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Vibration Effects on Spark Ignition Engine Fuelled with Methanol and Ethanol Gasoline Blends

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Abstract: An experimental investigation of vibration effects on spark ignition engine fuelled with ethanol and methanol gasoline blend fuels is presented in this paper. Three fuels were used, namely: unleaded gasoline as a base fuel for com arison, and two alcohols, namely methanol and ethanol, blended with gasoline at 10%, 20% and 30% (by volume). Engine test conditions were at 1000, 1300, 1600 and 1900 rpm. Apparatuses used in the present study were a non-road single cylinder spark ignition engine, a hydraulic dynamometer and a vibration analyzer. Experimental results indicated that vibration values of gasoline had higher amplitudes at 1000-1300 rpm, while methanol gasoline blend fuels had higher amplitudes at 1600-1900 rpm. These results can be explained by the changing of the combustion process, which was caused from fuel properties of blend fuels.

Key words: Ethanol, methanol, gasoline, blend, fuel, spark ignition engine, vibration

INTRODUCTION

There are a variety of ways to use bio-fuels for power generation. One possibility is to produce liquid or gaseous bio-fuels that can be burnt in engines that currently burn fossil fuels. Between bio-fuels are also the alcohols, such as ethanol and methanol. Sucrose and starch can be converted into ethanol by hydrolysis and fermentation. There is also the possibility of converting sugar in whey and starch and sugar in wastes into ethanol by fermentation (Prasad et al., 2007; Acharya and Young, 2008). Ethanol has lower heating value, and it is hygroscopic and more corrosive. However, in practice, ethanol may do well as transport fuel in spark ignition (SI) engines, both as such and as a blend with fossil fuel (Szklo et al., 2007). The methanol can be produced via synthesis gas from glycerol or biomass with acceptable energy cost (Huber et al., 2006). Methane can furthermore be converted into methanol (Cantrell et al., 2008). Methanol, in turn, can be blended into gasoline up to 15% by volume and applied in SI engines without major modifications.

The use of alcohol blended with gasoline was a subject of research in the 1980s and it was shown that ethanol and methanol gasoline blends were technically acceptable for existing SI engines. There is a considerable amount of literature relative to various blends of ethanol, methanol and gasoline. El-Kassaby (1993) investigated the effect of ethanol gasoline blends on spark ignition engine performance. Abdel-Rahman and Osman (1997) carried out performance tests using different percentages of ethanol in gasoline fuel, up to 40%, under variable compression ratio conditions. Al-Hasan (2002) showed that blending unleaded gasoline with ethanol increased the brake power, torque, volumetric and brake thermal efficiencies and fuel consumption, while it decreased the brake specific fuel consumption and equivalence air-fuel ratio. Wu et al. (2004) tested ethanol gasoline blended fuel in a conventional engine under various air–fuel equivalence ratios (λ) for its performance and emissions. Liu et al. (2007) show that the engine power and torque will decrease with the increase fraction of methanol in the fuel blends under wide open throttle (WOT) conditions.

The effects of using ethanol and methanol unleaded gasoline blends on emissions characteristics in spark ignited engine have been investigated by other researchers. Palmer (1986) showed that 10% of ethanol addition to gasoline could reduce the concentration of CO emission up to 30%. Bata et al. (1989) had tested different blend rates of ethanol gasoline fuels in engines, and found that the ethanol could reduce the CO and UHC emissions. Taylor et al. (1996) used four alcohol fuels to blend with gasoline and concluded that adding ethanol can reduce CO, HC and NO emissions. Ceviz and Yüksel (2005) investigated the effects of using ethanol unleaded gasoline blends on cyclic variability and emissions in a spark-ignited engine.

While the effects of use alcohols (methanol and ethanol) on spark ignition engine performance and emissions has been investigated adequately, very little research has been done reported on the effects of methanol and ethanol on spark ignition engine vibration characteristics and noise emissions. Othman et al. (1998) investigated vibrations with different fuels, such as kerosene, gas, oil, methanol, and methanol-kerosene blend, using a simple turbo-shaft gas turbine engine with a free turbine driving dynamometer. Vibration patterns over the range of operating conditions were obtained with a real time spectrum analyzer. It was found that the combustion driven oscillations increase with the carbon-hydrogen ratio of the fuel. The frequency and amplitude of the fundamental harmonics decreases with load increase. It was shown that the combustion-induced vibration levels in an engine could be predicted for off-design speeds and fuels; this will be useful for design and diagnostic purposes. Ajovalasit and Giacomin (2003) have studied the variations in diesel engine idle vibration caused by fuels of different composition and their contributions to the variations in steering wheel vibrations. The time-varying covariance method (TV-AutoCov) and time–frequency continuous wavelet transform (CWT) techniques were used to obtain the periodic and transient characteristics of the vibration data acquired from two turbocharged four-cylinder, four-stroke diesel engine vehicles at idle under 12 different fuel conditions. Flekiewicz et al. (2007) investigated effects of gasoline and liquefied petroleum gas (LPG) on combustion pressure and vibration of a spark ignition engine. Increase of engine load and speed caused the increase of engine block vibration accelerations, for gasoline in the range of 22.1 to 100.5 m/s^2, and for LPG operation from 4.1 to 95.5 m/s^2. Keskin (2010) investigated effects of ethanol-gasoline-oil blends on the spark ignition engine vibration characteristics and noise emissions. Experimental results indicated that when the blend fuels were used, vibration amplitudes and noise emission of the engine showed a trend of increasing significantly at 1500 and 2500 rpm. These cause of these results is probably the higher oxygen content and higher latent heat of evaporation of ethanol, due to which the increasing rate of pressure and peak pressure values in the cylinder rise during the combustion processes.

The aim of this paper is to study effects of ethanol and methanol gasoline blends on the SI engine vibration characteristics. During the experimental procedure vibration measurements were carried out for different engine running conditions. Vibration characteristics of the engine with blend fuels and gasoline were analyzed and compared.

MATERIALS and METHOD

A series of experiments were carried out using standard gasoline, and the various ethanol and methanol gasoline blend fuels, with different blended rates such as 10%, 20% and 30%, which are called E10, E20, E30, M10, M20 and M30 respectively. The test blends were prepared just before starting the experiment to ensure that the fuel blend was homogeneous and prevent the reaction of ethanol with water vapor. The engine was started and allowed to warm up for a period of 20–30 min. Before running the engine with a new fuel blend, it was allowed to run for a sufficient time to consume the remaining fuel from the previous experiment. All the blends were tested under varying load and engine speed conditions. Engine tests were performed at maximum to idling rpm engine speed; especially tests were performed at 1900, 1600, 1300 and 1000 rpm. The required engine load was obtained through the dynamometer control unit.

Each fuel has its own set of combustion-related properties. These properties change the engine performance, emission and vibration characteristics. Laboratory tests were then carried out using ASTM tests standards to determine the combustion-related properties. A list of fuel properties that compares ethanol and methanol gasoline blended fuels is given in Table 1.

Table 1. Properties of different ethanol and methanol gasoline blended fuels.

Property item	Test fuel							Test method
	Gasoline	**E10**	**E20**	**E30**	**M10**	**M20**	**M30**	
Heat of combustion (MJ/kg)	44.133	42.447	40.672	38.673	41.615	38.233	36.247	ASTM D340
Reid vapour ressure (kPa)	35.00	59.53	54.61	53.31	57.43	66.58	68.74	ASTM D323
Research octane number	84.8	88.3	93.4	98.9	88.2	94.4	98.4	ASTM D2699
Density at 15.5ºC (kg/l)	0.7678	0.7760	0.7782	0.7794	0.7692	0.7707	0.7734	ASTM D1298
Distillation temperature (°C)								
IBT	38.5	39.5	40.3	40.7	43.2	43.7	44.5	ASTM D86
10 vol.%	57.2	52.3	55.4	55.7	48.2	50.4	51.3	
50 vol.%	93.5	71.8	71.6	72.5	81.0	79.7	81.6	
90 vol.%	156.0	143.7	143.1	142.7	165.1	164.8	164.7	
End point	181.7	176.1	176.6	176.5	206.2	206.3	206.7	

Apparatuses used in the present study were an engine, a dynamometer and a vibration analyzer. The schematic diagram of the experimental set-up is shown in Figure 1. A single cylinder, carburetted, four-stroke, spark ignition non-road engine (type Bernard moteures 19A), was chosen. Non-road gasoline engines differ from automotive engines in several technical specifications. This engine had a 56 mm bore and a 58 mm stroke (total displacement 143 cm^3). Its rated power is 2.2 kW. The ignition system was composed of the conventional coil and spark plug arrangement with the primary coil circuit operating on a pulse generator unit. The engine was coupled to a hydraulic dynamometer through elastic couplings. The dynamometer was equipped with an instrument panel fitted with a torque gauge and switches for load remote control.

The mechanical vibrations of the engine cylinder block, when an engine is operated with gasoline and alcohol gasoline blended fuels, were measured by a compact triaxial piezoelectric accelerometer type 4524-B from Brüel & Kjaer. An accelerometer was attached on the engine surface via mounting clip (UA-1407) bonded to the surface. The voltage signals of the accelerometer were sampled with the data acquisition unit PULSE type 3560-C from Brüel & Kjaer. PULSE system is a versatile, task-oriented sound and vibration analysis system. Its controller module handles communication with the PC while the input/output module handles measurement input and provides a sample clock. PC-based measurement system consists of a laptop PC with LAN interface, PULSE software, Microsoft Windows operating system, and Microsoft Office. The PULSE software system is a signal analysis software for performing FFT, CPB (1/n-octave) and Overall Level analysis with simultaneous measurements of exponential, linear, impulse and peak levels.

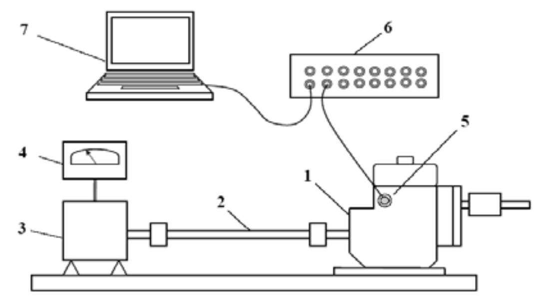

Figure 1. The schematic diagram of the experimental set-up

KEY

(1) Engine	(5) Triaxial piezoelectric accelerometer
(2) Shaft	(6) Vibration analyzer
(3) Dynamometer	(7) Laptop PC
(4) Dynamometer control unit	

RESULTS and DISCUSSION

Internal combustion engine vibration signals measured by accelerometer are multi-harmonic signals, which are recognizable, concentrated in short-time intervals, and distributed on the cycle period. Therefore, more appropriate analysis tools, like Fast Fourier Transform (FFT), are needed, to obtain frequency spectrum of vibration signals.

As it is well known, the vibration of an engine structure comprises of harmonic responses at frequencies that are integrally related to the engine combustion cycle frequency and of non-harmonic, constant frequency response due to excitation of the structure at its natural frequencies (Marples, 1977). Fgure 2 shows a 0-3x10^4 Hz and 0-1000 Hz spectrum along Z axis of the surface vibration at a particular point on the side wall with the engine running with test fuel E10, at maximum load, at 1000 rpm. The spectrum is plotted on a linear frequeny scale and not as a function of logarithm of frequency. It is evident that the most prominent components appear to lie between 153 Hz and 160 Hz. Other points of inerest revealed by the spectrum of Figure 2 are the presence of significantly high levels in the band centered at 69.21 Hz, the peak at the centre of the 424.4 Hz and the peak at 804.4 Hz. It should be noted that the above peaks are indicative harmonics of cycle frequency.

The analysis of the results for the X, Y and Z axis has shown similar features. Therefore, the results for the Z axis are presented as a first case study. In Figure 3, the frequency spectra along Z axis for the engine at different speeds when burning neat gasoline (G) and ethanol methanol gasoline blended fuels (E10 and M10). The frequency spectra of the engine with all fuels change significantly between 153-177 Hz. In general, vibration amplitude of the fundamental harmonics decreases with load increase. Vibration characteristics of gasoline had higher amplitude 4.729 m/s2 (158.3 Hz) at 1300 rpm, while methanol gasoline blend M10 had higher amplitude 6.066 m/s2 (162.5 Hz) at 1900 rpm. Ethanol gasoline blend E10 gave in comparison with others test fuels more stable amplitudes 3.933 m/s2 (160.6 Hz), 4.482 m/s2 (167 Hz) and 4.863 m/s2 (156.4 Hz) at 1300, 1600 and 1900 rpm respectively.

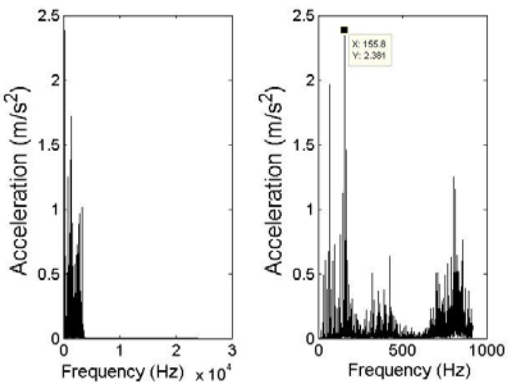

Figure 2. Accelaration spectrum along Z axis, when engine operated with E10, at 1000 rpm, averaged over 7 seconds.

As second case study the frequency spectra along Z axis are presented, when engine operated with gasoline (G) and ethanol gasoline blended fuels (E10, E20, E30), at different speeds (Figure 4). In comparison with gasoline, the vibration characteristics of the engine with other test fuels showed a trend of increasing. E10 exhibits the lowest acceleration level. Vibration characteristics of the engine with test fuels, at 1000 rpm, had similar amplitudes between 153 and 158 Hz. The maximum vibration value of the gasoline 5.954 m/s^2 (158.3 Hz) was measured at 1300 rpm, while the others test fuels E10, E20 and E30 gave significant lower values of 3.933 m/s^2 (160 Hz), 3.984 m/s^2 (159 Hz) and 3.471 m/s^2 (158.7 Hz) respectively. When burning test fuels at 1600 rpm, the overall vibration acceleration levels for the engine are very similar between 158.9-167.2 Hz. Also, as can be observed, vibration characterstics of the engine with E20 and E30 gave the highest acceleration amplitudes 7.41 m/s^2 (159 Hz) and 6.807 m/s^2 (158.8 Hz) respectively at 1900 rpm. Hence the vibration level was found to increase from E10 to gasoline and further to E30 and E20.

According to the above results, it is shown that the variation of the test fuels properties has an effect on the engine block vibration, because of changes in the combustion process. This behaviour is reported by two other investigators on different types of engines and fuel tests (Othman et al., 1998; Keskin, 2010).

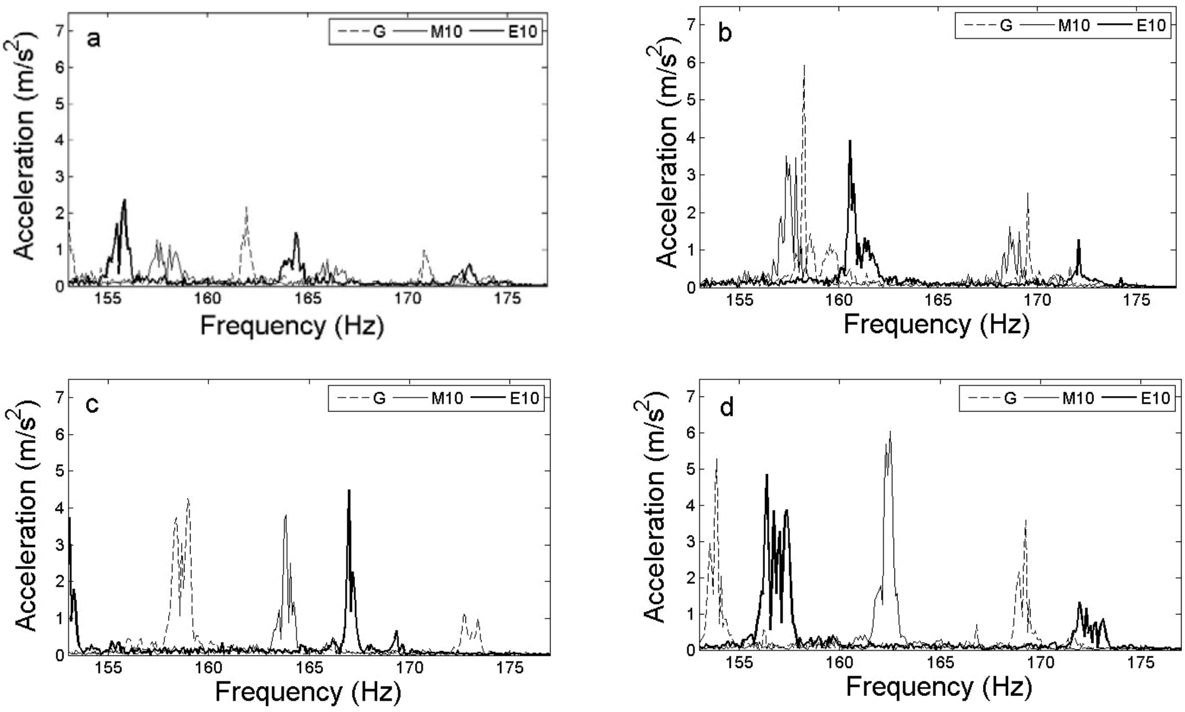

Figure 3. Frequency spectra along Z axis, when engine operated with gasoline (G) and alcohol gasoline blended fuels (E10 and M10), at different speeds: (a) 1000 rpm, (b) 1300 rpm, (c) 1600 rpm, and (d) 1900 rpm.

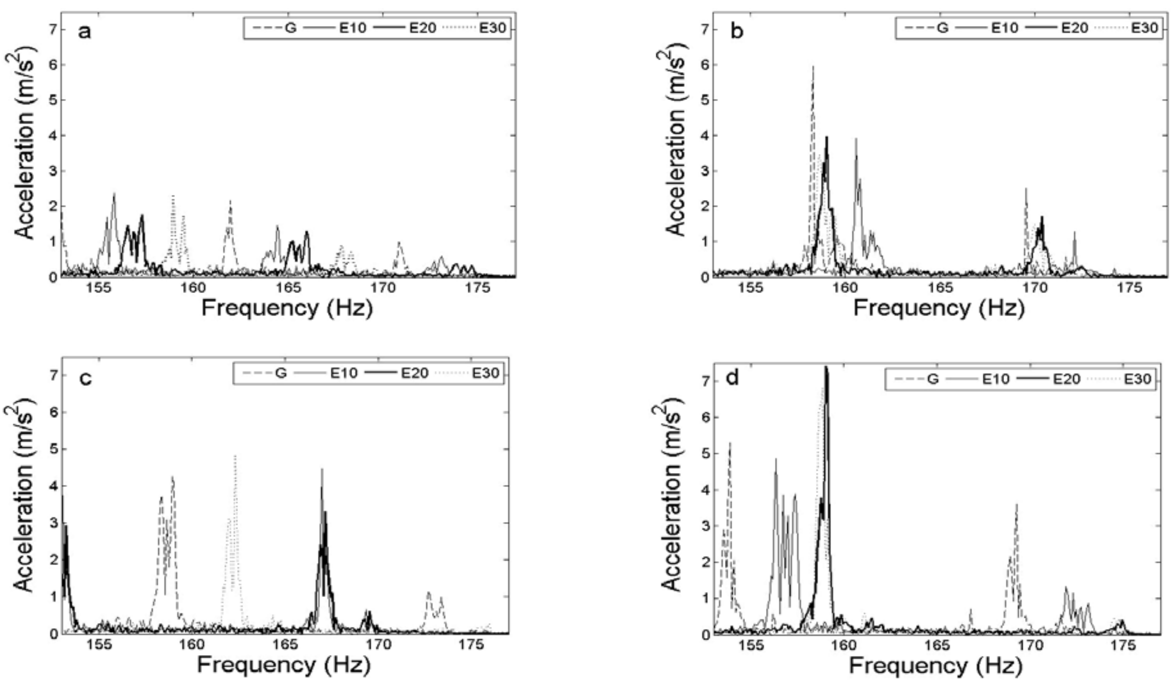

Figure 4. Frequency spectra along Z axis, when engine operated with gasoline (G) and ethanol gasoline blended fuels (E10, E20, E30), at different speeds: (a) 1000 rpm, (b) 1300 rpm, (c) 1600 rpm, and (d) 1900 rpm.

CONCLUSIONS

The use of appropriate hardware and software instrumentation for the detection and quantification of SI engine mechanical vibrations have been assessed and facilitated the comparison between vibration signals produced by different ethanol or methanol and gasoline blended fuels.

The frequency spectra of the engine with gasoline as base fuel and ethanol or methanol and gasoline blended fuels change significantly between 153-177 Hz. The acceleration amplitude of the fundamental harmonics decreases with increase of load or decrease engine speeds. Gasoline peaks appear to lay between a narrow band of 153-158.9 Hz. Ethanol gasoline blend E10 exhibits in comparison with others test fuels the most stable acceleration level. The frequency spectra of engine vibration at 1600 rpm can be used for fuel recognition.

These results can be explained by the changes in the combustion process, which was caused from fuel properties of blend fuels. Future work will focus more on vibration waveforms analysis using new signal processing methods.

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