_C}{c_S + c_C}, \text{ for chain and}$$

$$\kappa_S = 1 - \kappa = \frac{c_S}{c_S + c_C}, \text{ for shafts.} \quad (6)$$

The release of the shafts is $2\kappa_S F_c$ and the supplementary tensioning of the chain on the whole length is $\kappa_C F_c$.

The resulted coefficients $\kappa_C$ and $\kappa_S$, for the chain rig equipped with chain B8, 64 links, 23 teeth sprockets and with chain B8, 110 links, 28 teeth sprockets are presented in figure 8 depending on tensioning force $F = 2F_0$. The case of B8, 110 links, 23 teeth is close to the case B8, 110 links, 28 teeth.

In order to determine by experiments the release of the shafts under the effect of the centrifugal forces, the following testing procedure was developed:
- The initial tensioning $2F_0$ is established at rest;
- With blocked tensioning system, the rotational speed $n$ is increased in steps of constant values (1000, 3000, 5000 rpm);
- For each constant rotational speed step, the difference between the initial tensioning and the measured value of tensioning represents the release of the shafts $\text{Exp}_2F_c$;
- Procedure repeats for several initial tensioning and different chains and sprockets.

Figures 9, 10 and 11 presents the calculated centrifugal component $2F_c$, the calculated release of shafts $2\kappa_3F_c$ and the experimental results for release of shafts $\text{Exp}_2\kappa_3F_c$.

4. Conclusion
The results of the experiments are relatively close with the theoretical data, proving that the theoretical bases are correct. There is anyway a lack of accuracy both in experimental measurements of forces and in the procedure of establishing the stiffness of components. The presented results shows that in the conditions of relatively stiff chains shaft release could be important at high rotational speed. As smaller is the stiffness of the chain as bigger is the shaft release.
Figure 11. B8, 110 links, 28 teeth sprockets.

5. References

[1] Horovitz B 1971 Transmisii si variatoare prin curele si lanturi (in Romanian) (Bucuresti: Ed. Tehnica)
[2] Niemann G 1975 Machinenelemente. Band. II. (Berlin: Springer Verlag)
[3] Jula A 1989 Organe de masini (in Romanian), vol.2. (Universitatea din Brasov)
[4] Lates, M T, Velicu R and Papuc R 2014 Multiscale modeling of chain-guide contact by using tests and FEM 11th World Congress on Computational Mechanics; 5th European Conference on Computational Mechanics; 6th European Conference on Computational Fluid Dynamics, II – IV pp 1062-1069
[5] Lates M T, Velicu R 2012 Stresses distributions in bush chains MODTECH 2012: New Face of TMCR International Conference ModTech Proceedings vol.I and II pp 505-508
[6] Velicu R, Jurj L and Saulescu R 2017 On the centrifugal effect on the load of chain and belt transmissions ICOME Conference Craiova
[7] Velicu R and Lates M 2015 On the measurement procedure for testing friction in bearing boxes, Annals of the Oradea University, Fascicle of Management and Technological Engineering 14 (24) no. 1 pp 59-64
[8] Schaeffler Group Automotive 2009 Schaeffler Chain Drive Systems Catalogue pp 8-10