

IC Engine Fault Diagnosis Using Vibration & Acoustic Signals – A Review

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Abstract: Basic analysis of an engine is an integral part of quality control for an automobile which may help in total enhancement in efficiency of the system. The paper deals with the comparative study of various types of analysis methods which fulfill the above requirement of quick and efficient quality control. It comes across the methodology, experimental setup, experimentation procedure and conclusions of different methods used till date. All the methods ultimately culminate into increasing the efficiency of the automobile used for consideration. And hence all methods can be compared with respect to their results. The conclusion of the paper would help in determining the best option for the analysis of an engine.

Keywords: Vibrational signals, Acoustic signals, ANN method, LabView method.

1. Introduction:

In a fast paced world where technological advancement plays a major role in the quality of standard of living, emphasis is given on increasing the quality of materials provided for the use of man. Great innovations, new and improved methods of analysis and research and really speedy repair systems provide an impetus to such high demand in quality and quantity. An automobile is one such innovation which has changed the evolution of humanity drastically. Over a period of time, vehicles with greater speed and efficiency came into existence. With this trend, need rose for speedy analysis of faulty condition of an engine and its repair. Importance was given to systems which consume less time in an economical way, both for the customer and the manufacturer. Systems based on the extent of vibration in the engine, the neural system analysis, acoustic analysis, etc gave a boost to these technological innovations in analysis and repair.

Some notable and economical methods are listed below:

1. Acoustic analysis
2. Vibration analysis
3. Infrared thermography
4. Lubricant analysis
5. Ultrasound emission

2. Basic Engine Faults:

Regardless of age, mileage, make or model, occasional engine problems are an inevitable part of automobile ownership. As a vehicle accumulates miles, the chances of engine problems increase. Repairing of any IC engine, whether SI or CI engine, may take into consideration many types of faults which causes a percentage decrease in the efficiency of the engine. Some basic faults are categorized below:

1. Acc. to part of engine
 - spark plug gap
 - valve clearance (inlet and outlet)
 - air filter fault
 - gudgeon pin fault
 - piston ring fault
 - inlet and exhaust manifold fault

2. Acc. to engine condition

- powerless engine condition
- idling engine condition
- engine which goes missing (jerk)

The process of monitoring these conditions basically refers to condition monitoring of the engine. In order to identify significant change which is indicative of a developing fault, it is a major component of predictive maintenance. Even many other things can go wrong. For example, if the battery is dead, you cannot turn over the engine to start. Or if the engine runs out of oil, the piston cannot move up and down freely in the cylinder, and the engine will seize. In a properly running engine, all these factors are within tolerance. This paper deals with the review of analysis methods of some of these types of engine faults.

3. Major Fault Detection Techniques:

Two basic methods are described in this paper. Vibration signals and acoustic signals method are the methods which are mostly widely used for condition monitoring. These two methods deals with the changes in the performance of the engine due to the various types of faults described above. For example, if valve clearance fault is induced in the system, there may be a possibility that the engine may not produce power as efficiently as it does in healthy condition. A basic model setup of vibration signal analysis system is shown below.

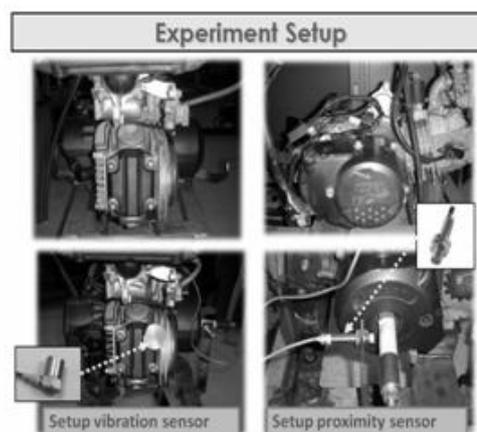


Fig 1: Vibration analysis setup

A vibration pattern analysis is the evaluation of vibration signal related to TDC signal and can give a detail of various mechanical conditions in the engine cycle associated with gas leaks or mechanical impacts. The mechanical impacts, such as valve closure, produce sharp vibration amplitudes. The gas leaks, on the other hand, typically occur over a longer period of time and produce lower amplitudes. In addition, gas leaks are usually affected by changing pressure in the cylinder. Roughness or friction also produces vibration that is characterized by a noisy low amplitude pattern. [1]The vibration pattern analysis of a four-stroke, petrol engine involves the determination of the presence and absence of expected events associated with the engine processes which occur as a measurable amplitude at a specific time. Abnormal events based on mechanical experience and the maintenance history of the engine operation can be predicted using an engine knowledge. Thus, specific regions of the vibration pattern can be isolated. The potential faults can be identified with the vibration pattern by comparing with a baseline normal condition pattern.

Signal analysis techniques used were based on time domain and crank angle domain. The analysis techniques were used to describe some useful parameters such as statistical parameters and energy content from acquired vibration signals.

The parameters are

1. Root mean square (RMS)
2. Variance (var)
3. Skewness
4. Energy content

These analysis methods can be applied to complicated signals. Thus, the mechanical and fluid flow processes in the engine cycle can be described from vibration signals.

Also, acoustic 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. The main advantage of acoustic signal is that they are airborne. [2]Hence the microphone is enough to capture the signals whereas in vibration monitoring, the sensor has to be mounted on the machine under interest hence error in the monitoring may be produced due to misalignment of the sensor. As sound signals are airborne, the portable system can be realized. The audio signals from the IC engine are captured by using simple carbon microphone placed in front of the engine head. The signals are recorded at sampling frequency of 11025 Hz in Simulink by creating a simulink model and are normalize, processed to find signal parameters again like energy, mean, standard deviation, maximum, minimum and variance.

[1]Frequency domain techniques for machine condition monitoring and diagnostics are being used widely for different kinds of machine. In the case of engine condition monitoring for quality control at the end of the assembly line, few applications of these techniques exist.

4. Methodology:

[3]Normally, inputs in the form of vibration signals and sound (acoustic) signals may be analyzed with the help of many methods

which include some like LabView, ANN method, ROC method etc. For example, a small petrol engine is run at normal speed of 1500 rpm with various simulated conditions such as normal, intake/exhaust valve clearance fault and spark plug gap fault conditions. All fault conditions were simulated on the engine. In this work, the engine may be a 4 stroke, single cylinder, petrol engine with capacity of 100 cc. Two signals acquired using LabVIEW program are vibration signal and TDC signal. Vibration signal was detected using accelerometer and TDC signal was detected using proximity sensor given one pulse per revolution.

[6]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. 1000rpm to 5000rpm with 1000rpm interval. Then fault is induced inside the engine to have reading for faulty condition and again signals are recorded at same speed and gear positions. The simulink model is used to record the sound signals captured by 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.

5. Result:

[6]Vibration and acoustic signals when analyzed with methods like Labview and Artificial Neural Network method give results which define a faulty condition in an unknown engine. Labview is a software which gives results in the form of graphs as shown below.

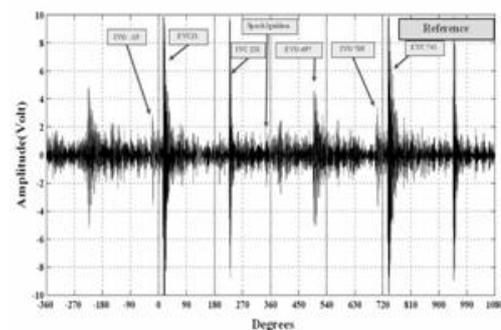


Fig 2: Vibration signal acquired from the engine for normal condition.

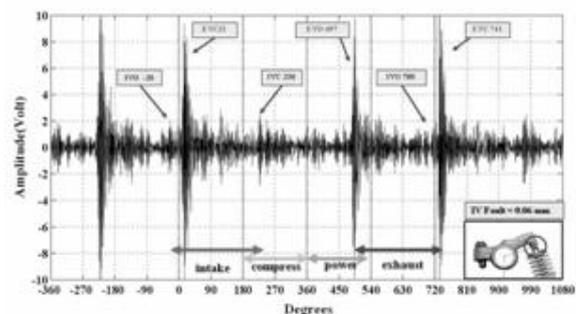


Fig 3: Vibration signal acquired from the engine for intake valve clearance fault condition.

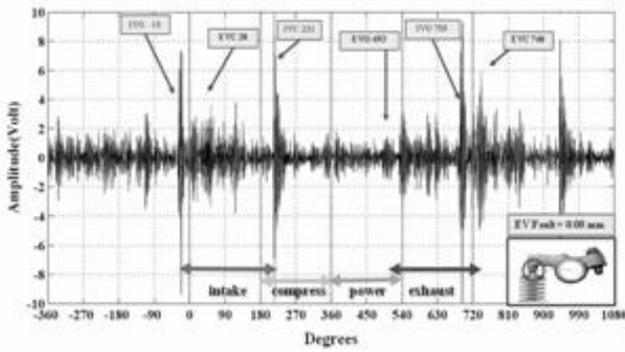


Fig 4: Vibration signal acquired from the engine for exhaust valve clearance fault condition.

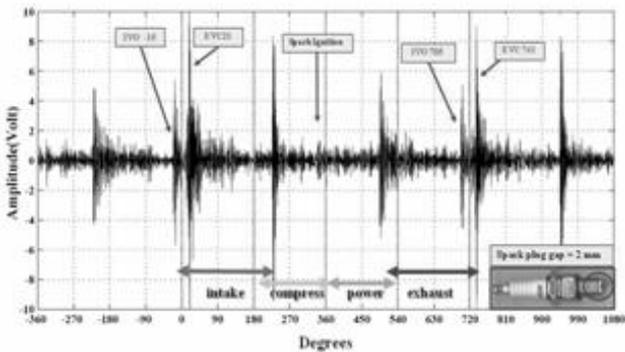


Fig 5: Vibration signal acquired from the engine for spark plug gap fault condition.

[7]Whereas, in ANN method, results are calculated in 3 stages. First stage is Fault detection, second stage is Subsystem identification and the third, Fault source localization. A simple example is given below.

Table 1 shows the fault detection results for the first stage.

Legend: 433 samples are drawn as: VS-85;FC-83;CK-37;TC-83;ML-56;SL-57;ES-32
 VS-Valve setting; FC-Faulty crank; CK-Cylinder kit; TC-Timing chain; ML-Muffler leakage; SL-Silencer leakage; ES-Excess smoke

Total number of test samples			Target	
			Healthy	Faulty
70	70	Healthy	70	0
		Faulty	0	70
140	140	Healthy	140	0
		Faulty	1	139
210	210	Healthy	210	0
		Faulty	1	209
433	433	Healthy	433	0
		Faulty	1	432

Table 2 summarizes the results of second stage of classification.

Total number of test samples			Target	
			Engine	Exhaust
40	30	Engine	40	0
		Exhaust	0	30
80	60	Engine	79	0
		Exhaust	1	60
120	89	Engine	119	0
		Exhaust	1	89
289	143	Engine	288	4
		Exhaust	1	139

Table3. shows the classification performance for the third stage of classification process.

No. of samples	Output	Target						
		F1	F2	F3	F4	F5	F6	F7
10	F1	10	0	0	0	0	0	0
10	F2	0	10	0	0	0	0	0
10	F3	0	0	10	0	0	0	0
10	F4	0	0	0	10	0	0	0
10	F5	0	0	0	0	10	0	0
10	F6	0	0	0	0	0	10	0
10	F7	0	0	0	0	0	0	10
20	F1	14	0	0	0	0	0	0
20	F2	2	17	0	0	0	0	0
20	F3	0	1	19	0	0	0	0
20	F4	3	0	1	19	0	0	0
20	F5	0	0	0	0	20	1	0
20	F6	0	0	0	0	0	18	0
20	F7	1	1	0	0	0	1	19
30	F1	27	0	0	0	0	0	0
30	F2	0	30	0	0	0	0	0
30	F3	0	0	30	0	0	0	0
30	F4	0	0	0	29	0	0	0
30	F5	0	0	0	0	30	0	0
30	F6	3	0	0	0	1	29	0
30	F7	0	0	0	0	0	0	28
85	F1	85	0	5	2	0	0	0
83	F2	0	82	0	0	0	1	2
37	F3	0	0	32	0	0	1	1
83	F4	0	0	0	81	0	0	1
56	F5	0	0	0	0	55	0	0
57	F6	0	1	0	0	1	54	0
32	F7	0	0	0	0	0	1	23

Table 4. Summary of Classification for Each Stage.

Total number of input samples	Classification accuracy										
	Stage 1		Stage 2		Stage 3						
	Healthy	Faulty	Engine	Exhaust	F1 VS	F2 CK	F3 FC	F4 TC	F5 ML	F6 SL	F7 ES
140	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
280	1.0000	0.9928	0.9873	1.0000	0.7000	0.8500	0.9500	0.9500	1.0000	0.9000	0.9500
420	1.0000	0.9952	1.0000	0.9888	0.9000	1.0000	1.0000	0.9666	1.0000	0.9666	0.9333
866	1.0000	0.9976	0.9965	0.9720	1.0000	0.9879	0.8648	0.9759	0.9821	0.9473	0.8518

Legend: VS: Valve setting; CK: Cylinder kit; FC: Faulty crank; TC: Timing chain; ML: Muffler leakage; SL: Silencer leakage; ES: Excess smoke

These simple examples describe clearly how vibration and acoustic signals are analyzed using Labview and ANN methods. The reverse operating characteristic (ROC) method is also a branch of ANN method and acoustic signals give a vibrant result for the same.

6. Conclusion:

Input methods based on time and frequency analysis play a major role in finding faults in an IC engine and they produce a significant

accurate result for monitoring. This study has shown that a simple, non-intrusive vibration measurement technique offers information of the behavior of running engine mechanism. The benefit of this non-intrusive technique is no detrimental effects to engine performance and requires little or without engine modification. With further development, vibration monitoring technique could prove to be an alternative tool for monitoring of engine performance and could significantly aid condition based monitoring strategies. Typical finding from a small, four-stroke petrol engine i.e. intake/exhaust valve operation and spark ignition events can be applied to determine more complicated engine such as a medium or large, four-stroke, four-cylinder, petrol engine. The vibration signal can be used to detect engine operation processes in the engine cycle. Typical recorded vibration signals consists of both burst and continuous signals which associated with mechanical and fluid flow activities in the engine cycle.

Minimum classification accuracy of 85% can be observed in the acoustic signals method when uneven number of samples is used. The riders and the mechanics in service stations can be benefited by the findings. The work finds applications in fault source localization of machinery, vehicles, musical instruments based on acoustic signals. The present work leaves scope for further exploration of fault source localization internal to subsystems of motorcycles.

7. References

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