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SIGNAL ANALYSIS FOR LPG-MODIFIED GASOLINE ENGINE WITH ENGINE FAULTS

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ABSTRACT: At the present time, the number of vehicles and the cost of gasoline has been immensely risen, liquefied petroleum (LPG) is a prominent alternative choice of fuel because of its popularity and economical cost. However, the LPG-installation may cause some degradations of the engine efficiency. The important perceptions of the driver are the engine vibration and sound. Therefore, an analysis of vibration signals and sound signals to distinguish between the LPG-modified and the normal oil-usage 2,200-cc engine has been reviewed in the first stage of this paper. The power of the signal is applied for both engines at five different engine speeds. A ten-second sample of the signal has been measured with the sampling rate of 2,048 Hz. The experimental results of the analysis of vibration signals show that the power of signals of the LPG-modified engine is mostly above that of the normal oil-usage engine. As for the analysis of sound signals, the LPG-modified engine has higher power than that of the normal oil-usage engine at low engine speed. Meanwhile, the normal oil-usage engine causes higher power of signals when comparing with the LPG engine at the engine speed over 1,300 rpm. In the second stage, a study of fault simulations has been reviewed. The fault simulations of the butterfly valve and the sparking plug have been studied. The results show that the vibration of the engine is directly proportional to the engine speed. Moreover, the engine faults cause significant engine vibration at the speed above 1,500 rpm for both normal gasoline and LPG modified engines. Last but not least, LPG-installation and engine faults cause degradations in engine efficiency which can be substantially evidenced by using the proposed approach.

Keywords: Vibration signal, Sound signal, Liquefied petroleum gas, Signal Power, Engine Fault

1. INTRODUCTION

Presently, alternative sources of energy are the primary importance to drive the current business and the ongoing industrial sector. Supply preparation of energy in accordance with user's need must be vitally considered. Moreover, the quality of energy such as gasohol and biodiesel are very important for the engine in the transportation system. Furthermore, renewable energy is an alternative way for the automotive industries. The factors of economics and the decrease of petroleum resources indispensably reinforce the current research and development of energy made from natural gas.

Basically, natural energy can be divided into two types. Compressed Natural Gas (CNG) which is known as the Natural Gas for Vehicle (NGV) and Liquefied Petroleum Gas (LPG) are both made from hydrocarbons. Almost all demands in Thailand, the LPG is however much more popular because its installation cost is more economical [1-3]. The number of service stations is also greater than that of NGV. Therefore, the LPG-installation engine is an interesting issue to be chosen to study in this research.

In the review exploration on detection and diagnosis of the faults in rotating machinery, the vibration-based techniques have been colossally and efficiently developed. These techniques are seldom applied to gasoline or diesel engines. The applications of vibration-based techniques to these engines are very burdensome due to the transient and non-stationary nature [1]. The exploitation of vibration signals of engines gives much dynamic information of mechanical system condition. Many useful techniques of signal analysis have been applied as useful methods for fault diagnosis of the engines [2]. The power spectrum, cepstrum, higher order spectrum, and neural network analyses were applied in the specified induction motor fault diagnosis [4]. Power of signal has been successfully used in the previous work to compare the engine sound of the LPG-modified engine [5]. As for the fault diagnosis, the discrete wavelet transform was efficiently exploited with the vibration signal of the diesel engine and the gearbox [2, 3]. The power of signal analysis; one of the powerful and simple techniques [5, 6], has been chosen to adaptively apply in the paper thanks to its low complexity and extremely minimal time consumption.

The LPG modification of the engine and also the temperature differentiation of the combustion make the working condition of the engine changed. The problems of LPG-installation cause the engine vibration and sound both direct and indirect effects [7-10]. Consequently, the vibration and sound signals are investigated and analyzed to differentiate between the LPG-modified engine and the normal oil-usage engine, because they are the essential measurable attributes to indicate the causes of irregular conditions of engines [11, 12].

To find the cause of the engine faults, the expertise and experience of the mechanic are exploited in the traditional engine diagnosis. To improve the conventional approach, this research aims at discovering a suitable technique to compare the signal power of vibration and sound of the LPG-modified engine and the normal oil-usage engine. At the first stage of this study, two cases of a normal engine and LPG-modified engine are focused. The research study is limited at the personal car with gasoline engine only. The power of the sound signal of speech analysis has been applied to extract the power of engine vibration and sound. It has been expected that the signal processing techniques are applicable and powerful for adapting to the vibration and sound of the car engine. It can be stated that the first objective of the study is to analyze vibration signals and sound signals to distinguish between LPG-modified and normal oil-usage engine. In the second stage of this study, the simulation of engine faults for both normal gasoline engine and LPG modified engine has been conducted to study the characteristics of them in some conditions. It can be indicated that the second objective of the study is to investigate the fault simulation by using the vibration signal.

2. MATERIAL AND METHODS

At the first stage of the study, the comparison between two cases of the normal engine and the LPG-modified engine is introduced. The gasoline engine with 2,200 cc piston has been used in the study. The installation of alternative LPG system has been conducted. There were two modes of fuel supply including normal gasoline supply mode and LPG supply mode. At the beginning of these modes, the engine has been started and waited until reaching the stable period of the working engine. Five various levels of engine speeds have been set at 900, 1,100, 1,300, 1,500 and 1,700 rpm. To measure the vibration and sound signals, a number of accelerometers and microphones have been installed. The positions of these sensors are partly allocated in Fig. 1. A wireless receiver which perceives the measured vibration and sound signals has been attached to a computer notebook. The corresponding data are therefore recorded in a specified file format, subsequently.

By adopting from the conventional speech processing, power of signal calculated for engine vibration or sound is mainly applied in this paper due to its simplicity and fast calculation. The signal power is an amount of energy consumed per unit of time. This quantity is very useful to describe the signal which its energy goes to infinity where this engine vibration and the sound signal can be assumed to be not-squarely-summable as long as the engine does not stop running. The calculation is developed by using the sum of the square of the signal samples [6, 10]. The average power of an aperiodic sequence x[n] is stated mathematically as

$$\boldsymbol{Px} = \lim_{K\to\infty} \frac{1}{2K+1}\sum_{n=-K}^{K}|x[n]|^2, \qquad (1)$$

where K is the sequence half-length which extends its limit of the number of samples to infinity. In the practical experiment, this extension has been limited to the signal length.

The vibration and sound signals have been measured by a number of accelerometers and microphones and recorded by the G-link microstrain serial base station and an amount of software through a host computer. These infinite energy signals (called power signal) in this research have been measured and recorded with some approximately periodic sequences. Therefore, this

Fig. 1 Sensor allocation design: the first stage

Fig. 2 Sensor allocation design: the second stage

the equation has been adapted with a specific length which reflects the whole vibration and sound sequences for both normal oil-usage and LPG-modified engines. Therefore, this equation has been adapted with a specific length recorded in a number of iteration samples for all five various levels of engine speeds.

At the second stage of the study, the simulation of engine faults for both normal gasoline engine and LPG modified engine has been conducted. In this experiment, the 1,500-cc gasoline engine has been chosen as a specimen. The LPG installation has been implemented by using the European standard. The LPG with injection system has been installed by an experienced mechanics. To simulate [9] two faults of working conditions, the engine has been set up the mechanics [10] as follows. Type I, the engine with butterfly valve fault has been conducted by releasing the corresponding valve out. Type II, the engine with sparking plug fault has been done by pulling the plug off. These fault simulations have been performed with both the regular gasoline engine and the LPG modified engine. Figure 2 illustrates the sensor allocation which is used to measure the vibration from the engine. It can be seen that a couple of accelerometers are attached with the engine piston surface [1].

3. EXPERIMENTAL DESIGNS

The two stages of experiments have been organized and explained in this section including the comparison of the normal gasoline engine and the LPG-modified engine and the simulation of engine faults. At the first stage, the study focused on the comparison between the normal gasoline engine and the LPG-modified engine by considering the extracted parameters of engine vibration and sound signals; averaged power, as described in the previous section. Thereafter, the second study concentrated on two major engine faults (type I and type II) simulated by the experienced mechanics. The averaged power of engine vibration at various speeds has been investigated to differentiate some condition of faults of the engine.

3.1 Comparison of Normal Gasoline Engine and LPG-Modified Engine

To differentiate between the normal gasoline engine and LPG-modified engine, the experimental procedure for the first stage of study has been implemented as depicted in Fig. 3 [5, 13]. The accelerometers are attached at the top of the pistons of the engine. Meanwhile, the microphone with recording software is applied to implement the database of engine sound. The vibration and sound signals are recorded in the form of connected samples to attain the database of LPG modified engine's vibration and sound signals. The database consists of the vibration and sound signals of both conditions including normal engine and LPG-

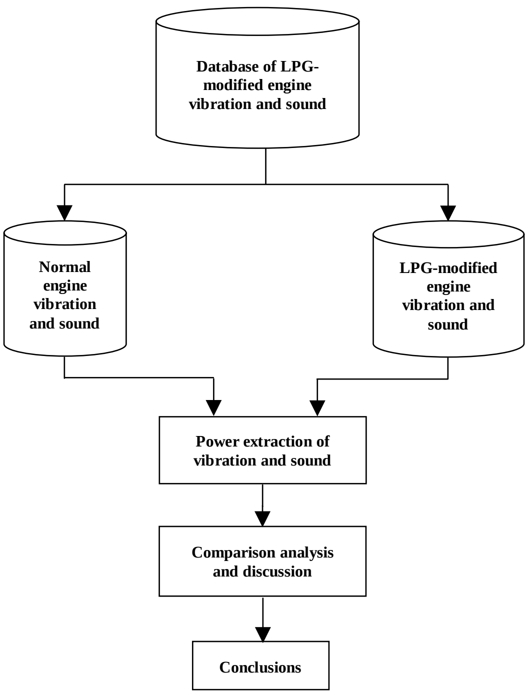

Fig. 3 Experimental procedure: the first stage

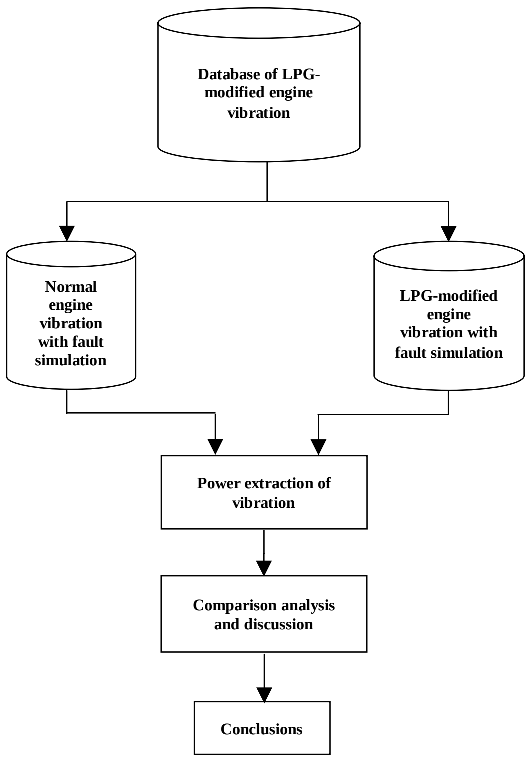

Fig. 4 Experimental procedure: the second stage

modified engine. A number of repetitions of signals were measured at the engine speeds of 900, 1,100, 1,300, 1,500, and 1,700 rpm for both engine conditions. The duration of each sample lasts 10 seconds at the sampling rate of 2,048 Hz. Subsequently, the calculation of the signal's power has been conducted as described in the previous section. The signal powers, thereafter, were analyzed using a comparative approach. The analysis and discussion are presented in the next section. In the final process, the conclusions have been performed. In this study, five couples of linear plots of the vibration and sound signals at different samples have been presented. The overall presentation of the averaged powers of vibration and sound signals at various engine speeds is also summarized, consequently.

3.2 Simulation of Engine Faults

To achieve the second objective of the study, the experimental procedure for the second stage of the study has been implemented as depicted in Fig. 4 [14-16]. The accelerometers are attached at the pistons of the engine. The vibration signal is recorded in the form of acceleration to attain the database of LPG modified engine's vibration signal [7]. The database consists of the vibration signals of two conditions including normal gasoline engine and LPG-modified engine. A number of repetitions of vibration signals were measured at the engine speeds at 700, 900, 1,100, 1,300, 1,500, 1,700, 1,900, and 2,100 rpm for six engine conditions. The duration of each sample lasts 10 seconds at the sampling rate of 2,048 Hz. Subsequently, the calculation of signal power has been performed. The signal powers, thereafter, were analyzed using discrete signal formulation in Eq. (1) [8, 12]. Subsequently, the comparative analysis and discussion are presented. The overall presentation of the averaged powers of vibration signal at different engine speeds is depicted and summarized in the next section.

4. EXPERIMENTAL RESULTS

In this section, the experimental results consist of two stages according to the objectives of the study; including the comparison of the normal gasoline engine and the LPG-modified engine, and the simulation of engine faults, respectively.

4.1 Comparison Results of Normal Gasoline Engine and LPG-Modified Engine

At the first stage of the study, the comparisons between the normal gasoline engine and the LPG-

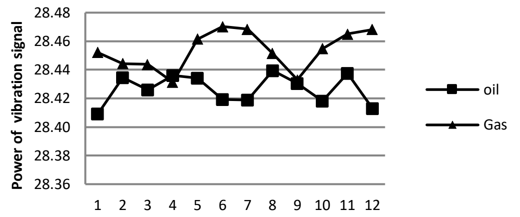

Fig. 5 Normalized power of vibration signal at different samples with the engine speed of 900 rpm

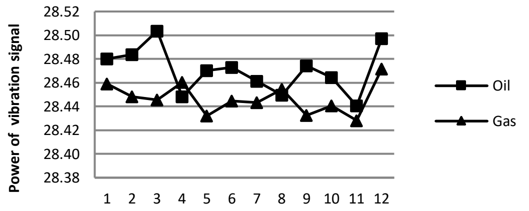

Fig. 6 Normalized power of vibration signal at different samples with the engine speed of 1,100 rpm

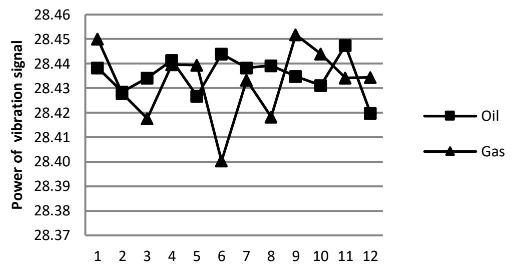

Fig. 7 Normalized power of vibration signal at different samples with the engine speed of 1,300 rpm

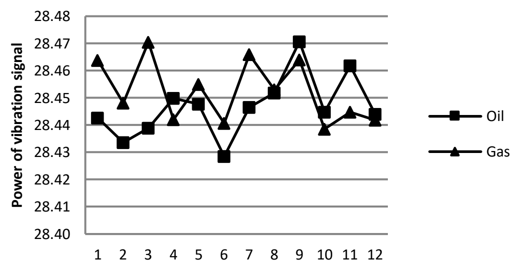

Fig. 8 Normalized power of vibration signal at different samples with the engine speed of 1,500 rpm

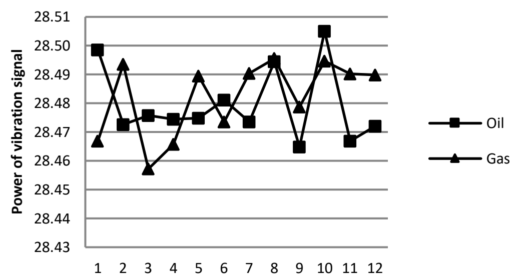

Fig. 9 Normalized power of vibration signal at different samples with the engine speed of 1,700 rpm

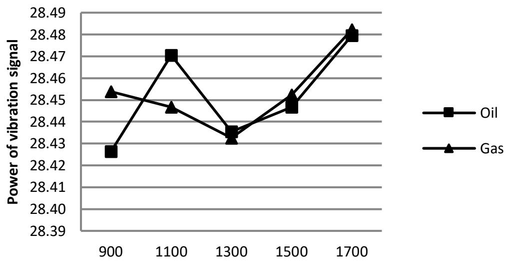

Fig. 10 Normalized averaged power of vibration signal at different engine speeds (rpm)

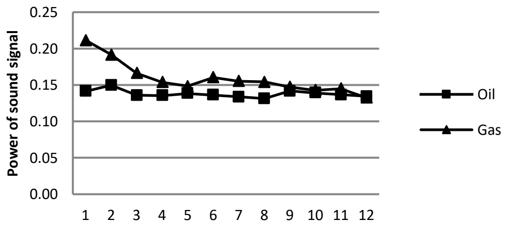

Fig. 11 Normalized power of the sound signal at different samples with the engine speed of 900 rpm

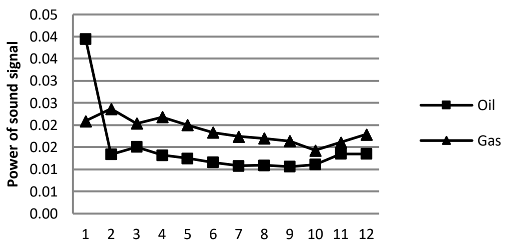

Fig. 12 Normalized power of the sound signal at different samples with the engine speed of 1,100 rpm

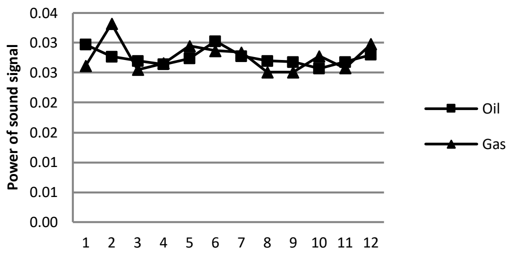

Fig. 13 Normalized power of the sound signal at different samples with the engine speed of 1,300 rpm

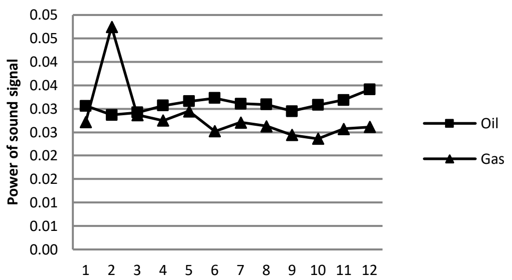

Fig. 14 Normalized power of the sound signal at different samples with the engine speed of 1,500 rpm

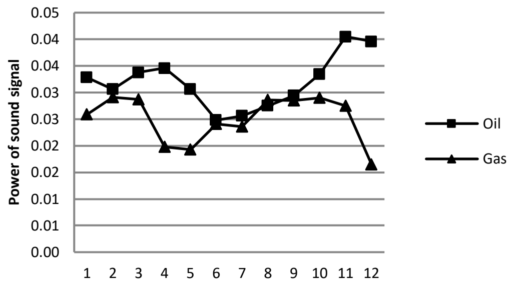

Fig. 15 Normalized power of the sound signal at different samples with the engine speed of 1,700 rpm

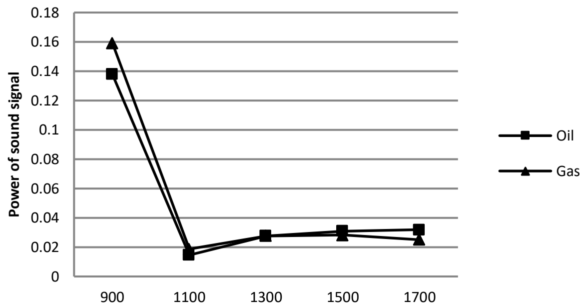

Fig. 16 Normalized averaged power of the sound signal at different engine speeds (rpm)

modified engine is comprised of the comparison by exploiting engine vibration and the comparison by using engine sound. Both of the comparisons utilize the averaged power of the corresponding signals. The experimental results are subsequently discussed.

4.1.1 Comparison by Using Engine Vibration

The focused signal at this point is the engine vibration. The normalized averaged powers of the vibration signal for both engine conditions including normal oil-usage engine and LPG-modified engine are calculated and thereafter comparatively plotted in different engine speeds. Figures 5-9 present the normalized averaged power of vibration signal at different samples for the engine speeds of 900, 1,100, 1,300, 1,500, and 1,700 rpm, respectively. It can be explicitly observed from Fig. 6 (at the engine speed of 1,100 rpm) that the normalized averaged signal power of the normal oil-usage engine is mostly above than that of the LPG-modified engine. Meanwhile, at the other engine speeds, the averaged signal powers are totally similar. All in all, figure 10 summarily presents the averaged power of vibration signal at different engine speeds. It can be noticeably concluded that the normalized averaged power of vibration signals of the LPG-modified engine is mostly above those of the normal engine with oil supply except for those of the engine speeds at 1,100 and 1,300 rpm.

4.1.2 Comparison by Using Engine Sound

The key signal at this point is the engine sound. After measuring the sound signals through the provided microphones, the normalized averaged power of sound signals is calculated. A comparison in power of the sound signal of all engine's conditions including the normal oil-usage engine and the LPG-modified engine is shown. Figures 11-15 show the normalized averaged power of the sound signal at different samples from the engine speeds of 900, 1,100, 1,300, 1,500, and 1,700 rpm, respectively. It has been evidently observed that the line plots of the LPG-modified engine are above those of the normal oil-usage engine at the lower engine speed. When the engine speed is increased more than 1,300 rpm, the line plots of the normal oil-usage engine become lying above that of the LPG-modified engine.

Figure 16 summarily illustrates the conclusion of these experimental results. It can be obviously observed that at the engine speeds of 900 and 1,100 rpm, the LPG-modified engine has the power of sound signal more than that of the normal engine with oil supply. When the engine speed is increased above 1,300 rpm, the LPG-modified engine has the power of engine sound signal lower than that of the normal gasoline engine.

4.2 Simulation Results of Engine Faults

At the second stage of the study, the main issue is how the simulated engine faults affect the vibration of the engine at different engine speeds. From the first stage, it can be noticed that both vibration and sound give quite corresponding results. The vibration has been therefore selected as the main signal to study for the fault simulation in the second stage. The range of engine speeds has been consequently broadened for investigating the vibration in deep. The averaged powers of the vibration signal for these engine conditions including normal oil-usage engine and LPG-modified engine are calculated and comparatively plotted in different engine speeds. Figures 17-18 demonstrate the absolute averaged power of vibration signal at different samples at the engine speeds of 700 - 2,100 rpm.

As for Fig. 17, the absolute averaged power of vibration signal for the normal gasoline engine in three engine's conditions have been compared in those different engine speeds. When noticing at low engine speeds, the powers of the vibration signal of all conditions are closed to each other. When the engine speed is increased above 1,500 rpm, the powers of engine vibration signal with faults type I and type II become significantly lying above than that of the normal engine without faults.

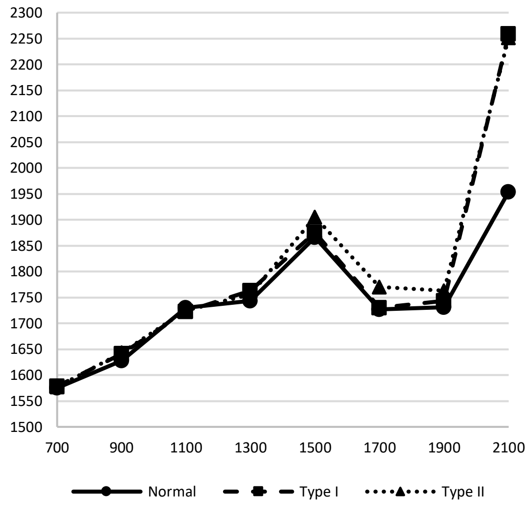

Fig. 17 Absolute averaged power of vibration signal for normal gasoline engine at different engine speeds with 3 conditions (power of vibration signal vs engine speeds)

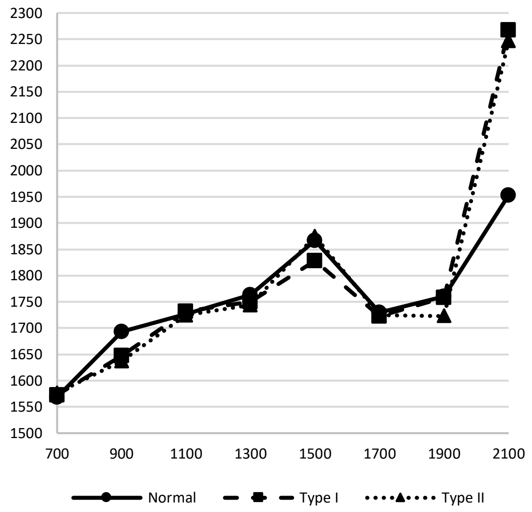

Fig. 18 Absolute averaged power of vibration signal for LPG modified engine at different engine speeds with 3 conditions (power of vibration signal vs engine speeds)

Fig. 19 Absolute averaged power of vibration signal for normal gasoline engine vs LPG modified engine at different engine speeds with normal condition (power of vibration signal vs engine speeds)

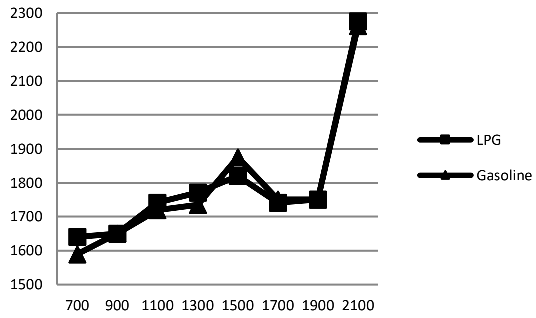

Fig. 20 Absolute averaged power of vibration signal for normal gasoline engine vs LPG modified engine at different engine speeds with type I fault condition (power of vibration signal vs engine speeds)

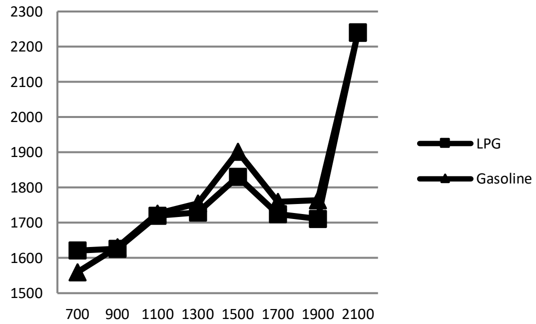

Fig. 21 Absolute averaged power of vibration signal for normal gasoline engine vs LPG modified engine at different engine speeds with type II fault condition (power of vibration signal vs engine speeds)

As for Fig. 18, the absolute averaged power of vibration signal for LPG modified engine in three engine's conditions have been displayed in those different engine speeds. The experimental results are corresponding to those of the normal gasoline engine as demonstrated in Fig. 17. Last but not least, it can be noticeably seen from both figures that almost all of the absolute averaged powers of vibration signal are increasing from lower engine speeds to higher engine speeds. Therefore, it can be concluded that the averaged power of the vibration signal is directly proportional to the speed of the engine.

When focusing on Figs. 19-21, the absolute averaged power of vibration signal for LPG modified engine in three engine's conditions have been displayed and compared to those of normal gasoline engine in different engine speeds. These absolute averaged powers of vibration signal are directly proportional to the engine speeds. All of them have similar behaviors, the absolute averaged powers of vibration signal at 1,700 rpm and 1,900 rpm fall slightly compared to those of the previous engine speed of 1,500 rpm.

5. CONCLUSIONS

A study of vibration and sound signal analysis for a gasoline engine with LPG-installation and fault simulations has been presented in this paper. The paper is organized as two stages including the comparison of the normal gasoline engine and the LPG-modified engine and the simulation of engine faults. In the first stage, the study focused on the comparison between the normal gasoline engine and the LPG-modified engine by considering the averaged power extracted from the engine vibration and sound signals. From the experimental results, it can be seen from the vibration analysis that the power of vibration signals of the LPG-modified engine is mostly above those of the normal engine with oil supply except for the engine speeds of 1,100 and 1,300 rpm. Moreover, it has been concluded from the sound analysis that at engine speed at 900 and 1,100 rpm, the LPG-modified engine has lower power of sound signal more than that of the normal engine with oil supply. At the engine speed of 1,500 and 1,700 rpm, the LPG-modified engine has the power of sound signal lower that of the normal engine with oil supply. In the second stage, the study concentrated on two major engine faults. The absolute averaged power of engine vibration at various engine speeds has been investigated to differentiate all conditions of faults. From the experimental results, it can be summarized that the vibration of the engine is directly proportional to the speed of the engine. Moreover, the engine faults cause significant engine vibration at the speed above 1,500 rpm for both normal gasoline and LPG modified engines. In conclusions, LPG-installation and engine faults cause degradations in engine efficiency which can be concretely evidenced by using the proposed signal processing technique. To improve and broaden the study, other types of engines should be applied. Moreover, other types of engine faults should be further investigated in the future study.

6. ACKNOWLEDGMENTS

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