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Analysis of the Effect of G95M5 Fuel Mixture on Engine Vibration Characteristics at Various Operating Speeds

S.M Rosdi[1], Mohd Hafizil Mat Yasin[1], Erdiwansyah[2,3], Muhtadin[4]

[1]Automotive Technology Center (ATeC), Politeknik Sultan Mizan Zainal Abidin KM 8 Jalan Paka, 23000 Dungun Terengganu
[2]Centre for Automotive Engineering, Universiti Malaysia Pahang Al Sultan Abdullah, 26600, Malaysia
[3]Department of Natural Resources and Environmental Management, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia
[4]Department of Mechanical Engineering, Universitas Abulyatama Aceh, Aceh Besar, 23372, Indonesia

Corresponding author: rosdi.salleh@psmza.edu.my

Abstract
This study analyzes the effect of using a G95M5 fuel mixture (95% gasoline + 5% methanol) on engine vibration characteristics at various operating speeds. The analysis was carried out in the frequency and time domains to identify changes in vibration patterns due to fuel variations. Tests were carried out at 1000 rpm and 1500 rpm, with an acceleration sensor used to measure vibration amplitude. The frequency spectrum results show that at 1000 rpm, G100 fuel (100% gasoline) produces a higher vibration acceleration peak of around 0.030 m/s², while G95M5 only reaches 0.005 m/s², indicating that methanol helps dampen vibrations at low speeds. However, at 1500 rpm, there is an increase in vibration acceleration in G95M5, with a maximum peak reaching 0.07 m/s², compared to G100, which is only 0.035 m/s². Time domain analysis shows the same trend: at 1000 rpm, G95M5 has a maximum vibration amplitude of ±0.006 m/s², lower than G100, which reaches ±0.028 m/s². Conversely, at 1500 rpm, the vibration amplitude of G95M5 increases to ±0.065 m/s², greater than G100, which is only ±0.04 m/s². These results indicate that methanol in the fuel mixture can dampen vibration at low speeds but increase vibration intensity at high speeds. Therefore, methanol content optimisation is needed to balance combustion efficiency and engine mechanical stability.

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1. Introduction

The use of alternative fuels in internal combustion engines has become a significant focus of research to improve energy efficiency and reduce environmental impacts. One of the most widely studied alternative fuels is methanol, which has advantages such as high-octane number, cleaner combustion, and the potential to improve engine thermal efficiency. Several previous studies have shown that methanol blends in gasoline can improve engine performance, reduce exhaust emissions, and affect combustion characteristics in the engine cylinder (Iliev, 2021; Pandey, 2022; Sani et al., 2018; Verhelst, Turner, Sileghem, & Vancoillie, 2019). However, its impact on engine vibration still needs further study, considering that changes in the physical and chemical properties of the fuel can affect combustion dynamics and engine mechanical stability. Previous studies have shown that adding methanol to fuel can improve combustion efficiency due to the higher oxygen content, which supports more complete combustion (Chen, Chen, Wang, Geng, & Zeng, 2020; Tian, Wang, Zhen, & Liu, 2022; Zikri, Sani, Yusop, Izzudin, & Sapee, 2019). The use of methanol blends in gasoline showed an increase in engine efficiency of up to 5%, with reduced carbon monoxide (CO) and hydrocarbon (HC) emissions (Bharath & Arul Mozhi Selvan, 2021; Sani, Zaki, Kadarohman, Sardjono, & Gani, 2021; Zhang et al., 2021). In addition, methanol mixtures can reduce knocking in high-compression engines, increasing engine components' service life, as found (Gandolfo, Lawler, & Gainey, 2024; Harrington, Hall, Bassett, & Cooper, 2023; Pu, Dejaegere, Svensson, & Verhelst, 2024). However, research on the effect of methanol mixtures on engine vibration is still limited, even though vibration is an important factor affecting the comfort and reliability of engine systems.

Several previous studies have examined the relationship between fuel characteristics and engine vibration levels in the context of vibration analysis. Changes in fuel composition can cause variations in vibration patterns, especially in the medium to high-speed range (Hunicz et al., 2023; Mahdisoozani et al., 2019; Masri, Amer, Salman, Ismail, & Elsisi, 2024). Another study revealed that fuels with lower calorific values, such as methanol, can change engine vibration patterns due to changes in in-cylinder combustion pressure (Bharath, 2022; Chandekar, Deka, Debnath, & Babu, 2022; Huang et al., 2020). This study emphasizes that it is essential to understand how fuel characteristics affect vibration dynamics to optimize engine performance and reduce component wear due to excessive vibration. Although various studies have discussed the benefits of methanol in improving combustion efficiency, only a few studies have specifically examined its effects on engine vibration frequency and amplitude in the time and frequency domains. An experimental study showed that adding methanol to gasoline causes changes in vibration patterns due to ignition characteristics and combustion pressure (K Bharath & V, 2024; Shen et al., 2023; Wei et al., 2020). However, this study is still limited to low engine speeds, so it cannot fully describe how methanol affects vibration at various engine speed levels. Therefore, further research is needed to understand how methanol blends affect vibration stability at low to high speeds.

This study aims to evaluate the effect of the G95M5 (95% gasoline + 5% methanol) mixture on engine vibration characteristics at 1000 rpm and 1500 rpm, both in the frequency and time domains. This study is expected to provide new insights into how this blended fuel affects engine operating stability by analysing the frequency spectrum and vibration acceleration. The results of this study are expected to contribute to the development of alternative fuel blending strategies that improve combustion efficiency and consider mechanical aspects such as vibration levels that can impact engine life. Thus, this study attempts to fill the gap in the existing literature by providing a more in-depth analysis of how methanol-based fuels affect engine vibration patterns at various speeds. This study can also provide a reference for the automotive industry in designing more stable and efficient blended fuels to improve overall engine performance.

2. Methodology

Fig. 1 shows a schematic diagram of a fuel blend engine test system with various sensors and measuring instruments. The engine under test has four cylinders (C1, C2, C3, and C4) with fuel supplied from the tank via a fuel pump, passing through a fuel return valve before being distributed to the engine. An in-cylinder pressure sensor is installed to measure the combustion pressure in the cylinder. At the same time, a vibration measurement system is connected to a computer to monitor the engine's operating dynamics. In addition, a crankshaft encoder is used to record the position and rotational speed of the crankshaft concerning the combustion cycle. In this system, the fuel flow can come from the main tank or an external fuel source, which passes through a heat exchanger before entering the engine to control the fuel temperature. The fuel flow is measured using a fuel flow rate sensor, while an exhaust gas analyzer analyzes the exhaust gas to evaluate emissions from the combustion process. Data from the various sensors is collected by a data acquisition system connected to the main computer, which also communicates with the dynamometer control to regulate the engine load. With this setup, the system can optimize engine performance and evaluate the impact of fuel mixture usage on engine operational and emission characteristics.

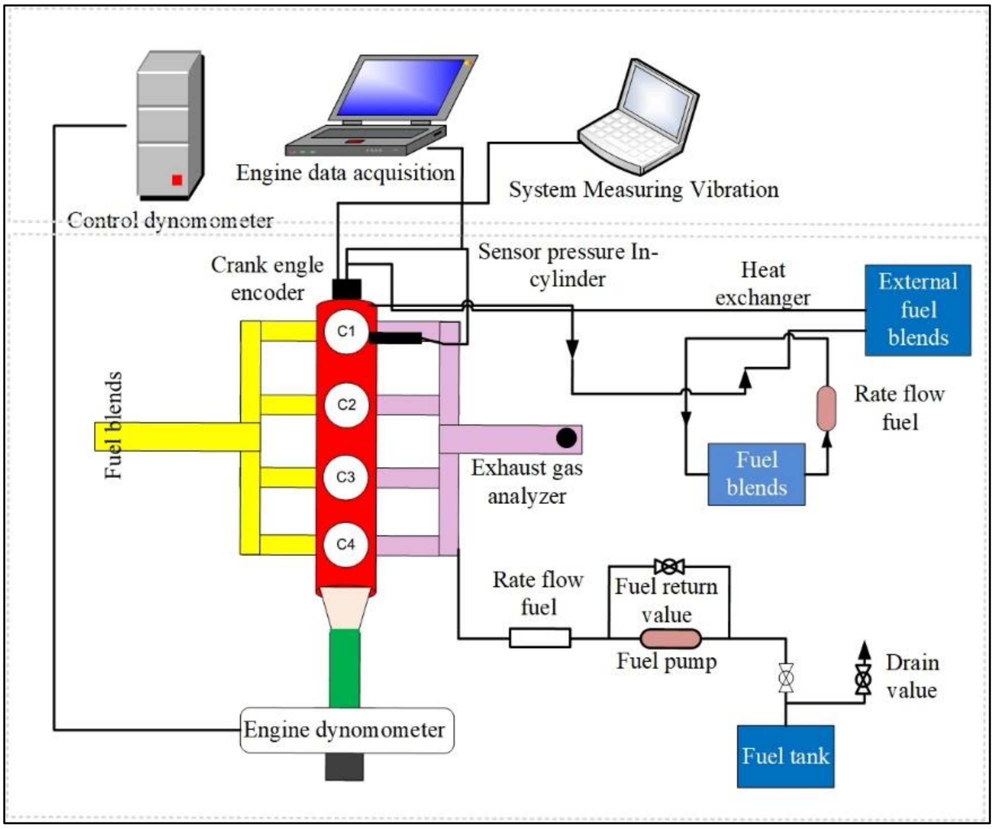

Fig. 1: Diagram of Schematic

3. Result & Discussion

Fig. 2 shows the vibration frequency spectrum at an engine speed of 1000 rpm for two types of fuels tested, namely G100 (100% gasoline) and G95M5 (95% gasoline + 5% methanol). The horizontal axis represents the frequency in Hertz (Hz), while the vertical axis shows the vibration acceleration in meters per second squared (m/s^2). The results show that G100 fuel produces higher vibration than G95M5, especially at the peak around 1000 Hz, where the acceleration value reaches around 0.030 m/s^2. In contrast, G95M5 fuel shows a much lower vibration response across the entire frequency range, with a peak value around 0.005 m/s^2. These findings indicate that adding 5% methanol to the fuel reduces engine vibration, which can be attributed to methanol's cleaner and more even combustion properties. In addition, the vibration energy distribution in G100 fuel is more spread out, with significant intensity at several harmonic frequencies above 1000 Hz, while G95M5 shows a more damped vibration spectrum. These results indicate that using fuel mixtures with methanol has the potential to reduce engine vibration levels, which in turn can impact operational comfort and reduce the potential for engine component wear due to excessive vibration.

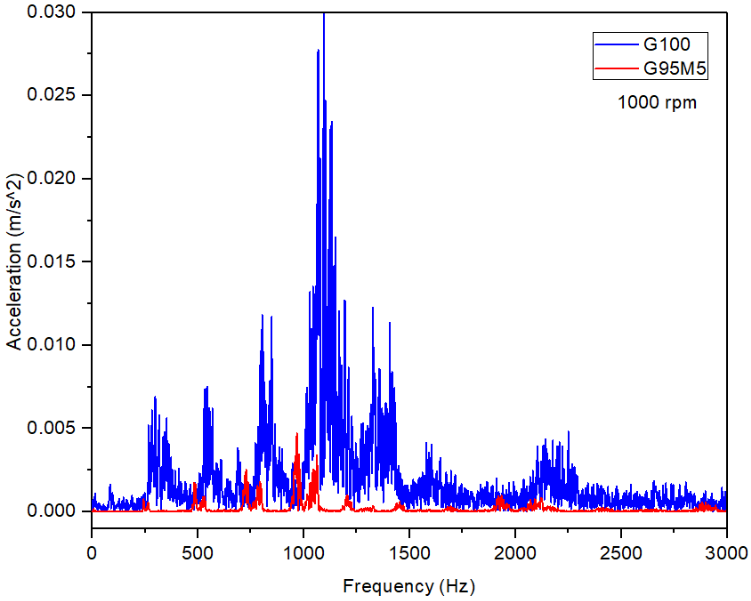

Fig. 2: Engine Vibration Spectrum at 1000 rpm with G100 and G95M5 Fuels

Fig. 3 shows the frequency spectrum of engine vibration at 1500 rpm for two types of fuel, namely G100 (100% gasoline) and G95M5 (95% gasoline + 5% methanol). The horizontal axis represents the frequency in Hertz (Hz), while the vertical axis shows the vibration acceleration in meters per second squared (m/s^2). In contrast to the results at 1000 rpm, at 1500 rpm, there is a significant increase in vibration acceleration, especially in G95M5 fuel compared to G100. The highest vibration peak in G95M5 occurs at around 1500 Hz with an acceleration value reaching 0.07 m/s^2, while G100 fuel has a lower peak of around 0.035 m/s^2 at the same frequency. These results indicate that at 1500 rpm, fuel with a mixture of 5% methanol produces a higher vibration level than pure fuel. This may be due to the difference in the combustion properties of methanol, which has a higher flame speed than pure gasoline, causing more significant pressure fluctuations in the combustion chamber. In addition, there is an essential secondary peak at around 1000 Hz for G95M5 fuel with an acceleration value of around 0.04 m/s^2, which is not dominant in G100. This phenomenon shows that although fuel with a mixture of methanol can increase combustion efficiency at certain speeds, it can also increase the level of engine vibration, which has the potential to affect operational comfort and the durability of engine components.

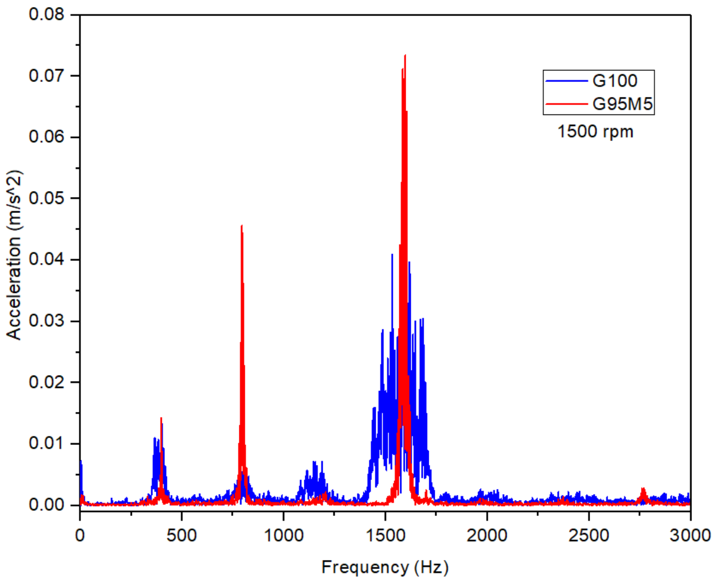

Fig. 3: Engine Vibration Spectrum at 1500 rpm with G100 and G95M5 Fuels

Fig. 4 shows the vibration acceleration response in the time domain at an engine speed of 1000 rpm for two types of fuel, namely G100 (100% gasoline) and G95M5 (95% gasoline + 5% methanol). The horizontal axis represents time in seconds (sec), while the vertical axis shows the vibration acceleration in meters per second squared (m/s^2). This graph shows that G100 fuel produces more significant acceleration fluctuations than G95M5, which is indicated by the dominance of the blue colour at the maximum vibration peak. The highest acceleration peak in G100 reaches around ±0.028 m/s^2, while in G95M5, the maximum acceleration value is only around ±0.006 m/s^2. This shows that using fuel with a mixture of methanol can significantly reduce the vibration intensity. In addition, the vibration distribution in G100 is more unstable, with a more considerable amplitude spike throughout the test time, especially at around 1000 seconds, with a very sharp increase in acceleration.
In contrast, in G95M5, the vibration pattern is more damped and regular, indicating that fuel with methanol content can reduce vibration instability during engine operation. This phenomenon can be attributed to methanol's more homogeneous combustion properties and increased combustion efficiency, which contribute to the reduction of excessive vibration. Thus, the use of G95M5 has the potential to improve operational comfort and extend the life of engine components due to reduced dynamic vibrations that can cause mechanical wear.

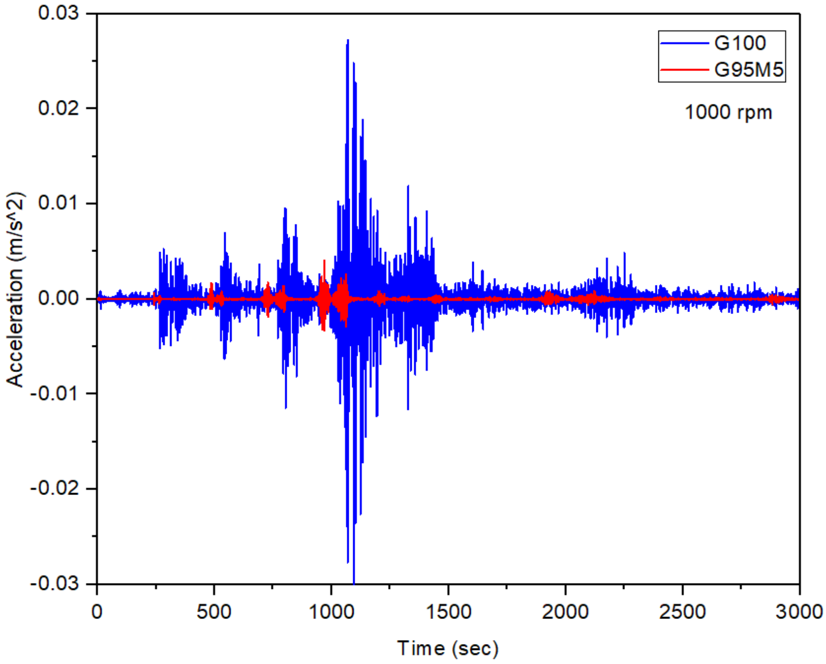

Fig. 4: Time-Domain Vibration Response of G100 and G95M5 at 1000 rpm

Fig. 5 shows the vibration acceleration response in the time domain at an engine speed of 1500 rpm for two types of fuel, namely G100 (100% gasoline) and G95M5 (95% gasoline + 5% methanol). The horizontal axis represents time in seconds (sec), while the vertical axis shows the vibration acceleration in meters per second squared (m/s^2). The results of this test show that the G95M5 fuel (marked in red) shows a higher vibration amplitude than G100 (marked in blue). The highest acceleration peak in G95M5 fuel reaches around ±0.065 m/s^2, while G100 fuel has a maximum acceleration value of around ±0.04 m/s^2. This shows that at 1500 rpm, the fuel mixture with methanol causes an increase in vibration amplitude compared to pure gasoline. In addition, the vibration pattern in G95M5 appears more intense and occurs over a more extended period, especially at around 1500 seconds, where there is a reasonably significant amplitude spike.
In contrast, G100 fuel shows lower and more damped vibration fluctuations. This indicates that although methanol can improve combustion efficiency, it can also increase engine vibration instability at a certain speed. This increase in vibration can affect performance and operational comfort, as well as accelerate engine component wear if not adequately controlled. Therefore, further optimization is needed in using methanol blends to provide a balance between improving performance and reducing engine vibration.

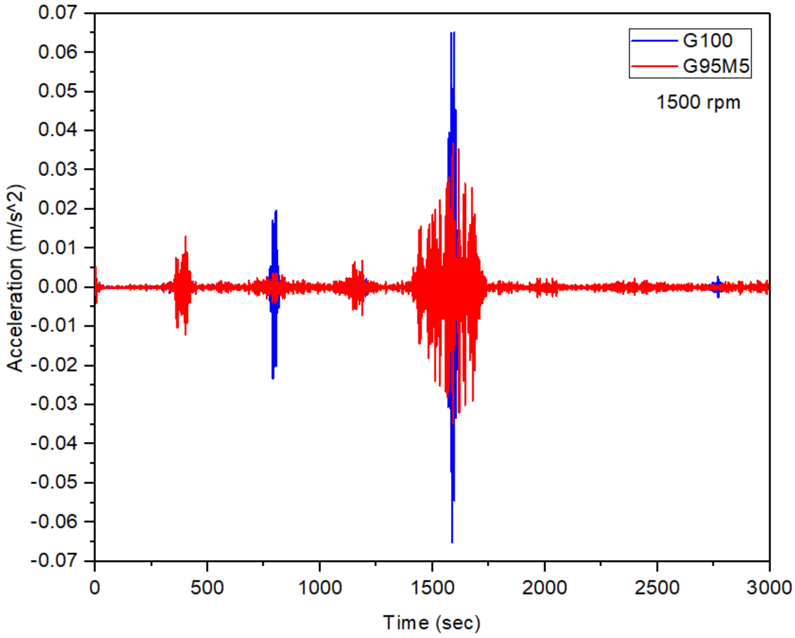

Fig. 5: Time-Domain Vibration Response of G100 and G95M5 at 1500 rpm

Comparison between **Figs. 2** and **3**, which show the vibration frequency spectrum at 1000 rpm and 1500 rpm, shows that increasing engine speed significantly impacts vibration characteristics. At 1000 rpm (**Fig. 2**), G100 fuel produces higher vibration acceleration than G95M5, with a maximum peak of about 0.030 m/s² at a frequency of about 1000 Hz, while G95M5 only has about 0.005 m/s². However, this pattern changes at 1500 rpm (Fig. 3), where G95M5 produces higher vibration acceleration than G100. The highest peak in G95M5 occurs at about 1500 Hz with a value of 0.07 m/s², while G100 has a lower maximum value, about 0.035 m/s². This indicates that using methanol in the fuel mixture can reduce vibration at low speeds but increase vibration at higher speeds, possibly due to the faster combustion characteristics of methanol and its effects on engine dynamics.

Meanwhile, a comparison between **Figs. 4** and **5**, which displays the vibration response in the time domain at 1000 rpm and 1500 rpm, shows a similar pattern to the frequency analysis. At 1000 rpm (**Fig. 4**), G100 fuel produces more significant vibration fluctuations with a peak acceleration of around ±0.028 m/s², while G95M5 shows more damped vibrations with a maximum amplitude of only ±0.006 m/s². However, this pattern changes at 1500 rpm (Fig. 5), where G95M5 produces higher vibration accelerations, reaching ±0.065 m/s², while G100 only reaches ±0.04 m/s². This confirms that the effect of adding methanol to engine vibration depends on the operating speed. In contrast, at low speeds, methanol helps to dampen vibration, but at high speeds, it increases its intensity. Therefore, optimization of the fuel mixture needs to consider the engine operating speed to minimise the negative impact on vibration.

The results of this study show the novelty in the analysis of the impact of the use of G95M5 fuel mixture on engine vibration characteristics at various operating speeds, especially in the frequency and time domains. The main finding is that methanol can reduce vibration at low speeds (1000 rpm) but increase vibration amplitude at high speeds (1500 rpm). This provides new insights regarding optimising alternative fuels to improve combustion efficiency without sacrificing engine mechanical stability. The differences in vibration patterns between G100 and G95M5 identified in the frequency spectrum and time domain analysis provide valuable information for the automotive and energy industries in designing more optimal fuel mixing strategies. In addition, this study confirms that fuel evaluation can be done not only in terms of performance and emissions but also from the aspect of engine vibration, which plays an essential role in operational comfort, component life, and overall combustion system efficiency.

4. Conclusion

Based on the frequency spectrum and time domain analysis results, this study shows that the use of G95M5 fuel mixture (95% gasoline + 5% methanol) significantly affects engine vibration characteristics at various operating speeds. At 1000 rpm, G95M5 fuel produces lower vibration acceleration than G100 (100% gasoline), with a maximum vibration peak of around 0.005 m/s^2 for G95M5, while G100 reaches 0.030 m/s^2. This indicates that the addition of 5% methanol can help dampen vibrations at low engine speeds, which has the potential to improve operational stability and comfort of engine use. However, at 1500 rpm, this pattern changes, where G95M5 fuel produces higher vibration acceleration than G100. The highest vibration acceleration peak for G95M5 was recorded at 0.07 m/s^2 at around 1500 Hz, while G100 only reached 0.035 m/s^2. A similar pattern is also seen in the time domain, where the maximum amplitude in G95M5 reaches ±0.065 m/s^2, greater than G100, which is only ±0.04 m/s^2. These results indicate that although the methanol mixture can dampen vibrations at low speeds and high speeds, this fuel actually increases the intensity of vibrations, which can impact engine component wear. Therefore, optimization of the methanol content in the fuel mixture needs to be considered to balance increasing combustion efficiency and reducing engine vibrations, especially under various operating conditions.

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