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Detecting damage on engine mounts using hilbert-huang transform vibration analysis

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Abstract: Engine mounts, which are usually composed of elastomeric materials like rubber that can absorb excessive vibrations, are built to withstand vibration sources from engines. Engine mounts may eventually degrade from extended use. When rubber products age or sustain damage, they may grow harder and crack. Engine mounts need to be maintained regularly to ensure optimal performance. Visual examinations and the detection of excessive vibrations can be used to accomplish this. Vibration sensors are mounted on the engine mount in axial, vertical, and horizontal orientations using a vibration detection technique utilizing the Hilbert-Huang Transform (HHT) methodology. Matlab is used to examine the data that is gathered at three distinct rotational speeds: 750 rpm, 2000 rpm, and 3000 rpm. The HHT approach combines two key components: the Hilbert Transform, which analyzes the time-frequency signal of the first decomposition until only residuals remain, and Empirical Mode Decomposition (EMD), which breaks down the signal into Intrinsic Mode Functions (IMFs). According to test data, a damaged mount had an amplitude of 0.00005212 m/s^2 and a frequency of 8 Hz. On the other hand, in typical circumstances, the highest frequency was 7 Hz with the same amplitude. Five frequency increases were made in the damaged mount throughout this operation. In the damaged mount, the Hilbert Transform showed a frequency of 2124 Hz with an amplitude of 0.007594 m/s^2, indicating a significant resonance. This illustrates how the Hilbert-Huang Transform's capacity to handle non-stationary and nonlinear signal forms allows it to detect damage in components efficiently.

Keywords: Vibration; hilbert huang transform; mounting engine; matlab

1. INTRODUCTION

An essential part that keeps the engine inside the car chassis and lessens excessive vibrations is the engine mounting [1][2]. As a result, this part is crucial to guaranteeing the driver's and passengers' comfort and safety. The performance and comfort of the ride can be impacted by damage to the engine mounts. Energy absorption, damping, and rigidity are the three primary parts of engine mounts [3][4]. Condition maintenance aims to detect engine mounting breakdown early [5][6]. This approach, which uses the vibration method to be processed into the Hilbert Huang Transform, was selected over the Fast Fourier Transform (FFT) analysis because it is more flexible in evaluating nonlinear and non-stationary phenomena.

Because of its adaptive character, the Hilbert-Huang Transform (HHT) is a signal-processing method that is perfect for examining nonlinear and non-stationary processes [7]. Breaking down the input signal, x(t), into multiple intrinsic mode functions (IMFs) and a residual signal using a technique known as empirical mode decomposition (EMD) [8][9]. To obtain the instantaneous energy density, $e_i(t)$, and instantaneous frequency, fi(t), one must translate each IMF into a Hilbert transform, with the iii-th IMF represented by the subscript iii. putting every $e_i(t)$ and $f_i(t)$ in the three-dimensional space of energy, frequency, and time [10]. The Hilbert spectrum is the name given to this form. The Marginal Hilbert Spectrum (MHS) is a 2-D energy-frequency representation that is a further summary of the Hilbert spectrum [11]. Similar to spectrogram representations and Power Spectral Density (PSD), the Hilbert spectrum and marginal Hilbert spectrum have the benefit of instantaneous frequency and energy values [12][13]. The HHT has been used for several purposes, including flight path analysis and health monitoring [14]. Since it deals with non-linear and stationary phenomena, it should be a suitable approach for the task at hand. The Hilbert spectrum is formed by HHT, and the condition indicators that are employed are defined by the marginal Hilbert spectrum [15].

This research is significant because it can identify engine mounting damage, which could compromise the mounting's ability to support the engine and reinforce the automobile chassis [16]. Because the vibration characteristics of the machine installation are non-linear, non-linear vibration analysis techniques, like the Hilbert-Huang Transform method, must be used [17].

Thus, the primary goal of this study is to use the Hilbert-Huang Transform (HHT) approach to determine engine mounting damage caused by excessive vibration and engine rotation speed.

2. METHOD

Data is collected for the study an accelerometer sensor that is coupled to Onno Sokki's FFT Analyzer as a vibration sensor. MATLAB 2020a software is used for data processing and analysis. A 1000 cc Daihatsu Ayla was used for testing; Table 1 provides more information about the 3-cylinder car's specs.

Table 1. Daihatsu Ayla specification.

Item	Specification
Type Machine	1KR-DE 1.0 DOHC 3 Silinder
Capacity Machine	998 cc
Maximum Power	64,1 hp @ 6.000 rpm
Maximum Torque	86 Nm @ 3.600 rpm
Transmission	Setup automatic
Drive voltage belt	5- speed MT/4- speed AT
Type of material burn	Material burn gas without lead

Vibration signals are recorded at each engine speed in the 1000 cc Ayla car's engine mounting region. Testing is done using the Onno Sokki CF-3600 instrument.

Accelerometer sensor with the following specifications:

a) Type piezoelectric accelerometer
b) Sensitivity conversation ratio: pCs2m 5.0 – 7.0
c) Frequency range, Hz: 0 - 40 Hz
d) Transverse sensitivity: < 5%
e) Dimensi, mm: ϕ25, π24
f) Weight: 50g, 8oz
g) Accelerometer cable: 1,5 m

Following the accelerometer sensor's attachment to the vehicle's engine mounting, vibration data is collected using an FFT analyzer to produce a text file with findings presented as a matrix in axial, vertical, and horizontal orientations. Following the acquisition of the vibration data, Matlab 2020a is used to process it before the Hilbert-Huang Transform method is applied Figure 1.

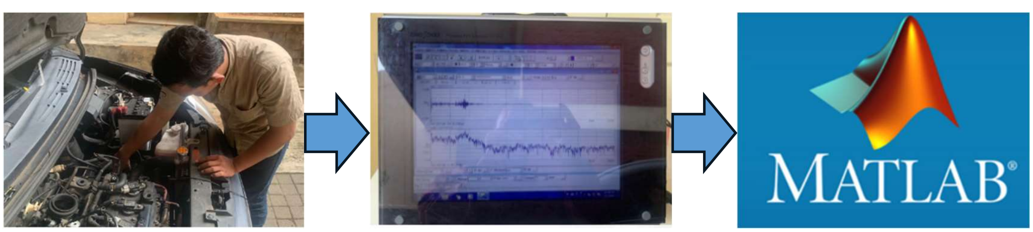

Figure 1. Data collection and processing process.

The sensor is positioned horizontally, vertically, and axially on the engine mounting. The testing phase that follows involves varying engine speed by 750, 2000, and 3000 rpm in Figure 2.

Tool and material preparation employing an accelerometer sensor, Onno Sokki CF-3600 FFT Analyzer, and sensor wire for the Ayla 1000 cc engine mounting test object. By attaching the accelerometer sensor to the channel 3 connection on the Onno Sokki, the object is fixed (static) on a level surface. Configure the screen display, choose Velocity measurement, and enter the test frequency (0–40 kHz) and sample count (4097).

(a) (b) (c)

Figure 2. Accelerometer sensor installation location.

Once the Onno Sokki CF-3600 has been configured, click the record button on the screen display. Once the data has been read, hit the start button to store the data in a text file (.txt). importing data from txt files into Matlab and using the Hilbert Huang Transform and the Fast Fourier Transform graph technique.

3. RESULTS AND DISCUSSION

The accelerometer sensor examined the engine mounting and subsequently processed the test findings using Matlab software at three different rotation speeds: 750 rpm, 2000 rpm, and 3000 rpm. Under typical circumstances, the frequency breakdown on the Empirical Mode Decomposition (EMD) of the second intrinsic mode function appears at 7 Hz frequency with an amplitude value of 0.0001274 m/s2, according to testing conducted in a vertical position on the engine mounting. The signal resurfaces in IMF 3 with a frequency of 10.9 Hz and an amplitude value of 0.00002709 m/s2. It then appears again at a frequency of 36.6 Hz and an amplitude value of 0.00002451 m/s2. The residual on the HHT rises, indicating a rise in the signal's frequency Figure 3.

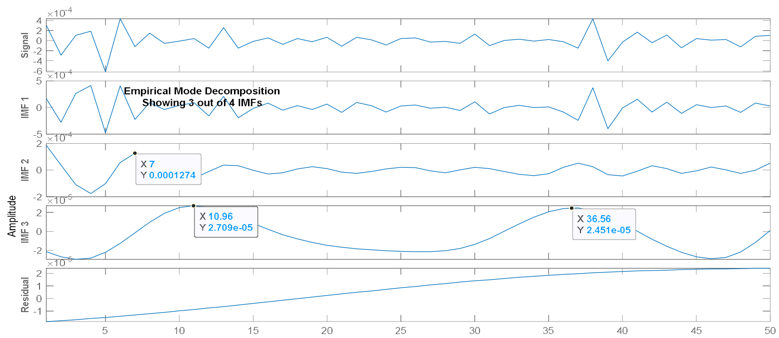

Figure 3. Empirical mode decomposition (EMD) results normal condition 750 rpm speed.

A rise in residuals and IMF breaking signals was observed when the engine mounting was damaged. At the second IMF, the frequency increased five times and appeared at 8 Hz with an amplitude of 0.00005212 m/s2. At the third IMF, a mode shape frequency of 15.2 Hz with an amplitude value of 0.000006205 m/s2 appeared three times the increase in mode shape. Because of the high frequency and growing signal, the residuals rise and demonstrate an increase, as seen in Figure 4.

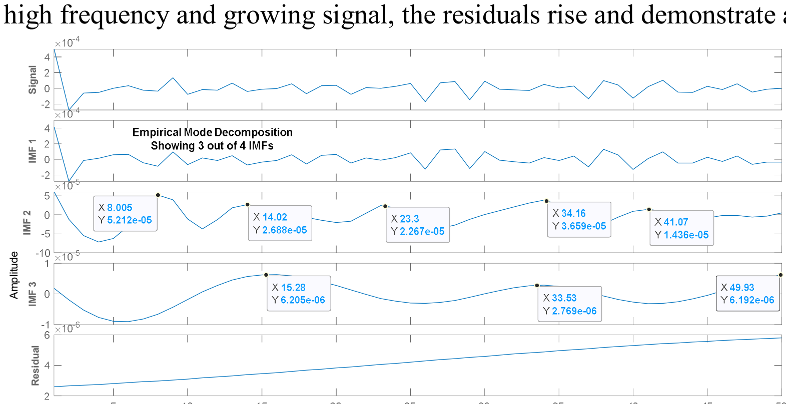

Figure 4. Empirical mode decomposition (EMD) results in broken condition at 750 rpm speed.

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Signal residuals and the intrinsic mode function (IMF) are used to simplify the signal after it has undergone empirical mode decomposition (EMD). To obtain the non-linear value, the next step is to continue with each IMF's Hilbert transform procedure.

Three strong resonances and faint resonances can be seen in the test results of the engine mounting under normal conditions in Figure 5, which are displayed at a speed of 750 Rpm and a peak frequency value of 2125 Hz with an amplitude of 0.001519 m/s^2.

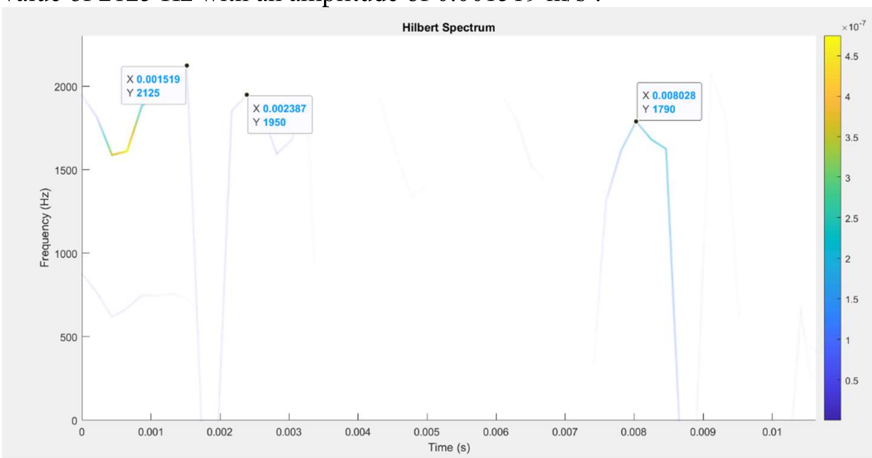

Figure 5. Results of HHT mounting normal conditions at a speed of 750 rpm.

Although the engine mounting in a damaged state, when subjected to HHT processing at 750 Rpm, produced the highest frequency of 2124 Hz with an amplitude of 0.007594 m /s^2, and resonated up to 10 mode shapes, Figure 6 illustrates that the frequency appears higher than that of the normal engine mounting due to the damaged rubber mounting and the absence of engine vibration and shake.

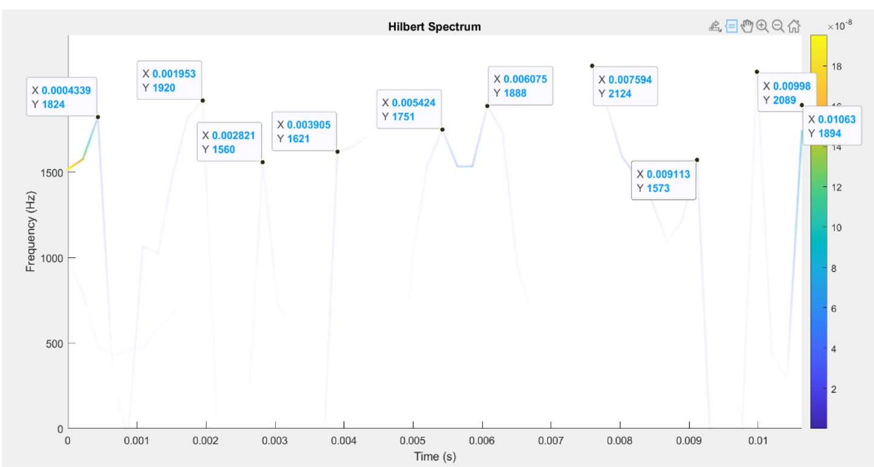

Figure 6. Results of HHT mounting damaged condition at a speed of 750 Rpm.

The Hilbert-Huang Transform approach is appropriate for decomposition and time and frequency analysis with nonlinear, non-stationary signals and can aid in the effective study of high-frequency decomposition. Furthermore, Figure *4* illustrates this with numerous mode shapes showing up, and Figure 6 finds ten resonant mode shapes.

4. CONCLUSION

Hilbert Huang Transform method in detecting engine mounting damage through vibration approach shows EMD results from vertical measurements with a frequency of 7 Hz with an amplitude value of 0.0001274 m/s^2 under normal conditions. While in damaged conditions the frequency appears at 8 Hz with an amplitude of 0.00005212 m/s^2 and 5 times the frequency increase. After simplifying the signal through the intrinsic mode function (IMF) and signal residuals. The Hilbert transform value obtained under normal conditions appears at a frequency of 2125 Hz with an amplitude of 0.001519 m/s^2. And obtained damaged engine mounting appears at the highest frequency of 2124 Hz with an amplitude of 0.007594 m/s^2 and resonates as many as 10 mode shapes. This shows mounting damage that needs to be followed up for the replacement of mounting rubber to reduce vibration from the engine, in order to create comfort in driving due to excessive vibration.

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