International Journal of Science & Advanced Technology
ISSN: 3083-9335

Influence of Methanol-Gasoline Blends on Vibration Characteristics of Spark-Ignition Engine at Different Speeds

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Abstract

This study analyzes the effect of methanol blending in gasoline on a spark-ignition engine's spectrum and vibration response at various operating speeds. Two fuels used are G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). Tests were conducted at speeds of 2000 rpm, 2500 rpm, and 3000 rpm using a vibration sensor to obtain acceleration data in the frequency and time domains. The spectrum analysis results show that at 2000 rpm, G95M5 fuel produces a peak vibration acceleration of 0.28 m/s², higher than G100, which only reaches 0.18 m/s². At 2500 rpm, the difference is still visible, with G95M5 reaching 0.19 m/s², while G100 is 0.16 m/s². However, at 3000 rpm, the difference between the two fuels becomes smaller, with the peak acceleration almost the same, which is 0.032 m/s². Time domain analysis shows a similar trend: at 2000 rpm, G95M5 fuel produces a maximum vibration spike of 0.22 m/s², while G100 is only 0.15 m/s². At 2500 rpm, the vibration of G95M5 is still higher, but it starts to decrease at 3000 rpm with a peak value of 0.028 m/s² for G95M5 and 0.026 m/s² for G100. These results indicate that methanol blending increases vibration at low to medium speeds, but the effect is more damped at high speeds. Thus, although G95M5 can improve combustion efficiency, the increase in vibration at low speeds should be considered because it can affect the reliability and service life of engine components in the long term.

Article Info
Received: 14 March 2025
Revised: 15 April 2025
Accepted: 25 April 2025
Available online: 15 May 2025

Keywords
Engine vibration
Vibration spectrum
Time domain
Methanol
Gasoline

1. Introduction

In recent decades, alternative fuels have been increasingly studied to reduce dependence on fossil fuels and improve combustion efficiency. One alternative fuel that has attracted attention is methanol, which has a higher oxygen content than gasoline, so it can improve combustion efficiency and reduce exhaust emissions. However, methanol's combustion characteristics differ from pure gasoline and can affect engine performance, including the vibrations produced during operation. Engine vibration is an essential factor to consider because it can affect user comfort, mechanical system reliability, and engine component service life (Arena, Collotta, Luca, Ruggieri, & Termine, 2021; Maghfirah, Yusop, & Zulkifli, 2025; Sani, Mamat, Zikri, & Razak, 2019; Zikri, Sani, Yusop, Izzudin, & Sapee, 2019). Several previous studies have examined the impact of methanol blending in fuel on engine performance and emissions. Blending methanol in gasoline can increase the octane number of the fuel and produce cleaner combustion, but also increase combustion pressure, which has the potential to affect engine dynamics (Gani, Saisa, et al., 2025; Ghazali, Rosdi, Erdiwansyah, & Mamat, 2025; Lei et al., 2024; Li et al., 2022). Blending methanol in gasoline in spark-ignition engines causes more significant pressure variations in the combustion chamber, which contributes to increased engine vibration (Chen, Chen, Wang, Geng, & Zeng, 2020; Gani, Zaki, Bahagia, Maghfirah, & Faisal, 2025; K Bharath & V, 2024). However, most studies are still limited to analysing combustion performance and emissions, while its impact on engine vibration has not been studied, including operational speed.

In addition, the use of methanol in the fuel mixture can cause increased engine vibration, especially at low to medium speeds, due to changes in combustion properties that affect engine rotation stability (Mishra, Gupta, Kumar, & Bose, 2020; Muhibbuddin, Hamidi, & Fitriyana, 2025; S. M. Rosdi, Maghfirah, Erdiwansyah, Syafrizal, & Muhibbuddin, 2025; Wirawan, Putra, & Aziz, 2021). However, in this study, the data provided was still limited to specific operating conditions and did not include a more comprehensive vibration spectrum analysis. Therefore, further studies are needed to understand how mixing methanol in gasoline affects engine vibration characteristics at various operating speeds (Fitriyana, Rusiyanto, & Maawa, 2025; Lei et al., 2024; S. M. M. Rosdi, Erdiwansyah, Ghazali, & Mamat, 2025). In this study, vibration spectrum analysis and vibration response in the time domain were carried out on a spark-ignition engine using two types of fuel, namely G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). Tests were carried out at three operating speeds, namely 2000 rpm, 2500 rpm, and 3000 rpm, to see how different fuel compositions affect engine vibration patterns. Using an accelerometer sensor, vibration acceleration data was collected and analyzed in the frequency and time domains to identify vibration change patterns at each test condition.

The results of this study indicate that blending methanol into gasoline increases the amplitude of engine vibration at low to medium speeds, but this difference decreases at high speeds. At 2000 rpm, G95M5 fuel produces a peak vibration acceleration of up to 0.28 m/s², higher than G100, which only reaches 0.18 m/s². This trend is still visible at 2500 rpm, with a peak acceleration of 0.19 m/s² for G95M5 and 0.16 m/s² for G100. However, at 3000 rpm, the difference between the two fuels becomes more petite, with almost the same vibration peak, around 0.032 m/s². This study provides new insights into the effects of blending methanol on engine vibration characteristics, which can be considered in developing alternative fuels for automotive applications. With the increasing trend of using environmentally friendly fuels, understanding side effects such as increased vibration is crucial to ensure that the engine continues to perform optimally and has good durability. Therefore, this study is expected to be a reference for fuel technology developers and the automotive industry in balancing combustion efficiency and engine operational stability.

2. Methodology

Fig. 1 illustrates a schematic diagram of the engine testing system using a gasoline-powered 4G93 SOHC engine, integrated with various sensors and measuring instruments to evaluate performance and emission characteristics. The engine is connected to an engine dynamometer, which is controlled by a central control unit to measure engine torque and power output accurately. The test system includes an in-cylinder pressure sensor that records combustion pressure in real time and a crank angle encoder that detects piston position and synchronizes combustion data with the crankshaft rotation. These signals are processed through an engine data acquisition system for real-time monitoring and recording. A dedicated vibration measuring system is also linked to analyze the mechanical behavior of the engine during operation.

Fuel is supplied from an external fuel blend reservoir, passed through a heat exchanger to maintain consistent temperature, and delivered by a fuel pump. The system is equipped with rate flow meters to monitor fuel consumption precisely, and a fuel return valve ensures any excess fuel is returned to the fuel tank. A drain valve is also included for system purging or sample collection. An exhaust gas analyzer is used to measure emissions such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), and unburned hydrocarbons from the engine exhaust stream, providing data for combustion efficiency and environmental impact assessment. All sensor outputs including in-cylinder pressure, crank angle, fuel flow rate, engine torque, vibration signals, and exhaust emissions are recorded via a computer-based data acquisition system, enabling comprehensive analysis of engine performance under controlled experimental conditions.

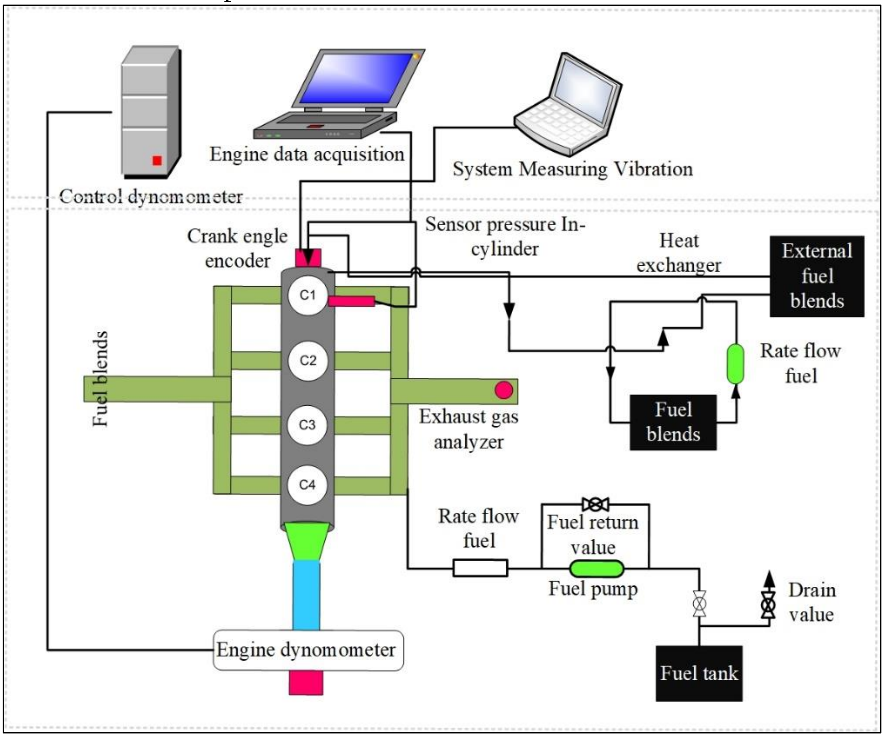

Fig. 1. Schematic Diagram

3. Result & Discussion

Fig. 2 shows the engine vibration spectrum at 2000 rpm using two types of fuel, namely G100 (100% gasoline) and G95M5 (95% gasoline + 5% methanol). This graph displays the vibration acceleration (m/s^2) on the y-axis and the number of rows of data on the x-axis, representing the engine vibration response to fuel variations. From the results shown, both fuels produce different vibration patterns, especially in the high-frequency range. G95M5 fuel (red line) shows a higher vibration peak spike than G100 (blue line), especially around the 2200-row number point. This indicates that adding methanol to the fuel can potentially increase engine vibration at certain speeds. The main findings from this vibration spectrum indicate that fuel with a mixture of methanol (G95M5) tends to cause more significant vibration acceleration than pure gasoline (G100). This may be due to the difference in combustion properties between petrol and methanol, where methanol has a higher-octane number and a faster combustion rate, affecting engine vibration characteristics. In addition, the higher peak vibration intensity in G95M5 may indicate increased combustion imbalance or a more significant variation of inertia force due to changes in fuel characteristics. Therefore, although adding methanol can improve combustion efficiency in practical applications, it is necessary to pay attention to its impact on engine reliability and durability due to the increased vibration.

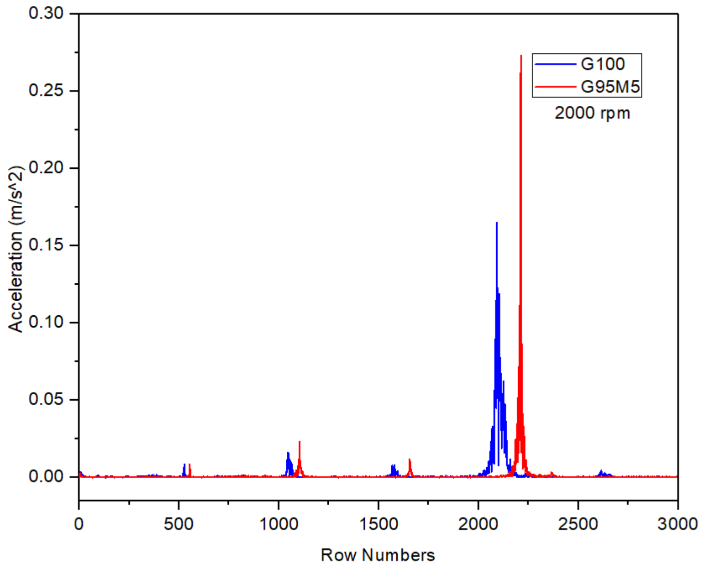

Fig. 2. Engine Vibration Spectrum at 2000 rpm with G100 and G95M5 Fuels

Fig. 3 shows the engine vibration spectrum at 2500 rpm for two types of fuel, namely G100 (pure gasoline) and G95M5 (gasoline with 5% methanol). The y-axis shows the vibration acceleration in m/s², while the x-axis represents the frequency in Hz. This graph shows that both fuels produce almost similar vibration patterns in most of the frequency range, but there is a significant difference in the vibration peak around 2500 Hz. G95M5 fuel (red line) shows a tremendous increase in vibration acceleration compared to G100 (blue line) at high frequencies, indicating the effect of methanol on engine dynamics when operating at high speeds. The main finding from this vibration spectrum shows that at 2500 rpm, G95M5 still produces more significant vibration than G100, especially at high frequencies. This is similar to the trend observed at 2000 rpm (Figure 2), where fuels with methanol blends tend to increase engine vibration levels. The contributing factors to this increase in vibration are most likely related to the nature of methanol, which has a faster burning rate and higher cooling effect than pure gasoline, which can affect combustion stability and piston and crankshaft dynamics. Therefore, although methanol can benefit combustion efficiency, further evaluation is needed regarding its impact on engine component life due to increased vibration at high speeds.

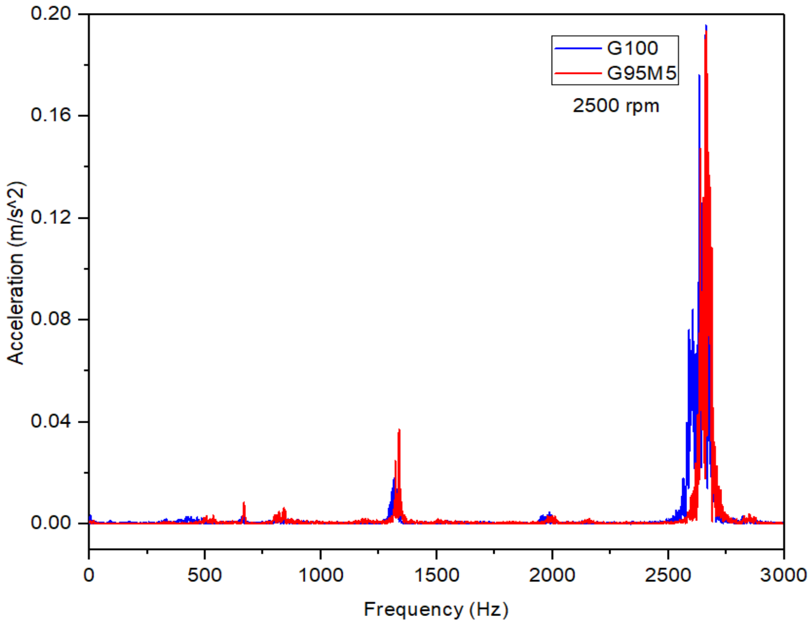

Fig. 3. Engine Vibration Spectrum at 2500 rpm with G100 and G95M5 Fuels

Fig. 4 shows the vibration spectrum of the engine at 3000 rpm with two types of fuel, namely G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). The graph depicts the vibration acceleration in m/s² on the y-axis and the frequency in Hz on the x-axis. At this speed, the vibration patterns for both fuels show almost similar characteristics over most of the frequency range, with some significant peaks reflecting resonance or increased inertia forces due to engine dynamics. The prominent peak occurs around 1500 Hz, where the G95M5 fuel (red line) shows a slightly higher vibration amplitude than the G100 (blue line). This indicates that the methanol blend still affects the combustion dynamics and engine vibration, although the difference is less apparent at high speeds than at lower speeds. The main findings from this vibration spectrum show that although at 3000 rpm, the vibration difference between the two fuels is negligible compared to 2000 rpm and 2500 rpm, the G95M5 fuel still produces slightly higher vibrations at some major frequency peaks. One factor that may affect this pattern is the nature of methanol, which has a higher oxygen content than gasoline, which can change the combustion rate and increase the combustion pressure in the cylinder. In addition, the more even vibration pattern over a wider frequency range indicates that the engine experiences more complex resonance excitation at high speeds. Therefore, using G95M5 fuel may still impact the engine's long-term reliability, especially regarding component wear due to increased dynamic forces at specific frequencies.

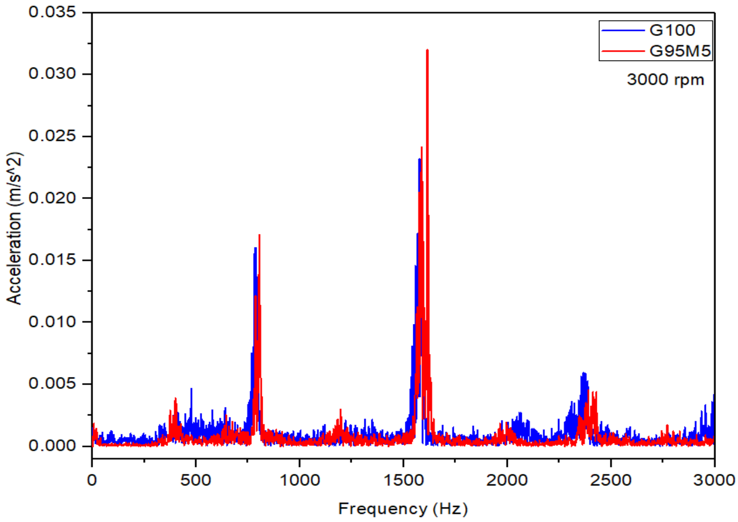

Fig. 4. Engine Vibration Spectrum at 3000 rpm with G100 and G95M5 Fuels

Fig. 5 shows the vibration response in the time domain for an engine operating at 2000 rpm with two types of fuel, namely G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). The graph displays the vibration acceleration (m/s²) on the y-axis and time (seconds) on the x-axis. From the visible pattern, the vibration amplitude is low for most of the test duration, but there is a significant spike approaching a time of around 2000 seconds. This spike indicates a more dominant momentary increase in vibration in the G95M5 fuel (red line) compared to G100 (blue line). This difference is likely due to the combustion characteristics of methanol, which affect the pressure dynamics inside the combustion chamber and result in more significant vibration fluctuations. The main findings from this time domain analysis indicate that the G95M5 fuel produces higher vibration peaks than G100, especially during transition periods or changes in engine operating conditions. This demonstrates that blending methanol into gasoline can increase vibration variability under certain conditions, possibly related to changes in combustion pressure distribution or inertial imbalance in engine mechanisms. In addition, the more extreme vibration patterns in the G95M5 may affect the long-term life of engine components, especially those susceptible to material fatigue due to high vibration cycles. Therefore, although methanol can provide benefits in terms of combustion efficiency, further evaluation is needed regarding its impact on engine operational stability.

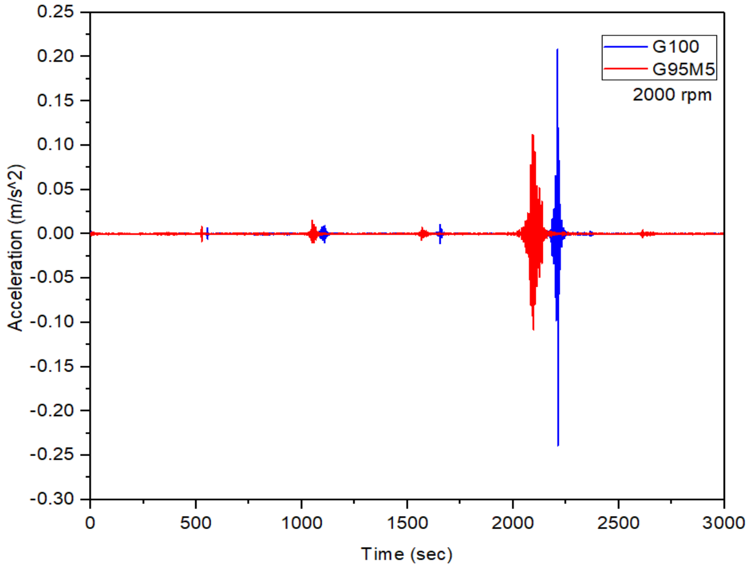

Fig. 5: Time-Domain Vibration Response of G100 and G95M5 at 2000 pm

Fig. 6 shows the vibration response in the time domain for an engine operating at 2500 rpm with two types of fuel, namely G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). The graph displays the vibration acceleration (m/s²) versus time (seconds), illustrating how the engine responds during the test period. The vibration is usually in the low range, but a significant spike occurs near about 2500 seconds. This spike is higher in G95M5 fuel (red line) than in G100 (blue line), indicating that the methanol blend causes more significant vibration fluctuations during certain operating conditions. This can be attributed to the different combustion effects of methanol from pure gasoline, resulting in higher pressure variations in the combustion chamber. The main finding of this analysis is that G95M5 fuel causes more extreme vibration responses than G100, especially during transitions or changes in engine conditions. This is consistent with the trend at lower engine speeds (Figure 5), where adding methanol increases the vibration amplitude at certain times. In addition, although most of the test duration showed similar vibration patterns for both fuels, large spikes in G95M5 can potentially accelerate the wear of engine components sensitive to high vibrations, such as bearings and the crankshaft system. Therefore, although methanol can benefit combustion efficiency, further analysis is needed to address its negative impact on engine stability and durability in long-term operation.

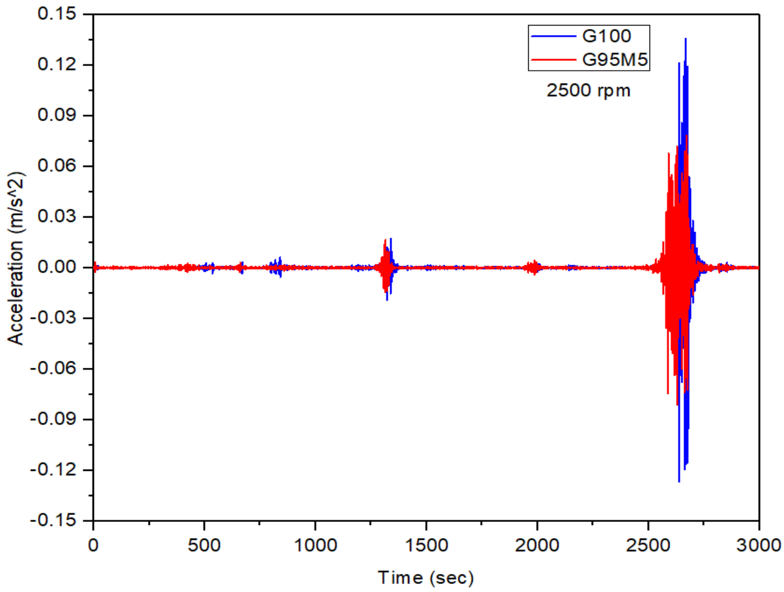

Fig. 6: Time-Domain Vibration Response of G100 and G95M5 at 2500 rpm

Fig. 7 shows the vibration response in the time domain for an engine operating at 3000 rpm using G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). The y-axis displays the vibration acceleration in m/s², while the x-axis represents the time in seconds. Based on the visible patterns, both G100 (blue line) and G95M5 (red line) show a more even vibration pattern than at lower speeds (2000 rpm and 2500 rpm). However, some significant vibration spikes occur at around 1000 seconds, 1500 seconds, and 2000 seconds, which are most likely related to load variations or engine operational transitions. G100 fuel has higher spikes at some time points than G95M5, indicating that pure gasoline can cause momentary vibration increases under certain conditions. The main findings of this analysis show that at 3000 rpm, the vibrations produced by both fuels are more stable compared to lower speeds, although there are still spikes at specific points. Interestingly, the G95M5 fuel shows a more even vibration pattern and smaller extreme spikes than the G100. This indicates that the blending of methanol in gasoline can help to dampen the vibration spikes at high speeds, which may be due to the cooling effect of methanol and more homogeneous combustion. However, although methanol seems to reduce sharp spikes, it is still necessary to consider its impact on overall performance and engine life, especially related to component durability due to the slightly different vibration pattern compared to pure gasoline.

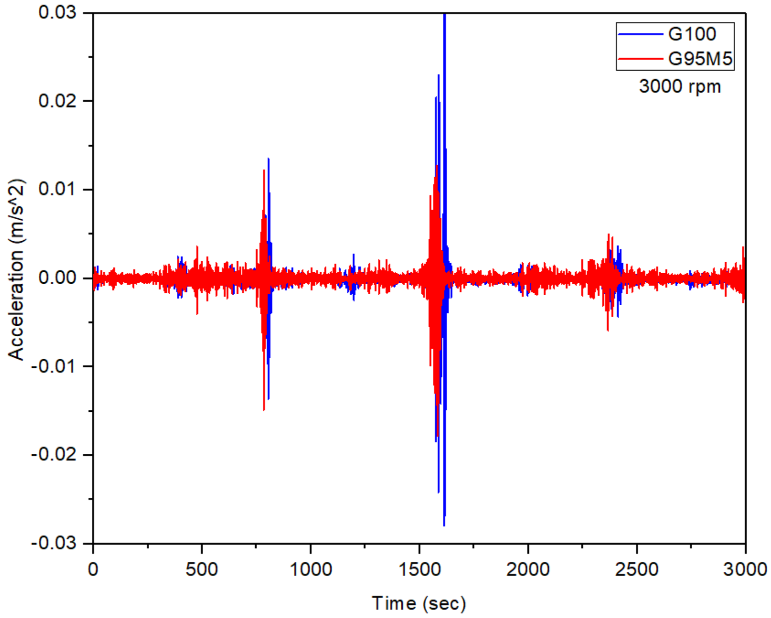

Fig. 7: Time-Domain Vibration Response of G100 and G95M5 at 3000 rpm

Figs. 2-4 show the engine vibration spectra at 2000 rpm, 2500 rpm, and 3000 rpm for two types of fuel, namely G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). All three graphs show that vibration increases with increasing engine speed, with a more pronounced vibration peak at high frequencies. At 2000 rpm (**Fig. 2**), G95M5 fuel produces a higher vibration spike than G100, especially around 2200 row number, indicating that methanol blending causes an increase in vibration at low to medium speeds. The same pattern is still visible at 2500 rpm (**Fig. 3**), where G95M5 fuel produces a higher vibration amplitude than G100, especially around 2500 Hz. However, at 3000 rpm (**Fig. 4**), the differences between the two fuels diminish, with a more balanced vibration spectrum between G100 and G95M5. However, a significantly higher peak remains in the methanol blended fuel. From the comparison of these three figures, it can be concluded that the use of methanol in the fuel tends to increase vibration acceleration at lower to medium engine speeds (2000–2500 rpm). Still, this effect begins to diminish at 3000 rpm. This phenomenon can be attributed to methanol's faster combustion properties and higher oxygen content than pure gasoline, which cause increased combustion pressure and inertial imbalance effects at low speeds. However, these effects appear to be more damped at high speeds, possibly due to better combustion stability and increased inertial forces dampening fluctuations. Therefore, although methanol blending can benefit combustion efficiency, it is essential to be aware of its impact on engine mechanical stability, especially at low to medium speeds, where increased vibration can impact component wear in the long term.

Figs. 5 - 7, respectively, show the vibration responses in the time domain for engine speeds of 2000 rpm, 2500 rpm, and 3000 rpm with two types of fuels, namely G100 (pure gasoline) and G95M5 (95% gasoline + 5% methanol). The three graphs show that at lower speeds (2000 rpm, **Fig. 5**), G95M5 fuel produces a larger vibration spike than G100, especially at around 2000 seconds. This trend continues at 2500 rpm (**Fig. 6**), where G95M5 still shows a higher vibration peak than G100, but the vibration spike is not as significant as at 2000 rpm. At 3000 rpm (**Fig. 7**), the vibration patterns between the two fuels become more uniform, and although there are still vibration spikes, their amplitudes are more even than at lower speeds. This indicates that at high speeds, the effect of fuel differences on engine vibration levels becomes smaller. From the comparison of these three figures, it can be concluded that G95M5 fuel tends to increase vibration spikes significantly at low to medium speeds (2000–2500 rpm), but this effect begins to decrease at higher speeds (3000 rpm). This can be attributed to the faster combustion characteristics of methanol and its higher oxygen content, which cause pressure variations in the combustion chamber and increase vibrations at low speeds. However, at high speeds, the effects of inertial forces and better combustion stability seem to help dampen vibration spikes, resulting in a more uniform pattern between the two fuels. Therefore, although blending methanol in gasoline can improve combustion efficiency, its impact on engine vibrations must be considered, especially at low to medium speeds, as it can contribute to increased mechanical stress and wear of engine components in the long term.

4. Conclusion

Based on the results of the engine vibration spectrum analysis and the vibration response in the time domain (**Figs. 5-7**), it can be concluded that the use of G95M5 fuel (95% gasoline + 5% methanol) affects the engine vibration level compared to G100 (pure gasoline). At a speed of 2000 rpm, the vibration spectrum shows that G95M5 produces the highest vibration acceleration spike of up to 0.28 m/s^2, higher than G100, which only reaches 0.18 m/s^2. This indicates that methanol mixing increases vibration at specific frequencies. The same trend occurs at 2500 rpm, where G95M5 still has a higher vibration peak than G100, with an acceleration reaching 0.19 m/s^2 compared to 0.16 m/s^2. However, at 3000 rpm, the difference between the two fuels began to narrow, with almost the same vibration peak, which is about 0.032 m/s^2, indicating that at high speeds, the effect of methanol blending on engine vibration is more damped. From the time domain analysis, extreme vibration spikes occur more frequently at low to medium speeds. At 2000 rpm, G95M5 fuel produces a vibration peak of up to 0.22 m/s^2, while G100 is only 0.15 m/s^2. At 2500 rpm, the vibration amplitude of G95M5 is still higher than that of G100 but begins to decrease. At 3000 rpm, the vibration patterns of both fuels are more uniform, with almost the same maximum vibration peak values (0.028 m/s^2 for G95M5 and 0.026 m/s^2 for G100). This indicates that blending methanol in gasoline increases vibration at low to medium speeds, but the effect decreases at high speeds. Therefore, although using G95M5 can improve combustion efficiency, its impact on increasing vibration, especially at low speeds, must be considered because it can affect engine components' reliability and long-term service life.

Acknowledgement

The authors would like to acknowledge the support provided by the Centre for Automotive Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah, in conducting this research.

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