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The Condition Monitoring of I.C. Engine using Acoustic Signal Analysis

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Abstract - *The proposed work emphasizes on creating a simple yet effective technique for Acoustic Analysis of Engine Sound Signature taken at specific operating condition according to the ISO 6798. The Acquired Signal of a healthy engine will act as a litmus test for Condition of that specific Engine. This is done by using FFT Conversion of the acquired Audio Signal and comparing it with Sound Signature of the healthy one. The Signal processing is performed using MATLAB Software. The experimentation will conclude the Changes in Sound signature of an I.C. Engine at different condition which can be used for Condition Monitoring and performing preventive maintenance.*

Key Words: Condition Monitoring, Preventive Maintenance, NVH, Acoustic Signal Analysis, Signal Processing, ISO 6798, Data Acquisition

1. INTRODUCTION

As per the recent trends in the automotive industry, more emphasis given on environmentally sustainable vehicles. One of the ways this can be done by designing vehicles with efficient powertrains. The difficult task comes next is to maintain the powertrains in their optimum working conditions by diagnosing any faults or failures in the earliest stage. This would also help the user for planning the maintenance task before any Mechanical Failure of Engine. There are two types of test that are carried out on I.C. Engine Vehicles by manufacturer – Hot and Cold Test. The Hot Tests are focused on verifying the engine performance whereas, on other hand, the Cold tests are more concerned about identifying anomalies by means of torque, pressure and Acoustic monitoring. The main challenge that manufacturers face is to monitor engine's health over its lifespan to avoid any surprise failures from happening. This can be now achieved thanks to advancements in MEMS (Micro Electro-mechanical Systems) technology Microphones. This can be formed in On-board Condition Monitoring System for Vehicles with help of advanced Signal Processing Techniques. The Major challenge faced will be filtering the acoustic signature from the environmental background noise. The Scheme for this task will be like –
(1) Data Acquisition;
(2) Data Processing;
(3) Comparison and Interpretation;
(4) The Conclusion.
The Condition Monitoring can be done using various techniques as highlighted by David J. Moore et.al.[1] such as, Engine Oil Analysis, Vibration Monitoring, Cylinder Pressure Monitoring, Exhaust Analysis etc. Normally a component follow 'Bathtub Curve' during its lifecycle for failure and its occurrence as shown in figure 1. It shows that failure rate is more in early stages of operation, as it approaches middle of its lifecycle the failure rate plateaus. So it is hard to predict when the engine needs any maintenance.

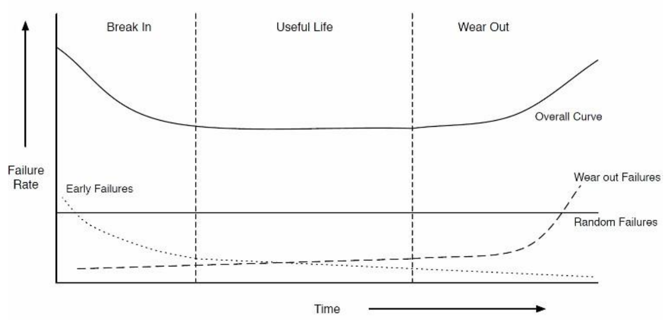

Fig -1: Bathtub Curve [1]

The main advantage of using Acoustic Monitoring over vibration monitoring (or any other method like Cylinder Pressure monitoring) is the non-intrusive behavior [2]. Where the modification needed to make for the later tests to be performed for gathering the data. This can be integrated as an On Board Diagnostic package in an I.C.E. vehicle after it leaves the production line, making it easy to plan maintenances accordingly by monitoring the engine throughout its service life. The challenges in using the Sound Monitoring is of Background Noise so it needs controlled environment or signal filters in Signal processing stage of operation.

The Characteristics of Sound produced by an Engine is mainly based on its combustion parameters. The performed Simulation indicate that the frequency bandwidth of the generated acoustic signals is noticeably widened around the engine's top dead center (TDC) positions, with the energy concentrated predominantly at the firing frequency and its harmonics [3]. So the first task for creating Condition Monitoring System is to understand the Sound Generation Mechanism (figure 2).

Austen and Priede [4] studied various factors affecting engine noise, including engine size, speed, load, and type of fuel injection. Yasuhiro et al[5] studied the frequency characteristics of noise generated by the camshaft, and Osama and Yuichi[6] analyzed the noise generation mechanism of the crankshaft.

Li and Gu[7] explored the feasibility of utilizing acoustic monitoring for the fault detection in electric motors (a machine with far less non-stationary noise output than an I.C.E.).

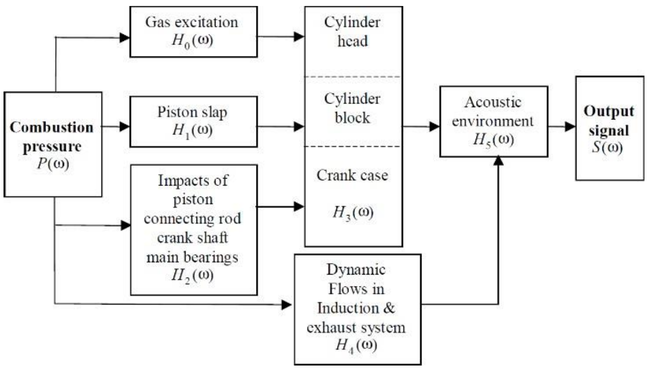

Fig -2: Sound Generation process of a reciprocating I.C. Engine

2. METHODOLOGY

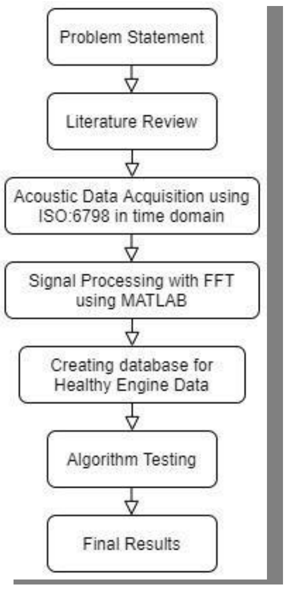

Fig -3: General Framework for the proposed work.

2.1 Data Recording using ISO 6798

2.1.1 Environmental Conditions to be Satisfied

1. The ambient and intake temperature shall not be higher than 45 °C [8].
2. At the microphone positions, the A-weighted sound pressure level due to the background noise including influence of wind shall be at least 3 dB below the A-weighted sound pressure level with the source operating (for survey method).
3. No reflecting objects that are not part of the source under test shall be located inside the measurement surface other than the reflecting plane (ground).

2.1.2 Measurement Points and The Reference Box

To facilitate the location of the microphone positions, a hypothetical reference box is defined [8]. This reference box is the smallest possible rectangular parallelepiped that just encloses the engine and terminates on the reflecting plane (Figure 4).

The box dimensions are determined on basis of the hypothetical box dimensions in which engine would fit. The sound is recorded using iNVH Android app and the generated .wav file is used for further Signal processing.

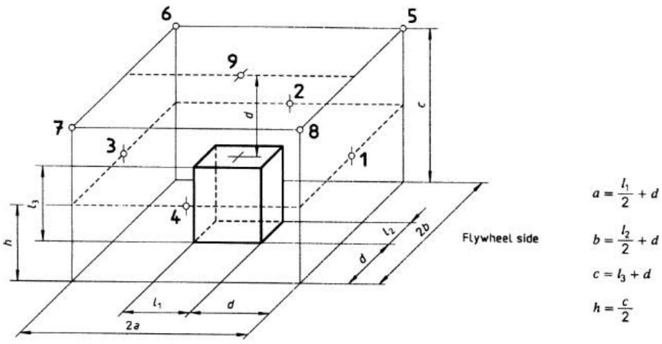

Fig -4: Measurement Points and Surfaces [8]

Table -1: Engine Dimensions and Microphone Position [8]

Length l_1 m	Width l_2 m	Height l_3 m	Number of microphones	Figure showing the positions
≤ 2	≤ 2	≤ 2,5	9 (5)	1
2 to 4	a	≤ 2,5	12	2
> 4		≤ 2,5	15	3
a		> 2,5	19	4

[a] For this engine dimension any value is acceptable with only one exception: for the engineering method this dimension must be less than or equal to 15 m.

2.2 Actual Setup and Specifications

Table -2: Engine Specifications of the Engine Used for Study

Make		Honda
Displaced volume		149.2 cc
Stroke		57.3 mm
Bore		57.8 mm
Emissions type		BS IV
Compression ratio2.2 Actual Setup and Specifications		9.1:1
Number of Valves		2
Engine	Length (inc. muffler)	1180 mm
	Width	450 mm

Table-3: Ambient conditions during testing

Ambient NoiseLevel	L_{eq}	46.2 dB(A)
	L_{max}	60.9 dB(A)
Noise Level during Test	L_{eq}	68.8 dB(A)
	L_{max}	97.6 dB(A)
Ambient Temperature		23°C
Wind Speed		17 km/h

2.2.1 Position of Microphone with respect to flywheel Side of Engine

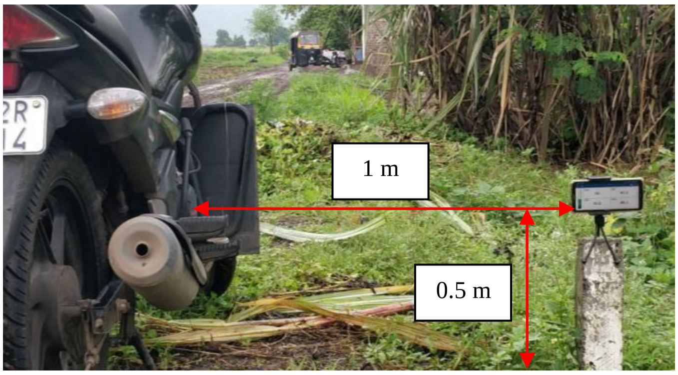

Fig -5: Microphone Position with respect to Vehicle from rear

2.3 Signal Processing using MATLAB

Fig -6: Signal processing strategy for current work

2.3.1 Data Processing Steps

1. Acquiring .wav using BOSCH iNVH™ app
2. Pre-processing the Signal (filtering)
3. Time domain visualization (Amplitude Vs. time)
4. FFT Representation of Signal (Frequency Domain)
5. Comparison of Signals

3. TIME DOMAIN AND FREQUENCY DOMAIN COMPARISION OF ACQUIRED SIGNALS

The Acoustic data acquired in form of .wav file format is then processed in MATLAB to visualize and analyze it in Time and Frequency Domain. From Plotted charts the statistical data like Maximum and Minimum Amplitude, Standard Deviation and Mean are Calculated.

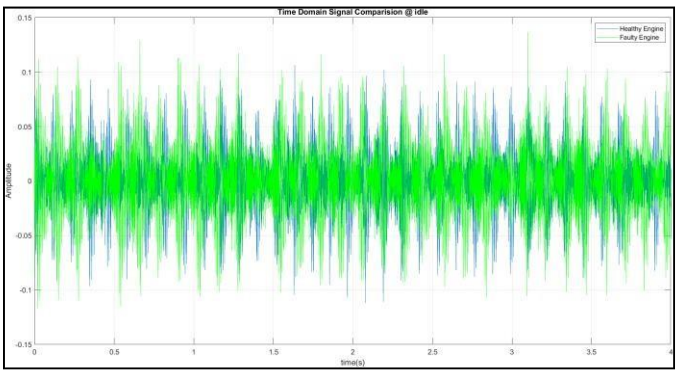

Chart-1: Time Domain representation of engine sound signal at Idle

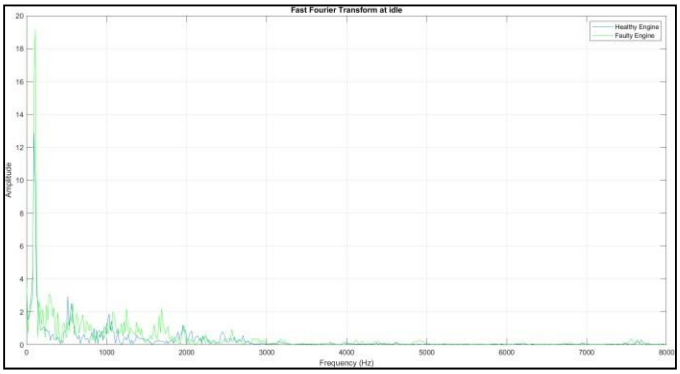

Chart-2: Frequency Domain representation of engine sound signal at Idle

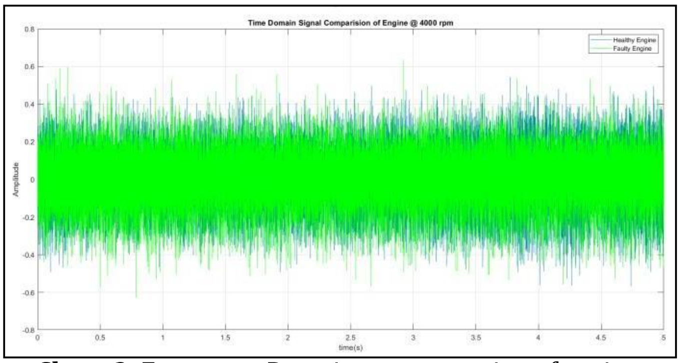

Chart-3: Frequency Domain representation of engine sound signal at 4000 rpm

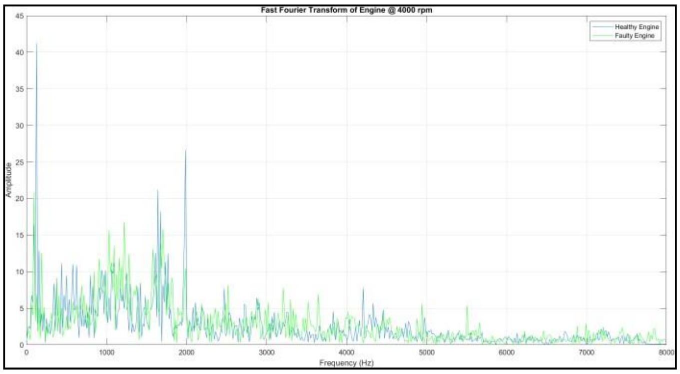

Chart-4: Frequency Domain representation of engine sound signal at 4000 rpm

3.1 Statistical Comparison of the Signals

Table-4: Signal Comparison of Engine at Idle

Parameters	Values for Engine at Idle	
	Faulty Engine	Healthy Engine
Max. Value	0.1065	0.1368
Min. Value	-0.1120	-0.1161
Mean Value	1.4654e-05	1.0834e-04
Std. Deviation	0.0240	0.0290

Table-5: Signal Comparison of Engine at 4000 rpm

Parameters	Values for Engine at Idle	
	Faulty Engine	Healthy Engine
Max. Value	0.6366	0.5543
Min. Value	-0.6285	-0.5687
Mean Value	2.1711e-05	-2.796e-05
Std. Deviation	0.1294	0.1359

4. CRITICAL DISCUSSIONS

The Process used in this experimentation is well-suited for a quick and easy fault diagnosis of any I.C. Engine or any Machinery giving out the Acoustic Signals. As seen from Chart-1 and Chart-3 showing time domain representation of the Signals it can be observed that the Faulty Engine Sound Signature has Clearly Identified higher peaks and troughs as compared to Healthy engine sound signature. This graphical representation can be numerically enforced by higher peak values shown in Table 4 and 5; also the higher Standard Deviation Values.

From Analyzing the FFT plots of Signal of engine running at 4000 rpm its can be seen that there is a prominent peak at 2000 Hz, which is exactly the frequency of Exhaust Pulses that engine will emit at 4000 rpm being a 4-Stroke Engine (Clearly shown in Chart-5). Also the Healthy Engine maintains a Lower mean value of sound signal showing a more silent engine operation as compared to the faulty engine sound signature.

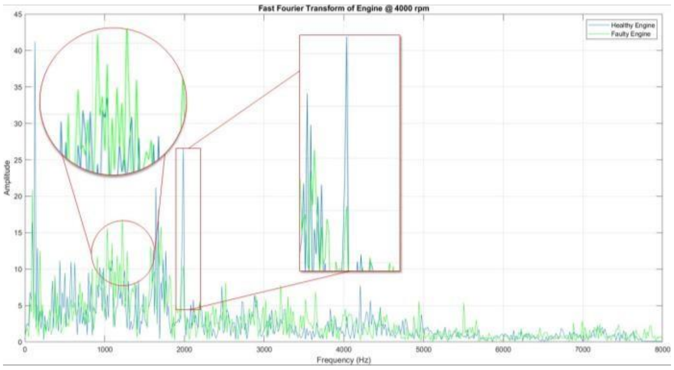

Chart-5: Frequency Domain representation of engine sound signal at 4000 rpm at 2000 Hz

5. CONCLUSIONS

The Technical Condition diagnostics/Monitoring is particularly important for the purpose of uninterrupted operation of internal combustion engines. Ensuring failure-free service requires ongoing monitoring of the technical condition of selected components as well as comprehensive diagnostics of entire subassemblies on an immediate basis, which is a hard thing to do using vibration signals. Proposed method in this paper in unintrusive in nature. And also gives quick results. Thus, the preventive maintenance can be performed thus, reducing maintenance costs.

For Future work a dedicated program can be created using the MATLAB script used for this analysis and experimentation.

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