

Diesel Engine Fault Detection Using Vibration and Acoustic Emission Signals

Prof. Dr. Sabry Allam¹, Mohammed Abdo¹ and Dr. M. Rabie²

¹Automotive Technology Department

Faculty of Industrial Education, Helwan University, Cairo, Egypt.

²Automotive Engineering Department

Faculty of Engineering, Minia University

Egypt

ABSTRACT

The vibration and acoustic methods are among the most useful techniques for monitoring the conditions of machines. The internal combustion engine one of machine which has the reciprocating parts can cause progressive damage that ultimately affects the engine efficiency. Therefore, following the performance of these parts can save a lot of time, money, effort and maintain the acceptable performance of the engine. This paper gives a brief review and evaluates the most of effective monitoring techniques to the internal combustion engine based on acoustic and vibration emissions.

Keywords: Diesel engine, Vibration signal, Acoustic Emission signal, Fault detection.

1. INTRODUCTION

The diesel engine has been vastly used in trucks and some private vehicles due to its good economy and dynamic performance. Development of diesel engine performance has appeared because of the increasing concern about environmental problems, a decrease of noise and pollutant emissions. The diesel engine when operating normally can give thousands of hours of uninterrupted service. However, if a fault develops, the growth of the fault tends to be rapid and can lead to major failure which can cause loss of life, damage to property and incur high costs when it occurs in, for example, commercial transport vehicles or ships. This is why, it is essential to implement reliable and sensitive engine condition monitoring techniques. People attach great importance to the status monitoring and fault diagnosis technology of diesel engine both domestic and overseas, and they put a lot of manpower and material resources to actively carry out application technology studies. In general, timely detection, diagnosis and taking effective measures can increase the safety and reliability of diesel engine, reduce maintenance costs and the resulting losses, and prevent sudden accidents [1]. Figure 1 shows the classification of faults according to engine systems and components.

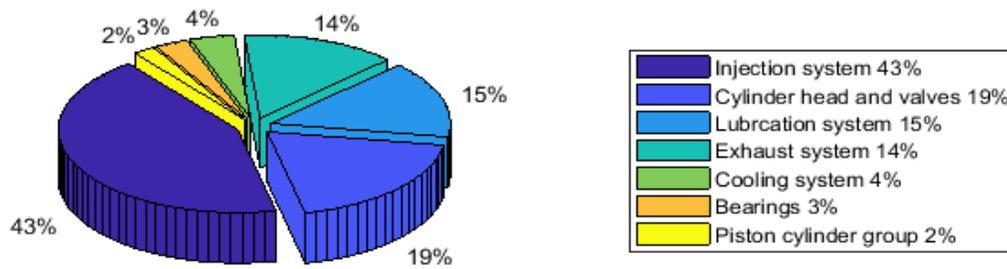


Figure. 1 Principal faults in diesel engines.

Fuel injection system fault is one of the most important elements, which is responsible for about 43% of the engine faults [2] and it's one of the key components, which determine engine torque, emissions, noise and specific fuel consumption [3]. Fuel quantity, injection timing, injection pressure and other parameters are keys to the optimum injection procedure case monitoring system. These parameters must be kept at their ideal values to decrease the fuel consumption, pollutant emissions and increase the power [4]. Great innovations, new and improved methods of analysis, research and speedy repair systems provide an impetus to such high demand in quality and quantity. Different predictive maintenance methods and non-intrusive such as vibration and acoustic emission monitoring using time and frequency domains have been developed to detect and diagnose faults, improving maintenance and hence, the performance of both engines and systems [5]. To identify significant change which is indicative of a developing fault, it is a major component of predictive maintenance.

2. AVAILABLE METHODS FOR FAULT DETECTION

All machines with moving parts give rise to sound and vibration. Each machine has a specific vibration signature related to the construction and the state of the machine. If the state of the machine changes the vibration signature will also change. Most modern techniques for diesel engine diagnostics are recognized on the analysis of vibration signals collected from cylinder block or the head. A change in the vibration signature can be used to detect initial faults before they become critical. The acoustic emission method is also among the most useful techniques for monitoring and diagnosing the condition of engines. Combined with vibration measurements, they offer a great potential over all the non-intrusive diagnosis techniques [6]. The Acoustic Emission (AE) as a phenomenon can be defined as transient elastic waves resulting from local internal micro-displacements in materials of the tested structures. AE gives much information about materials response to applied stress. It is useful for the detection and identification of growing defects in material [7]. Acoustic emission signals are a type of analysis input, which gives a detailed report on the condition of an engine to an encouraging percent. The acoustic and vibration signals can be closely allied together. AE signal can be measured by using two techniques, airborne and structural borne. In airborne technique, the microphone is enough to capture the signals, whereas the sensor must be mounted on the machine in structural borne monitoring [8]. AE analysis is a reliable method to measure a high frequency vibration above 20 kHz. Such as detect valve and ring leakage (blow-by), injection failure and timing problem. In traditional engine monitoring, the analysis techniques used to interpret AE and vibration signals are the same [6].

The vibration and AE signal are the basics of many condition monitoring methods. Condition monitoring can save money through increased maintenance efficiency by reducing the risk of serious accidents and preventing breakdowns [9]. Early detection faults and diagnosis not only provides information about the nature of the problem, but also allows maintenance personnel to plan the necessary corrective action. Thus, the operating losses can be minimized in lower labor, parts cost, less downtime and more efficient use of maintenance resources [10]. With the developments in electronic equipment, transducers, computers and software, nowadays machine monitoring devices is almost completely automated. This paper deals with the review of detection methods that were used to engine faults. Some basic faults are categorized below:

1. According to part of engine; spark plug gap, valve clearance (inlet and outlet), air filter fault, piston ring fault, inlet and exhaust manifold fault and injector valve.
2. According to engine condition; powerless, idling and engine which goes missing (jerk).

As a summary, the fault detection of internal combustion engine can be detected by using vibration and AE analysis method. There are a number of ways to analyze the signals which, measured by vibration and AE sensors. The analysis methods can be divided into some areas as time domain approaches, frequency domain approaches and others.

2.1 Fault Detection using Vibration Sensors:

Z. Ranachowski and A. Bejger [11] presented the possibility of application of a portable system for registration of the vibration signal in the frequency range of 1000–10000 Hz for diagnosing common faults of the fuel injection system of the maritime diesel engine. A

portable system was used to record the vibration signals were measured from the sensor was fixed on the injector stub inlet, which working correctly, and the injector affected by the fault (The nozzle orifice of the injector was blocked with products of fuel combustion – the obstruction exceeded 50% of the orifice area). Plotting the results shows clearly the difference between the two signals was recorded. So that, the portable system is considered to be an easy and efficient method to detect the faults which occur due to the change in the vibration. Liu Jianmin et al. [12] diagnosed a fuel injection system fault based on the cylinder head vibration signal. Fuel injector needle valve closing crash can excite cylinder head vibration and generate a dual - peak phenomenon in the combustion stage signal of diesel engine cylinder head vibration under certain work conditions. From the results under different work conditions and faulty conditions it's revealed that these characteristics can accurately describe injection information and can be used for fuel injection system fault diagnosis. Suphattharachai and Chomphan [13] presented a study of vibration analysis of the normal engine and the engine with three different fault conditions. The accelerometer has been used on the surface of the engine to measure the vibration in the form of acceleration for all possible directions. Three conditions of engine faults including the engine that is not smooth while idling, the engine that goes missing while idling and the engine that has no power are selected. Five vibration signal parameters including fundamental frequency, long term spectrum, energy, long term spectrum and zero crossing rate, are computed from all databases. And the main purpose of this work is to develop a tool to assist the engine mechanic to diagnose the engine faults. Ben-Ari et al. [14] performed a series of experiments and measured the vibration of an engine block while the engine was running under normal and abnormal conditions. They found that the vibration level of the engine provides reliable information regarding the engine condition, demonstrated that in many cases and the vibration signature can be used to identify the source of the fault. Feng Xia [15] carried out vibration tests, respectively, on the faulty engine and fault-free engine under the idling condition, the test signals were compared and analyzed, and thus, the existing fault of the oil pump was determined through the study of signal data. Based on wavelet de-noising and frequency spectrum analysis of vibration signals, the common features of such fault are summarized, and the reasons for the fault are successfully diagnosed. And it found the vibration from the faulty oil pump at a low temperature was more severe than the fault-free pump, especially near the pressure limiting valve, and the vibration amplitude of the faulty pump was very big. E. Ftoutou et al. [16] investigated the detection of misfire in an internal combustion diesel engine by vibration analysis. The measurements were carried out on a 6-cylinders in line, 4-stroke diesel engine mounted on a test bench. The vibration signal was sensed successively at 7 positions on the engine block and cylinder head by a piezoelectric accelerometer. By blocking of injector hole is supposed to be the cause of the misfire and was simulated by the disconnection of the fuel supply of cylinder 1 found that at idle speed, the isolation of this fault is possible only by the peak to peak value (PP), root mean square value (RMS) features and an accelerometer positioned near the misfired cylinder or in the middle of the engine block. At 1300 rpm and with the averaged features PP and RMS, the isolation of the misfire fault is possible for all the selected sensor positions. The averaged features crest factor (C) and kurtosis Factor (K) failed to isolate the misfire fault. Zhiqiang Wang [17] measured the vibration signals of high-pressure fuel injection pipes' nozzle of different cylinders with different fuel injection advance angles by the external oil pressure sensor. Then through signal processing and theoretical analyzing, an important parameter the fuel injection advance angle was extracted, which was used to identify the state of fuel injection and described the relationship between the fuel injection advance angles and the vibration characteristic quantities of high-pressure fuel injection pipes' nozzle. A new method was presented to measure the fuel injection advance angle, which achieve the nondestructive detection and fault diagnosis of diesel engines without disintegration. Yousef Alhouli et al. [18] studied the effect of the exhaust valve clearance changed from 0.4mm (Healthy condition) to 0.0 mm (Faulty condition) on engine vibration and performance. The diesel engine vibration sources were reviewed, time domain method and the frequency domain method were applied to the engine body vibration to extract the useful information and determine the condition of the diesel engine under different speeds and loads. From the results they found that the signatures of vibration engine body are rich in information about operating parameters and physical condition. S. Xiaochun and H. Hongying [19] explained that it is very difficult to analyze vibration signal of diesel engine fault because it is non-stationary and nonlinear. So, they used 'Wigner Trispectrum (WT)' method to describe the characteristics of vibration signals got from diesel engine and that method is reliable to analysis and classification of diesel engine faults.

Flett, J. and Bone, G. M. [20] applied the fault detection and diagnosis system using the vibration signals with a diesel internal combustion engine. Faults caused by deformed valve spring and abnormal valve clearance were detected on a diesel engine using one accelerometer. Five classification methods were implemented experimentally and compared. The results indicated the accuracy of the application and the possibility of its use for Fault detection and diagnosis of diesel engine valve trains. Fengli Wang and Shulin Duan [21] their studies aiming at the characteristics of the surface vibration signals measured from the diesel engine, and they proposed a novel method combining local wave decomposition (LWD) and lifting wavelet denoising to use for feature extraction and condition evaluation of diesel engine vibration signals. The vibration signals of diesel engine piston-liner wear are analyzed, and the results show that the method is feasible and effective in feature extraction and condition evaluation of diesel engine faults. Chao Jin et al [22] presented an integrated approach of diagnosing combustion faults and valve leakage by combining vibration signal with cylinder

pressure and revolution speed signals. He used the wavelet decomposition method to extract features from data collected under different health conditions. The proposed approach was applied on a small-scale diesel engine test rig as a feature can be used in a real-world health monitoring system. Alireza Zabihi-Hesari et al [23] presented a condition monitoring and combustion fault detection technique for a 12-cylinder 588 kW trainset diesel engine based on vibration signature analysis using fast Fourier transform, discrete wavelet transforms, and artificial neural network. Vibration signals which captured from both intake manifold and cylinder heads of the engine were analyzed in time, frequency, and time–frequency domains. Results show that power spectra of vibration signals in the low-frequency range reliably distinguish between normal and faulty conditions, but they cannot identify the fault location. Hence, a feature extraction method based on discrete wavelet transform and energy spectrum was proposed. The extracted features from discrete wavelet transform were used as inputs in a neural network for classification purposes according to the location of sensors and faults. Shiyuan Liu et al [24] proposed a simple technique for the detection of incipient engine valve faults by vibration signals measured on the cylinder head. The characteristics of the vibration signal are analyzed, indicating that its time domain and frequency domain characteristics are both useful for engine diagnosis, but the cycle-by-cycle variation seems a disadvantage. So, a simple diagnostic technique named partial sampling and feature averaging (PSFA) has been presented. The experimental results show that the proposed technique is feasible, effective and simple in implementation.

2.2 Fault Detection using Acoustic Emission (AE) Sensors:

Douglas et al. [25] had shown that it's easy to record the peak amplitude of the AE signal correspond to the injection/combustion period with the standard variation of the instantaneous crankshaft angular velocity waveform. Wael et. al. [26] designed an injector test rig containing an injection pump, injectors and used AE sensor to receive the signals generated during the injection period and then compare the signals with another extracted from the engine that contains the same equipment previous. This initial analysis has shown that there is a perceptible AE around the expected time of the injection events in the diesel engine, and that the shape of these pulses is widely like that observed in the injector rig. J.D. Gill et al. [27] compared a detailed study into the effect injector discharge pressure has on the AE response of the injector body. Two different fault conditions have been examined; injector discharge pressure reduced from 258 bar to 165 bar in all cylinders and injector discharge pressure reduced to 100 bar in cylinder 4. A comparison was also made with similar studies using vibration measurements, and it was found that the use of AE is more reliable at higher engine speeds and loads. Bejger [28] presented the experimental results of acoustic emission signals application to the investigation of the fuel injection system of a medium-speed marine diesel engine. And used the features extracted from the raw acoustic emission signal to monitoring the condition of the main process of the injection system. This study aims to use the advantage of AE application in comparison to traditional methods is that the non-intrusive nature of the sensors can result in reduced set-up times and cost. And in this study, it has been shown that there is a relationship between acoustic emission signal energy and the condition of fuel injection system. Elamin et al. [29] proved that signals stemming from a four-cylinder diesel engine are suitable for detecting AE signal injector faults. Four tests were performed under various engine conditions. AE signals in the angular domain can aid in the diagnosis for no load condition. A Continuous Wavelet Transform (CWT) was used for the analysis. It can be easily assumed that CWT can tell a part small injection fault from healthy and demonstrate diagnosis, including both high and low load conditions. Elamin et al. [30] examined the possibility of detecting injector faults in a JCB 444T2 diesel engine utilizing AE technique. Short time Fourier transformation (STFT) was applied to process AE signals acquired from a cylinder head of an engine. It was proved that less fuel was provided into the cylinder and less energy was produced when the injection pressure was elevated. In contrast, when the injection pressure was lowered, more fuel was provided into the cylinder and a more profound AE transient was observed. It was discovered that the main AE transients were derived from the combustion inside the cylinders and that the injection faults can be inferred from the main AE transients due to their high impact on the combustion. Lin et al. [31] presented a method to analyze the signal of simulated injector faults by using AE and pressure inside the cylinder. A comparison between the pressure and AE against baseline data from normal engine operating conditions has shown that the AE technique is capable of detection of simulated injector faults. When operating at full load condition, the AE signal from the simulated fault can be utilized for detecting similar injector faults occurring in diesel engines in practice. Jorge Arroyo et al. [32] presented a fast and automatic engine diagnosis method based on a single parameter: the vibration/AE signal's energy. The method is based on the comparison of the vibration and AE energy with reference values to determine whether the engine condition is faulty. The method was applied in a test engine and proved to work satisfactorily. Therefore, it was used to diagnose the Emergency Diesel Generators (EDGs) in a nuclear power plant, where regular rigorous inspections are affected periodically.

2.3 Fault Detection using Microphone:

Long et al. [8] used airborne sound signals. The audio signals from the IC engine are captured by using a simple carbon microphone placed in front of the engine head. The signals are recorded at a sampling frequency of 11025 Hz in Simulink by creating a Simulink

model and are normalized, processed to find signal parameters again like energy, mean, standard deviation, maximum, minimum and variance. Parate et al. [33] Similarly, to capture the signals from the IC engine, initially the engine is started in healthy condition and audio signals are recorded at different speed i.e. 1000 rpm to 5000 rpm with 1000 rpm interval. Then the fault is induced inside the engine to have a reading for faulty condition and again signals are recorded at the same speed and gear positions. The Simulink model is used to record the sound signals captured by the carbon microphone from the engine. These audio signals are processed using Simulink in MATLAB to find the parameters as minimum value, maximum value, mean value, energy, standard deviation and variance.

3. SIGNAL PROCESSING TECHNIQUES

3.1 Time Domain Display:

Time-domain analysis can be used to reveal the overall signal amplitude and cyclic features, while frequency-domain analysis gave spectral information of the signal. This method was used to study the vibration and AE signals to give the individual features of the sources. Time domain was used to view the mechanical events of the vibration and AE waveform recorded in a laboratory environment from a test rig as shown in figure.2

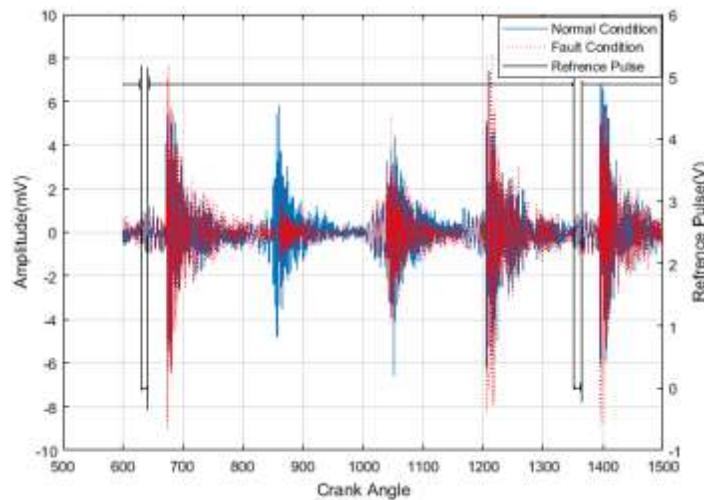


Figure. 2 Mechanical events of diesel injection system

3.2 Frequency Domain Display:

Frequency domain analysis gives spectral information of vibration and AE signals by transforming them from the time-domain to the frequency-domain. The frequency domain can be achieved by using the digital Fast Fourier transform of the time waveform. Frequency domain analysis is a signal processing method that makes it possible to see both the amplitude and frequency information at the same time.

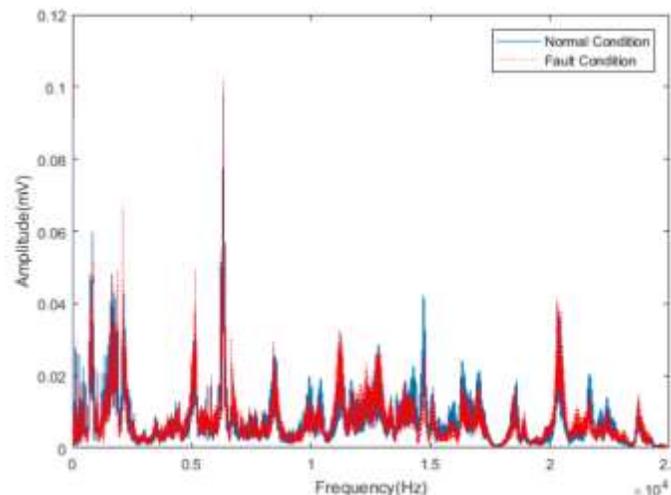


Figure. 3 Frequency spectrum of vibration signal from diesel injection system

3.3 Time-Frequency Domain Display:

Conventional spectral analysis using Fourier transforms of periodic and stationary signals cannot accommodate the temporal variation of the spectral characteristics of a non-stationary signal. The Fourier transform is not a suitable technique for non-stationary signals, and transient signals which are important in diesel engines. Time-frequency analysis is a signal processing method that makes it possible to see both the time and frequency information at the same time. It displays the combined results from time and frequency analyses in a three-dimensional way which plots the amplitudes against time and frequency axes as shown in Figures 4 and 5.

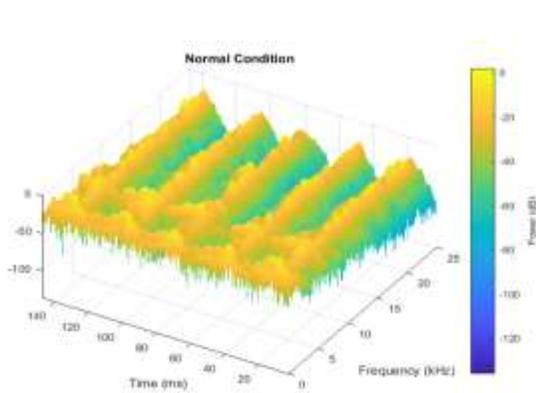


Figure. 4 Time-Frequency domain of vibration signal from healthy diesel injection system

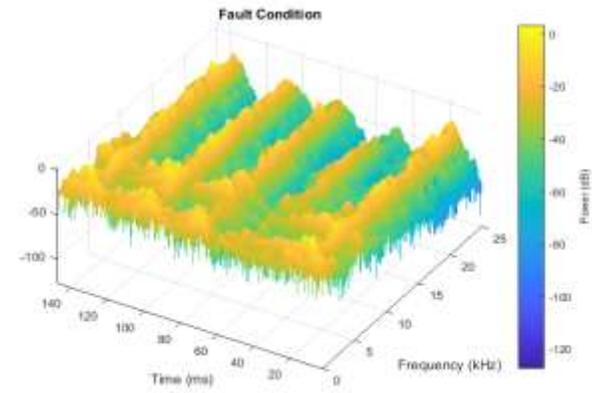


Figure. 5 Time-Frequency domain of vibration signal from unhealthy diesel injection system

4. SUMMARY

Many measurement techniques are available for monitoring and diagnosis of internal combustion engine faults, a survey of the present researches showed that both vibration and acoustic emission techniques are an operative tool for the condition monitoring and fault diagnosis. Vibration and AE measurement technique are a simple, non-intrusive and offers information about the behavior of running engine mechanism. The fast Fourier transform (FFT) is not a suitable technique for non-stationary signals, and transient signals which are important in diesel engines normally highly non-stationary. The most common of the current method for obtaining the time-frequency distribution is the short-time Fourier transform (STFT). The STFT is a linear time-frequency transformation which maps a signal onto the time-frequency (scale) plane and is sensitive to transient signals.

REFERENCE

- [1] F. Feng, A. Si, H. Zhang,, "Research on Fault Diagnosis of Diesel Engine Based on Bispectrum Analysis and Genetic Neural Network," *Procedia Engineering*, vol. 15, pp. 2454-2458, Jan. 2011.
- [2] P. Arques, "Parametrical Assessment of Damage for Diesel Fuel Injection Systems," in *Seminar on Diesel Fuel Injection System of Institution of Mechanical Engineers*, Birmingham, 1989.
- [3] Parlak, H. Yasar, C. Hasimoglu, A. Kolip, "The effects of Injection Timing on NOx Emissions of a Low Heat Rejection Indirect Diesel Injection Engine," *Applied Thermal Engineering*, vol. 25, pp. 3042-3052, 2005.
- [4] K. Purushothaman, G. Nagarajan, " Effect of Injection Pressure on Heat Release Rate and Emissions in CI Engine Using Orange Skin Powder Diesel Solution," *Energy Conversion and Management*, vol. 50, p. 962–969, 2009.
- [5] Ball, A D., and Gu, F., "A Basis for the Vibration monitoring of Diesel Fuel Injector," *Journal of Maintenance*, vol. 10, pp. 24 - 30, 1995.

- [6] Jiang J, Gu F, Gennish R, Moore DJ, Harris G, Ball AD, "Monitoring of diesel engine combustions based on the acoustic source characterization of the exhaust system," *Mech Syst Signal Process*, vol. 22, p. 1465–80, 2008.
- [7] G. Sposito, "Advances in Potential Drop Techniques for Non-destructive Testing," *Imperial College London*, January 2009.
- [8] Long, B. R. and Boutin, K. D., "Enhancing the process of diesel engine condition monitoring," in *Proc. of the 18th Annual Fall Technical Conference of the ASME Internal Combustion Engine Division*, Fairborn, USA, 1996.
- [9] Vikram A. Jagtap, Pavankumar R. Sonawane, "A Review on Fault Detection of Gearbox by using Vibration Analysis. . Vol. 6, Issue 7, ,, " *IJRSET*, vol. 6, no. 7, pp. 14627-14633, July 2017.
- [10] Claudio, A. H., "Multi-sensor Approach to the Diagnostics of Reciprocating Compressor," PhD, thesis University of Arkansas at Little Rock, 1994.
- [11] Z. RANACHOWSKI, A. BEJGER, "FAULT DIAGNOSTICS OF THE FUEL INJECTION SYSTEM OF A MEDIUM POWER MARITIME DIESEL ENGINE WITH APPLICATION OF ACOUSTIC SIGNAL," *ARCHIVES OF ACOUSTICS*, vol. 30, p. 465–472, 2005.
- [12] Liu Jianmina, Shi Yupenga, Zhang Xiaominga, Xu Shiyongb, Dong Lijunc, "Fuel Injection System Fault Diagnosis Based on Cylinder Head Vibration Signal," *procedia Engineering* , vol. 16, pp. 218-223, 2011.
- [13] S. Chomphan, "Vibration Analysis of Gasoline Engine Faults," *American Journal of Applied Sciences*, vol. 10, pp. 1166-1171, 2013.
- [14] BenAri, J., deBotton, G., Itzhaki, R., and Sher, E., "Fault Detection in Internal Combustion Engines by the Vibrations Analysis Method," *SAE Transactions- Journal of Engines* , vol. 108, 1999.
- [15] F. Xia, "Fault Diagnosis of Diesel Engine Oil Pump based on Vibration Signal Processing," *Atlantis Press*, vol. 123, pp. 1778-1783, 2017.
- [16] E. Ftoutou, M. Chouchane, N. Besbès, R. Ouali, "Detection of diesel engine misfire by vibration analysis," in *Congrès Tunisien de Mécanique COTUM'08*, Hammamet, 2008.
- [17] Z. Wang, "Study on Fault Diagnosis of Fuel Injection Based on Vibration Signal Analysis of High-pressure Fuel Injection Pipe," *Applied Physics Research CCSE*, vol. 1, pp. 102-106, 2009.
- [18] Yousef Alhouli, Abdullah Alkhaledi, Abdulaziz Alzayedi, Mohsen Alardhi & Ahmed I. Abed, "Study of Diesel Engine Vibration Condition Monitoring," *Global Journal of Researches in Engineering*, vol. XV, pp. 37-44, 2015.
- [19] S. Xiaochun and H. Hongying, "Diesel Engine Fault Diagnosis and Classification," in *8th international Conference on Signal Processing*, Beijing, 2006.
- [20] Flett, J. and Bone, G. M., "Fault detection and diagnosis of diesel engine valve trains," *Mechanical Systems and Signal Processing*, vol. 72–73, pp. 316-327, May 2016.
- [21] Wang F., Duan S, "Fault Diagnosis of Diesel Engine Using Vibration Signals," in *Intelligent Computing and Information Science*, Berlin, 2011.
- [22] Chao Jin ; Wenyu Zhao ; Zongchang Liu ; Jay Lee ; Xiao He, "A vibration-based approach for diesel engine fault diagnosis," in *International Conference on Prognostics and Health Management*, Cheney, WA, USA, 2014.
- [23] Alireza Zabihi-Hesari, Saeed Ansari-Rad, Farzad A Shirazi and Moosa Ayati, "Fault detection and diagnosis of a 12-cylinder trainset diesel engine based on vibration signature analysis and neural network," *Mechanical Engineering Science*, p. 1–14, June 3, 2018.
- [24] Shiyuan Liu, Fengshou Gu and A Ball, "Detection of engine valve faults by vibration signals measured on the cylinder head,"

Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering, vol. 220, pp. 379-386, 2006.

- [25] R M Douglas, J A Steel, R L Reuben and T L Fog, "On-line power estimation of large diesel engines using acoustic emission and instantaneous crankshaft angular velocity," *International Journal of Engine Research*, vol. 7, pp. 399-410, 2006.
- [26] Wael ABDOU, Nikolaos BALODIMOS, Bob REUBEN, "Acoustic emission in diesel engines – towards a time series model for the injection process," in *30th European Conference on Acoustic Emission Testing & 7th International Conference on Acoustic Emission*, University of Granada, 2012.
- [27] Gill, J. D., Reuben, R. L., Steel, J. A., Scaife, M. W. and Asquith, J., "A study of small HSDI diesel engine fuel injection equipment faults using acoustic emission. Journal of Acoustic Emission," *Journal of Acoustic Emission*, vol. 18, pp. 96-101, 2000.
- [28] A. BEJGER, "THE APPLICATION OF ACOUSTIC EMISSION SIGNAL TO THE INVESTIGATION OF DIESEL ENGINE FUEL INJECTION SYSTEMS," *PROBLEMY EKSPLOATACJI*, vol. 3, pp. 17-23, 2007.
- [29] F. Elamin, F. Gu and A. Ball, "Diesel Engine Injector Faults Detection Using Acoustic Emissions Technique," *Modern Applied Science*, vol. 4, pp. 3-13, 2010,.
- [30] F. Elamin, Y. Fan and F. Gu, Andrew Ball, "Detection of Diesel Engine Injector Faults Using Acoustic Emissions," in *COMADEM: Advances in Maintenance and Condition Diagnosis Technologies towards Sustainable Society*, Nara, Japan, 28 June-2 July 2010.
- [31] T. R. Lin, A. C. C. Tan and J. Mathew, "Condition Monitoring and Diagnosis of Injector Faults in a Diesel Engine Using In Cylinder Pressure and Acoustic Emission Techniques," in *14th Asia Pacific Vibration Conference APVC*, The Hong Kong Polytechnic University, 5-8 December 2011.
- [32] Jorge Arroyo , Mariano Muñoz, Francisco Moreno, Nuria Bernal, Carlos Monné, "Diagnostic method based on the analysis of the vibration and acoustic emission energy for emergency diesel generators in nuclear plants," *Applied Acoustics*, vol. 74 , p. 502–508, 2013.
- [33] M. R. Parate & S. N. Dandare, "IC Engine Fault Diagnosis Using ROC," *International Journal of Advancements in Technology*, vol. 4, pp. 68-78, 2013.