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Experimental Investigation on Engine Vibration Behavior Caused by Crankshaft Mechanism Under Different Lubricant Type and Temperatures

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ABSTRACT

Vibration is one of the important factors in engine design, so that it can negatively affect the product, such as discomfort to the vehicle's occupants, premature wear of components, reduction in useful life. The main objective of this study is to investigate the vibrational behavior of the crankshaft mechanism of an internal combustion (IC) engine operated on motoring mode as a function of the lubricant type, oil temperature. This attempt included instrumenting the engine block with accelerometers to measure the horizontal and vertical vibration intensity and running the engine on an electromotor test rig in a specific test procedure namely strip-down method. The experiments were conducted with various cranktrain configurations under different engine speeds, lubricant types and oil temperatures. The results showed that the vibration intensity of the cranktrain mechanism increases with increasing engine speed. This vibrations level was maximum in the highest speed. Changes in the vertical vibrations caused by the crankshaft in different conditions were almost similar to the horizontal vibration changes. Also, the engine vibration caused by the crankshaft were not affected by the oil type and oil temperature at all engine speeds, and increase in the speed had a very slight effect on this vibration. The engine vibrations due to the reciprocating masses increased significantly with the speed rise, and altered by changes in oil temperature. Changing the oil type had almost no effect on the vertical vibration caused by the movement of the reciprocating masses at any engine speed. But the horizontal vibration caused by them at a constant oil temperature increased by changing the oil type from 20w50 to 10w40. The experimental results showed that the contribution of the reciprocating masses from the vibrations caused by cranktrain mechanism was much higher than that of the crankshaft.

1. Introduction

In internal combustion engines, one of the most important systems affecting engine performance

is the engine lubrication system. The main purpose of lubrication is to send a suitable lubricant between the friction and high

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temperature surfaces of the engine. In a lubricant, the greasing and viscosity properties play the main role in lubrication [1]. Due to the multiple functions of the lubricant in new internal combustion engines, the type of oil in terms of physical properties and viscosity is important for use in the engine. Viscosity index is a numerical value that indicates viscosity [2]. The viscosity of engine lubricating oils changes with temperature variations which is depend on the type of lubricating oil.

Engine vibration is one of the important parameters in engine design which is a complicated phenomenon to be analyzed. Many excitation sources are available in any engine which have a specific contribution each one in overall engine vibration. Apart from being a main cause in component failure and durability of the engine [3, 4], vibration is also a factor that annoys customers in all types of vehicles, so engine designers are always trying to reduce this parameter in engines. Given the importance of vibration in engines, many studies have been conducted on engine vibrations from various aspects. In this among, a theoretical, numerical and experimental investigation of the torsional vibrations of the crankshaft of several types of vehicles was carried out in [5]. By comparing the results of these three methods, the best model for designing the crankshaft, investigating the torsional vibrations due to the engine speed has been obtained. In another research, the effect of changing biodiesel fuel on engine vibration was investigated and a suitable model was presented to predict the relationship between fuel properties and engine vibration based on linear and non-linear regression analysis [6]. In a study, the effect of high viscosity of biodiesel fuels on combustion and engine vibration effects was surveyed. The results of this research showed that the overall vibration acceleration of the engine decreases when using biodiesel fuel and adding hydrogen [7]. In another work, the effect of fuel injection pressure on the vibrations of a single cylinder engine with diesel-biodiesel fuel has been studied experimentally [8]. The effect of oil viscosity on the vertical vibrations of an internal combustion engine showed that with increase in the engine speed and oil temperature and the decrease in its viscosity, the root mean square of

the acceleration of the engine vibration in the vertical direction increases significantly [9]. In [10], the flow of a 20w50 oil in a porous media was simulated using the Darcy-Brinkman-Forthiem equation and the thermophysical properties of the oil that were extracted experimentally. In [11], the effect of fuel injection pressure on the vibration of an internal combustion engine using alternative fuels was investigated. By using ethanol and gasoline fuels in a spark ignition engine, it was determined that the type of fuel directly affects the vibration of spark ignition engines. In an article, the effect of oil temperature entering the turbocharger on its vibration was investigated [12]. In [13], adding nanofluid in 20w50 engine oil was studied numerically in three dimensions to investigate its effect on forced convection in a porous media oil cooler. In order to partition the governing equations, ANSYS-FLUENT software was used.

Nowadays, according to new technologies in engines, the type of oils used in terms of viscosity is very important to provide better conditions in cold start, pumping, lubrication, cooling, fuel consumption and vibration behavior [2]. In [14], it was determined that the level of vibration increases with the use of the lubricant, and this increase is very significant from the moment when the viscosity has reached the minimum limit set by the manufacturer of the lubricant. In [15], the effect of fuel and lubricant on gasoline engine vibration was investigated. The results showed that the engine vibration using ethanol fuel is more than gasoline fuel and increasing the viscosity of the lubricant in the engine reduces the vibration.

According to the mentioned research, it is important to investigate and reduce vibration in internal combustion engines. Information about the amount of the effect of the oil viscosity, oil temperature and cranktrain configuration on engine vibrations under different speeds is among the important inputs for engine design and development processes. In literature, there is few researches have experimentally been done on determination of contribution of each mentioned parameters on engine vibrations. Therefore, the present work has been conducted based on this concern and research gap. The present work is important because it shows the pure vibrations

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caused by the mechanical excitations of the cranktrain mechanism without the influence of other sources such as combustion phenomenon, camshaft mechanism, etc. Also, the contribution of different components of the cranktrain mechanism from the overall vibrations caused by it has been determined under different lubrication conditions, which did not exist before.

2. Methodology

The experimental procedure involved the instrumentation of the engine with two single axis accelerometers in order to measure the level of vibration in a specific point of the engine, besides the employment of testing procedures and the analysis of the experiment data.

Two uniaxial accelerometers installed on the thrust side of the engine block was used in order to acquire data on both horizontal and vertical accelerations of the engine block. The accelerometers used for testing were a piezoelectric accelerometer model PCB 357B11 (Table 1). Figure 1 shows the orientation of the accelerometers on the block to measuring the engine vibration. The direction (Y) represents the horizontal vibration in the block and (Z) represents the vertical vibration in the block. The vibration signals passed through a Brüel & Kjær (B & K) NEXUS conditioning amplifier type 2692 low noise version with a high bandwidth which has comprehensive high and low-pass filtering facilities. The data acquisition system consisted of an Advantech PCLD-8710 terminal board and data acquisition card type PCI-1710. The signals were recorded in a computer using MATLAB software.

Table 1: The specification of the used accelerometer sensor

Sensitivity ($\pm 10\%$)	0.31 pC/ms ⁻²
Frequency range (+10%)	16 kHz
Measurement range	± 22600 m/s ² pk
Temperature range	-71 to +288 °C
Weight	2 g
Dimension	7.1×8.4 mm

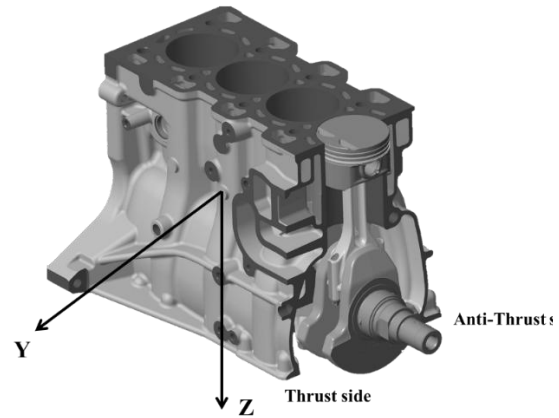


Figure 1: Orientation of the accelerometers on the engine block

The tests were carried out on a four-cylinder spark-ignition (SI) engine with the follow specification presented in Table 2. According to the purpose of this research, in order to eliminate the effects of the combustion phenomenon and the resulting forces on the engine vibrations, the standard test procedure of friction strip-down [16] was implemented.

Because the purpose of the present work was to investigate the vibrational behavior of crank mechanism, all other parts and mechanisms were removed from the engine, such as cylinder head,

Table 2: Technical Specifications of the used engine

Engine type	4-cylinder inline
Engine volume (L)	1.649
Combustion type	Spark ignition
Compression ratio	11
Cylinder diameter (mm)	78.6
Piston stroke (mm)	85
Maximum engine power	83 kW @ 6000 rpm
Maximum engine torque	153 N.m @ 3500 rpm
Valve number	16
Idle speed (rpm)	850
Maximum speed (rpm)	6500

accessories, etc. Instead of the cylinder head, a dummy cylinder head was used in this test. Dummy cylinder head was an empty box which was installed on the cylinder block instead of the real cylinder head, and had a similar function of the cylinder head with the difference that there was no any valvetrain and other moving components of the cylinder head to generate vibration. In the dummy cylinder head, the water and oil paths were inserted and one hole was replaced for each combustion chamber in order to see the piston movement. In other words, the only function of the dummy cylinder head was the completion of the water and oil circulation circuit of the engine and sealing the water and oil paths. For this test, the dummy cylinder head was made with the same dimension of the engine cylinder head (39×17×22 cm).

The friction strip-down test is normally carried out on a motoring test rig consisting of an electromotor to run the engine. Hence, the experiments in this paper were performed on a motoring test cell. In order to rotate the engine an electromotor was employed with power consumption of 360 V and 113 A, and maximum output power, torque and rotational speed of 60 kW, 143 Nm and 10000 rpm, respectively. The engine rotational speed was measured during the tests by a torque flange. The equipment used for the experiments is given in Table 3. Figure 2 shows the engine under study installed on the test cell with all equipment needed for vibration tests.

To ensure the repeatability of the test in terms of temperature, different sensors were installed in different places of the engine. The oil temperature in the main gallery of the engine block and the oil sump temperature sensors were among the important sensors such that their accuracy and precision could affect the test results. In each test, the same oil temperature and pressure was provided by an oil conditioning system. For measuring the temperature at different locations of the engine, resistance temperature detector (RTD) sensors with a high precision were used. The experiments were performed with a temperature accuracy of 0.2 °C. Before starting the data acquisition, in order to ensure the accuracy of sensors and other equipment, all of them underwent careful calibrations.

Table 3: Equipment used for the experiments

Equipment name	Accuracy	Description
Electric Motor	---	Manufactured by WITTUR Electric Model 2SB3
Torque flange	0.1 N.m	Manufactured by Dr. Staiger Mohilo Type 0125DF
Data logging software	---	Manufactured by Dr. Staiger Mohilo Model UMV2000
Oil flow meter	0.05 lit/min	Manufactured by Bopp & Reuther Messtechnik Model UST1
Coolant meter	flow 1 lit/min	Manufactured by ISOIL
Ambient air temperature sensor	1 °C	Sensor type was RTD (with high resolution for measurement) It was calibrated before the test
Engine coolant temperature sensor	0.1 °C	
Engine oil temperature sensor	0.1 °C	
Engine coolant pressure sensor	2 kPa	It was calibrated before the test
Engine oil pressure sensor	1 kPa	It was calibrated before the test
Water heat exchanger	---	To control the engine cooling fluid temperature
Oil conditioning system	---	Engine oil pressure and temperature controller device manufactured by AVL
External water pump	---	To pump engine coolant

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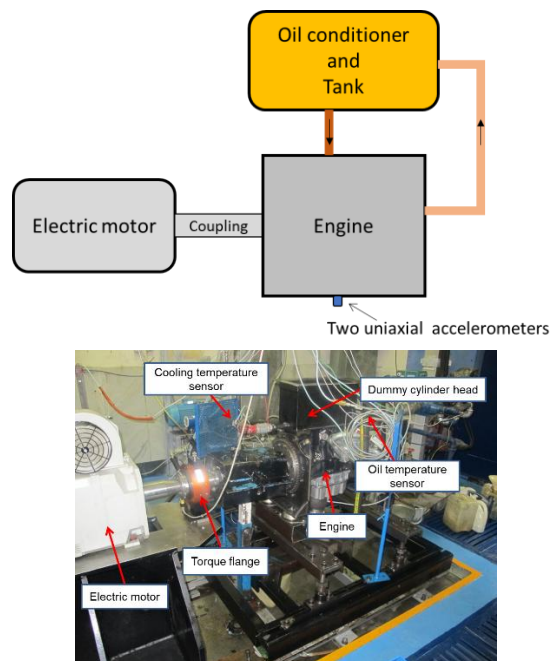


Figure 2: Schematic and real experimental test setup used in the present study

Data were acquired with SAE 20w50 and 10w40 lubricant oils under three temperatures of 35, 60 and 90 °C. The experiments were carried out at specific engine speeds between 1000 to 6000 rpm with increments of 500 rpm. In each test, the engine speed was held for 10 min until the coolant and oil temperatures became stable and reached the allowable range. Simultaneously with the vibration data, the engine data including speed and coolant and oil temperatures were acquired for 30 s at a rate of 1 Hz. The tests were performed twice for each case to ensure the repeatability.

In order to investigate fully the vibrational behavior of the cranktrain components, the following two different cases were considered for the tests:

- 1) Engine block containing complete cranktrain mechanism (crankshaft + reciprocating masses)
- 2) Engine block containing crankshaft alone: To eliminate the reciprocating masses, the connecting rods were cut from their center of gravity to prevent unwanted excitations by unbalance.

3. Results and Discussion

The analysis of the results consisted in correlating the vibration data measured on the cylinder block in horizontal and vertical directions as analyzed as a function of the engine rotational speed, oil type and temperature and crankshaft mechanism used in the tests. The analysis of the data in average of the horizontal and vertical vibration was done using the Root Mean Square (RMS). The obtained results are presented and discussed in this section.

3.1. Comparison of the effect of oil temperature on vibrations

In this section, in order to show the effect of oil temperature on the vibrations over different engine speeds, the results were obtained for a same oil type. These results are presented for the mentioned two cases; 1) the complete cranktrain mechanism (crankshaft + reciprocating masses) 2) crankshaft alone:

3.1.1. With complete cranktrain mechanism

Figure 3 shows both horizontal and vertical vibration measurements of the cylinder block as a function of the engine speed and oil temperature. The intensity of the horizontal and vertical vibrations of the engine cylinder block running with SAE 20W50 lubricant oil under different oil temperatures increased with the engine speed rise. This increase is due to increased dynamic load on the cranktrain components with increased engine speed. However, the vibration amplitude of the fundamental frequency of the rotation speed and its harmonics increases with speed rise.

A closer look shows that RMS values of the vertical vibration for the temperatures of 35, 60 and 90 °C were the same at the speed of 1000 rpm as approximately 0.4 V. This value increased equally up to around 2500 rpm for the three temperatures, but from this point on, the increase was different for the temperatures until the vertical vibration value at 6000 rpm for the temperatures of 35, 60 and 90 °C reached 0.85, 0.86 and 0.9 V respectively. The reason why this increase was greater for the temperature of 90 °C is because the oil viscosity decreases with increasing temperature and the oil loses its damping properties with decreasing viscosity. Although decrease of viscosity improves the

engine friction, it has a negative effect on the vibration damping.

Similar to the vertical vibration, the RMS value of the horizontal vibrations for all three temperatures were approximately the same up to 2500 rpm and from this point on, the differences began. Unlike the vertical vibration, the horizontal vibration at oil temperature of 35 °C up to 5500 rpm was higher than of the vibration at oil temperature of 60 °C. Also, from 3500 rpm to about 4500 rpm, the oil temperature of 35 °C generated more horizontal vibration even than 90 °C temperature, but from about 4750 rpm onwards, the horizontal vibration at 35 °C experienced a decreasing trend, but at 90 °C temperature, it continued to increase. It can also be seen that the difference in RMS value of the horizontal vibration at 6000 rpm between different temperatures was greater than the vertical vibration. In this speed, the oil temperature of 90 °C generated the highest horizontal vibration with value 0.61 V. In general, in this test case, for all three oil temperatures, the vertical vibration amplitude level was significantly higher than the horizontal vibration of the engine block.

3.1.2. Cranktrain mechanism without reciprocating masses

Figure 4 shows both horizontal and vertical vibration measurements of the cylinder block under working of alone crankshaft as a function of the engine speed and oil temperature.

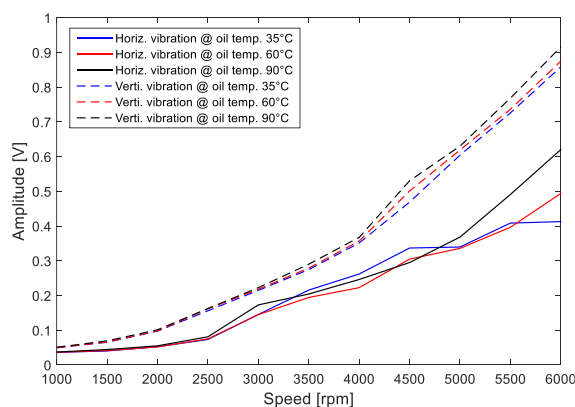


Figure 3: Engine vibration in horizontal and vertical directions with complete cranktrain configuration under different oil temperatures

According to this figure, it can be seen that the horizontal and vertical vibrations of the engine block that only had a crankshaft experienced an almost increasing trend with increasing engine speed under all three oil temperatures. This is due to the increase in the vibration amplitude at the fundamental frequency of the revolution. This increase in the vibration was almost the same for all three temperatures in both horizontal and vertical directions, so that at different speeds the horizontal and vertical vibration values were almost constant for the temperatures of 35, 60 and 90 °C. This shows that the oil temperature does not have much effect on the block vibrations caused by the rotation of the crankshaft. It can also be seen that the horizontal and vertical vibrations were generally almost the same up to 4500 rpm. This is because since the alone crankshaft has a rotational motion, the forces it exerts in the horizontal and vertical directions are almost uniform. Of course, it can be seen in the diagram that from 4500 to 6000 rpm, the horizontal vibration experiences a greater increase than the vertical vibration. This could be due to the different paths that the vibration is transmitted to the measurement point through the horizontal and vertical directions. It could also be due to the different shape modes of the vibration of the block in the horizontal and vertical directions and the greater excitations caused by the crankshaft rotation at the speeds above 4500 rpm. The highest values of the horizontal and vertical vibrations at 6000 rpm belonged to the temperatures of 60 °C and 35 degrees with the values of 0.091 V and 0.085 V, respectively.

3.2. Comparison of the effect of cranktrain components on vibrations

In this section, in order to show the effect of crank system components on the vibrations at different engine speeds, the results were presented for 50w20 oil type. These results are presented for the three temperatures of 35, 60, and 90 °C as follows:

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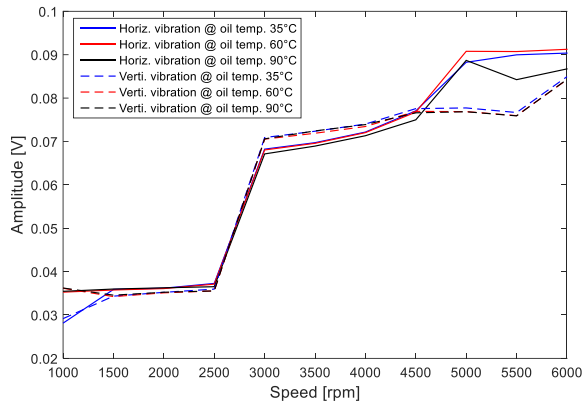


Figure 4: Engine vibration in horizontal and vertical directions with crankshaft alone under different oil temperatures

3.2.1. At oil temperature of 35 °C

Figure 5 shows both horizontal and vertical vibration measurements of the cylinder block with/without reciprocating masses at 35 °C oil temperature under different engine speed. According to this figure, it can be seen that the amplitude of the vertical and horizontal vibrations of the engine in the two cases of crankshaft alone and crankshaft+reciprocating masses increased with increasing speed. This increase was very significant for the case where the engine had crankshaft and reciprocating masses, so that for the vertical vibration, this increase occurred exponentially. But for the case where the engine only contained the crankshaft, the amplitude of the horizontal and vertical vibrations was firstly almost the same, which is because the forces and movements applied by the crankshaft the bearings cause its uniform movement around its center, in the horizontal and vertical directions. Secondly, the amplitude of the horizontal and vertical vibrations in the case of the crankshaft alone remained almost constant from 1000 to 2500 rpm, experienced a 50% increase from 2500 to 3000 rpm, and from this speed to 6000 rpm, it remained almost constant again. This is probably due to the complete balance and alignment of the crankshaft and bearing assembly. That is, there is no major imbalance or misalignment in the assembly that the oil would try to dampen. In the crankshaft+reciprocating masses configuration, the engine's vertical vibration amplitude was

approximately 2 times the maximum horizontal vibration amplitude of the engine. The vertical and horizontal vibrations of the engines containing only the crankshaft, with 50w20 oil at 35 °C, reached their maximum value at 60 rpm and were close to 0.1 V, while the engine with the crankshaft+reciprocating masses configuration had a maximum at 6000 rpm. The vertical and horizontal vibrations were approximately 0.85 and 0.4, respectively. Consequently, by removing the reciprocating mass, the amplitude of the vibrations was greatly reduced, with the vertical and horizontal vibrations being reduced by a factor of 8.5 and 4, respectively, compared to the case where the reciprocating masses were present. This indicates that the contribution of the reciprocating masses to the vertical and horizontal vibrations was much greater than that of the crankshaft alone, so that the ratio of the contribution of reciprocating masses to the crankshaft to vertical and horizontal vibrations of an engine with 50w20 oil at a temperature of 60 °C is approximately 7.5 to 1 and 3 to 1, respectively.

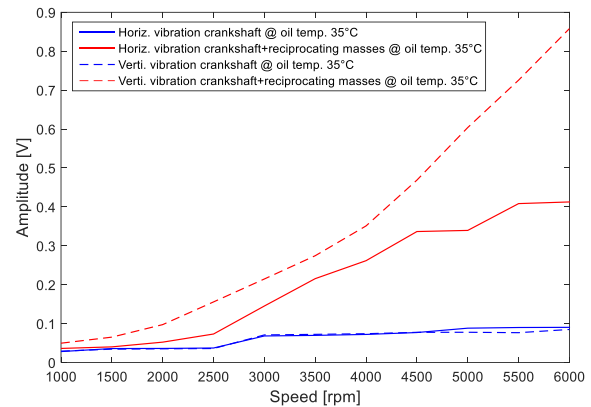


Figure 5: Engine vibration in horizontal and vertical directions with different cranktrain configurations under oil temperature of 35 °C

3.2.2. At oil temperature of 60 °C

Figure 6 shows both horizontal and vertical vibration measurements of the cylinder block with/without reciprocating masses at 60 °C oil temperature under different engine speed. As show in this figure, it can be seen that, similar to the 35 °C oil temperature, the amplitude of the vertical and horizontal vibrations of the engine in

the two cases of crankshaft alone and crankshaft + reciprocating masses configuration increased with increasing speed. However, this increase was much less for the case in which the engine contained only the crankshaft than for the case in which reciprocating masses were also present. Reciprocating masses caused the vertical and horizontal vibrations to raise sharply and exponentially with increasing the engine speed. According to this figure, similar to the 35 °C oil temperature, the amplitude of the horizontal and vertical vibrations in the crankshaft alone case was almost constant from 1000 to 2500 rpm, and at 3000 rpm it increased by 50% and remained almost constant again until 6000 rpm. In the crankshaft+reciprocating masses case, the maximum amplitude of the vertical vibration of the engine was approximately 1.7 times the maximum amplitude of the horizontal vibration of the engine. The amplitude of vertical and horizontal vibrations of the engine containing only the crankshaft, with 50w20 oil at a temperature of 60 °C, reached its maximum value at a speed of 6000 rpm to about 0.1 V, while the engine with the crankshaft and reciprocating mass at 6000 rpm had vertical and horizontal vibrations of about 0.85 and 0.5 V, respectively. Consequently, by adding reciprocating masses, the amplitude of vibrations increased sharply so that compared to the case where only the crankshaft was present, it increased by 8.5 and 5 times in the vertical and horizontal directions, respectively. This indicates that the ratio of the contribution of the reciprocating masses to the crankshaft in the vertical and horizontal vibrations of the engine with 50w20 oil at a temperature of 60 °C is about 7.5 to 1 and 4 to 1, respectively. Compared to the previous figure, at an oil temperature of 60 °C, the contribution of reciprocating masses from vertical vibrations is almost constant, but from horizontal vibrations it has increased.

3.2.3. At oil temperature of 90 °C

Figure 7 shows both horizontal and vertical vibration measurements of the cylinder block with/without reciprocating masses at 90 °C oil temperature under different engine speed.



Figure 6: Engine vibration in horizontal and vertical directions with different cranktrain configurations under oil temperature of 60 °C

According to this figure, it can be seen that, similar to the two oil temperatures of 35 and 60 °C, the amplitude of the vertical and horizontal vibrations of the engine in the two case of crankshaft alone and crankshaft+reciprocating masses configuration increased with increasing speed. However, this increase was much more significant for both vertical and horizontal vibrations in the case where reciprocating masses were present, so that its changes were exponential. According to this figure, similar to the two oil temperatures of 35 and 60 °C, the amplitude of the horizontal and vertical vibrations of the engine with the crankshaft alone increased by 50% only from 2500 to 3000 rpm and was constant before 2500 rpm and after 3000 rpm. In the crankshaft+reciprocating masses case, the maximum amplitude of the vertical vibration of the engine was approximately 1.5 times the maximum amplitude of the horizontal vibration of the engine. The amplitude of vertical and horizontal vibrations of the engine containing only the crankshaft, with 50w20 oil at a temperature of 90 °C, reached its maximum value at a speed of 6000 rpm to about 0.1 V, while the engine with a crankshaft and reciprocating masses at 6000 rpm had vertical and horizontal vibrations of about 0.9 and 0.6, respectively. Consequently, with the presence of reciprocating masses, the amplitude of the engine vibrations increased sharply so that compared to the case where the reciprocating masses were not present, the vibrations in the vertical and horizontal

directions grew by 9 and 6 times, respectively. This indicates that the ratio of the contribution of the reciprocating masses to the crankshaft in the vertical and horizontal vibrations of the engine with 50w20 oil at a temperature of 90 °C is about 8 to 1 and 5 to 1, respectively. Compared to the previous figure, with the oil temperature increasing to 90 °C, the reciprocating masses increased both vertical and horizontal vibrations more than before, but they affected horizontal vibrations more than vertical vibrations. This increase is due to the decrease in oil viscosity due to the increase in temperature, which causes the oil film between the piston and the cylinder to become thinner and less able to support and dampen the forces resulting from the secondary movement of the piston, so this effect is more manifest in the horizontal direction. The effect of the crankshaft in changing the vertical and horizontal vibrations of the engine with the change in oil temperature was not noticeable, which indicates that the role of balancing and alignment in the crankshaft and bearing assembly was more prominent than the change in oil viscosity due to the increase in temperature from 35 to 90 °C.

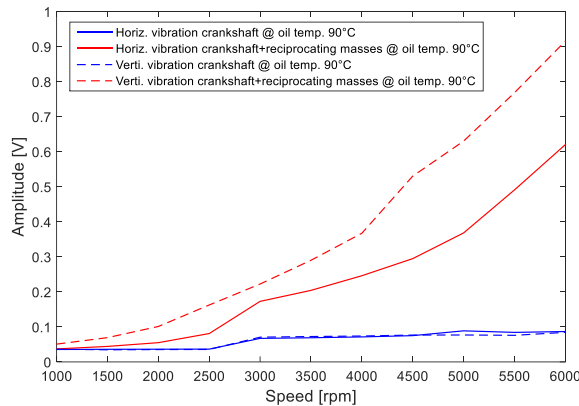


Figure 7: Engine vibration in horizontal and vertical directions with different cranktrain configurations under oil temperature of 90 °C

3.3. Comparison of the effect of oil type on vibrations

In this section, in order to show the effect of oil type on the vibrations at different engine speeds, the results are presented for different oil types, oil temperatures and cranktrain configurations.

3.3.1. With complete cranktrain mechanism at a constant oil temperature of 60 °C

Figure 8 shows the changes in the amplitude of the vertical and horizontal vibrations of the engine at complete cranktrain mechanism and with two types of oil 10w40 and 20w50 at a temperature of 60 °C. As can be seen in this figure, the amount of vertical and horizontal vibrations with both types of oil increased with increasing engine speed, but the rate of increase for vertical vibrations was greater than for horizontal ones, so that the maximum value of vertical vibration in this case reached approximately 0.85 V whereas the maximum value of horizontal vibration reached approximately 0.5 V. Another thing that can be understood from this figure is that changing the type of oil had almost no effect on the vertical vibrations of the engine at any of the engine speeds. This means that the change in oil viscosity has no effect on the vibrations caused by the movement of the reciprocating masses and crankshaft in the vertical direction of the engine, because, considering the greater share of forces caused by the movement of the reciprocating masses in the vibrations of the engine compared to the crankshaft, oil has no role in damping these forces in the vertical direction. On the other hand, considering that one of the main factors in damping horizontal forces caused by the movements of the piston and rings is oil, its viscosity should logically affect the vibrations caused by these horizontal forces. This hypothesis is proven in Figure 8. It can be seen that the amount of horizontal vibrations of the engine up to 2000 rpm is similar for both types of oil, but from 2000 rpm onwards, this amount is higher with 10w40 oil than with 20w50 oil, but at 6000 rpm they are almost equal. Therefore, the results show that at a temperature of 60 °C, the use of thinner oils due to lower viscosity causes the oil film to become thinner and less able to maintain horizontal forces caused by piston and ring movements, resulting in increased vibration in this direction, but it has virtually no effect in the vertical direction.



Figure 8: Engine vibration in horizontal and vertical directions with complete cranktrain configuration and two lubricant types under oil temperature of 60 °C

3.3.2. With complete cranktrain mechanism at a constant oil temperature of 90 °C

Figure 9 shows the changes in the amplitude of the vertical and horizontal vibrations of the engine for complete cranktrain mechanism with two types of oil 10w40 and 20w50 at a temperature of 90 °C. As can be seen in this figure, the amount of vertical and horizontal vibrations increased with both types of oil with increasing engine speed, but the rate of increase for vertical vibrations was slightly higher than for horizontal vibrations. Compared to a temperature of 60 °C, the rate of increase in horizontal vibration due to increasing engine speed was higher at a temperature of 90 °C. In this case, the maximum value of vertical vibration reached 0.9 V and the maximum value of horizontal vibration reached 0.6 to 0.7 V. It can also be seen that, similar to a temperature of 60 °C, changing the type of oil had almost no effect on the vertical vibrations of the engine at any of the engine speeds. However, the amount of horizontal vibrations of the engine from 3000 rpm onwards was higher with 10w40 oil than with 20w50 oil. These results again show that the use of thinner oils, due to lower viscosity, increases vibration in the horizontal direction but has no effect in the vertical direction.

3.3.3. With crankshaft alone at oil temperatures of 35 and 60 °C

Figures 10 and 11 show the changes in the amplitude of the vertical and horizontal vibrations of the engine in the presence of only the crankshaft, that is, in the absence of reciprocating masses, and with two types of oil 10w40 and 20w50, respectively, at temperatures of 35 and 60 °C. Considering these two figures, which contain almost similar results, it can be said that in practice the amount of horizontal and vertical vibration of the engine in the operation case of crankshaft alone does not differ significantly from each other. As mentioned earlier, this is because the balanced and aligned crankshaft introduces similar excitations in the radial direction to the bearings, so the amount of vibrations in the two horizontal and vertical directions will be the same due to these similar excitations. It can also be seen in these two figures that changing the type of oil practically did not have a noticeable effect on the horizontal and vertical vibrations caused by the operation of the crankshaft alone, except from 4500 rpm onwards, when this difference was small at a level of 0.02 V. This was also due to the good balancing of the crankshaft and the absence of components such as pistons that cause imbalance, so the viscosity of the oil will play a lesser role in this case. At high speeds, the increase in vibration could have been due to phenomena such as oil whirl and oil whip, although this claim needs to be investigated and proven more precisely.

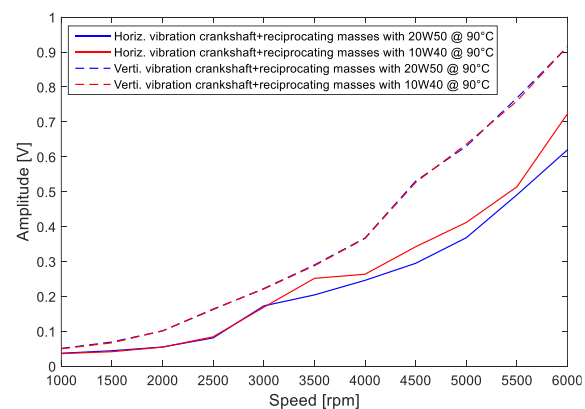


Figure 9: Engine vibration in horizontal and vertical directions with complete cranktrain configuration and two lubricant types under oil temperature of 90 °C

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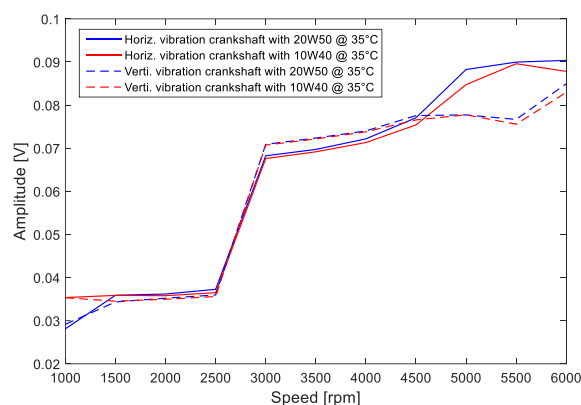


Figure 10: Engine vibration in horizontal and vertical directions with crankshaft alone and two lubricant types under oil temperature of 35 °C

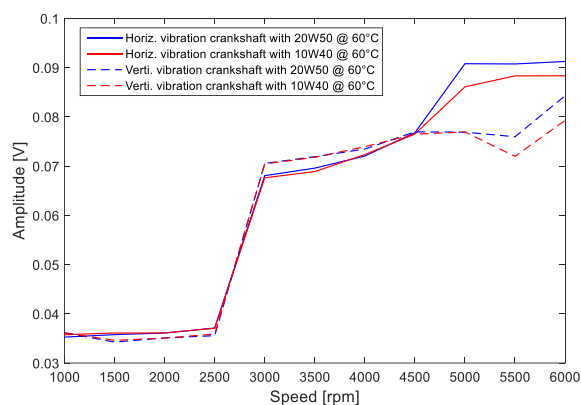


Figure 11: Engine vibration in horizontal and vertical directions with crankshaft alone and two lubricant types under oil temperature of 60 °C

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Conclusion

The Investigation of vibration behavior of different engine components and its change in different engine operating conditions, as well as the contribution of each component to the overall engine vibrations, are important factors that help designers in optimal design. Accordingly, in this work, the horizontal and vertical vibrations of the

crankshaft mechanism under different conditions of oil type and temperature were investigated by designing and implementing a special test in the motoring mode. The results demonstrated that the vibration due to cranktrain mechanism in both horizontal and vertical directions increases with increasing engine speed in all of the oil type and temperature variations. The contribution of vibrations due to reciprocating masses with the same oil type under all three different temperatures of 35, 60 and 90 °C, was much higher than that of the crankshaft, with a ratio of about 7 to 9 to 1. Due to the balance and alignment of the crankshaft, the changes in vibrations due to the crankshaft alone were not noticeable. The changes in vibrations due to reciprocating masses were affected by changes in the oil temperature. This amount was about 5% at its maximum for vertical vibrations, but about 50% for horizontal vibrations. Vertical vibrations caused by reciprocating masses at a constant temperature of 90 °C, were not noticeably different for the 10w40 and 20w50 oils, so changing the oil type has almost no effect on the vertical vibrations of the engine caused by the movement of reciprocating masses at any of the engine speeds. Horizontal vibrations caused by reciprocating masses at a constant oil temperature changed with the change in the oil type, so that this value, at its maximum, which occurred at 6000 rpm, increased by 16% with 10w40 oil compared to 20w50 oil. These results indicate the strong role of oil viscosity in suppressing horizontal excitations to the engine block, meaning that higher viscosity results in thicker oil films and, consequently, greater damping of the applied forces.

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