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# INFLUENCE OF GASOLINE AND ETHANOL COMBUSTION PROCESS ON THE BLOCK VIBRATION LEVEL OF OTTO CYCLE ENGINE

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***Abstract.*** *Ethanol and gasoline are widely used with fuels in Otto cycle engines. These fuels have different heating power, advance ignition and octane number and the engine behaves differently depending on the type of fuel used. The objective of this study is to measure, compare and investigate the factors that affect the block vibration of an internal combustion engine as a function of the fuel used ethanol or gasoline. The experiment consisted of instrumenting the side of the engine block with an accelerometer to measure the level of vibration intensity of the engine running on a dynamometer bench varying engine speed and load conditions. The analysis correlated heating power, advance ignition and octane number of gasoline and ethanol fuels running in Otto cycle engine on a dynamometer bench varying engine speed and load conditions. The results showed that the engine vibration level increases with the increase in engine speed, load, advance ignition and octane number. The highest level of vibration was achieved in the region of maximum torque. The combustion process is mainly responsible for the highest level of vibration achieved with ethanol. In all operating conditions the vibration level of the engine block was higher as ethanol. On average, the vibration in the engine block was 12% higher with ethanol compared to gasoline. This research is important because it correlates the vibration level of the block of an internal combustion engine as an engine combustion process fueled with ethanol and gasoline.*

***Keywords:*** *Internal combustion engine, Cycle Otto combustion process, Gasoline combustion process, Ethanol combustion process, Advance ignition Otto cycle engine.*

## 1. INTRODUCTION

The objective of this study is to measure, compare and investigate the factors that affect the block vibration of an internal combustion engine as a function of the fuel used ethanol or gasoline. Internal combustion engines are classified according to the burning mode of the fuel in both spark-ignition and compression-ignition engines, (Heywood, 2003). 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, (Taylor, 1990). Combustion of the air-fuel mixture in spark ignition occurs during the expansion time of four-stroke engines. However, the ignition of the mixture should begin at the end of the combustion time. Thus, the high voltage spark produced by the coil must be thrown into the cylinder in advance, moments before the piston reaches the top dead center (TDC), (Nora et al., 2018). This advance in the ignition is due to the fact that the mixture does not ignite completely instantaneously, but in a progressive manner. This means that it takes some time before all gaseous mass is completely burned, generating the maximum pressure required to develop a good thermal efficiency inside the engine, (Heywood, 2003) and (Nora et al.,2018). The measurement of the feed rate is relative to the rotation angle of the crankshaft. When the piston is in the TDC, the angle is considered being at 0° degree. As the spark is released before the TDC, it means that the crankshaft has not yet reached that angle. The advance ignition is then determined by the remaining angle so that the crankshaft reaches 0° degree, (Nora et al., 2017). 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, (Gerges, 2005). 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, (Thomas, 1996). 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. The type of fuel used will influence directly by establishing particular characteristics to this kind of vibration, (Satsangi and Tiwari, 2018). (Gravalos et al., 2013) investigated the effects of vibrations on spark ignition engine fueled with gasoline and gasoline blend with ethanol and methanol at concentrations of 10%, 20% and 30%. per volume. The experiments were realized a single cylinder spark ignition engine and were performed at rotational speed of 1000, 1300, 1600 and 1900 rpm onto a hydraulic dynamometer. The results demonstrate that vibration amplitude of the fundamental harmonics decrease with increase of load or decrease of engine speeds. The vibration values of gasoline had higher amplitudes at 1300 rpm, gasoline blend with 10% of methanol fuel had higher amplitudes at 1900 rpm. Gasoline blend with 10% of ethanol gave more stable vibration intensity, in comparison with others fuels. The results are due the changing of the process combustion, which was caused by combustion characteristics of bend fuels. (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 rotational 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 showed a trend of increasing. (Alisaraei et al., 2016) investigated vibration characteristics of internal combustion engines when ethanol was added to diesel fuel with concentration 2, 4, 6, 8, 10 and 12% per volume. The experiments were realized at 1600, 1700, 1800 and 2000 rpm engine rotational speed. The results demonstrated that vibration intensity of engine block increased between 4,75% to 7,75% with increasing concentration of ethanol into diesel, associated with an 8% increasing of engine speed. (Santana et al., 2019) investigated the vibration intensity of an internal combustion engine due to the degradation of the lubricating oil used in the engine. The level of vibration increases with the time of use of the lubricant and it is very significant when the viscosity had reached the minimum limit stipulated by the lubricant manufacturer. The type of fuel and viscosity of the lubricant influenced the level of vibration in the engine. The results showed that engine running on ethanol with lubricant of lower viscosity have the highest vibration intensity.

## 2. METHODOLOGY

The experimental procedure involved the instrumentation of the engine with a tri axis accelerometer on the side wall of the engine block in order to measure the level of vibration of the engine during testing. The accelerometers used for testing were a piezoelectric accelerometer model Kistler K Shear 8704B100. A spark plug with integrated pressure sensor model AVL Z122 was installed in the first and third cylinder of the engine to measure the pressure inside the cylinder during the test. An encoder model D83301 was installed at the end of the crankshaft to measure the ignition advance angle. A hydraulic dynamometer, passive FE model 150s, was used in order to measure engine speed, torque and power engine generated during testing. The measured engine vibration data are acquired in LMS Test Lab Software by SIEMENS. All other experimental data are acquired in test bench acquisition system. The analysis of the vibration data was an average mean of the engine block vibration intensity. This was done using the Root Mean Square (RMS) of the accelerometer signal amplitudes during the time acquired during each test condition. The RMS value is the root mean square of the signal and is used to represent the energy in the signal and it is the most relevant measure of vibration intensity in internal combustion engine since it gives an amplitude value by considering time history of the signal vibration measured. The RMS acceleration value can be calculated by the following Eq. (1):

$$RMS = \sqrt{\frac{1}{T}\int_{0}^{T} a_w^2(t)dt} \tag{1}$$

Were, $[a_w]$ (m/s$^2$) represents the weighted accelerations and [t] (s) represents measurement time. The Figure 1 shows the accelerometer position in the engine block and the orientation of measurement engine block vibration. The direction Y represents the longitudinal vibration in the engine block, X represents the transversal vibration in the engine block and Z represents the vertical vibration in the engine block.

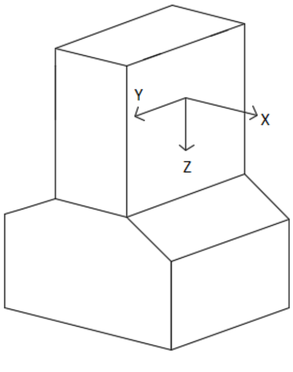

Figure 1 - Orientation of accelerometers measurement to measuring the engine block vibration.

The tests were carried out on a four-cylinder flex-fuel spark-ignition engine with the follow specification presented in Table 1.

Table 1 – Specification of spark ignition engine.

| Parameter | Type or value |
|---|---|
| Cycle | Four strokes |
| Compression ratio | 10.35: 1 |
| Bore × stroke | 72.00 × 84.00 mm |
| Number of cylinders | 4, in line |
| Total displacement | 1368 cm³; |
| Intake system | Naturally aspirated |
| Maximum power | 58.84 KW at 5750 rpm with gasoline<br>62.58 KW at 6000 rpm with ethanol |
| Maximum torque | 112,80 Nm at 4500 rpm with gasoline<br>114.60 Nm at 4500 rpm with ethanol |
| Maximum pressure combustion | 89.20 bar at 4250 rpm with gasoline<br>92.40 bar at 4250 rpm with ethanol |

The test was conducted with full load according the (ISO 3046-1, 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. At each test speed, data was acquired for 2 minutes at a rate of 100 Hz. SAE 5W30 lubricant oil with gasoline fuel and ethanol fuel were used during the tests. 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 parameters of rotation engine, engine block vibration, torque and power engine, advanced ignition and pressure combustion engine and other parameters were processed and stored in the Software LMS Test Lab and data acquisition system. The Figure 2 shows the experimental setup scheme.

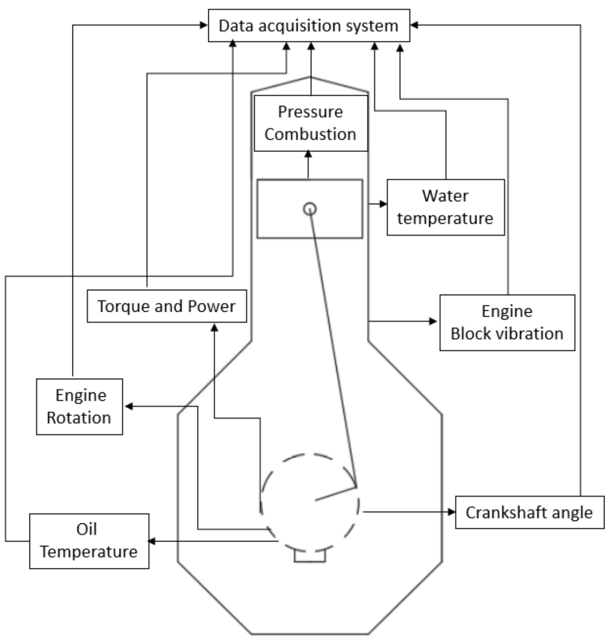


Figure 2 - Experimental setup scheme.

The analysis of the results consisted in correlating the data of vibrations measured on the engine block as analyzed as a function of rotation of engine, combustion pressure, torque, power and advanced ignition of gasoline and ethanol fuel used in the tests. (Santana et al., 2019) investigated the levels of crankshaft engine vibration relative to the fuel used, ethanol and gasoline, and assess the influence of lubricant oils on theses vibration levels as a function of the lubricant viscosity. 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. (Santana et al., 2013) correlated and identified across the frequency spectrum the main sources of vibration and noise from an internal combustion engine.

## 3. RESULTS AND DISCUSSION

All This section will be present and discuss the measurements results of vibration in the engine block installed in the dynamometer working in full load. The Figure 3 shows transverse, longitudinal and vertical vibration measurements of engine block as a function of the engine speed using SAE 5W30 lubricant oil, gasoline fuel and ethanol fuel.

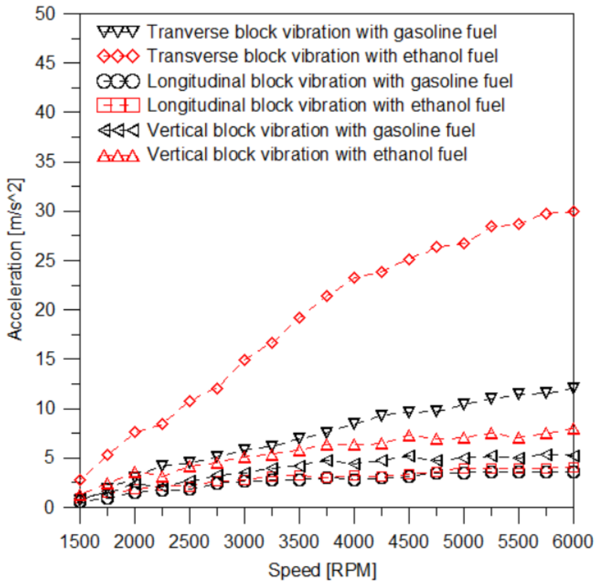


Figure 3 - Vibration measurements of the transverse, longitudinal and vertical engine block with SAE 5W30 lubricant oil, gasoline fuel and ethanol fuel.

The transverse acceleration measured in engine block with gasoline fuel varied from 0.65 $m/s^2$ at 1500 rpm to approximately 12 $m/s^2$ at 6000 rpm, for vertical acceleration the measured varied from 0.67 $m/s^2$ at 1500 rpm to approximately 5.20 $m/s^2$ at 6000 rpm and for longitudinal acceleration the measured varied from 0.61 $m/s^2$ at 1500 rpm to approximately 3.60 $m/s^2$ at 6000 rpm. In tests with ethanol fuel, the transverse acceleration measured in engine block varied from 3 $m/s^2$ at 1500 rpm to approximately 30 $m/s^2$ at 6000 rpm, for vertical acceleration the measured varied from 1.30 $m/s^2$ at 1500 rpm to approximately 8 $m/s^2$ at 6000 rpm and for longitudinal acceleration the measured varied from 0.67 $m/s^2$ at 1500 rpm to approximately 4 $m/s^2$ at 6000 rpm. The vibration intensity in the engine block is influenced by the degree of freedom of the movable engine components such as piston, connecting rod, crankshaft, bearings, camshaft and intake and discharge valves, air displacement in the intake manifold and burned gases in the discharge manifold, type of fuel used in the engine, engine performance parameters such as torque, power and mean effective pressure and calibration parameters of the electronic injection such as advance ignition and pressure combustion. The results showed that in the longitudinal direction the engine had the same intensity vibration operating on gasoline and ethanol fuel. In this direction, the internal components piston, connecting rod, crankshaft, bearings and camshaft have less degrees of freedom. (Santana et al, 2020) demonstrated that the mobile components of the engine have a low degree of freedom in the longitudinal direction and this limited movement produces, as shown in Figure 3, low intensity vibration in the longitudinal direction in both tests with gasoline and ethanol fuel. In the vertical direction, the results showed that the vibration intensity of the engine increased with increasing speed and was more intense in the tests with ethanol. The factors that most influenced the vibration in this direction were the dynamics of the opening and closing of the valves in the cylinder head and the engine combustion process. In the thermal cycle of a four-stroke spark ignition engine, there are four openings and four closings of the intake and discharge valves. This contact of the valves with the valve seats is a factor that produces vibration in the vertical direction. (Santana et al, 2013) demonstrated through the frequency spectrum, that the dynamics of the opening and closing movement of the valves in the cylinder head is an important source of vibration generation in the engine. In a four-stroke spark ignition engine there are four combustion processes per work cycle, this combustion process is also a factor that contributes to the increase in the vibration intensity in the vertical direction. (Santana et al., 2020) correlated the combustion process with the vibration intensity in the 1st and 5th crankshaft bearings of an Otto cycle internal combustion engine. In the transverse direction, the results showed that the intensity vibration engine also increased with increasing speed and was also more intense in the tests with ethanol. The factor that most influenced the vibration in this direction was the ignition advance of the engine. This calibration parameter relates the start of the combustion process and the increase in pressure inside the cylinder.

The Figure 4 shows the vertical block vibration measurements as function of engine speed and torque curves of engine with gasoline and ethanol fuel during the experiments. The engine torque was measured directly on the crankshaft of the engine coupled to the bench dynamometer with full load conditions.

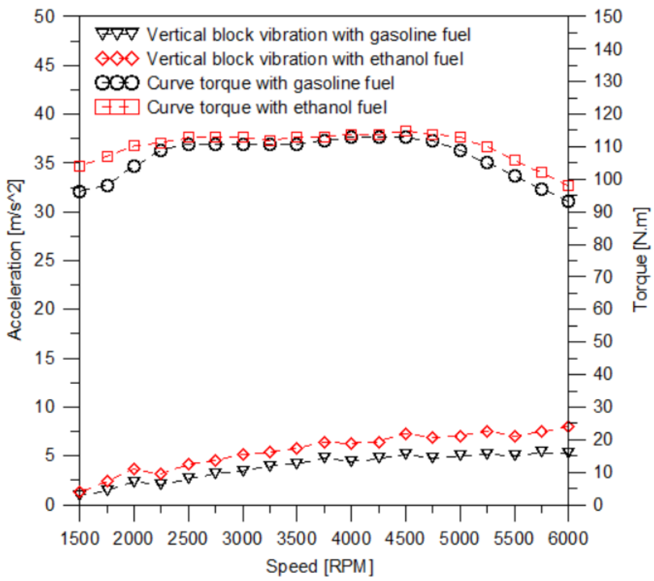


Figure 4 - Torque curve and vertical block vibration of engine with gasoline and ethanol fuel.

The gasoline fueled engine reaches maximum torque of 112.80 N.m at 4500 rpm and the ethanol fueled engine reaches maximum torque 114.60 N.m at 4500 rpm. The intensity of vertical engine block vibrations running with gasoline fuel increases with increase rotation of engine and the maximum RMS acceleration of vertical block vibration measured value was 5.20 $m/s^2$ from 4500 rpm to 6000 rpm. With ethanol fuel, the intensity of engine block vibrations also increases with increase rotation and the maximum RMS acceleration of vertical block measured value varied from 7.35 $m/s^2$ at 4500 rpm, to approximately 8 $m/s^2$, at 6000 rpm. This result shows that the torque generated in the engine due to combustion of the air and fuel mixture in the combustion chamber produces a force that is transmitted to the crankshaft. This load generated on the crankshaft is transmitted to the engine block which results in vertical vibration in the engine block. The higher intensity vertical vibration verified in the engine block with ethanol can be justified because with ethanol the engine achieves a higher torque. The present study confirms the results found by (Ftoutou and Chouchane, 2018) that investigated the potential of vibration analysis for early detection of fuel injection faults in an internal combustion diesel engine. The experiments were realized in six cylinders in line and was used the piezoelectric accelerometer for vibration measurement fixed between cylinder 3 and 4. The results demonstrate that vibration reduced with the injection pressure at cylinder is reduced respectively by 10% and 50%.

The Figure 5 shows the vertical block vibration measurements as function of engine speed and power curves of engine with gasoline and ethanol fuel during the experiments. The engine power was calculated by the following Eq. (2):

$$\dot{W} = \frac{2.\pi.N.T}{60} \tag{2}$$

Were, [N] is engine speed in (RPM) and [T] is the engine torque measured to the bench dynamometer with full load conditions in (N.m).

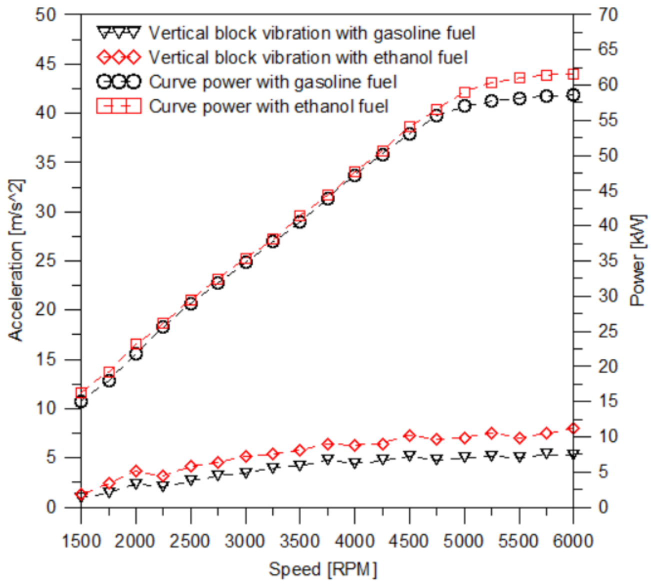


Figure 5 - Power curve and vertical block vibration of engine with gasoline and ethanol fuel.

The intensity of vertical engine block vibrations with gasoline fuel increases with increase rotation of engine and the maximum RMS acceleration value 5.25 $m/s^2$ was reached in the region of maximum engine power at 6000 rpm. With ethanol fuel the intensity vibration also increase of increase rotation and the maximum RMS acceleration value from 7.35 $m/s^2$ to 8 $m/s^2$ was reached in the region of maximum engine power that ranging from 5000 to 6000 rpm. The gasoline fueled engine reaches maximum power of 58.80 kW at 6000 rpm and the ethanol fueled engine reaches maximum power 61.60 kW at 6000 rpm. The higher intensity vertical vibration verified with ethanol in relation gasoline can be justified because with ethanol the engine achieves a higher power.

The Figure 6 shows the vertical block vibration measurements as function of engine speed and mean effective pressure curves of engine with gasoline and ethanol fuel during the experiments. The engine mean effective pressure was calculated by the following Eq. (3):

$$mep = \frac{2.\pi.nr.T}{Vd} \tag{3}$$

Were, [nr] is number of revolutions per cycle, [T] is the engine torque measured to the bench dynamometer with full load conditions in (N.m) and [Vd] is displacement volume in ($m^3$).

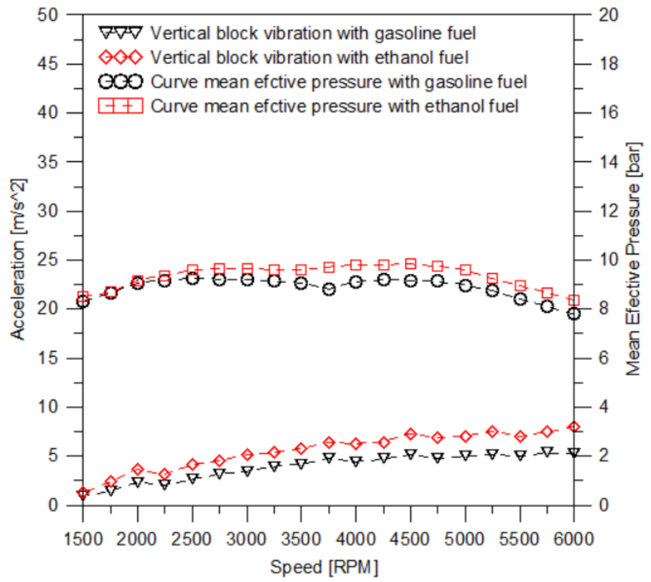

Figure 6 - Mean effective pressure curve and vertical block vibration of engine with gasoline and ethanol fuel.

In the entire engine range speed, the intensity of vertical vibration in the tests with ethanol was higher in relation to the tests with gasoline and this difference increases with the increase in the engine speed. At low speeds the dynamic load on the engine due to torque was low and in this condition the intensity of vertical vibration was also low. At speeds between 4000 and 6000 rpm the dynamic load on the engine is high and in this condition the vibration intensity was maximum. The average intensity of vertical vibration in the entire speed range of the engine operating on gasoline was 4.42 $m/s^2$ and with ethanol was 6.33 $m/s^2$. This represents an average increase of vertical vibration in the engine block of 31% of the engine operating with ethanol in relation to gasoline. The present study confirms the results found by (Alisaraei et al, 2016) and (Alisaraei et al, 2012) that also presented results that indicates that fuel type inflow at the level vibration on engine.

The Figure 7 shows the transverse block vibration measurements as function of engine speed and advanced ignition curves of engine with gasoline and ethanol fuel during the experiments.

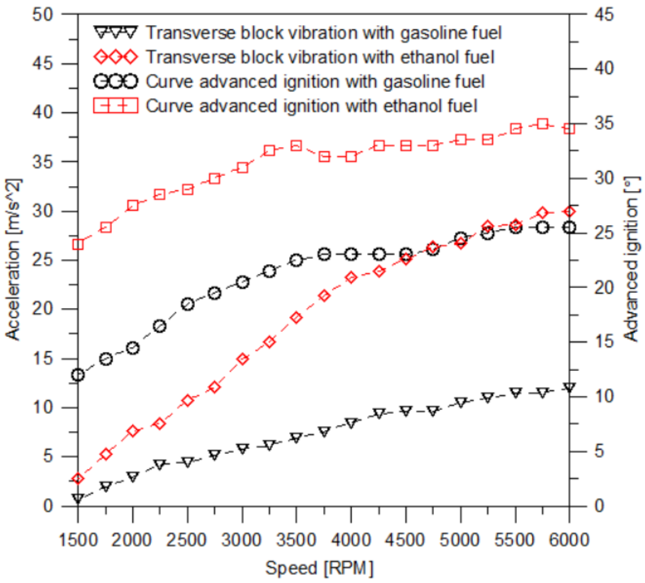


Figure 7 – Advanced ignition curve and transverse block vibration of engine with gasoline and ethanol fuel.

The intensity of transverse engine block vibrations operating with gasoline and ethanol fuel increases with increase rotation of engine. With gasoline the maximum RMS acceleration of transverse block vibration measured value was 12 $m/s^2$ to 6000 rpm. With ethanol the maximum RMS acceleration of transverse block vibration measured value was 29.90 $m/s^2$ to 6000 rpm. The advanced ignition of the gasoline engine varied from 12° at 1500 rpm to approximately 25.50° at 6000 rpm and with ethanol engine varied from 24° at 1500 rpm to approximately 34.50° at 6000 rpm. This result shows that the transverse vibration on engine block is due to the combination of two factors such as advanced ignition and combustion pressure. Due to the fact that the engine running on ethanol reaches a higher pressure and temperatures in the combustion chamber it reaches higher combustion pressure. Higher combustion pressure and the further advanced ignition causes the firing of the spark rod of an ethanol engine work more inclined than a gasoline engine, consequently, the lateral force will be higher resulting in higher transverse vibration in the engine block when run on ethanol fuel in relation gasoline fuel. The average intensity of transverse vibration in the entire speed range of the engine operating on gasoline was 9.56 $m/s^2$ and with ethanol was 16.38 $m/s^2$. This represents an average increase of vertical vibration in the engine block of 56% of the engine operating with ethanol in relation to gasoline. The present study confirms the results found by (Chiavola et al., 2010) that also demonstrated that the combustion pressure in an engine influences the vibration level in the engine block. This study confirms that the vibration level of an internal combustion engine depends on the type of fuel used in the engine.

## 4. CONCLUSIONS

This study confirms that the vibration level of an internal combustion engine depends on the type of fuel used in the engine. In the present work, the vibration level of the engine running with ethanol was more intense than the engine running with gasoline in all operating conditions.

The factors that most influenced the engine block vibration in the vertical direction were the opening and closing movement of the intake and discharge valves, combustion pressure and torque.

The highest intensities vertical vibration was found in the region with the highest torque. This vertical engine vibration was 31% higher in the engine running on ethanol compared to the engine using gasoline.

In the longitudinal direction of the engine, there was little difference in the intensity vibration in the tests with gasoline and ethanol. On average, the longitudinal vibration was 3% higher in the engine running on ethanol compared to the engine using gasoline.

The factors that most influenced the engine block vibration in the transverse direction were the combustion pressure and advance ignition engine.

The higher the combustion pressure and higher advanced ignition the greater transvers vibration intensity in the engine block. On average, the transverse vibration was 56% higher in the engine running on ethanol compared to the engine using gasoline.

The contribution of this work in relation to previous works is that the present research analyzes and correlates the longitudinal, transversal and vertical engine block vibrations of the engine with ethanol and gasoline fuels as functions engine performance parameters.

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