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Use of Entropy of Sound to Detect Faults in I.C. Engines

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Abstract: Emission of carbon products from automobiles is one of the main reasons for Global Warming, so wide-spread attempts are on to reduce carbon exhausts from I.C. Engines.
I.C. engines have limited efficiency, as proven by the Second Law of Thermodynamics, and they invariably produce exhaust, which can be minimized by proper operation and maintenance, leading to less carbon exhausts.
Preventive / Predictive Maintenance can help in diagnosing problems / defects arising in automobiles at the onset itself. There are / can be devices / methods in Condition / Performance Monitoring, which indicate onset of problems in machines, enabling fixing them at infant stage, saving machines from a possible drastic defect.
Use of Entropy of Sound is a technique for diagnosing defects / faults in I.C. Engines at their onset. Normal, efficient working of any engine is characterized by a sound, having a particular frequency pattern. Any deviation in working changes / distorts this sound, which can be detected and analyzed to repair the fault immediately. Thus, operation and maintenance cost of engine get reduced, its life gets increased and it operates at lower carbon emissions (for which it is designed) for a longer time.
To get a practical idea, we performed some 'Sound Entropy Tests' on various models of 2-wheelers and got a set of readings that show change in entropy between their idling and throttling processes. The results are amazing and self-explanatory. This paper contains study of determining entropy of sound and the results of these experiments.

Keywords : Global Warming, Entropy of sound, Fault diagnosis in I.C. Engines, Preventive maintenance in I. C. Engines.

Introduction

Entropy is a thermodynamic quantity which is related to uniformity of a system. Entropy is central to the second law of thermodynamics. The second law of thermodynamics determines which physical processes can occur, for example it predicts that heat will flow from high temperature to low temperature and not vice versa. The second law of thermodynamics defines Entropy and in terms of Entropy, it can be stated as : "The entropy of a closed system never decreases on its own" and "Processes which increase entropy will occur unless prevented." Since entropy increases as uniformity decreases, qualitatively the second law says that uniformity decreases.

Entropy is mathematically defined in two ways, first as a relationship between heat flow into a system and absolute temperature at which it takes place, and second as the natural logarithm of the number of microstates of a system.

The first definition can be mathematically stated as:

$$ds = [dQ/T] \text{ kJ / K},$$

where, ds is the change in entropy and dQ is the heat added to the system. If the temperature is allowed to vary the equation must be integrated.

Sound waves flowing through a medium contain energy. The entropy increases or decreases with the magnitude and uniformity of sound waves. As the magnitude of sound waves increases the entropy increases and vice versa. Also, as the uniformity of sound waves decreases, entropy increases and vice versa.

In the given paper, we have compiled the study of determining entropy of sound and observations and results of some experiments that show the change in magnitude and uniformity of the sound waves coming out of the I.C Engines of different selected two-wheelers, namely Honda Passion, Honda Splendor, Honda Splendor Plus and Honda Activa (used with a broken silencer). With increase in magnitude of sound waves, entropy increases and hence the disorder increases in the functioning of I.C Engines. Similarly, change in the uniformity of sound frequencies also causes increase in entropy. Our main objective is to detect these disorders at the earliest and take remedial action so that the I.C Engine does not get affected. The study and experiments discussed in this paper were done by two students, Sumit Tyagi and Kaushik

Purnavairagi under the guidance of the author Vanita Thakkar as their B.E. Final Year project during the academic year 2009-2010 at the Department of Mechanical Engineering, Faculty of Engineering and Technology, Charotar University of Science and Technology, Changa, Dist. : Anand, Gujarat, India.

Entropy of Sound : Measuring Techniques

Several methods have been identified for measuring the entropy of sound for several applications, such as – alignment of music performances (matching musical renditions of the same piece of music), which finds application in many Music Information Retrieval disciplines such as Polyphonic Audio Matching [1], Querying by melody [2] and Score-performance matching [3], or its on line version called Score-performance following [4].

Earlier, efficient and versatile aligning techniques commonly used in matching DNA sequences [5] and in finding strings occurrences in texts allowing errors [6] were suspected to be useful in the issue of matching musical performances, then techniques like Dynamic Time Warping (DTW) and Hidden Markov Model (HMM) were used. Entropy has been used in speech signals as a segmentation criterion in noisy environments [7] and in deciding the desirable frame rate in the analysis of Speech signals [8]. Entropy-based Audio Finger Print (AFP) is used in estimating the information content in audio signals every second directly in time domain using histograms [9]. According to Claude Shannon, the level of information in a signal could be measured with Boltzman's formula (Equation 1) for computing entropy in gases which as we know is a measure of chaos or disorder [10].

$$H(x) = E[I(p)] = \sum_{i=1}^{n} p_i I(p) = -\sum_{i=1}^{n} p_i ln(p_i) \qquad (1)$$

Spectral entropy based AFP is more robust to noise, equalization and loudspeaker to microphone transmission than the spectral flatness based AFP adopted by MPEG-7 [11, 12]. The spectral entropy based AFP results from the codification of the sign of the derivative in time of the entropy for critical bands 1 to 24 according to Bark scale. Fast Fourier Transforms (FTT) and Gaussian distribution are used for determining the spectral entropy [13]. The spectral entropy for band p is determined using equation (2)

$$H = ln(2\pi e) + \frac{1}{2} ln(\sigma_{xx}\sigma_{yy} - \sigma_{xy}^2) \qquad (2)$$

where σ_{xx} and σ_{yy} also known as σ_x^2 and σ_y^2 are the variances of the real and the imaginary part respectively and $\sigma_{xy} = \sigma_{yx}$ is the covariance between the real and the imaginary part of the spectrum in its rectangular form and so $\sigma_{xy}\sigma_{yx} = \sigma_{xy}^2$

Using this method, an entropygram is obtained, which shows the information level for every critical band and frame position in time, just as a spectrogram indicates the amount of energy a signal has both on time and frequency.

In the present study, experiments were conducted using sound recording and graphical representation obtained using Sound Wave Frequency Detector software, as described below.

The Experiment

The throttling or acceleration sound at the exhaust of four different motor bikes, namely a Honda Splendor, a Honda Splendor Plus, a Honda Passion and a Honda Activa were recorded using a microphone connected to a laptop, in which the software – Sound Wave Frequency Detector was installed. The experiments were conducted at a noise-free location. Sound during idling process and sound during throttling or acceleration process was recorded and its graphs were obtained as listed in table 1. The graphs of sound waves obtained for different bikes, under different conditions are also shown below.

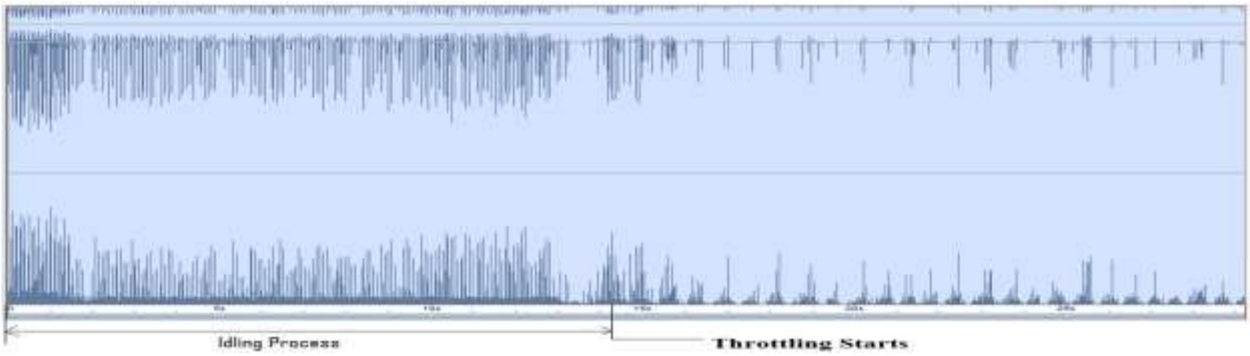

Figure 1 : Sound waves for Honda Activa (had a damaged silencer).

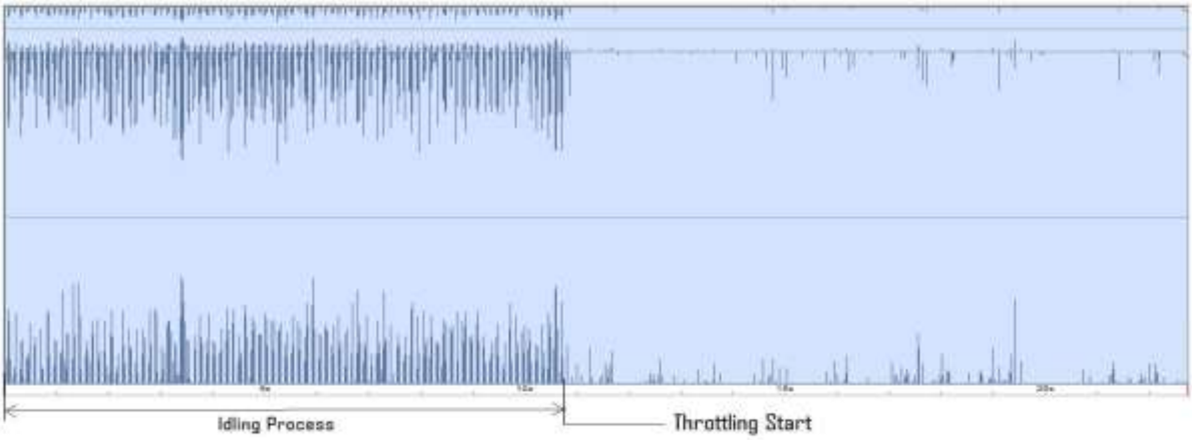

Figure 2 : Sound waves for Hero-Honda Splendor.

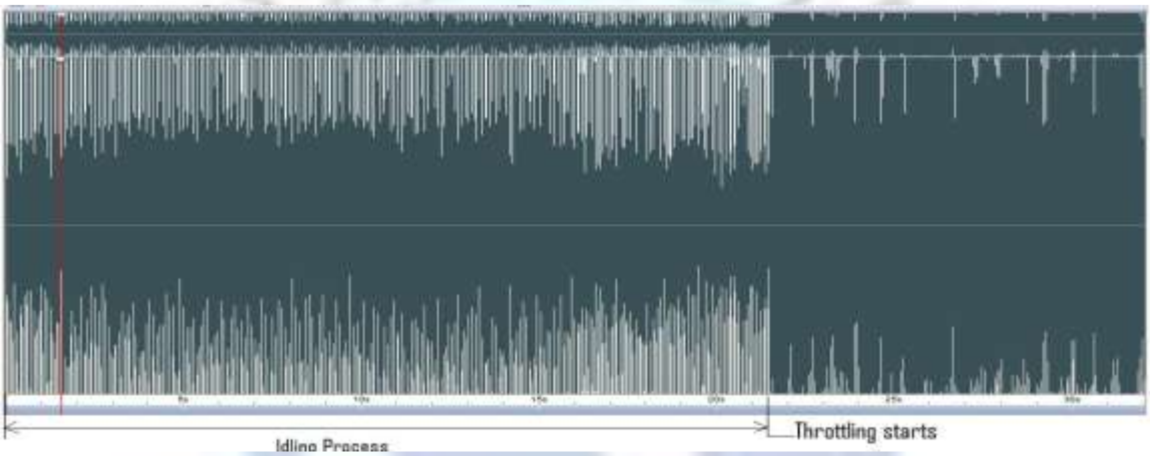

Figure 3: Sound waves for Hero-Honda Splendor Plus.

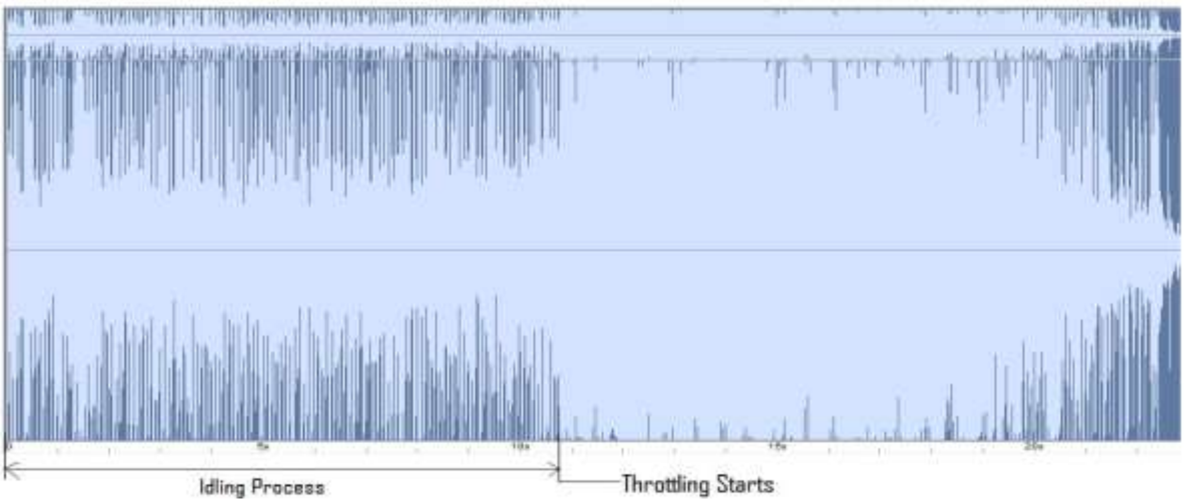

Figure 4: Sound waves for Hero-Honda Passion Plus.

Table 1: Time duration for idling and acceleration process

Name of Motor Bike	Time for Idling (sec.)	Time for Acceleration (sec.)	Remarks
Honda Activa	14:05	15:00	Due to broken silencer, the sound patterns are dense, of higher magnitude and of varying amplitude indicating higher sound entropy.
Hero-Honda Splendor	10:05	12:05	More sound entropy rise than Hero Honda Splendor + and Hero Honda Passion+.
Hero-Honda Splendor +	21:05	10:05	Sound wave patterns show entropy rise less than that of Hero Honda Splendor.
Hero-Honda Passion +	10:05	13:00	During Idling as well as throttling, sound wave patterns with lowest frequency and least distortions, hence best performance among the four motor bikes tested.

Result and Discussion

The four audio files of the test set are put into comparison against each other. The results obtained are as follows:

1. During the idling process Hero-Honda Passion Plus gives the sound waves at lowest frequency i.e. the increase in entropy during idling process is the least in this motor bike. Honda Activa (having a broken silencer) gives the sound waves in the highest frequency i.e. increase in entropy is the highest in this case. This shows that the I.C. Engine in Hero-Honda Passion Plus is working well comparatively.
2. During the throttling or acceleration process, we again find that Hero-Honda Passion Plus gives the sound waves at lowest frequency and least distortions, i.e. increase in entropy during throttling or acceleration process is the least in this motor bike. Here again Honda Activa gives the sound waves at highest frequency due to its broken silencer.

The concept used here can be a part of Condition Monitoring / Performance Monitoring Systems for Machines / Machine Tools. Standard sound patterns for normal, efficient working of the machines can be identified and any abnormalities can be detected by the changes in frequencies of the sounds being recorded using a proper (microphone + filter) arrangement at appropriate location(s), connected to a (data logging + feedback) system, giving indications / alarms in case of deviations. Problems can be identified and remedial measures can be taken at a very early stage during the onset of the defect / fault.

Figure 5 shows the block diagram of a typical condition monitoring system.

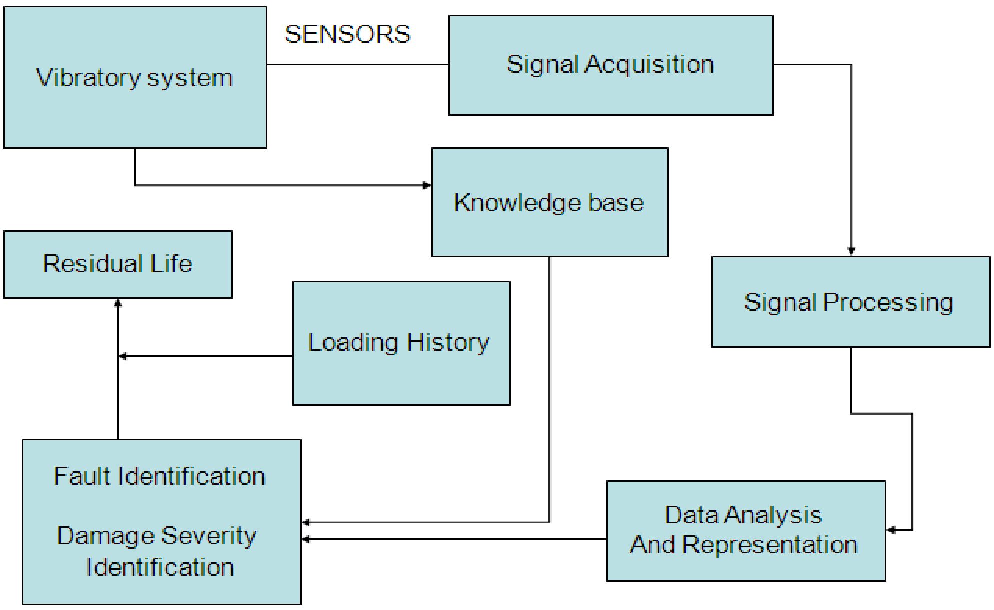

Figure 5: Typical Condition Monitoring System.

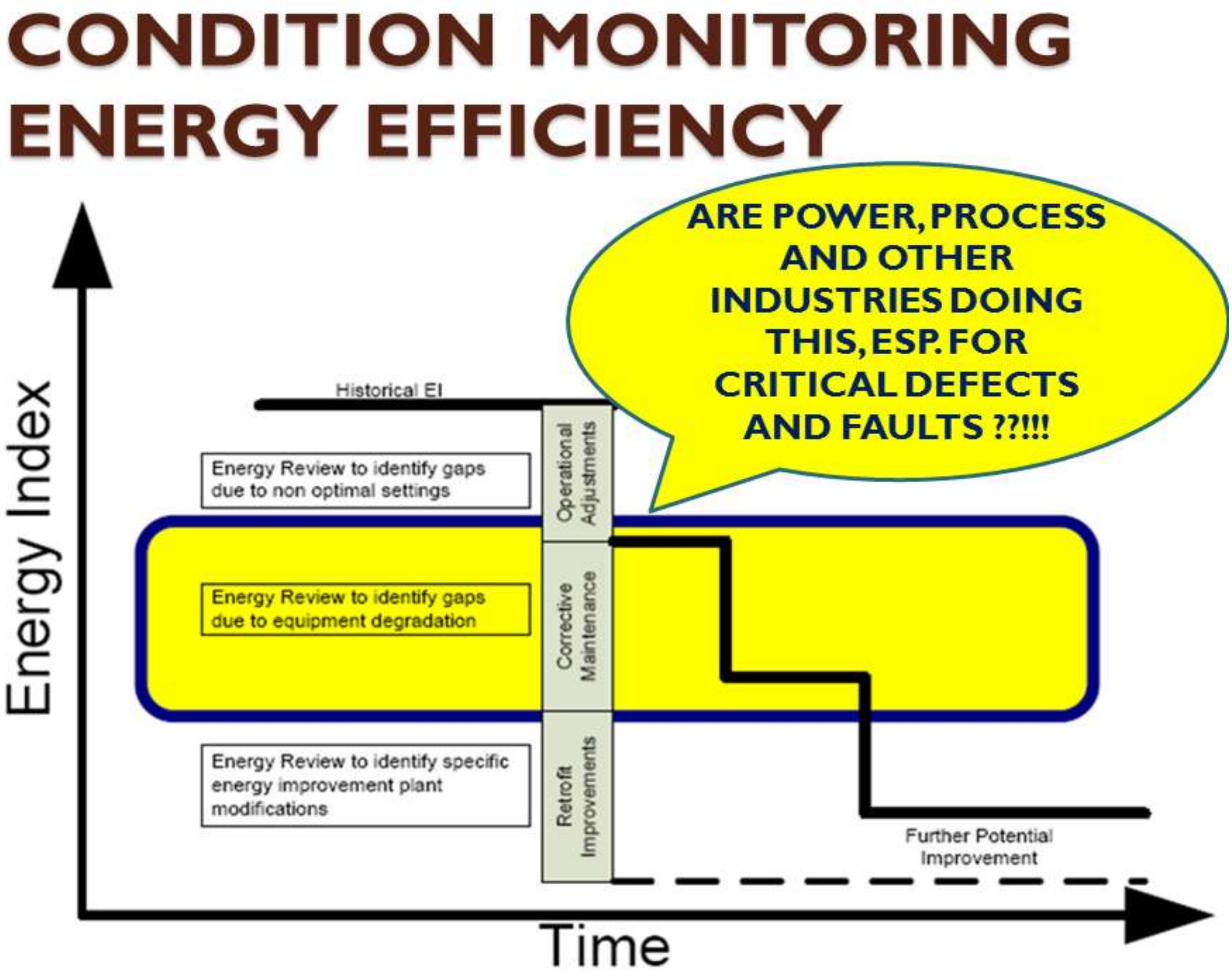

Figure 6: Scope of using the concept in the industries

Conclusion

Increase in entropy of sound due to increase in magnitude as well as non-uniformity is indicative of defective or faulty working of automobile engine, or any machine, in general. The patterns of sound changes – in terms of magnitude as well as uniformity – can be used for a very early diagnosis of faults and immediate remedial measures can help prevent drastic damage to the working of the automobile as well as to the environment, which suffers a great deal from pollution due to running of ever-increasing number of vehicles on roads and which asks for conservation and protection, as evident from the ill-effects of global warming in the form of unpredictable, undesirable changes creeping into the natural cycles and increase in natural calamities [14].

The experimental set-up used was simple and unsophisticated. The results obtained are, however, clear and self-explanatory. Test rigs based on the concept would be simple and inexpensive to make. Using comparison of on-road vehicle sound patterns with standard sound patterns for efficient working for detection of critical defects and faults can help in better maintenance, smooth as well as environment-friendly running and increased life of the vehicle.

The same concept can be tried for proper maintenance and efficient working of heavy machinery, machine tools, etc.

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