

Vibroacoustic Method of IC Engine Diagnostics

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ABSTRACT

The article provides the rationale for, and describes a new internal combustion engine (ICE) diagnosing method, which involves obtaining a signal within the audio frequency range and its examination together with engine performance through the use of algorithms of high resolution time-and-frequency analysis and techniques involving partial signal reconstruction in the phase space.

Examples of how the method may be applied to reveal defects and faults of various units and systems are also described in the article. The paper shows that the method may also be used for other assemblies and units of cars (apart from engines) to analyze patterns for periodic wave structures.

CITATION: Beresnev, A. and Beresnev, M., "Vibroacoustic Method of IC Engine Diagnostics," *SAE Int. J. Engines* 7(1):2014, doi:10.4271/2014-01-0282.

INTRODUCTION

ICE diagnostic equipment includes technical tools and devices designed to determine quantitative values of diagnostic parameters. The above equipment includes various sets of the following basic components: test-mode-setting devices, sensors detecting diagnostic parameters and transforming them into processable or usable signals, a measuring device and an outcome indicator. Apart from the above, such equipment may include job automation and test systems, measuring modules and automated logic units that perform diagnostics.

The engine tester is a universal diagnostic device that is used to detect engine troubles and faults in other car systems. Unfortunately, in recent times certain assembly problems associated with engine testers have led to their application in ICE mechanical troubleshooting. This use of engine testers not only presents a number of difficulties, sometimes it is virtually impossible in practice due to inadequate space for link-up of additional sensors or the need to make unacceptable modifications to the engine control system to make them compatible with the car. Nowadays, the "non-demountable" trend of engine diagnostics is becoming ever more widespread. One of the techniques used in such diagnostics is vibroacoustic monitoring that may be used for all kinds of mechanisms. It originates from an evaluation method employed by specialists which involves troubleshooting by the sound of a running mechanism. Experience has proven that by listening to a car a skilled mechanic can acquire important and

error-free information on its technical condition, which sometimes even enables him to classify the defects detected. Still, this expert evaluation method is, first of all, rather "subjective", and, secondly, requires engagement of a specialist with a wealth of experience in the operation of whatever car is in question. In mass production, those involved in the servicing of a large number of cars complain about the shortage of specialists possessing the above qualities. That's why the task is to formalize the process of defect recognition based on vibroacoustic signals, which task is comparable by its complexity to speech recognition problems.

VIBROACOUSTIC DIAGNOSTICS OF ICEs

Vibration-based diagnostics is a branch of expert systems designed for recognition of patterns generated on the basis of vibration signals. The vibroacoustic method usually is based in a comparison of the actual technical condition of ICE units with their reference condition through comparison of vibration performance. Let us compare, for instance, the vibrations measured on the surface of a piston with the limit values typical of good working condition: a minor excess in amplitude and frequency values indicates the occurrence of micro-galling on mating surfaces, and a considerable excess in amplitude values indicates increased clearance in friction pairs. This method necessitates the availability of a data base containing information as to car units and mechanisms in good working order, radiation frequencies typical of various defects being therein identified.

Theoretical Rationale

Traditional approaches to analysis of physically realized signals, patterns and time series generated by complex polymodal dynamic systems are generally based on statistical methods, and more often on spectral correlation methods and their variations [1,2]. And here, the dynamic nature of the processes that generate signals is made insignificant by the statistical approaches applied to analysis of such signals. Only a dynamic approach to complex system analysis characteristic of the modern nonlinear dynamics permits factoring in signal analysis in the process of identification of dynamic systems according to test data analysis results [3,4].

A major feature of complex dynamic systems behavior is their considerable transiency - up to chaotic character of the signals that they generate. The traditional Fourier-transform-based spectral analysis sometimes does not work, e.g. for non-stationary (transient) signals, the transiency time scale of which is much smaller than the realization period under analysis. This is explained by averaging the fluctuation power during spectral analysis throughout the period that the signal is observed. The most natural way to apply this method to transient signal analysis is to decompose realization in separate short segments of equal length. This technique is widely known in practical analysis of signals in their short realizations (Short Time Fast Fourier Transform or STFFT [2]).

Mathematically, such an approach to signal analysis is based on a widely-known method of solution of linear dynamic equations, which is called Green's function. It involves solution of convolutional equations for physically realized dynamic systems [5,6].

At the same time, one should take into account that the analysis is characterized by low frequency resolution. In case a high-frequency fluctuation has a specific frequency (narrow-band fluctuation), the fluctuation amplitude may be underestimated. The well-known example of use of the transform [4] may lead to a conclusion that, in most cases, estimation of a mode evolution requires only the analysis of the fundamental harmonic and of three higher harmonics of the mode under consideration. But in fact, for such a complex acoustic system as an internal combustion engine that radiates within a broad frequency range with volume-distributed sound sources, some of which are constantly moving, this does not always allow one to unambiguously identify defects.

Usually, defects in rotation bodies are those that are most easily detected. For instance, to estimate the dimensions of a bearing [7] one can use a calculator (to determine the frequency of its radiation) and an inverse solution. The dimensions of the bearing correspond to parameters of the signal picked up. After that one can use technical specifications for the engine to detect the defective part or unit.

Figure 1 illustrates the algorithm of ICE defect detection based on a sound signal. The algorithm may be conditionally divided into two main parts: detection of phased and non-phased defects.

At the first algorithm stage, sound waves are recorded with a vibration sensor, and readings of a cylinder pressure gauge and of the first cylinder spark plug are taken for use in synchronizing vibration sensor signals. Afterwards, the frequency spectrum of the sound signal recorded is divided into intervals, which number shall, at the first iteration of the defect detection cycle, be taken equal to three [8]. This completed, the next signal interval is selected and expanded in a Fourier series. Proceeding from the readings of a knock sensor one must determine whether the signal is phased or not. If it is, the surge phase is determined, and after that the signal source is forecast and a wavelet transform is applied to the signal. If it is not, then a wavelet transform is first applied to the signal, and then, as per the data obtained, the peak amplitude frequency is determined.

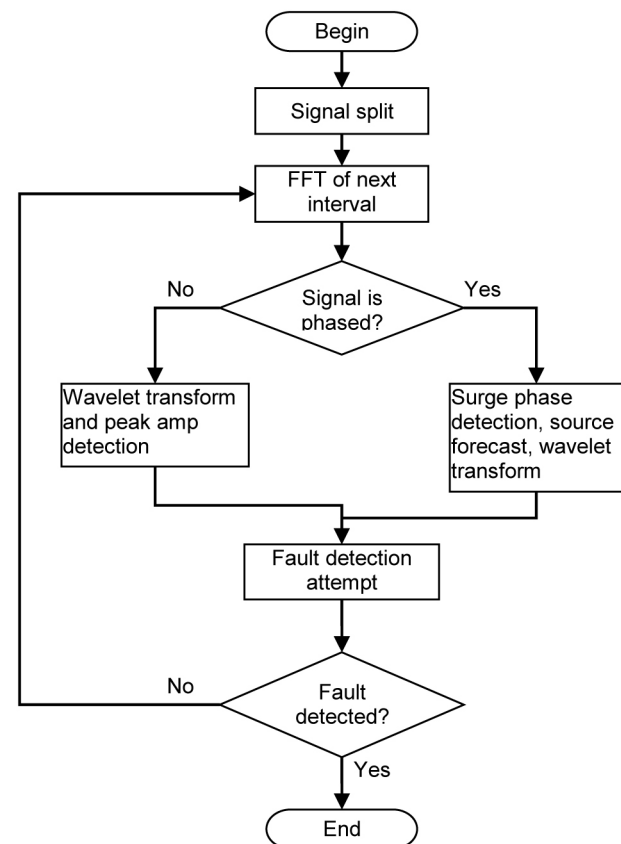


Figure 1. Defect detection algorithm

Sound signal processing results are used to detect faults and defects. And subject to a signal type, the following is performed with respect to a phased signal: the surge phase is determined, the signal source is forecast and a wavelet transform is applied