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INVESTIGATING THE HYDRAULIC TAPPET ROTATION FOR A DIRECT ACTING VALVE TRAIN

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Abstract: *The paper presents the research regarding the rotational movement of a hydraulic tappet from a direct acting valve train system. Firstly the advantages and disadvantages of the tappet rotation during engine functioning are described. Then, a description of the virtual model of the direct acting valve train modeling process is made and the parameters that influence the rotational movement are presented. The results obtained with the virtual model are presented in comparison with the experimental results obtained by other authors. The conclusions revealed that the position of the camshaft, the engine speed and the friction coefficient have a significant influence on the hydraulic tappet rotation.*

Key words: *direct acting valve train, tappet rotation, dynamic analysis, wear.*

1. Introduction

The analysis of the valve train system is very important because it influences the gas exchange process and the engine performance. The main role of this system is to ensure a suitable filling of engine cylinders with gasoline-air mixture for spark ignition engines or with air for compression ignition engine. Also it must ensure a good cylinder sealing during each cycle [1], [7].

Considering those aspects a few types of valve trains were developed. The most common type is the direct acting OHC valve train because it's simple configuration, small number of components and its high stiffness at high engine speeds. The main inconvenience of this type of valve train is due to high friction loses during functioning which entails a massive wear [5], [8], [12], [14].

An analysis of the tappet rotation is important because it is known the fact that friction loses because of the valve train represent almost 21% from entire engine friction loses. So if the tappet rotates the value of the friction loses decrease significant [6], [8-10].

Also the tappet rotation ensures a uniform film of oil between cam and tappet and the contact area is always different determining a uniform wear of tappet surface [11].

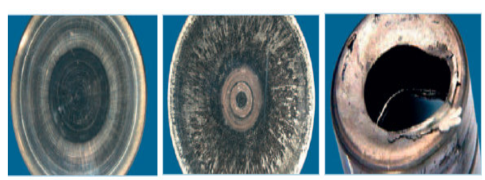

Fig. 1. *Different types of tappet wear* [8]

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As seen in Figure 1, the wear of the tappet is due to the cam contact force. If the tappet doesn't rotate then the cam acts on the same place causing the apparition of an unwanted phenomenon known as pitting. Also surface damages it might appear as a result of abrasive wear. Another unwanted phenomenon is the local welding between cam and tappet due to the lack of lubrication and the thermal stresses [3], [4].

After a literature study, it was concluded that several authors have analyzed tappet rotation on different test bench configuration.

Some of them used optical fiber and phototransistor placed under the tappet for measuring the rotational movement. Others used a dangerous method to measure this motion by placing radioactive marker on tappet surface. The newest method is represented by the using of eddy current sensor placed in front of the tappet surface on which a gap was machined [6].

In all those cases, the numbers of tappet rotation were measured and after that the tappet rotation speed was determined as seen in Figure 12.

Concluding this, we realize that is very important to know how many degrees and in which side tappet rotates. To solve this problem a 3D model of the direct acting valve train was created.

2. Configuration of the Valve Train

If we analyze the direct acting valve train we observe that the main motion of the tappet is the translational movement. But because of the tappet and tappet guide configuration looks like a cylinder, the tappet may have an additional movement: the rotation across its own symmetrical axis [2-4].

To obtain the tappet rotation the cam is placed with a slight offset from the symmetrical axis of the tappet as can be seen in Figure 2.

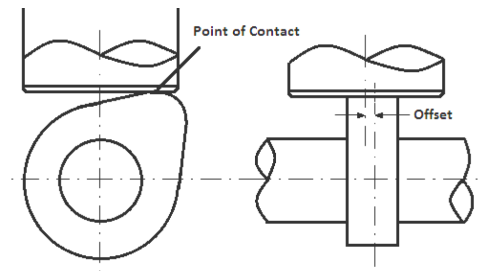

Fig. 2. *Cam/flat-faced tappet contact* [11]

If the tappet is with spherical top surface, see Figure 3, then the cam profile is manufactured with a small angle α for ensure an offset contact and to determine the tappet to rotate.

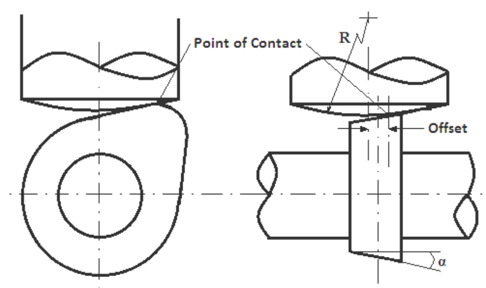

Fig. 3. *Contact between cam and a spherical surface tappet* [11]

Both solutions described above determine sideways movement of the contact zone. This causes a rotational torque to the axis of symmetry of the tappet, which tends to rotate the tappet.

Considering those affirmation we might conclude that the tappet rotation is influenced by the cam/tappet contact force and by the friction coefficient between those two surfaces. Also, the friction between tappet and its guide and the lateral forces that appear during tappet rolling as a result of thermal gap, are to be considered.

Other author reveals that the lubrication film thickness and oil viscosity and temperature, influence significantly the tappet rotation. The tappet rotates faster when oil has a high temperature and its viscosity is low. The same phenomenon happens when the oil pressure increases [6].

3. Virtual Model of the Valve Train

Based on the previous claims a 3D model of the direct acting valve train was created using Virtual Lab Motion software from LMS.

The components dimensions and masses were measured from a SAAB 900 cylinder head. After that the 3D bodies were created using Catia V5R16 software, Figure 4.

The next step was to create the assembly of the valve train using different constrains, joints and contact between components [5].

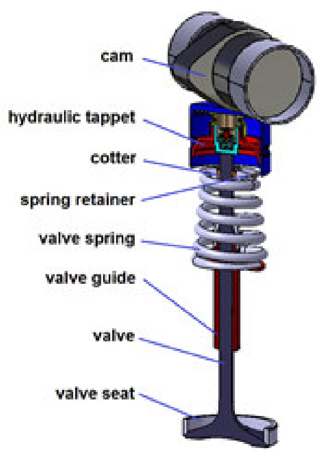

Fig. 4. *Section between 3D models of the direct acting OHC valve train* [2]

In Figure 5 the links between valve train components are presented. As it can be seen the camshaft bearings, valve guide, tappet guide and valve seat are fixed to the ground. Also by a bracket joint the cotters and the spring retainer are fixed tot the valve tip.

The valve and the tappet are connected to theirs guides with a cylindrical joint which allows to them to have a rotational and translational movement.

The contact between cam and tappet, tappet and valve, valve and valve seat is

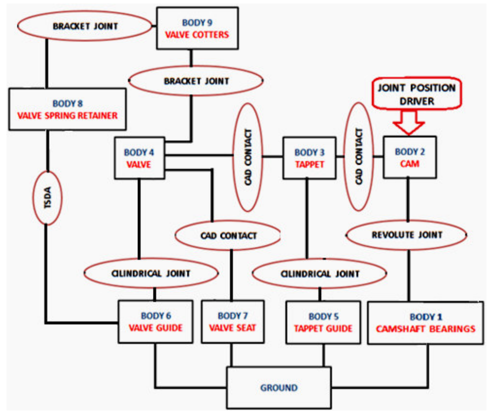

Fig. 5. *Valve train 3D model design* [2]

modeled using CAD Contact element which permits to simulate the contact between rigid bodies with complex geometry.

As seen in Figure 6 the bodies for which the contact is modeled are selected. Then the geometry of each body is tessellated by user specification [13].

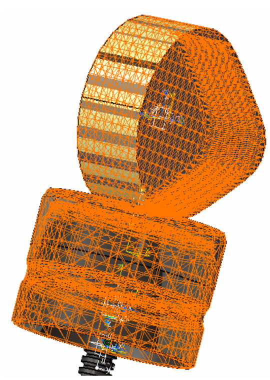

Fig. 6. *The CAD Contact element* [2]

As seen in Figure 7, the contact coefficients like stiffness, damping and friction must be defined. Because this type of contact use the triangle for bodies geometry approximation it might induce vibration in system during analysis if the triangles values are to large or it might increase the calculation time if those values are too small. So compromise had to be found between those inconveniences [13].

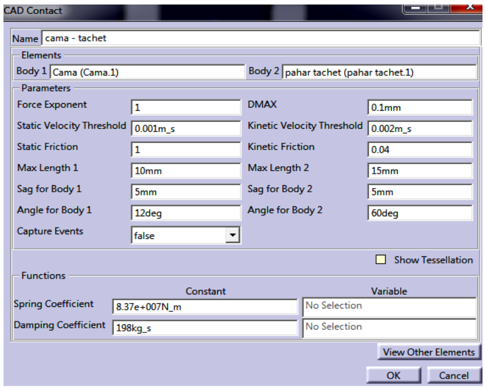

Fig. 7. *Defining the CAD Contact element*

The camshaft is connected to the bearing by a revolution joint on which a joint position driver is applied. The purpose of this joint position driver is to reproduce the camshaft rotational movement for different user speeds.

In the analysis of the tappet rotation the influence of the valve spring is not so important. For this, the valve spring was modeled using a Translational Spring Damper Actuator. This element is defined by the spring free length, stiffness and damping of the valve spring.

Also for a realistic model the friction between moving components was modeled using friction forces defined by friction coefficient.

4. Results

The results were obtained considering three different cam eccentricities: 1.5 mm, 2.5 mm and 3 mm.

The lubrication process was modeled considering two values for the friction coefficient. The first one was set to 0.05 and is representing the case of good lubrication, and the other one it was set to 0.1 which represent a worst lubrication.

All those parameters were monitored as a function of engine speed, in our case camshaft speed. The camshaft rotates with different speeds from 300 rpm to 3600 rpm.

The results obtained at 300 rpm camshaft speed are presented in Figure 8. It might be seen the fact that when the eccentricity value of the cam increases, the tappet rotation has the highest amplitude. But its rotational movement decreases progressively when the friction coefficient value varies from 0.05 to 0.1.

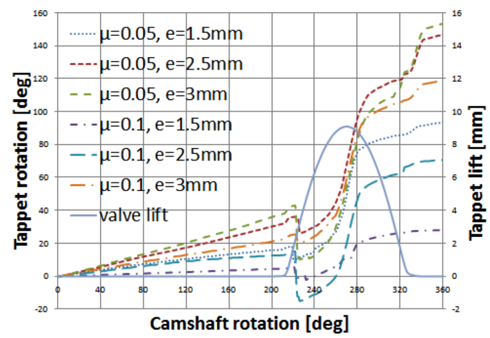

Fig. 8. *Tappet rotation for 300 rpm camshaft speed*

Also in the figure above it can be see that at this speed, when the tappet starts to lift, it tends to rotate in the reverse direction. This phenomenon was registered only at this engine speed and is a result of the cam contact force.

In Figures 9-12 the same evolution of the tappets rotation can be observed when the eccentricity value is increased.

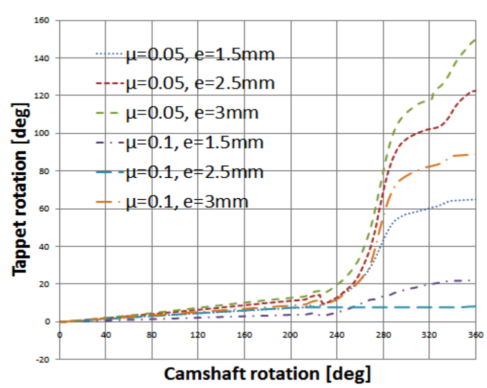

Fig. 9. *Tappet rotation for 900 rpm camshaft speed*

Also when the friction force increase as a result of modifying the friction coefficient from 0.05 to 0.1 the tappet rotation has small amplitude.

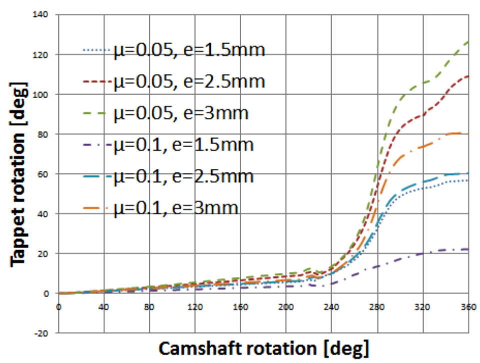

Fig. 10. *Tappet rotation for 1250 rpm camshaft speed*

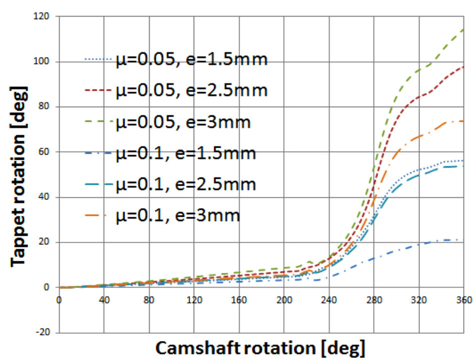

Fig. 11. *Tappet rotation for 1600 rpm camshaft speed*

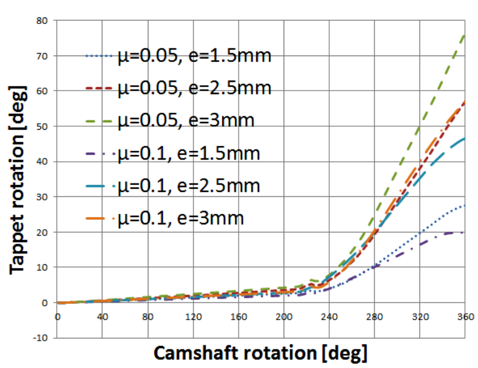

Fig. 12. *Tappet rotation for 3600 rpm camshaft speed*

An interesting phenomenon appears at high engine speed when the amplitude of the tappet rotation decrease significant.

The same fact was noticed by others author in their experimental work and it can be seen in Figure 13 were the tappet rotational speed has an increasing trend until 1500 rpm after which it starts to decrease.

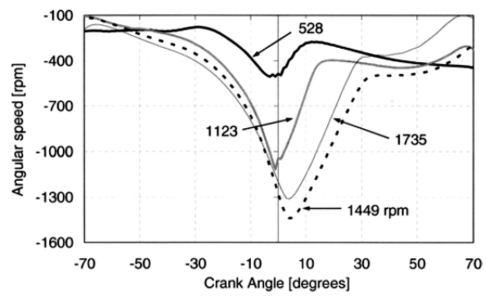

Fig. 13. *Tappet angular speed for different engine* speeds [10]

5. Conclusions

Using Virtual Lab software from LMS a 3D model of the direct acting OHC valve train was developed.

The results obtained with this model have similar values with experimental values obtained on test bench by other authors. So it might be concluded that this model can be used for future researches regarding tappet movement.

The results reveal that a high value of cam eccentricity causes an amplified tappet rotation.

If the lubrication process goes wrong then the friction coefficient increase which determine a reduction of the tappet rotational movement.

Future work should take into account the reaction forces of tappet guide and the lash resulted from thermal expansion.

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