Combustion and Resilient Mounting Condition Diagnostics thru Structural Vibration Monitoring of a Diesel Generator Set

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Abstract

Diesel engine real time condition can normally be depicted by its operational parameters. Condition management, on the other hand, can keep track of the machines' status on a long term approach utilizing vibration amplitude and resonance. The mounting support condition along with cylinder combustion pressure excitation influences the diesel engine structural vibration dynamics that may lead to component damage and misalignment. As such, engine mounting condition-based monitoring as a tool can be applied to continuously check on its damping limitations brought by material deterioration.

In this paper, a global vibration measurement in accordance with ISO 13373-1 with the measuring points and direction done in accordance with ISO8528-9 was carried on a large diesel generator set installed in a power plant. The test engine is coupled on a generator and fitted with a torsional damper. Vibration analysis established the occurrence of engine structural vibration phenomena at lower frequency range (<200Hz). It was also confirmed that the actual state of the resilient mount can be verified by the structural vibration natural frequency of the engine.

1. Introduction

Diesel engines common fault diagnostic considerations include temperature, pressure, vibration and noise. Temperature and pressure deviations are the result of operation and external conditions and a convenient method to check the system function. These parameters can be used in the machine control operating system but actual management is complicated for machine condition diagnosis over a long period of time. Hence, a vibration signal is a suitable method for continuously controlling the machine condition and monitor the vibration resonance point and amplitude change to suffice this difficulty. Further, vibration management target value by means of different factors such as engine output, rotation speed, size, type, support mount among others are difficult to set for diesel engine vibration.

This paper shows the preliminary results of a structural vibration monitoring system developed for medium speed diesel engine generator set using vibration signals. Vibration amplitude response from the cylinder head and the resilient mountings were acquired and analyzed in accordance with ISO 13373-1 and ISO 8528-9. Resilient mountings displacement coordinates was taken into account in the vibration analysis (Lee, Barro & Kim, 2016) together with the inertia force due to cylinder combustion pressure being the vibration excitation sources wherein these forces generate secondary unbalanced coupled forces being transmitted to the diesel engine generator set.

2. Fault Diagnosis Basic Algorithm Configuration

This study selected a 4-stroke diesel engine generator set installed in a power plant shown in Figure 1 and the specification given in Table 1.

Fig. 1 Overview for diesel generator at the diesel power plant of a small island

The basic algorithm which presents actual state diagnosis is based on a general procedure (ISO, 2004) and the flow illustrated in Figure 2. These signals can be processed through the raw signal and frequency analysis in the time domain. Although many studies on signal processing have been carried out, the recommended functions (ISO, 2005) are deemed as the most practical. These functions can be clustered to six while other functions can be introduced as needed, respectively termed as:

1) FFT standard order analysis (0.5, 1 ... 12th order)
2) FFT reference (crest factor)
3) Power spectrum effective value (r.m.s.)
4) Arbitrary time domain value (r.m.s.)
5) Frequency domain (Kurtosis)
6) Time domain (Kurtosis)

Table 1 Diesel engine generator set specification

Torsional damper	Type	Viscous
	Dia×Width	690 × 140 mm
	Ring inertia	12.46 kg.m^2
	Casing inertia	8.7 kg.m^2
	Weight	340 kg
Generator engine	Type	Hyundai-Himsen 6H21/32
	Cyl.bore×stroke	210 × 320 mm
	Power at MCR	1,070 kW× 900 r/min
	Pmi at full load	23.6 bar
	Nominal torque	29.4 kN-m
	Reciprocating mass	50 kg/cyl
	Firing order	1-4-2-6-3-5
	Dia. of crank shaft	190 mm
	Conn. ratio(r/l)	0.25
	Minimum speed	500 r/min
	Weight	26.1 ton (Including Generator)
Generator	Type	Air cooled type
	Diameter	1,500 mm
	No. of pole	8 ea
	Moment of inertia	68.8 kg.m^2

The most basic aspect in vibration is spectrum analysis and the crest factor can be calculated considering the order analysis used for this phase order. In addition, functions 3 and 4 are the assessed functions in the vibration evaluation standards (ISO, 2006) whereas function 5 and 6 are determined to be more convenient to apply as diagnostic information and the cylinder combustion state can be missed by function 1 to 4.

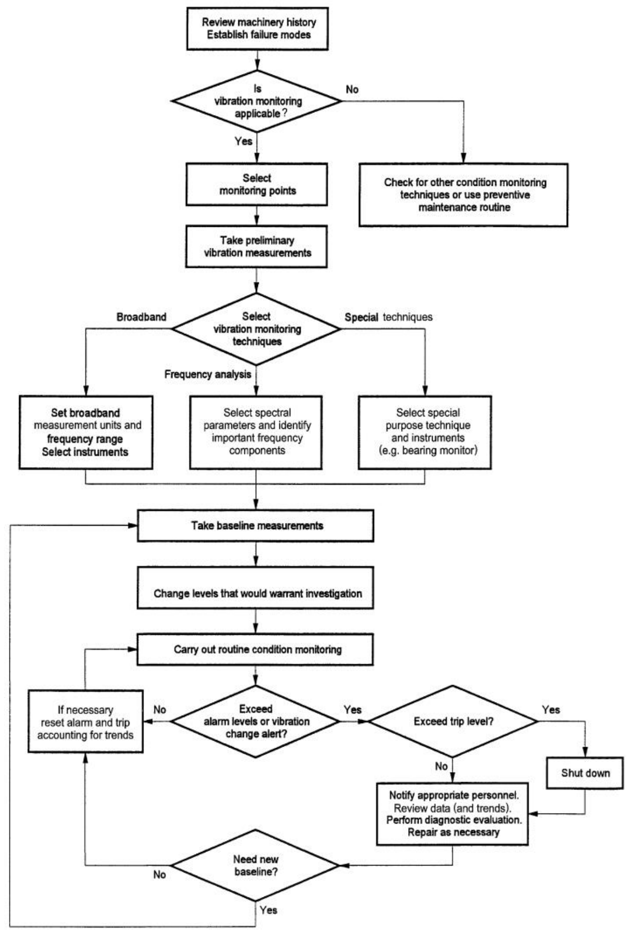

Figure 2 Vibration condition monitoring flowchart recommended by ISO 13373-1

3. Vibration Measurement and Analysis Results

The structural vibration monitoring and test was carried-out employing accelerometer transducers rather than the conventional speedometer. In Figure 3, the equipment schematic arrangement and accelerometers measuring positions are given.

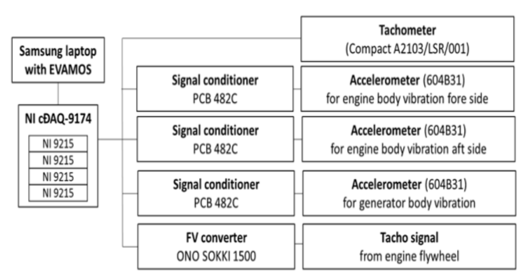

Figure 3 Vibration measurement equipment schematic arrangements

The vibration analysis was performed using the EVAMOS (Engine Vibration Analysis and Monitoring System) software developed by the Dynamics Laboratory of Mokpo Maritime University to confirm both the vibration measurement position and vibration signal condition (Lee, Joo, Nam & Kim, 2009). In order to analyze the combustion state of the cylinder, a three-axis accelerometer was used on all cylinders of a seven cylinder adjacent engine having the same rotational speed (ISO, 1995).

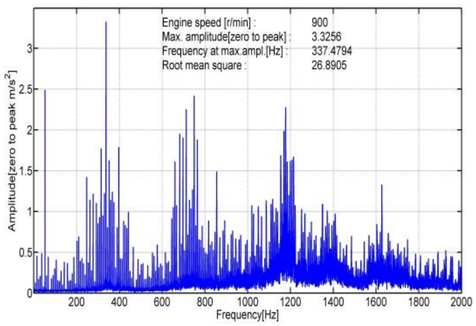

Figure 4 Acceleration of cylinder No. 4 head at transverse direction

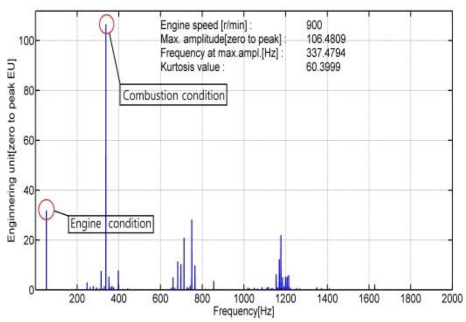

Figure 5 Kurtosis spectrum for cylinder No. 4 head acceleration at transverse direction

In Figure 4, cylinder head no.4 acceleration at transverse direction is given. In this data, the high frequency components can be obtained together with the 3.5-order H-type mode vibration and the cylinder combustion state. In addition, frequency analysis was performed only up to 6.4k Hz with a sampling rate of 16k/s. However, analysis at more than 2k Hz was excluded due to relatively small amplitudes. Further, the longitudinal vibration amplitude was similar to the vertical vibration direction amplitude. As such, when monitoring with a single acceleration sensor, the sensor positioned at 30°- 45° from the horizontal direction is appropriate and assumed to monitor both the transverse and vertical vibration at the same time. For the signal analysis, time domain analysis was distinguished from the frequency domain analysis results and the sampling rate more than 8k/s when the filter is not used. When using the frequency domain analysis result, this can be separated into the factors affecting the engine and combustion condition as can be seen in Figure 5. The structural vibration measured at engine top is shown on Figure 6. As natural frequencies changes according to the engine characteristics, additional research and reviews are required for the application of the diagnostic algorithm. In Figure 7, the same signal of Figure 6 was blocked at 20 Hz to 200 Hz. The natural frequency of the engine itself can be identified up to 150 Hz as the figure shows, the signal is flat and will be difficult to obtain. For Figures 8 and 9, actual vibration measurement results of the engine resilient mounting at transverse direction are shown and are done under the same method at 1.5 kHz and 200 Hz. In this case, it is easy to characterize signals below 200 Hz. Hence, when analyzing time signals of the engine over time, it is judged that the state of the rubber mounting can be verified through the natural frequency of the engine's structural vibration.

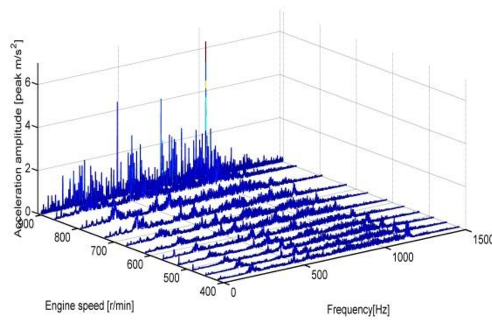

Figure 6 High frequency (less than 1500 Hz) acceleration for engine top-fore at transverse direction

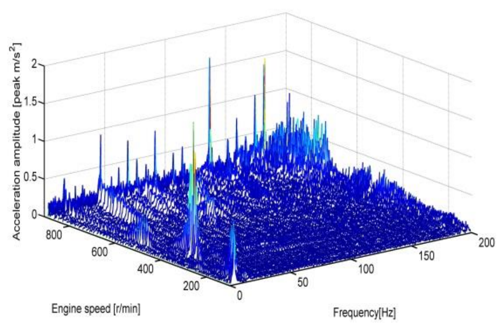

Figure 7 Low frequency (less than 200 Hz) acceleration for engine top-fore at transverse direction

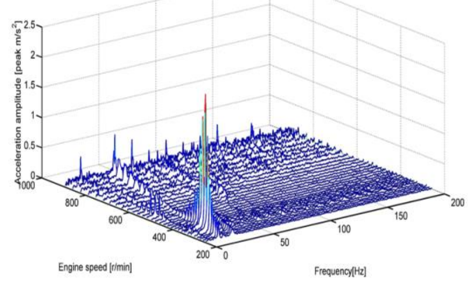

Figure 8 Low frequency (less than 200 Hz) acceleration for engine bottom-aft at transverse direction

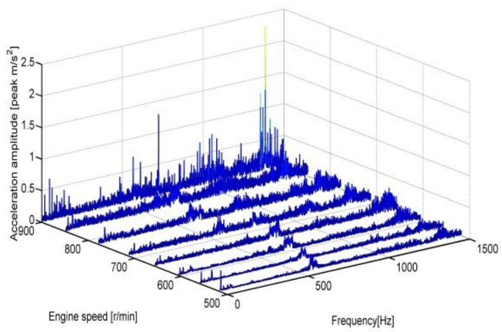

Figure 9 Acceleration for engine bottom-aft at transverse direction

In addition, two sensors were installed at the lower foreside and aftside of the engine for the resilient mount monitoring. The lower aftside was ascertained to be more sensitive and the signals are clearly distinguishable. This can be judged as the suitable sensor attachment position for the resilient mount.

4. Conclusion

In this paper, basic research for fault diagnosis using vibration signal in large diesel engine generator set was carried out and showed the preliminary vibration measurement results of combustion and resilient mounting diagnostics thru structural vibration monitoring. It is intended that a monitoring system will be developed by securing the time history data continuously. The results of the study are summarized as follows:

1) In order to diagnose the combustion state of the cylinder, the vibration signal was analyzed using the acceleration sensor. However, further study was required based on the results of the field measurements.

2) Vibration signals were acquired and analysis results confirmed that the engine bottom-aft is the optimum position for vibration measurement when least number of accelerometer sensors is considered. In this position, it is concluded that the analysis of the resilient mount condition and cylinder ignition failure is possible at the same time.

3) Torsional vibration is considered to be no problem by using a pickup sensor for existing engine revolutions, but it is considered that the torsional vibration should be applied to the diagnostic system after analysis and removing the 'spike' signals.

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Biographies

Ronald D Barro earned his Master and Doctorate degree on Applied Mechanics and Material Engineering at Mokpo National Maritime University graduating in 2007 and 2016 respectively. He is a training ship professor of Mokpo Maritime University. His research interests include diesel engine vibration and structural dynamics.

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Dr. Hee Soo Kim received his Ph.D. degree from the department of mechanical engineering at the Chonnam National University, Gwangju, Korea in 2009. Since 1995, he has been working for the Korea Electric Power Research Institute. His research interests include vibration analysis, mechanical integrity evaluation and intelligent digital power plant.