25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0519
EXPERIMENTAL ANALYSIS OF THE INFLUENCE OF LUBRICATING OIL AND FUEL ON THE VIBRATION LEVEL OF CRANKSHAFT SPARK IGNITION ENGINE

Claudio Marcio Santana
Jose Eduardo Mautone Barros
Juan Carlos Horta Gutiérrez
Helder Alves de Almeida
Jorgimara de Oliveira Braga
Federal University of Minas Gerais - Av. Antonio Carlos, 6627, Pampulha, Belo Horizonte – CEP: 31270-901
Claudiowsantana@gmail.com
mautone@demec.ufmg.br
horta@demec.ufmg.br
helder.alves.eng@gmail.com
jmarabraga@hotmail.com

Abstract.

Vibration problems in internal combustion engines produce premature wear on the internal components of the engine, which contributes both to reduce the lifespan of the engine itself as well as cause discomfort to the occupants of the vehicle. Thus, since it is impossible to totally eliminate vibrations from engines, it is important to understand the sources of vibration production and control them to acceptable levels. The general objective of this paper is to measure the vibration in the areas that undergo greater efforts due to the processes of combustion and mechanical forces. These areas are the fixed bearings located to the extremes of the crankshaft. The specified objective of this study is to correlate these levels of crankshaft engine vibration relative to the fuel used, ethanol and gasoline, and assess the influence of lubricant oils on the vibration levels as a function of the viscosity of the lubricant. The results demonstrated that the vibration intensity of the engine increases with increasing engine speed and load. In all operating conditions, the ethanol-run engine has higher vibration intensities than the gasoline-run engine. For the same type of fuel, an oil of higher viscosity attenuates the level of vibration of the engine. Measurements show an average increase of 18% of transverse vibration and 12% of longitudinal vibration in the crankshaft of the engine running on ethanol in relation to gasoline with low viscosity lubricant and 14% and 10% with higher viscosity lubricant.

Keywords: *Internal combustion engine, longitudinal crankshaft vibration, transversal crankshaft vibration, ethanol engine vibration, gasoline engine vibration.*

1. INTRODUCTION

Internal combustion engines are classified according to the burning mode of the fuel in both spark-ignition and compression-ignition engines. Both gasoline and ethanol-powered engines are examples of spark-ignited engines. Thus, the firing of the fuel is initiated with a spark provided by the spark plug (Heywood, 2003). Diesel engines typically run on diesel oil or a blend of diesel and biodiesel. The combustion in these engines occurs spontaneously, due to the air-fuel mixture under high pressures and temperatures inside the cylinder (Taylor, 1990). Viscosity is the main property of automotive lubricant oils for internal combustion engines and it also indicates the degree of resistance a lubricant oil allows on two surfaces in relative motion. Lubricant oils undergo changes in their viscosity when subjected to temperature variation and load and these variations can be very different depending on each type of lubricant oils. The SAE nomenclature with two numerical viscosity values indicates that this lubricant is multi-viscous and is suitable for engines operating at high temperature gradients, for example SAE 10W30, SAE 20W50 and SAE 5W30 (Haycock et al., 2004). The viscosity index is a numerical value indicating the viscosity change with respect to temperature variation and load. The higher the value of the viscosity index of a lubricant, lower is the variation of the viscosity with increasing temperature (SAE International Surface Vehicle Standard, 2013). Today's automotive lubricant oils have a high viscosity index, which allows a quick start in cold temperatures, immediate lubrication at the highest points in the engine when starting, lower oil consumption and efficient lubrication at high temperatures. In general, oils with lower viscosities present better pumping, better cold start, fuel economy and better engine cooling. Oils with higher viscosity have greater protection against wear, better oil film protection and lower oil consumption (Haycock et al., 2004). The engine, due to its constructive and functional characteristics, is the main source of vibration of a vehicle because it is through the engine that the vibrations and noises are transmitted to the body, and consequently felt by the occupants of the car (Gillespie, 1992). The vibrations from the engine can be divided into vibrations due to the combustion process, vibrations due to mechanical forces, vibrations due to air flow and combustion gases through the inlet and discharge manifolds. Vibration is generated due to the combustion of the fuel-air mixture inside the combustion chamber triggered by the addition of heat in each of the cylinders (Wang, 2010). The type of fuel used will influence directly by establishing particular characteristics to this kind of vibration. This feature will influence the vibration level in both ethanol and gasoline-run engines. Another factor related to the combustion process, which directly influences the vibration level of engines, is the compression ratio. The most important contributions of the mechanical forces are due to the lateral movements of the pistons, movement of the crankshaft relative to the bearings, movement of the intake and discharge valves and engine design parameters (Chandratre et al., 2015).

2. EXPERIMENTAL PROCEDURE

The experimental procedure involved the instrumentation of the engine with two tri axis accelerometers in order to measure the level of vibration in specific points of the engine, besides the employment of testing procedures and the analysis of the experiment data. A hydraulic dynamometer, passive FE model 150s, was used in order to measure force, torque absorption, engine generated power and engine speed. So as to acquire the vibration signal an LMS Test Lab Software by SIEMENS was used. Two tri-axial accelerometers installed on the 1° and 5° fixed bearings of the crankshaft were used in order to acquire data on both transverse and longitudinal displacements of the crankshaft. It was necessary to remove the oil sump to get access to the bearings in order to install the accelerometers**.** Two holes were bored in the oil sump itself in order to allow for the acquisition of data from the accelerometers. In order to avoid oil leakage (through the holes mentioned previously) while the engine was operating, a high-performance silicone paste was used to seal the flange. The Figure 1 shows the installation of the accelerometers on both sides of the bearings fixed of the crankshaft. The accelerometers used for testing were a piezoelectric accelerometer model Kistler K Shear 8704B100.

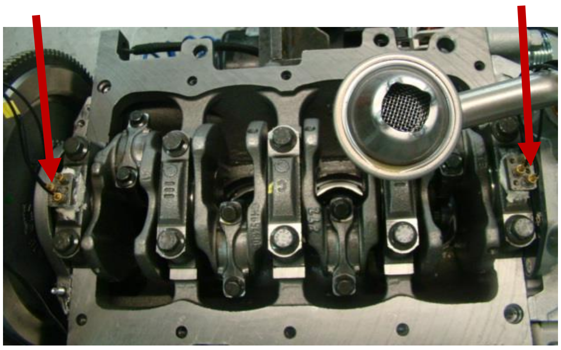

Figure 1 - Installation of the accelerometers in 1° and 5° fixed bearings of the crankshaft.

The Figure 2 shows the orientation of the accelerometers on bearing to measuring the crankshaft vibration. The direction (Y) represents the longitudinal vibration in the crankshaft and (X, Z) represents the transversal vibration in the crankshaft.

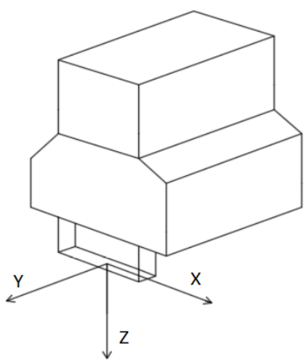

Figure 2 - Orientation of the accelerometers on bearing to measuring the crankshaft vibration.

The tests were carried out on a four-cylinder flex-fuel spark-ignition engine with 1368 cm³ of total displacement. The test was conducted with full load according the (International Organization for Standardization, 2002), which is the standard specifies the test conditions and methods of declaration of power and fuel consumption in internal combustion engines. Data were acquired under the following conditions: water average temperature at around 95 °C and oil at 135 °C. The test was performed at specific speeds between 1000 to 6000 rpm with increments of 250 rpm. SAE 5W30 lubricant oil with gasoline fuel and ethanol fuel were used during the first part of test. The experiment was repeated with SAE 15W40 lubricant oil, the same fuel (gasoline and ethanol) and under the same conditions of first part. The test consisted of running the engine dynamometer at specific speed and full load. After stabilizing the conditions of the temperatures of both water and oil, the acquisition of the parameters of speed, vibration signal in accelerometers and other parameters were processed and stored in the Software LMS Test Lab and data acquisition system. The Figure 3 shows the experimental setup scheme.

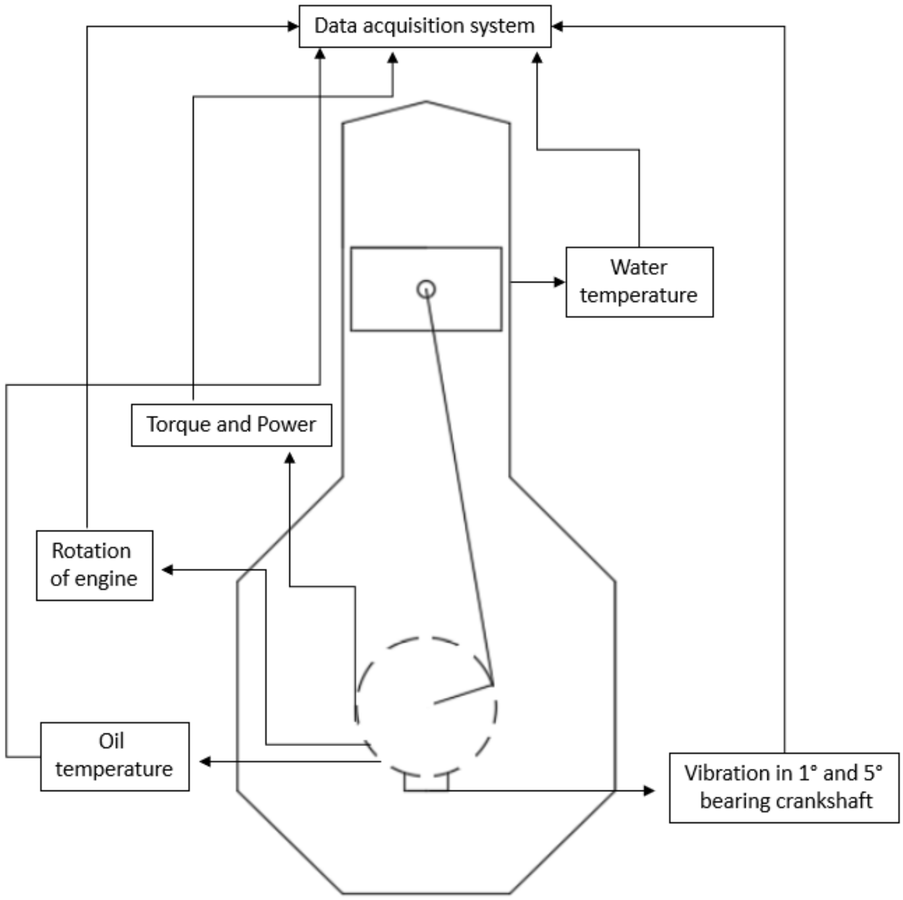

Figure 3 - Experimental setup scheme.

The analysis of the results consisted in correlating the data of vibrations measured on the 1° and 5° fixed bearings of the crankshaft as analyzed as a function of both the rotation of engine and the type of oil and fuel used in the tests. The analysis of the vibration data in average of the transverse and longitudinal vibration was done using the Root Mean Square (RMS).

3. RESULTS AND DISCUSSION

This section will be presented and discussed the results of the vibration measurements on the crankshaft of the engine installed in the dynamometer working in full load according the (International Organization for Standardization, 2002), which is the standard specifies the test conditions and methods of declaration of power and fuel consumption in internal combustion engines. The analysis of the measured parameters is analyzed according to the rotation of the engine, type of fuel and oil used during the tests. The Figure 4 shows both transverse and longitudinal vibration measurements of the 1° and 5° fixed bearing of the crankshaft as a function of the engine speed using SAE 5W30 lubricant oil and ethanol fuel.

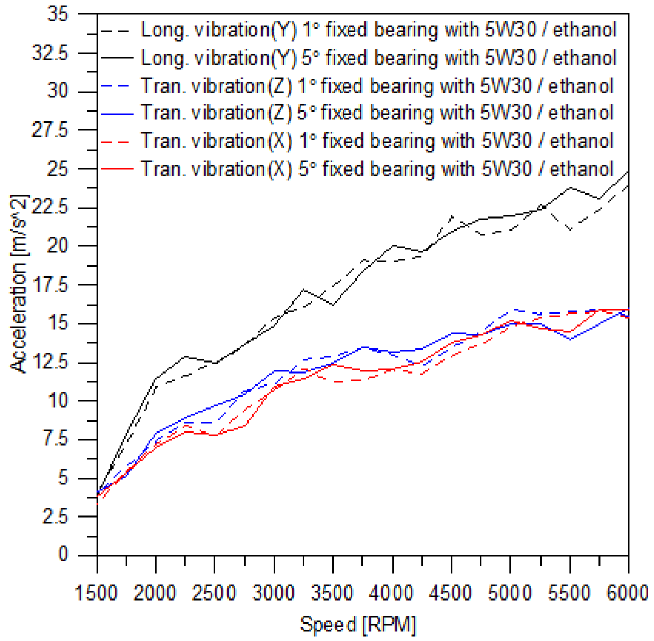

Figure 4 - Vibration measurements of the transverse and longitudinal of crankshaft with SAE 5W30 lubricant oil and ethanol fuel.

The intensity of transverse and longitudinal of crankshaft vibrations of engine running with SAE 5W30 lubricant oil and ethanol fuel increases with increase rotation of engine. The RMS values of transverse acceleration measured on the 1° and 5° fixed bearings of the crankshaft varied from 3.75 m/s^2 at 1500 rpm to approximately 15 m/s^2 at 6000 rpm and for longitudinal the acceleration varied from 4 m/s^2 at 1500 rpm to approximately 24 m/s^2 at 6000 rpm. This increase in vibration is due to increased dynamic load on the bearings with increased engine speed. Gravalos et al. (2011) demonstrate that, in general, vibration amplitude of the fundamental harmonics on spark ignition engine increases of increase engine speeds.

The Figure 5 shows both transverse and longitudinal vibration measurements of the 1° and 5° fixed bearing of the crankshaft as a function of the engine speed using SAE 5W30 lubricant oil and gasoline fuel.

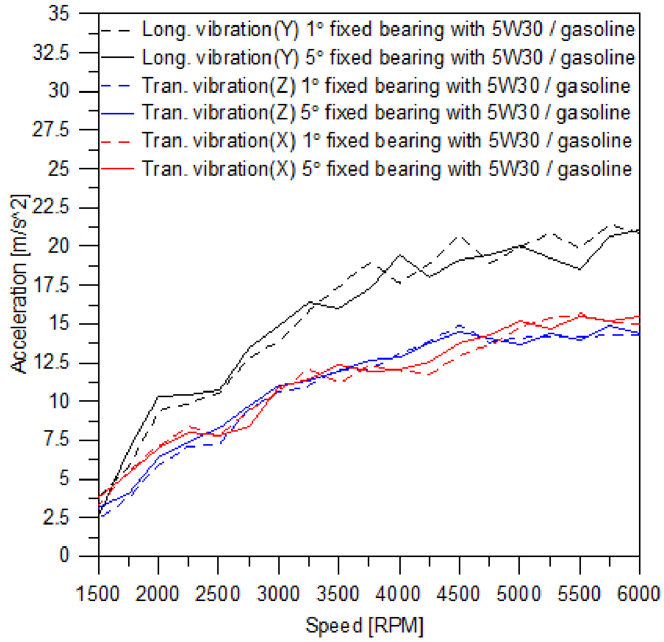

Figure 5 - Vibration measurements of the transverse and longitudinal of crankshaft with SAE 5W30 lubricant oil and gasoline fuel.

The RMS values of transverse acceleration measured on the 1° and 5° fixed bearings of the crankshaft varied from 3 m/s^2 at 1500 rpm to approximately 14.5 m/s^2 at 6000 rpm and for longitudinal the acceleration varied from 3.5 m/s^2 at 1500 rpm to approximately 22.5 m/s^2 at 6000 rpm. The tests show in Figs. 4 and 5 were performed with the same oil, SAE 5W30, and the different fuels, ethanol from the tests shown in Fig. 4 and gasoline in the tests shown in Fig. 5. The results of the measurements show that the level of vibration in the longitudinal direction (Y) was greater than in the transverse direction (X and Z). This relationally relies on the clearance between the crankshaft and the bearing to oil lubrification. The gaps measured before the tests were 0.008 mm in the transverse direction and 0.021 in the longitudinal direction. The intensity of the transverse and longitudinal vibrations of the crankshaft increase as the rotation increases and that such intensity reaches its maximum values close to the regions of maximum torque and maximum power of the engine. The gasoline-fueled engine reaches maximum torque close to 4250 rpm and maximum power close to 5750 rpm and the ethanol-fueled reaches maximum torque close to 4500 rpm and maximum power close to 6000 rpm. Alisaraei et al. (2012) presented results that indicates that the level vibration on engine is consistent with power-torque curve. Alisaraei et al. (2016) reported that the addition of ethanol into to diesel fuel increases the vibration level of the engine.

The Figure 6 show both transverse and longitudinal vibration measurements of the 1° and 5° fixed bearing of the crankshaft as a function of the engine speed using SAE 15W40 lubricant oil and ethanol fuel. The intensity of transversal and longitudinal axis vibrations of engine running with SAE 15W40 lubricant oil and ethanol fuel also increases with increase rotation of engine. The RMS values of transverse acceleration measured on the 1° and 5° fixed bearings of the crankshaft varied from 3.75 m/s^2 at 1500 rpm to approximately 14.75 m/s^2 at 6000 rpm and for longitudinal the acceleration varied from 3.75 m/s^2 at 1500 rpm to approximately 21 m/s^2 at 6000 rpm.

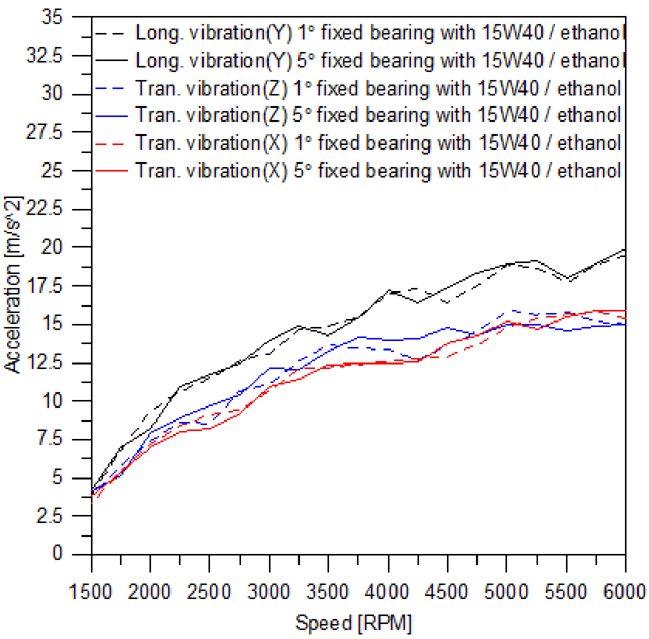

Figure 6 - Vibration measurements of the transverse and longitudinal of crankshaft with SAE 15W40 lubricant oil and ethanol fuel.

The Figure 7 show both transverse and longitudinal vibration measurements of the 1° and 5° fixed bearing of the crankshaft as a function of the engine speed using SAE 15W40 lubricant oil and gasoline fuel. The RMS values of transverse acceleration measured on the 1° and 5° fixed bearings of the crankshaft varied from 3.5 m/s^2 at 1500 rpm to approximately 14.5 m/s^2 at 6000 rpm and for longitudinal the acceleration varied from 3.5 m/s^2 at 1500 rpm to approximately 17.5 m/s^2 at 6000 rpm. The vibration intensity decreases with the use of SAE 15W40 lubricant oil in comparison to the use of SAE 5W30 lubricant oil. Such reduction in intensity is due to the higher viscosity of the SAE 15W40 lubricant oil. The higher the viscosity of the lubricant oil the greater the oil film protection. Chavan et al. (2015) demonstrated that the lubricant oil with higher viscosity reduces the vibration level on plain hydrodynamic journal bearing system.

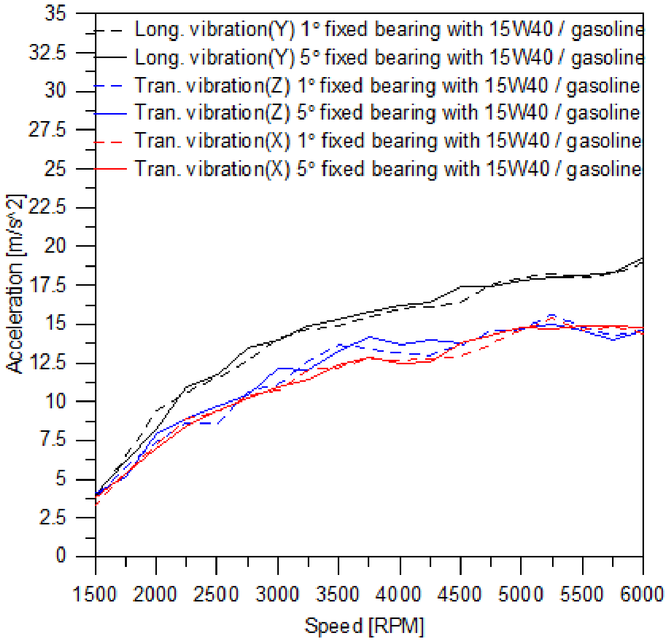

Figure 7 - Vibration measurements of the transverse and longitudinal of crankshaft with SAE 15W40 lubricant oil and gasoline fuel.

The tests show in Figs. 6 and 7 were performed with the same oil, SAE 15W40, and the different fuels, ethanol from the tests shown in Fig. 6 and gasoline in the tests shown in Fig. 7. The results of measurements show that the level of vibration in the longitudinal direction (Y) was greater than in the transverse direction (X and Z), the intensity of the transverse and longitudinal vibrations of the crankshaft increase as the rotation increases and that such intensity reaches its maximum values close to the regions of maximum torque and maximum power of the engine. Alisaraei et al. (2016) presented results that indicates that fuel type inflow at the level vibration on engine.

The Figure 8 show the mean longitudinal vibration of the 1° and 5° fixed bearing of the crankshaft as a function of the engine speed using SAE 5W30 and SAE 15W40 lubricant oil as well as ethanol and gasoline fuel.

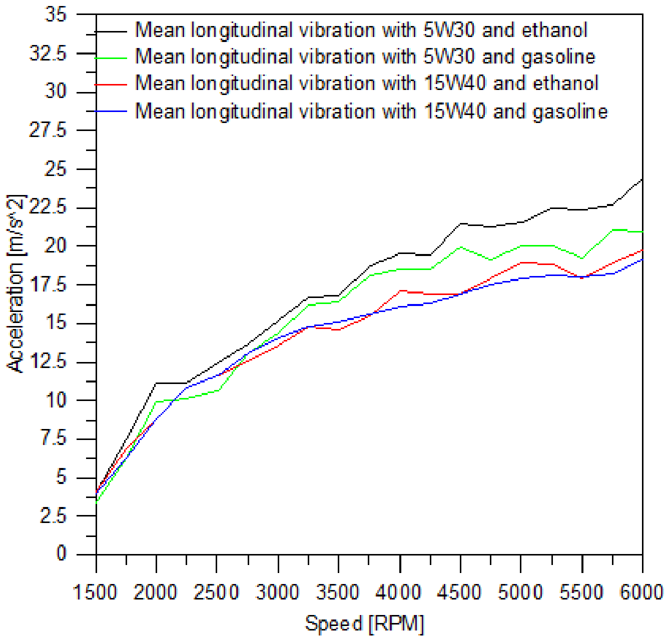

Figure 8 - Mean longitudinal vibration of the crankshaft as a function of the engine speed using SAE 5W30 and SAE 15W40 lubricant oil as well as ethanol and gasoline fuel.

At low speed of engine (rpm near 1500) all configurations tested presented similar level of mean longitudinal vibration in crankshaft. The vibration level increases with increasing speed and at high speed (rpm> 3500) observed that the configuration with SAE 5W30 lubricant oil and ethanol fuel presented an average increase of 18% of longitudinal vibrations in the crankshaft in relation the configuration with SAE 15W40 lubricant oil and gasoline fuel, increase of 14% in relation the configuration with SAE 15W40 lubricant oil and ethanol fuel and increase of 12% in relation to the configuration with SAE 5W30 lubricant oil and gasoline fuel. This study confirms that the vibration in crankshaft was influenced by the viscosity of the oil and the type of fuel used in the engine. The configuration that presented lower level of vibration was with the SAE 15W40 oil and gasoline fuel. This result was expected because, at 100° C, the SAE 15W40 oil have kinematic viscosity ranging from 12.5 to 16.3 cSt and the SAE 5W30 oil have kinematic viscosity ranging from 9.3 to 12.5 cSt, (SAE International Surface Vehicle Standard, 2013). The higher the viscosity of the lubricating oil, better oil film protection and greater protection against wear, (Haycock et al., 2004). Chandratre et al. (2015) investigated the influence of viscosity of oil by adding two grades of viscosity in damping coefficient of engine oil. The tests were realized with a four strokes engine with oil SAE 10W30, SAE 15W40, SAE 20W50 and two types of additive added in the three oil at 5%, 10% and 15% of additive. The results demonstrated that the presence of additive has significantly improved the damping properties of engine oil and the maximum damping effects was obtained with higher damping coefficient of SAE 20W50 blended with additive with higher viscosity. Chavan et al. (2015) correlated the vibration of the plain hydrodynamic journal bearing system with lubricant oil viscosity. The tests were realized with oil SAE 40, SAE 90 and SAE 140 varying load and speed. The results demonstrated that the lubricant viscosity has evident effect on vibrations of the system. SAE 40 shows fewer vibrations at higher speeds, while SAE 140 oils show less vibration at lower speeds. The Table 1 defines the limits for a classification of engine lubricating oils.

Table 1 - Limits for a classification of engine lubricating oils.

SAE Viscosity Grade	Low-Temperature (°C) Cranking Viscosity (3), mPa-s Max	Low-Temperature (°C) Pumping Viscosity (4), mPa-s Max with No Yield Stress (4)	Low-Shear-Rate Kinematic Viscosity (5) (mm^2/s) at 100°C Min	Low-Shear-Rate Kinematic Viscosity (5) (mm^2/s) at 100°C Max	High-Shear-Rate Viscosity (6), (mPa-s) at 150°C Min
0W	6200 at -35	60000 at -40	3.8	-	-
5W	6600 at -30	60000 at -35	3.8	-	-
10W	7000 at -25	60000 at -30	4.1	-	-
15W	7000 at -20	60000 at -25	5.6	-	-
20W	9500 at -15	60000 at -20	5.6	-	-
25W	13000 at -10	60000 at -15	9.3	-	-
8	-	-	4.0	<6.1	1.7
12	-	-	5.0	<7.1	2.0
16	-	-	6.1	<8.2	2.3
20	-	-	6.9	<9.3	2.6
30	-	-	9.3	<12.5	2.9
40	-	-	12.5	<16.3	3.5 (0W-40, 5W-40, and 10W-40 grades)
40	-	-	12.5	<16.3	3.7 (15W-40, 20W-40, 25W-40, 40 grades)
50	-	-	16.3	<21.9	3.7
60	-	-	21.9	<26.1	3.7

Available from: https://www.sae.org/standards/content/j300_200901/

The Figure 9 show the mean transverse vibration of the 1° and 5° fixed bearing of the crankshaft as a function of the engine speed using SAE 5W30 and SAE 15W40 lubricant oil as well as ethanol and gasoline fuel.

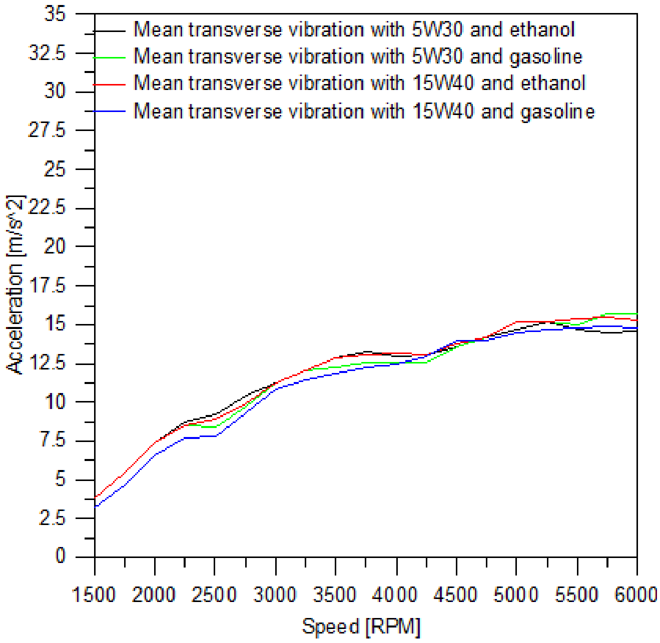

Figure 9 - Mean transverse vibration of with SAE 5W30 and SAE 15W40 oil as well as ethanol and gasoline fuel.

The mean transverse vibration of the crankshaft for all configurations of fuel and oil tested varied from approximately 3.5 m/s^2 at 1500 rpm to approximately 13.75 m/s^2 at 6000 rpm. In general, the results show that the level of vibration with ethanol fuel was greater than with gasoline fuel. With SAE 5W30 lubricant oil, the level of transverse vibration of the crankshaft with ethanol fuel was 14% higher than gasoline fuel. With SAE 15W40 lubricant oil, the vibration of the crankshaft with ethanol fuel was 10% higher than gasoline fuel. The gasoline-fueled engine reaches maximum torque close to 4250 rpm and maximum power close to 5750 rpm and the ethanol-fueled reaches maximum torque close to 4500 rpm and maximum power close to 6000 rpm. The greatest forces concentrated in region between maximum torque to maximum power which, as show in Fig. 10, corresponds to the region of the greatest dynamic load on the bearings and crankshaft, (Heywood, 2003). This study confirms that the vibration in crankshaft was influenced by the type of fuel used in the engine. In the maximum torque region of the engine (at 4250 and 4500 rpm to gasoline and ethanol fuel), the level of vibration in the transverse direction (Z) was greater than in the transverse direction (X).

Figure 10 – Curve torque of engine with gasoline and ethanol fuel.

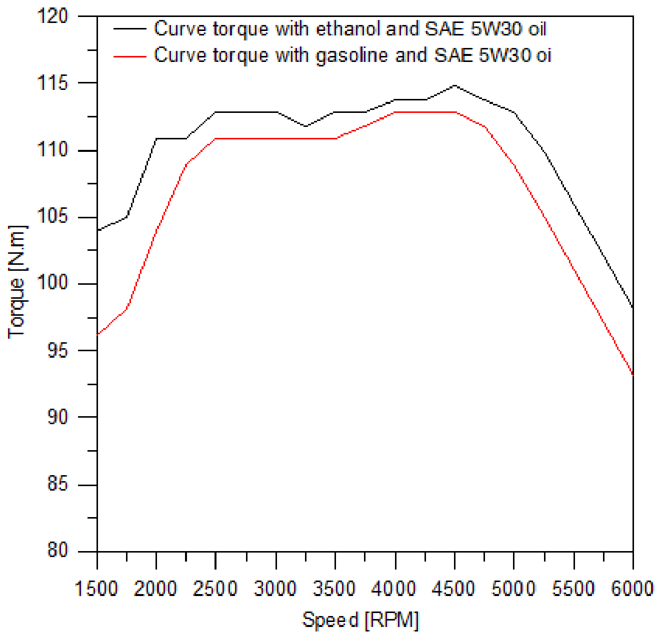

Figure 10 - Curve torque of engine with gasoline and ethanol fuel.

The Figure 11 show the main geometrical parameters of the piston rod and crankshaft mechanism, were "r" is the radius of the crankshaft, "L" is the effective length of the connecting rod, "d" is the diameter of the piston, "b" is the bearing of crankshaft and Fp represents the force acting on the piston due to the combustion process. The intensity of force Fb contributes with the greater level of the vibration in transverse direction (Z) in relation transverse direction (X) in crankshaft.

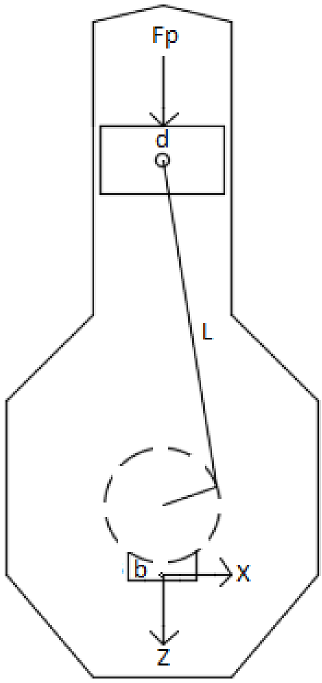

Figure 11 - Main geometric parameters of the piston rod and crank mechanism.

Keskin (2010) investigated vibration effect of ethanol and gasoline blends on two stokes spark ignition engine. The experiments were at 1500, 2000 and 2500 rpm engine speed. The results demonstrate that vibration characteristics of engine changed significantly at 1500 and 2000 rpm with gasoline blend with ethanol fuels and the vibration amplitude of the engine with ethanol pure showed a trend of increasing. Uludamar et al. (2016) investigated the vibration effect of canola biodiesel, sunflower biodiesel and their blends with low Sulphur diesel fuel. The experiments were realized a four-cylinder, four stokes diesel engine at 1300, 1600, 1900, 2200, 2500 and 2800 rpm engine speed. The results demonstrate that vibration amplitude increase with engine speed at every fuel.

4. CONCLUSIONS

The vibration intensity of the engine increases with increasing engine speed and load. This vibrations level was maximum in the regions between of torque and power of the engine;

In all operating conditions, the ethanol-run engine has higher vibration intensities than the gasoline-run engine. For the same type of fuel, an oil of higher viscosity attenuates the level of vibration of the crankshaft engine;

An average increase of 18% of transverse vibration and 12% of longitudinal vibration in the crankshaft of the engine running on ethanol in relation to gasoline with SAE 5W30 lubricant and 14% and 10% with SAE 15W40 lubricant;

The intensity of force due combustion process contributes with the greater level of the vibration in vertical transverse direction in relation horizontal transverse direction in crankshaft.

5. ACKNOWLEDGEMENTS

Federal University of Minas Gerais. Department of Mechanical Engineering.
CPGMEC – Collegiate of Post-graduation in Mechanical Engineering.

6. REFERENCES

Heywood, J.B. Internal combustion engine fundamental, 2nd edition, McGraw-Hill, 2003.

Taylor C. F., Analysis of internal combustion engines, 2nd edition, Edgard Blücher Ltda, 1990.

Haycock, R. F., Hillier, J. E. and Caines, A. J. Automotive lubricant reference book, 1st edition, Professional Engineering Publishing, 2004.

SAE International Surface Vehicle Standard, Engine Oil Viscosity Classification J300_201304, 2013.

Gillespie, T. D. Fundamentals of Vehicle Dynamics, Published by Society of Automotive Engineers, 1992.

Wang, X. Vehicle Noise and Vibration Refinement. 1st edition, Woodhead Publishing Limited, 2010.

Chandratre, K. V., Sarkar, A., and Varade, B. V. Experimental Investigation of Fluid Viscosity Effects on Free Damped Vibration, International Engineering Research Journal Page Nº 1401-1405.

International Organization for Standardization ISO 3046-1, Reciprocating internal combustion engines - Performance - Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods - Additional requirements for engines for general use, 2002.

Gravalos I., Moshou D., Gialamas T., Kateris D., Xyradakis P., Tsiropoulos Z. Vibration effects on spark ignition engine fueled with methanol and ethanol gasoline blends, Journal of agricultural Machinery Science, 2011.

Alisaraei A. T., Ghobadian B., Hashjin T. T., Mohtasebi S. S. Vibration analysis of a diesel engine using biodiesel and Petrodiesel fuel blends, Fuel 102: 414-422, December 2012.

Alisaraei A. T., Asi A. R. The effect of added ethanol to diesel fuel on performance, vibration, combustion and knocking of a CI engine, Fuel 185: 718-733, August 2016.

Chavan A. C., Thombare D., Chhapkhane N. Experimental investigation of effect of lubricant viscosity on vibrations of plain hydrodynamic journal bearing system, International Journal of Research and Development, 3(4):31-36, April 2015.

Keskin A., The Influence of Ethanol Gasoline Blends on Spark Ignition Engine Vibration Characteristics and Noise Emissions, Energy Sources Part A: Recovery (20): 1851-1860, August 2010.

Uludamar E., Tüccar G., Aydın K., Özcanlı M., Vibration Analysis of a Diesel Engine Fueled with Sunflower and Canola Biodiesels, Advances in Automobile Engineering, volume 5: 137, January 2016.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.