Identification Of Fault Components In Diesel Engine Sounds On Train Using Neural Network

Fathurozi Winjaya¹, Arief Darmawan², Mariana Diah³, Dhina Setyo⁴, Sunaryo⁵

¹,²,³,⁴,⁵Train Electric Engineering, Indonesian Railway Academy Madiun

¹fathurozi@pengajar.api.ac.id, ²darmawan@api.ac.id, ³mariana@api.ac.id, ⁴dhina@api.ac.id, ⁵sunaryo@api.ac.id

Abstract. The diesel engine damage is a typically found-problem in a train. One of the examples from such damage is the damage on components or known as fault components. Fault components occur because the engine does not attain its maximum performance due to the various causes starting from injector damage to injection pump damage. These damages have different sound characteristics. Based on the differences in sound characteristics, expert engineers might identify and categorize the type of damage within the diesel engine by using condenser microphone installed within 1 meter from the source of the engine sound with HPF and FFT (Fast Fourier Transform). The three sources of sound have different frequency. The normal diesel engine has dominant frequency under 1 kHz while the diesel engine sound with injector damage has the dominant frequency under 2 kHz and the diesel engine sound with injection pump damage has dominant frequency above 2 kHz. The data are gathered and processed using Neural Network with RMSE (Root Mean Square Error) 0.001.

1. INTRODUCTION

Train has occupied an increasingly important position in the national development because it serves as the core on the life of economy, socio-culture, politics and also security and defence. Such an important role that the train has is attained through a long process, starting from the very simple transportation mode with the assistance of cattle until the modern transportation mode with the assistance of electricity (which has been very popular throughout the world). Furthermore, train is also able to endure numerous loads in a long distance-journey; as a result, the role of train becomes highly necessary for both the society and the industrial sectors especially in terms of goods distribution [1].

In transporting both people and goods, the power of locomotive engine might be decreasing due to the certain factors, such as level of engine diesel durability and level of traction motor durability, under the hot temperature. Consequently, locomotive might suffer from overheating and the occurrence of overheating might lead to the occurrence of flash over due to the heat and the rain [2]. In addition, trivial problems that do not need sophisticated level of knowledge for problem-solving activities are also found in the engine diesel of a train. In order to solve this kind of problem, an individual might
only need to master the very fundamental knowledge of the diesel engine in a train [3]. However, sometimes these problems also demand higher level of knowledge on the components of the diesel engine and thus the presence of a special engineer will be demanded in the repairment process [4]. For example, in the case of repairing the diesel engine an engineer who already have experiences in dealing with numerous types of damage will only need to identify the type of the damage by hearing the engine sound [5].

Based on the above description, the recent study relies on a method of identifying the sound of diesel engine damage on Type CC2017806 Train and the damage in the train’s diesel engine is related to the injector and the injection pump. The sound will be recorded in certain period of time in order to detect the type of the damage that has occurred. In the same time, Neural Network is applied in order to automatically identify the kind of the sound that the damage of the diesel engine has.

2. MATERIAL AND DESIGN

2.1 Locomotive CC2017806

Electric diesel locomotive is a locomotive that has been equipped with diesel motor initiating engine for moving the wheels through electric power suspension and traction motor. Type CC201 in this case implies that the locomotive relies 3 rotating barrels with electric diesel engine transmission and this is the second locomotive type. The specification of the diesel engine in Locomotive CC2017806 might be consulted in Table 1 below.

| Table 1. Specifications of Diesel Engine CC2017806 |
|-----------------------------------------------|
| **MOTOR DIESEL**                              |
| 1. Type                                      | GE 7FDL 8                                   |
| 2. Category                                  | 4-wheel turbocharger                         |
| 3. Engine Power                              | 1950 HP                                     |
| 4. Power to Generator/Converter               | 1825 HP                                     |
| **PERFORMANCE**                              |
| 1. Maximum Speed                             | 120 km/hour                                 |
| 2. Maximum Pull-Power (Adhesion)             | 17,640 kg/f                                 |
| 3. Continuous Minimum Velocity               | 24 km/hour                                  |
| 4. Smallest Curved Radius                    | 56.7 m                                      |

2.2 Acoustic Control Program

The acoustic control program is designed by using Delphi 7 Software in order to attain or to send commands from the operator. The program is able to monitor the sound of diesel engine and is also able to regulate the output of high pass filter.

GUI (Graphical User Interface) is designed to communicate with the operator through form, graphic and other types of visual form as having been displayed in Figure 1. The program retrieves data periodically from the microphone by using serial port.

2.3 Electronic Architecture

The audio recording process from the diesel engine is conducted by using Krezt 1001 Mic Condenser with response frequency range from 20 to 20 kHz, sensitivity -42 dB ± 3 dB at 1 kHz and noise signal ratio under 56 dB at 1 kHz (1 Pa). The mic condenser is installed within 1 m from the diesel engine and
is connected directly to a computer unit. The audio recording process is run on the computer through High Pass Filter (HPF), which is useful for determining the incoming signal based on the frequency and the amplitude in the sound. Next, the audio is analysed by using Fast Fourier Transform (FFT) which functions to change the output signal of HPF into the form of frequency; the frequency later will serve as the input for Neural Network (NN) so that the type of diesel engine damage might be identified based on the sound. The results of the analysis might be consulted in Figure 2.

2.4 Fourier Transform

In order to differentiate between the engine diesel sound and the noise sound, a method for extracting the noise characteristics should be in application. The characteristics extraction that has been installed on the already designed software will filter the frequency under 500 Hz. The frequency from the membrane vibration that has been found on the microphone might be measured based on the ADC value [6].

$$\phi_{\text{frequency}} = \max(\text{FFT}(x[n]))$$ ................................................................. (1)

In order to define the dominant frequency from the noise, the above equation will be applied. Then, for the extraction of dominant frequency characteristics, 100 frames that contain 1,024 samples so that 100 values will be generated for each frame. The definition of the upper limit and the lower limit for the histerisi of the dominant frequency relies on the application of equation (2) and (3).

$$\lambda_{\text{frequency}} = \max(\phi_{\text{frequency}}) + \min(\phi_{\text{frequency}})$$ ......................................................... (2)

$$\delta_{\text{frequency}} = \frac{1}{2} \sum_{i=1}^{100} \phi_{\text{frequency}}$$ .................................................................................. (3)

In which $\lambda_{\text{frequency}}$ is the upper limit, $\Delta_{\text{frequency}}$ is the lower limit, $\phi_{\text{frequency}}$ is the dominant frequency of frame $i$.

Furthermore, in the sound frame the time domain is transformed into the frequency domain. The objective of using Fourier transformation is to attain the spectrum of the diesel engine frequency. The frequency domain-based signal processing is easier in comparison to the time domain-based signal processing. The time domain-based signal is vulnerable to noise and the vulnerability is apparent from the dominant frequency in the information signal and the frequency in the noise. The results of the transformation process generate 1 x 1,024 matrix. The resolution of frequency spectrum that has been generated by means of Fourier transformation is:

$$\frac{11025}{1024} = 10.766 \text{ Hz/point}$$

2.5 Neural Network

Pattern identification refers to the process of pattern characteristics identification based on the already existing pattern. The new pattern might be classified based on the pattern that has been studied. The classification process by means of NN is performed through training programs. A number of samples for the pattern of the data from the characteristics extraction results are trained on the NN. The input of the NN might be frequency spectrum. The frequency spectrum data that had been gathered from one randomly selected-frame under numerous period results in 1,024 data items.

The NN architecture for the frequency spectrum training has 512 input points. For the other architectures, equal number of hidden layer and neuron is used namely 100 hidden layers. The visualization for the output of artificial neural network architecture might be consulted in Figure 3. In the training program, 10 data items for the frequency spectrum is taken from each type of diesel engine sounds. Then, the frequency spectrum training programs are conducted separately. The NN architecture that has been used in the training programs are different in terms of layer input. There are three types of diesel engine sounds that have been found namely the normal diesel engine sound, the injector-
damaged diesel engine sound and the injection pump-damaged diesel engine sound. Due to the situation, the learning pattern for the NN contains 10 data items from the frequency spectrum [7].

Each type of diesel engine sound has 001, 010 and 100 output targets. Consequently, the NN is trained until the Mean Square Error (MSE) value for the actual output has been under the minimum error that has been inputted.

3. RESULTS AND DISCUSSIONS

The experiments were performed by recording the engine diesel sounds for 20 times in normal condition, injector-damaged condition and injection pump-damaged condition. The analysis on the diesel engine sound might be performed after the HPF has been processed by cutting the frequency around 500 Hz. In average, the recording was conducted for 30 seconds. The performance comparison among the normal diesel engine, the injector-damaged diesel engine and the injection pump-damaged diesel engine might be based on the decibel unit. The sound of the normal diesel engine is around -3 dB, the sound of injector-damaged diesel engine is around -4 dB and the sound of injection pump-damaged diesel engine is around -4.5 dB; the three types of diesel engine sound might be consulted in Figure 4. Then, these differences might be detected by the system through the High Pass Filter process between the normal diesel engine sound and the noisy diesel engine sound.

The diesel engine spectrum test on the frequency pattern was also performed in order to attain the character differences from each type of diesel engine sound. Each frequency was selected randomly in each recording process. By using FFT, the frequency spectrum of each sound type within the recording process might be identified. The comparison on the frequency spectrum between the normal diesel engine sound and the injector-damaged diesel engine sound might be consulted in Figure 5. In average, the characteristic of the frequency spectrum for the normal engine sound us below 1 kHz. This characteristic is certainly different than the injector-damaged diesel engine sound, which frequency spectrum is located on the normalization of dominant magnitude. Figure 6 shows the comparison on the frequency spectrum between the normal diesel engine sound and the injection-damaged diesel engine sound with different patterns. In the injection pump-damaged diesel engine sound, the dominant frequency is above 2 kHz with 0.6 magnitude.
After each frequency spectrum had been identified through FFT process, 10 samples from normal engine sound, injector-damaged engine sound and injection pump-damaged engine sound were put into the learning process by means of Neural Network. The Neural Network was applied in order to identify the type of the diesel engine sound. The learning process of artificial neural network was performed for data that consisted of 10 samples, 512 inputs, 100 hidden layers, 3 outputs, 0.6 learning rate and $10^{-3}$ targeted Root Mean Square (RMS). The convergence result in the learning process of Neural Network is 110,483.

![Comparing sounds of broken injector with normal engine](image.png)

**Figure 2.** Comparison for the frequency between the normal diesel engine sound and the injector-damaged diesel engine sound
In the subsequent stage, the sound sample testing was performed. The 20 samples of each sound were tested on the Neural Network in order to identify whether the Neural Network would recognize the type of sound or not. Then, from the 20 samples the Neural Network was able to identify 75% of total samples from injector-damaged diesel engine sound (as having been shown in Table 2), 85% of total samples from injection pump-damaged diesel engine sound and 90% total samples from normal diesel engine sound. From the three types of diesel engine sound, the highest percentage of identification had been attained by the normal diesel engine sound because the normal diesel engine sound has stable pattern of characteristics. As a result, the Neural Network has been able to identify the normal diesel engine sound in comparison to the injector-damaged diesel engine sound and injection pump-damaged diesel engine sound.

Table 2. The diesel engine sound that has been identified by the Neural Network

| Sample                                           | Success rate |
|--------------------------------------------------|--------------|
| Sound of injector-damaged diesel engine          | 75%          |
| Sound of injection pump-damaged diesel engine    | 85%          |
| Sound of normal diesel engine                    | 90%          |

4. CONCLUSIONS

Based on the results of the experiment, it might be concluded that the use of HPF and FFT is able to identify the differences between the normal diesel engine sound and the damaged diesel engine sound namely the injector-damaged diesel engine sound and the injection pump-damaged diesel engine sound. The frequency of the normal diesel engine sound is dominantly below 1 kHz while the frequency of injector-damaged diesel engine sound ranges between 1 kHz and 2 kHz and the frequency of injection pump-damaged diesel engine sound is above 2 kHz. Then, the results of the learning process in the Neural Network show that the Neural Network that has been designed might be convergent and might attain RMSE $10^{-3}$ with number of iterations 110,483. From the Neural Network Test, the successful rate is 75% for detecting the injector-damaged diesel engine sound, 85% for detecting the injection pump-damaged diesel engine sound and 90% for detecting the normal diesel engine sound.
5. References

[1] Kartiko P Don S Graham Moore 2003 *International Technology Transfer And Distribution of Technology Capabilities: The Case of Railway Development in Indonesia* Technology in Society pp 42-53

[2] Carter F W 1922 *Railway Electric Traction* Edward Arnold & Co. London.

[3] Justin F Gary M 2016 *Fault detection and diagnosis of diesel engine valve trains* Mechanical Systems and Signal Processing pp 316-327

[4] Nicholas W Joshua S Philip T Thomas W 2015 *Measurement Of Black Carbon Emissions From In-Use Diesel-Electric Passenger Locomotives In California Atmospheric Enviroment* pp 295-303

[5] Ning D Sun C Gong Y Zhang Z Hou J 2015 *Extraction of Fault Component From Abnormal Sound In Diesel Engines Using Acoustic Signal* Mechanical Systems and Signal Processing pp 544-555

[6] Moattar MHomayounpaur M 2009A *Simple But Efficient Real-Time Voice Activity Detection Algorithm* Amirkabir University of Technology Tehran.

[7] Winjaya F Rivai M Purwanto D 2017 *Identification of Cracking Sound During Coffee Roasting Using Neural Network* International Seminar on Intelligent Technology and Its Applications (ISITIA) 291-294