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TRIBOLOGICAL STUDY OF GUIDE-CHAIN CONTACT

Radu PAPUC[1], Radu VELICU[2]
[1] Transilvania University of Brasov, radu.papuc@unitbv.ro
[2] Transilvania University of Brasov, rvelicu@unitbv.ro

Abstract—The paper presents the study of tribological contacts between the guide and the links for the main types of chains used in timing mechanism of the combustion engines. In this regard it identifies the geometry defining the contact between guide and the common types of chains. In order to determine the pressure distribution in the contact area guide/links, the methodology of solving the Reynolds equation is proposed for general contacts of this type. The mathematical modeling and numerical solution of Reynolds equation are presented for a specific optimization problem.

Keywords— chain, contact, guide, Reynolds, tribology.

I. INTRODUCTION

CHAINS are flexible kinematic elements consisting of articulated links. The chain drive functioning is based on the engagement of the chain with sprockets. Due to chain engagement on the sprocket, an average constant transmission ratio is achieved. Chain transmissions are preferred when the system demands high torques with constant transmission ratio [1], [2]. Figure 1 presents the components of the main types of chains used in chain drives

The kinematic and dynamic functioning of the chain drives highlights the possibilities of vibrations. There can be mentioned transversal, longitudinal and twist vibrations. Chain functioning in vibration conditions reduces the durability performances due to specific dynamics. From this reason the presence of chain guide on the driven branch of the chain and of a chain guide tensioner on the driving branch is needed. Chain tensioning is also compensating the initial pitch errors and wear effects leading to extension of the length of the chain [1].

This work presents the tribological study of guide - chain contact for the main types of chains used in the timing mechanism of combustion engines. As rotational speed increases the chain – guide contact passes from boundary to mixed and hydrodynamic lubrication. For increased durability of the guide, the design should focus on achieving conditions for hydrodynamic lubrication of the guide - chain contact even for medium rotational speed. Thus it is identified the geometry of the contact with the guide for bolts, bushings, rollers and toothed chains. In order to determine the pressure distribution in the contact area guide/links, the methodology of solving the Reynolds equation [3]-[6] is proposed for general contacts of this type. The mathematical modeling and numerical solution of Reynolds equation are presented for a specific optimization problem.

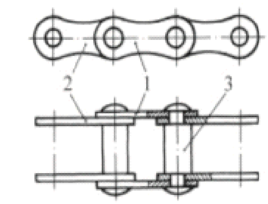
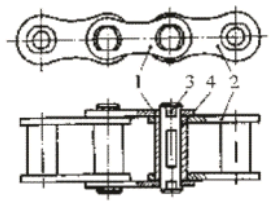
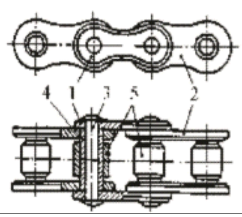
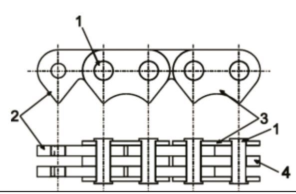
Bolt chain: 1- exterior link plates; 2- interior link plates; 3- bolts	
Bushing chains: 1-exterior link plates; 2-interior link plates; 3-bolts; 4- bushings	
Roller chains: 1-exterior link plates; 2-interior link plates; 3-bolts; 4- bushings; 5-rollers	
Toothed chains: 1-bolts; 2-exterior link plates; 3- sprocket guiding link; 4- interior link plates;	

Fig.1 Chain Types [1]

II. IDENTIFYING THE GUIDE-CHAIN CONTACT TYPE

The guide - chain contact is achieved on several contact areas between several exterior, interior and sprockets guiding links with the guide [7]. Figure 2 presents the simultaneous contact areas between guide and exterior and interior links of a bolts, bushings or rollers chain.

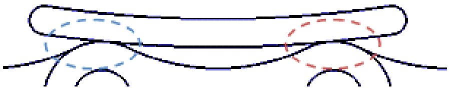


Fig.2 Guide-chain contact areas

Figure 3 presents a general picture with the components of the guide – chain system for the toothed chain drive where three types of links are in contact with the guide.

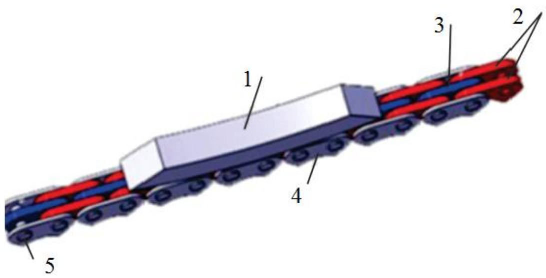


Fig.3 Toothed chain tensioning:
1-tensioning guide; 2- exterior link; 3- interior link; 4- guiding sprockets links

Figure 4 presents the types of tribological guide - chain contact which can be found for bolts, bushings, rollers and toothed chains.

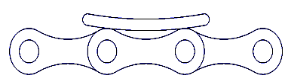
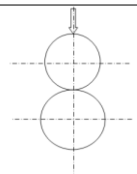
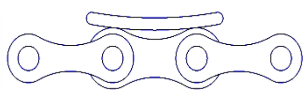
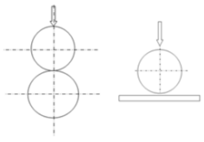
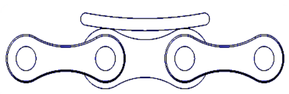
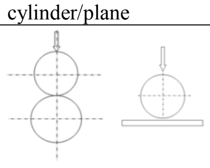
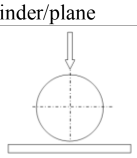
	
Bolts chains (Gall type)/guide	Contact type: cylinder/cylinder
	
Bushings chains / guide	Contact type: cylinder/cylinder or cylinder/plane
	
Rolls chains / guide	Contact type: cylinder/cylinder or cylinder/plane
	
Geared cover plates chains / guide	Contact type: cylinder/plane

Fig.4 Guide-chain contact types

III. Assumptions and Stages of Solving the Reynolds Equation

The general case of tribological contact for guide – chain contact is the cylinder/cylinder case. Figure 5 presents the geometry and functional parameters of the cylinder/cylinder contact applied for guide – chain contact. From the two cylinders of radii R_1 and R_2, cylinder 1 (chain link) is moving with speed U_1 while cylinder 2 is fixed (the guide).

The speed of the chain link is calculated in relationship with the rotational speed n_1 and the pitch diameter D_{d1} of the driving sprocket as:

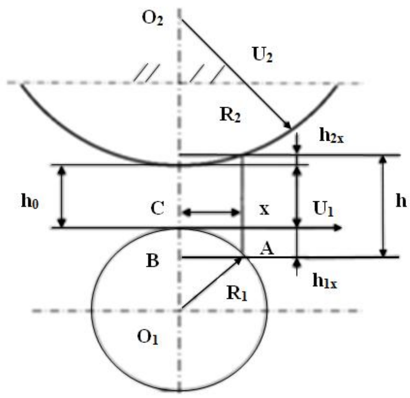


Fig.5 Guide/chain contact

$$\mathbf{U_1 = \frac{\pi}{60} \cdot n_1 \cdot D_{d1}} . \quad (1)$$

The one-dimensional Reynolds equation [5], considering uniform distribution of pressure on the depth of the lubricating film is

$$\mathbf{\frac{dp}{dx} = 12 \cdot \eta \cdot \overline{U} \cdot \frac{h - \overline{h}}{h^3}} \quad (2)$$

where:

η – represents the oil viscosity;

h – represents the lubricant film thickness;

$\overline{h}$ – lubricant film thickness in the point of maximum pressure $x = -\overline{x}((\frac{dp}{dx})_{x=-\overline{x}} = 0)$; Pressure will have a minimum at exiting the narrow space at coordinate $x = -\overline{x} \cdot ((\frac{dp}{dx})_{x=-\overline{x}} = 0)$, where $h = \overline{h}$ [5];

$\overline{U}$ is the medium speed of the lubrication film

$$\mathbf{\overline{U} = \frac{1}{2} \cdot (U_1 + U_2) = \frac{U_1}{2}} . \quad (3)$$

The lubricant film thickness h at the coordinate x is given by the relation:

$$\mathbf{h = h_0 + h_{1x} + h_{2x}} \tag{4}$$

where:

h_0 – minimum lubricating film thickness

h_{1x}, h_{2x} – lubricant film thickness at the coordinate x, approximated with relations:

$$\mathbf{h_{1x} \approx \frac{x^2}{2R_1}} \tag{5}$$

$$\mathbf{h_{1x} \approx \frac{x^2}{2R_2}} \tag{6}$$

For the reduced curvature:

$$\mathbf{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}} \tag{7}$$

Applying (5), (6) and (7) in (4) it becomes:

$$\mathbf{h = h_0 + \frac{x^2}{2R}} \tag{8}$$

The resulted Reynolds equation is

$$\mathbf{\frac{dp}{dx} = \frac{6 \cdot \eta \cdot U_1}{h_0^2}\left[\frac{1}{\left(1+\frac{x^2}{2Rh_0}\right)^2} - \frac{\bar{h}}{h_0\left(1+\frac{x^2}{2Rh_0}\right)^3}\right]} . \tag{9}$$

The following boundary conditions must be used in order to solve equation (9):

- Pressure at exiting the narrow space, is equal to 0, $p(\bar{x}) = 0$;
- Pressure at entering the space $p(-R) = 0$;

Normal load on the contact is

$$\mathbf{F = l\int_{-R}^{\bar{x}} p dx} , \tag{10}$$

where l is the width of the contact.

Equations (9) and (10) form a system from which the results are: pressure distribution p(x) (coordinate $\bar{x}$) and minimum gap of the space h_0.

IV. NUMERICAL COMPUTING OF THE REYNOLDS EQUATION

Table 1 presents the values and range of the parameters used as inputs in determining the pressure distribution for the guide – chain contact, considering the case of a given timing transmission, with variable speeds and variable tensioning. The calculus considers various geometry of guide and chains (different contact radii).

TABLE 1
PARAMETERS AND VALUE RANGE

No.	Parameter	Symbol, value (range)
1	Chain link radius, m	$R_1 = 5 \cdot 10^{-3}..\infty$
2	Guide radius, m	$R_2 = (150...600) \cdot 10^{-3}$
3	Reduced curvature, m	$R_r = (5...600) \cdot 10^{-3}$
4	Dynamic viscosity, Pas	$\eta = 0.150$
5	Pitch diameter of the driving sprocket, m	$D_{d1} = 0.05$
6	Driving sprocket rotational speed, rpm	$n_1 = 500...5000$
7	Chain speed, m/s	$U_1 = 1...10$
8	Guide normal force, N	$F = 10...80$
9	Chain link width, m	$l = 2 \cdot 10^{-3}$

Figure 6 presents the resulted diagram for determining the minimum gap of the space h_0, depending on relative speed, for various normal forces.

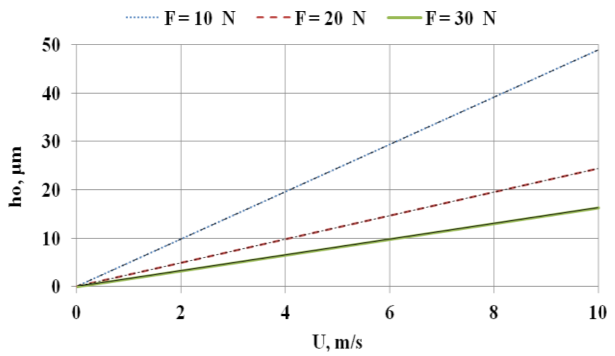


Fig. 6 Minimum gap of the space h_0, depending on relative speed, for various normal forces

Figure 7 presents the resulted diagram for determining the minimum gap of the space h_0, depending on normal forces, for few values of relative speed.

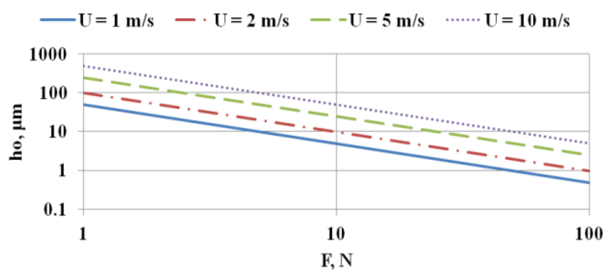


Fig.7 Minimum gap of the space h_0, depending on normal forces, for few values of relative speed

Diagrams from figures 6 and 7 show that the minimum gap of the space is dropping below a minimum gap of at least 5 μm getting to mixed lubrication instead of ideal hydrodynamic lubrication for smaller speeds and higher normal forces. A limitation of normal forces up to 30 N should be achieved.

Figures 8, 9, 10, 11 and 12 shows the pressure distribution for the same relative speed U = 5 m/s, for three values of normal force and several geometry of the contact: smallest radius on the chain link R = 0.03 m (fig. 8); R = 0.05 m (fig. 9); R = 0.2 m (fig. 10); R = 0.4 m (fig. 11); straight face of the chain link and maximum radius of the guide R = 0.6 m (fig. 12).

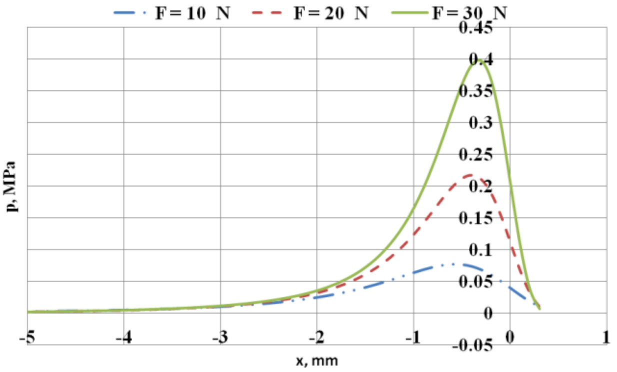


Fig. 8. Pressure distribution for relative speed U = 5 m/s and curvature radius R = 0.03 m

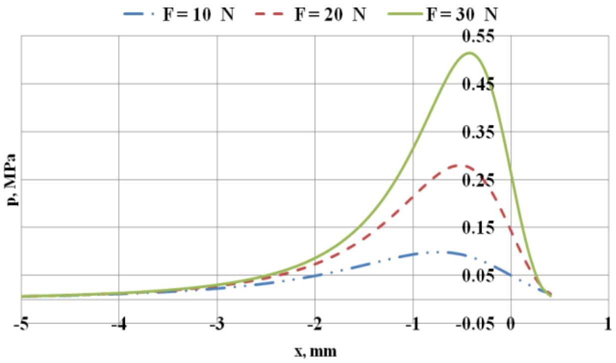


Fig. 9. Pressure distribution for relative speed U = 5 m/s and curvature radius R = 0.05 m

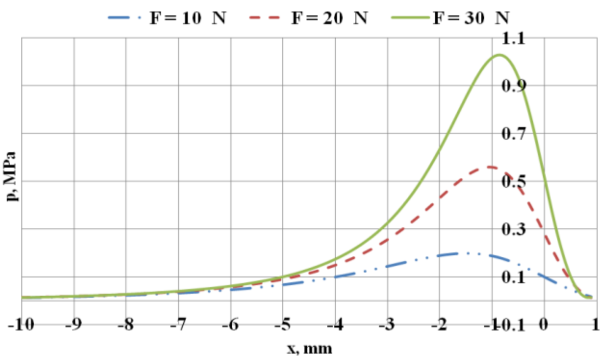


Fig. 10. Pressure distribution for relative speed U = 5 m/s and curvature radius R = 0.2 m

Figures 8-12 show the move of the point of maximum pressure towards the minimum gap point (decrease of $\bar{x}$) with increase of normal load.

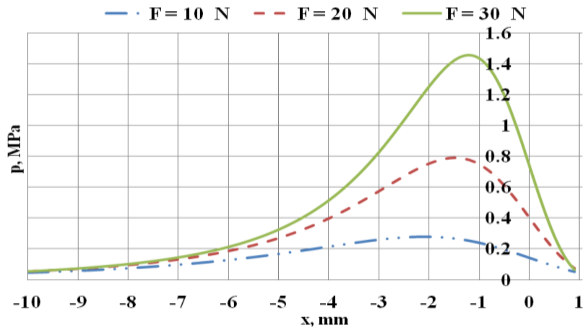


Fig. 11. Pressure distribution for relative speed U = 5 m/s and curvature radius R = 0.4 m

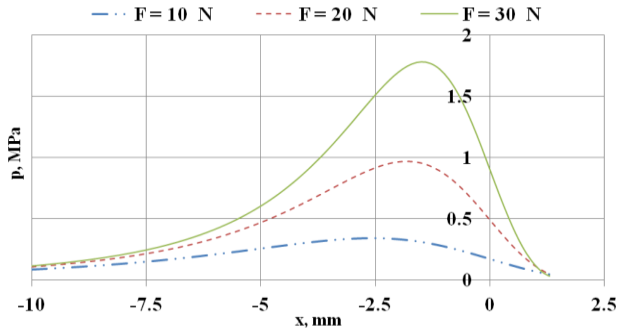


Fig. 12. Pressure distribution for relative speed U = 5 m/s and curvature radius R = 0.6 m

V. CONCLUSION

The results presented in this paper give useful data in understanding the transition between boundary, mixed and hydrodynamic lubrication in the case of guide-chain contact of the timing chain drive of combustion engines. It also gives the data for at least pre-dimensioning of the chain and guide geometry. An analysis based on considering the pressure distribution on the width of the contact (two-dimensional Reynolds equation) should be performed for more accurate data.

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