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AN ANALYSIS OF VIBRATION FOR A GASOLINE-ENGINE CAR DRIVING ON THREE TYPES OF ROADS

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ABSTRACT: An analysis of vibration signals has been proposed for a personal gasoline-engine car while driving on three types of roads including paved road, concrete road, and gravel road. The wired sensors are placed upon three positions inside the passenger room: right-front seat surface, left-front seat surface, and rear seat surface. The objectives of this analysis are to differentiate the corresponding vibration reflecting from driving upon three types of roads and to differentiate the vibration at three different positions of sensors inside the passenger room. The signal analysis technique of Fast Fourier Transform is utilized in this analysis, the obtained spectrum is investigated to extract the dominant peaks. Thereafter, the averages of the peak values are calculated for six different engine speeds ranging from 0-30 km/h. These averaging calculations are based on 50 five-second-length samples of vibration signals. To achieve the first objective, the experimental results insist that the highest peak values are mostly of the gravel road, meanwhile, the lowest peak values are of the paved road. To accomplish the second objective, the experimental results strongly confirm the following comparisons. In the case of paved road, the highest peak values are at the rear seat surface, meanwhile, in the case of concrete road, the highest peak values are at the left-front seat surface. Finally, in the case of gravel road, the highest peak values are at the rear seat surface. In conclusion, this study confirmed that the proposed approach can be used to differentiate the signal features of all scenarios.

Keywords: Fast Fourier transform, Vibration analysis of gasoline engine, Paved road, Concrete road, Gravel road

1. INTRODUCTION

In the present day, land transportation is playing a much important role in our daily lives. The vehicles such as trailers, trucks, pickups, or cars, have been utilized to transport goods, raw materials, tools, and equipment especially in the newly developed or developing countries. On the land, not only the non-living things but also the living things are transported via a variety of kinds of automobiles. Consequently, the effects of the road surface type and condition are very important factors on the vibration and sound within the vehicles.

The review of the effects of road surface type and condition has been inaugurated by Novikov et al. A study of the effects of the road surface type and condition on the traffic flows management mode in case of directive management has been investigated [1]. The main point is the method of assessment of the effects of the road surface type and condition on the capacity rate of the signalized area and then its effects on the traffic flow management mode. The conclusion is reinstated that there is a correlation between the friction coefficient and the capacity of the managed area resulting in the change of the traffic lights cycle, which is also corroborated by the conducted field experiment on a signalized intersection.

In another view of the vehicle durability, Hu and Zhong applied a conventional finite element model for linear and nonlinear analysis for multibody full-vehicle-durability simulation [2]. A number of different kinds of test road surfaces are conducted in the simulation, it has been concluded that the explicit–implicit co-simulation techniques are efficient and accurate enough for engineering purposes.

In another study of the road surface interrelation, the interaction between the type and technical condition of road surfaces, dynamic vehicle loads, and the level of vibration propagated to the environment has been introduced by Czech [3]. It has been insisted that the type of road surface and the technical condition and varied dynamic vehicle loads are explicitly affecting the level of vibration propagated to the environment.

One of the main environmental stress in vehicles is mechanical vibration. A study of the discomfort caused by vibration for three models of micro commercial vehicles running in four types of road conditions has been performed by Huang and Li [4]. Noise is also investigated in the study. Moreover, Litak et al. investigated the chaotic vibration which was the effect of critical Melnikov amplitude of the road surface profile to a quarter car model [5]. Blekhman and Kremer also conducted a study of the effect of road unevenness on the dynamics of the averaged longitudinal motion of a vehicle [6]. In the aspects of detection and diagnosis of the faults in rotating machinery, a number of the mechanical vibration-based studies have been considerably undertaken [7,9].

In the aspect of the signal processing techniques for machine diagnosis, a lot of research of signal processing adaptations have been performed for engine fault diagnosis [8]. The discrete wavelet transform in the temporal and the spatial domain was effectively applied with the vibration signal for the engine fault diagnosis of the diesel engine and the gearbox [8,9]. The power spectrum analysis with high order, the cepstrum analysis, and the neural network approach were utilized for fault diagnosis and indication of some of the specific induction motors [10]. The power of signal analysis with less time consumption and low computational cost was conducted in a comparative study of LPG-modified engine and normal oil-usage engine [11], and also in a fault diagnosis of rolling element bearings [12]. The problems of gasoline-substitution with LPG boiling system installation cause some significant variation in vibration and sound signals of the modified engines [13,16]. Consequently, some analysis techniques of the vibration and sound signals were developed to differentiate between the LPG-modified engine and the conventional gasoline engine, thereafter some significant attributes were applied to indicate the irregularities of the corresponding engines [17], [18]. Last but not least, the studies of vibration and sound signal analysis for gasoline engines with LPG-installation and some specified fault simulations were investigated, the experimental results confirmed that the LPG-installation and the specified faults concretely affected the engine efficiency degradations [19,21].

An approach of vibration signal analysis for a personal gasoline-engine automobile while driving upon three types of road surfaces including paved road, concrete road, and gravel road as mentioned in the previous related studies has been proposed in this paper [4,6]. A couple of significant objectives of this study are to compare the vibration affecting from driving upon three types of roads, and then to compare the vibration at three different areas of sensor positions. The signal processing technique of Fast Fourier Transform has been applied to extract the signal spectrum and the corresponding features [11,20,22].

2. MATERIAL AND METHODS

In this section, the road surface types selected in the experiment has been explained. The experimental procedure has been illustrated step by step. Subsequently, the proposed signal processing technique has been clarified. Finally the experimental setups have been therefore presented.

2.1 Road Surface Types

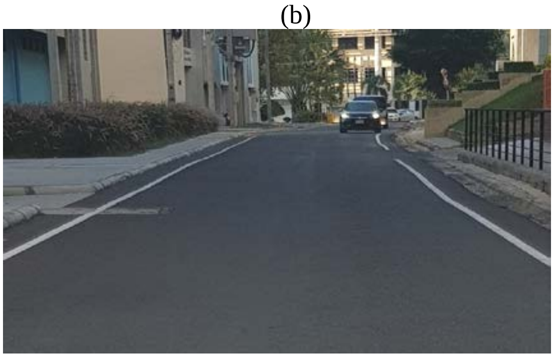
The study concentrates mainly on three types of roads, since almost all road surfaces in Thailand consist of three main types of gravel road, concrete road, and paved road, as depicted in Fig.1 (a), Fig.1 (b), and Fig.1 (c), respectively. Their attributes are concluded as follows.

1. Gravel road, this type of road surface is abundant in rural areas of Thailand. It does not require frequent maintenance as long as its surface is still smooth. However, the main disadvantage is the existing dust that occurs during use. Besides, it gets muddy during heavy rain.

2. Concrete road, this type of road takes a long time to build and has high construction costs with high durability. Concrete is a popular construction material consisting of three main components: cement, composite material (e.g. stone, sand, or gravel), and water. When mixing the mentioned components, the concrete will slowly harden. The

(a)

(b)



(c)

Fig. 1 Road surface types: (a) gravel road, (b) concrete road, (c) paved road.

major limitation is that it takes a relatively long time to build compared to the other two types of roads.

3. Paved road, this type of road is considered a road that has both advantages and disadvantages. Asphalt is commonly used in this road type construction. Asphalt is a black sticky product from crude oil distillation with high viscosity. It is used as a waterproofing binder and is highly resistant to weak acid or alkalinity, it can turn into liquid or soften when heated and freeze when cooled. Its advantage is its inexpensive quick-time construction, however, some disadvantages are still existing. For example, spray water asphalt to coat the road surface is needed while the broken surface is detected.

2.2 Experimental Procedure

After the experimental design process, the experiment procedure has been defined for this study. It consists of data preparation and signal processing sub-procedures as depicted in Fig. 2. At the data preparation stage, the experimental setup has been conducted at the beginning. Thereafter, the measurement of the vibration signal of the experiment automobile for all three types of road surfaces has been performed. Subsequently, the signal preparation and collection has been conducted to construct the signal database for three positions of sensors inside the passenger room; the right-front seat surface, the left-front seat surface, and the rear seat surface. The signal database consists of all scenarios of car speeds including 0, 10, 15, 20, 25, and 30 km/h, respectively.

At the signal processing stage, signal feature extraction has been inaugurated. Fast Fourier transform of the initially-provided signal has been applied to obtain its corresponding frequency spectrum. Monitoring the frequency spectrum brings about some frequencies at the dominant peak points and their corresponding amplitudes. These highest peaks are assumed to represent the important components of the vibration signal inherited from the movement of the automobile. These features are averaged among all collected samples and therefore analyzed comparatively. At the end of this stage, the discussion of this study has been conducted.

2.3 Signal Processing

To extract the retrieved signal features, some of the signal processing techniques of feature extraction are performed respectively. The explanation is presented as follows. The signal processing technique of Fast Fourier transform

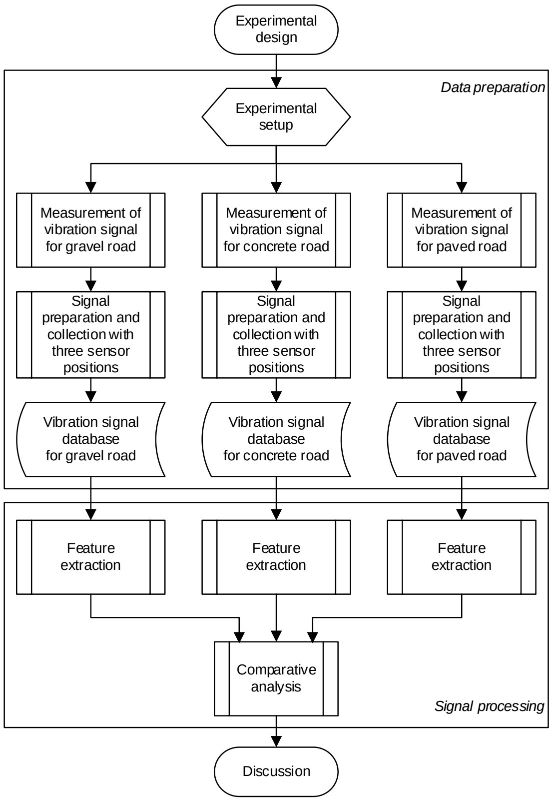
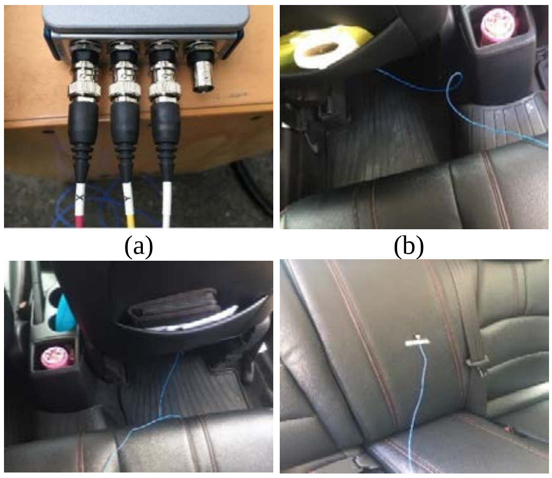


Fig. 2 Experimental procedure.



(a) (b) (c) (d)

Fig. 3 Experimental setups: (a) interface of NI9234 card, and installation locations of vibration sensors; (b) the left-front seat surface, (c) the right-front seat surface, and (d) the rear seat surface.

(FFT) has been applied with all of the portions of the vibration signals for all groups within the database. From the output frequency spectrum, the most dominant peak appearing in the frequency domain is extracted. Subsequently, the frequency and magnitude at the peak are investigated. The most dominant frequencies emerging peak along the frequency spectrum at six different engine speeds are extracted and averaged among all samples in the corresponding scenarios.

2.4 Experimental Setups

In the experimental setups, the automobile is a personal gasoline engine car of Mazda-2 model with 1,499-cc cylinder volume, Skyactiv-D, 4 cylinders, and 16 valves. The vibration sensors and their complementary parts, NI9234 card for interfacing with a computer, and a computer for signal processing are provided. The interface of the NI9234 card and installation locations of vibration sensors are illustrated in Fig. 3.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In the comparative analysis, FFT the efficient tool of frequency spectrum extraction has been selected to determine frequency components of the collected vibration signals in the databases. The most dominant frequencies emerging peak along the frequency spectrum at six different engine speeds are extracted. To achieve the first objective, the averaged magnitude of emerging peaks of the frequency spectrum of the vibration signals measured at all three positions of the left-front seat surface, the right-front seat, and the rear seat surface with different engine speeds have been illustrated in Fig. 4-6 respectively. On the other hand, to achieve the second objective, the averaged magnitude of emerging peaks of the frequency spectrum of the vibration signals for driving upon the gravel road, the concrete road, and the paved road with different engine speeds have been presented in Fig. 7-9 respectively.

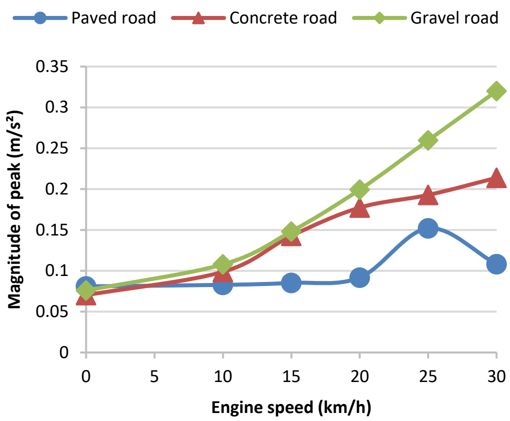


Fig. 4 The averaged magnitude of emerging peak of the frequency spectrum of the vibration signal measured at the left-front seat surface at different engine speeds.

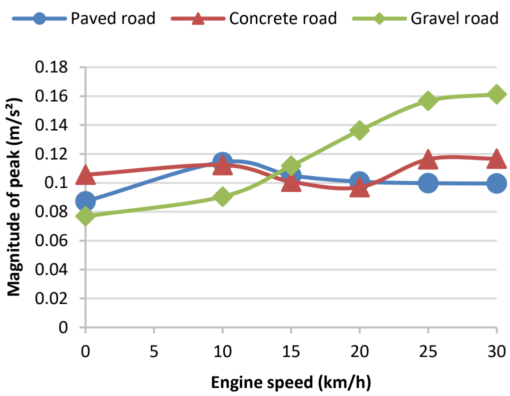


Fig. 5 The averaged magnitude of emerging peak of the frequency spectrum of the vibration signal measured at the right-front seat surface at different engine speeds.

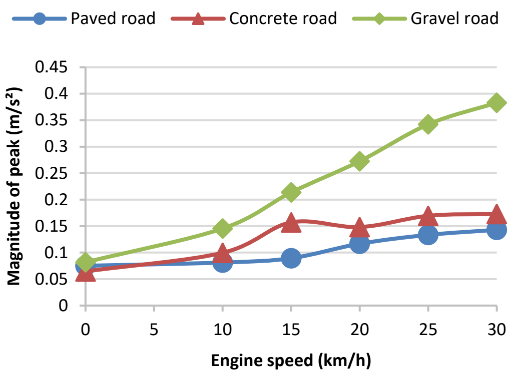


Fig. 6 The averaged magnitude of emerging peak of the frequency spectrum of the vibration signal measured at the rear seat surface at different engine speeds.

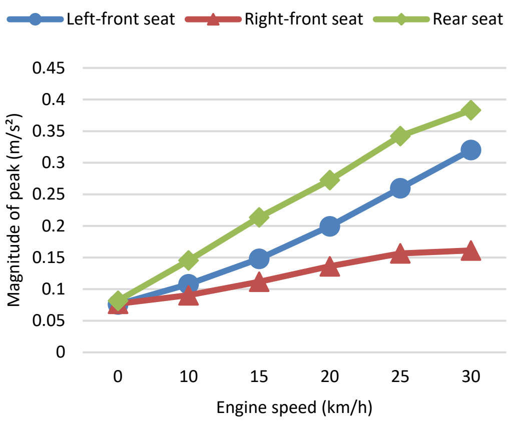


Fig. 7 The averaged magnitude of emerging peak of the frequency spectrum of the vibration signal of the gravel road at different engine speeds.

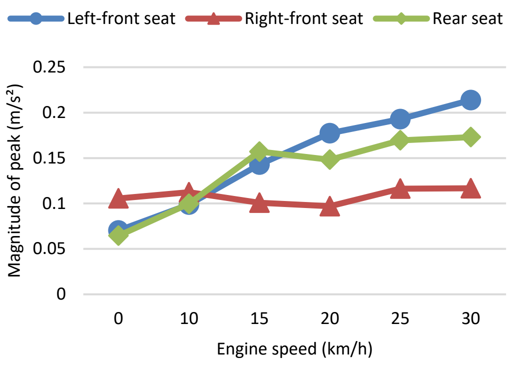


Fig. 8 The averaged magnitude of emerging peak of the frequency spectrum of the vibration signal of the concrete road at different engine speeds.

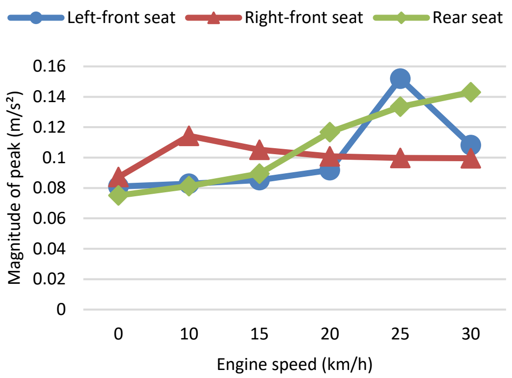


Fig. 9 The averaged magnitude of emerging peak of the frequency spectrum of the vibration signal of the paved road at different engine speeds.

From the first three figures (Fig. 4-6), the plotting of the averaged magnitude of the emerging peak of the frequency spectrum has been performed along with the different engine speeds. Three lines in each figure represent the characteristics of three types of roads including paved road, concrete road, and gravel road, respectively. These plots have been conducted for all three installation locations of vibration sensors.

From Fig. 4 with focusing on the left-front seat, the averaged magnitude of the emerging peak of the frequency spectrum of the vibration signal increases while the engine speed is being raised. The gravel road reflects the highest impact to the averaged magnitude when comparing with the others, meanwhile, the paved road shows the least vibration magnitude. Furthermore, it can be observed that the magnitudes of the FFT for all road surface scenarios at the low engine speeds of 0 and 10 km/h are quite not different.

From Fig. 5 with focusing at the right-front seat, the averaged magnitude of emerging peak of the frequency spectrum of the vibration signal increases while the engine speed is being raised as same as that of the left-front seat depicted in Fig. 4. The paved road and the concrete road are quite similar to each other especially at the engine speed under 15 km/h.

From Fig. 6 with focusing at the rear seat, the averaged magnitude of emerging peak of the frequency spectrum of the vibration signal has the same movement along the engine speed axis as those of the left-front seat surface and the right-front seat surface illustrated in Figs. 4 and 5, respectively.

From the last three figures (Fig. 7-9), the plotting of the averaged magnitude of the emerging peak of the frequency spectrum has been performed along with the different engine speeds. Three lines in each figure represent the characteristics of three locations of vibration sensors. These plots have been performed for all three main types of roads.

From Fig. 7 with focusing on the gravel road, the averaged magnitude of the emerging peak of the frequency spectrum of the vibration signal increases while the engine speed is being raised for all of the vibrations at all sensor locations. The rear seat gives the highest impact to the averaged magnitude when comparing with the others, meanwhile, the right-front seat gives the least vibration magnitude.

From Fig. 8 with focusing on the concrete road, the trends of all averaged are as same as those of the gravel road in Fig. 7. However, it has been noticed that the left-front seat rises from the second highest to the top highest impact for the engine speeds over 20 km/h.

From Fig. 9 with focusing on the paved road, the trends of all averaged are as same as those of the gravel road in Fig. 7.

4. CONCLUSIONS

This paper presents an analysis of vibration signals measured inside a gasoline-engine automobile of the Mazda-2 model driving upon three types of roads. The installations of vibration sensors are at the driver's or right-front seat surface, the left-front seat surface, and the rear seat surface. The frequency spectrum of FFT is used to extract a number of peaks where the dominant frequencies are located. The averaged magnitudes of the emerging peaks for six engine speeds ranging from 0-30 km/h are calculated. Comparing among three types of roads, the experimental results confirm that the highest peak values are mostly of the gravel road, meanwhile, the lowest peak values are of the paved road. Comparing among three locations of vibration sensors, the explicit results can be strongly concluded as follows. In cases of paved road and gravel road, the highest peak values are of the rear seat surface, moreover, in the case of concrete road, the highest peak values are of the left-front seat surface. Summarily, this study concludes that the proposed analysis technique of vibration signals can be used to differentiate the signal features of all scenarios of a personal gasoline-engine car while driving on three types of roads. In the future study, the other associated signal processing techniques should be developed to approach more efficient identification of all scenarios or automobile condition diagnosis.

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