FISITA 2004
World Automotive Congress
23 - 27 May, Barcelona, Spain

Fundació Politècnica de Catalunya: la formació contínua
UNIVERSITAT POLITÈCNICA DE CATALUNYA

TECHNICAL PAPER FOR STUDENTS AND YOUNG ENGINEERS

- FISITA WORLD AUTOMOTIVE CONGRESS, BARCELONA 2004 -

TITLE:

ASSESMENT OF THE QUALITY OF COMBUSTION IN COMPRESSION IGNITION ENGINES THRUOGH VIBRATION SIGNATURE ANALYSIS

Topic:

- ● FUTURE AUTOMOTIVE TECHNOLOGY
- ○ USER FRIENDLY AUTOMOBILE
- ○ VEHICLES & THE ENVIRONMENT
- ○ INTELLIGENT TRANSPORTATION SYSTEMS
- ○ ADVANCED PRODUCTION AND LOGISTICS

Author(s):

Gideon GOLDWINE , Gal deBOTTON , Boris RIVIN and Eran SHER

Nationality:

ISRAEL

University / Institution:

Dept. of Mechanical Engineering, Ben-Gurion University, Beer-Sheva, Israel

National Society: ● YES ○ NO

Name of the National Society: Israel Society of Mechanical Engineers – Automotive Section (ISME-AS)

Abstract:

When the relative contribution of an individual cylinder to the engine output is different from its counterparts, the engine is operating under non-balanced conditions. This may cause power deterioration, high fuel consumption and excessive engine emissions in the short term, and a mechanical damage breakdown in the long term. To improve the engine quality, there is a strong need for information concerning the inmbalance between the cylinders.

The methodology introduced in the present work suggests a newly developed approach towards analyzing the vibration analysis of diesel engines. The method is based on fundamental relationship between the engines vibration pattern and the relative characteristics of the combustion process in each different cylinder.

Place / Date:

Beer sheva 12/2/2004

INTRODUCTION

Information about the quality of the combustion in an internal combustion engine may provide a strong diagnostic tool regarding the engine operation and health. When the relative contribution of every cylinder to the engine output is not similar for all the cylinders the engine works at a non-balanced condition that may cause structural damage for the engine in the long term. Engine emissions are also dependant on the contribution of every cylinder to the engine's total output. When there is a large variance between the contributions of every cylinder, it has been shown that the composition of the emissions changes and becomes more polluted.

By knowing the general contribution of every cylinder to the engine output it is possible to indicate a fault situation. Moreover, it is possible to use such information as feedback for the injection system.

The parameter which best characterizes the quality of combustion is the pressure in the cylinder. However, this kind of measure requires an intrusive approach to the cylinder and a special mounting process. Pressure transducers for this kind of measurement are very expensive and unreliable at the hostile environment of the cylinder. These reasons make it unfit to be used at mass production.

Many different approaches have been suggested to measure the quality of the combustion in the different cylinders of the engine. Some of these only indicate whether there is a misfire at the engine while others provide more precise information about the combustion in the cylinders. Some of these approaches are based on a time domain analysis, others are based on frequency analysis and lately we are witnessing a joint time frequency analysis based on several theories such as wavelet and short time Fourier transform.

The approaches that have been used to quantify the combustion in the different cylinders of the engine are established on the characters of the internal combustion engine. These approaches have based the analysis on one of the characters of the engine.

The different approaches that have been suggested can roughly be divided into the following major groups:

- Analyzing the engine speed/torque variations (1).
- Analyzing the exhaust gas pressure (2).
- Analyzing the structural strains in the engine (3).
- Analyzing the vibration signature of the engine block (4).
- Analyzing the acoustic signature of the engine (5), (6).
- Analyzing the temperature of the exhaust gas.

Every approach is focused on a different phenomenon that indicates the quality of the combustion in the cylinder.

BACKGROUND

The methodology introduced in this work is based on the vibration signature of the engine. Establishing a connection between the vibration signature and the combustion process is enabled due to the strong relationships between the characteristics of the vibration signature and the unique characteristics of the combustion process in C.I. engines. The latter is characterized by the following three phases (Figure 1):

1. The delay period – the time between the initiation of injection and the appearance of the first flame. During this short period, the first injected fuel drops undergo partial evaporation, while the vapor mix to form regions of premixed mixture ready for ignition. The delay period depends on the compression ratio, injection angle, the entering air temperature, fuel Cetane number, etc.
2. Rapid combustion – the premixed mixture is auto-ignited, undergoes rapid combustion, and releases high heat flux.
3. Mixing controlled combustion period – the injected fuel undergoes atomization, evaporation, mixing, and diffusive combustion.

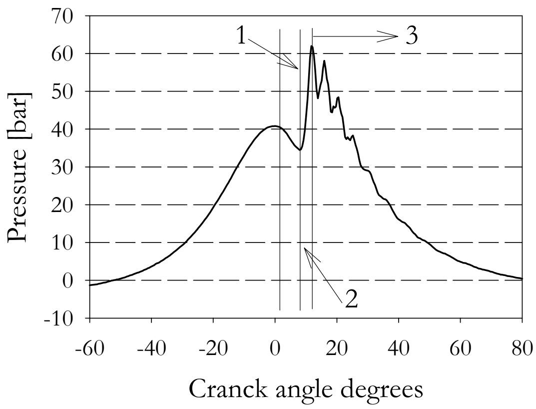

Figure 1. The different combustion phases on a pressure-crank angle diagram.

Auto-ignition occurs due to a sequence of chemical reactions that become more intense when the pressure and temperature rise in the cylinder space. Turbulence intensity, and local mixture ratio, influences the process to a large extent. The first flame in the cylinder will appear where satisfying terms to auto-ignition prevail. This is quite a random process that may happen at different cylinder locations for different cycles of the engine. It is expected that this process will dominate the engine vibration signature.

There are several possible locations to measure the vibration signature of the engine; the main three measurement directions are shown in figure 2. Previous studies (7) (8) have shown that measurements in the vertical direction provide better indication of the combustion process. In the present work we follow their recommendation.

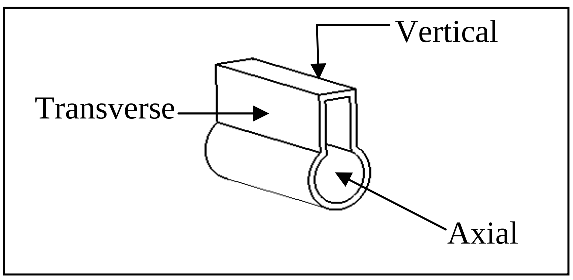

Figure 2. Measurement directions of the vibration signature

When the pressure waveform and the vibration waveform are plotted together (Figure 3), the strong relationship between the two waveforms is evident.

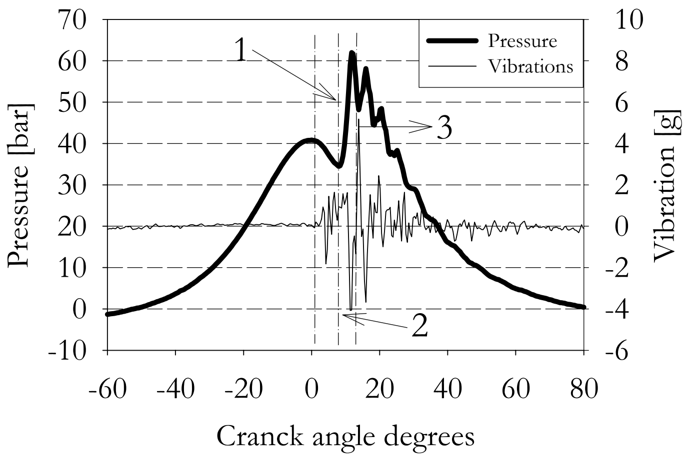

Figure 3. The pressure and the vibration traces.

A close inspection (Figure 3) of the pressure trace and the vibration trace shows that the peak vibration can be linked to the second phase of combustion, the premixed combustion. This stage of combustion is characterized by rapid pressure change, which resembles a single knock that happens due to auto ignition.

The information that can be extracted from the vibration trace and may be used to assess the quality of combustion is (Figure 4):

A – The duration between a timing signal (initiation of injection) and the initiation of combustion. This is information about the ignition timing.

B – The maximum amplitude of the vibration. This provides an assessment of combustion intensity.

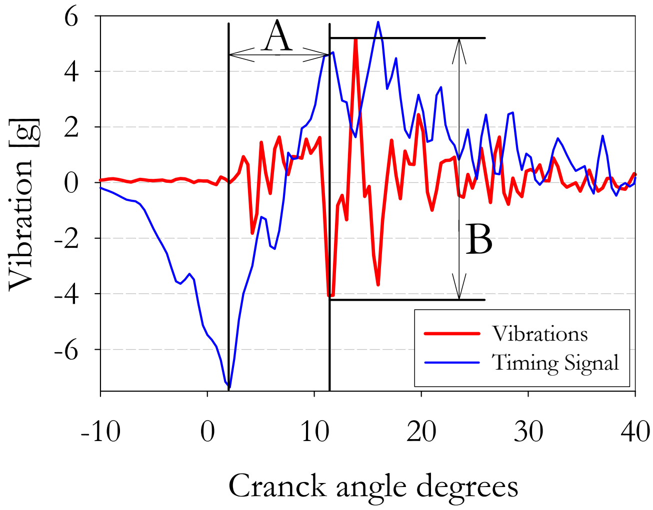

Figure 4. Vibration trace analysis.

Combining these two parameters enables assessment of the combustion quality at every cylinder separately. The ignition timing is determined and this information may be used to control the injection angle. The maximum amplitude of the vibration provides information about combustion intensity, high amplitude may indicate early ignition or presence of a large amount of fuel in the cylinder prior to ignition, lower amplitude may indicate late ignition, injection malfunction or engine compression malfunction.

METHODS

The above principles are integrated together to a computer program which with the suitable equipment is capable of testing different kinds of diesel engines. The computer program code is written in Labview. By using several accelerometers, depending on the size of the engine, timing device, proper analog filter and sampling card, it is possible to characterize the combustion in the different cylinders of the engine.

In contrast to other methods, the program does not use a database. The main principal is that a comparison is made between the different parameters for a specific engine. Each cylinder parameters are presented on a continuous chart and the comparisons between the cylinders are carried out online.

RESULTS

Various types of diesel engines were tested by the above-described method. The results presented are an outcome of a series of experiments that were made on several engines from the same type.

The engine model is G.M. 6V53 (figure 5). This is a two stroke 6 cylinder V shape diesel engine with a mechanical unit injection and a mechanical super charger. The main use of this engine is in very heavy vehicles.

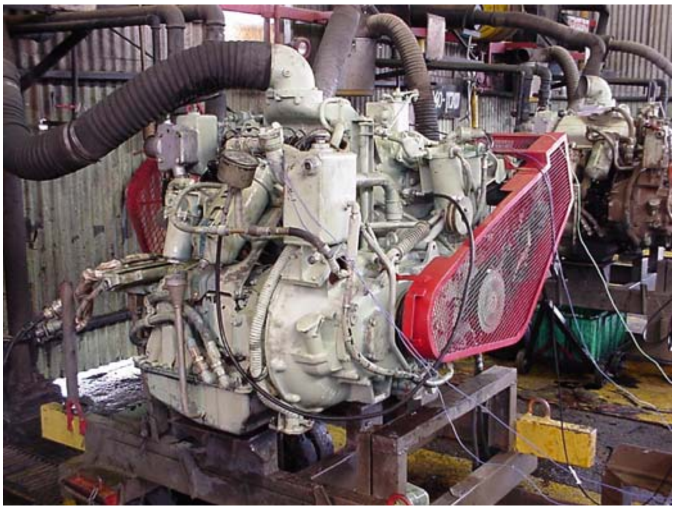

Figure 5. The engine.

The results are presented by means of the above-mentioned two parameters (the maximum vibration amplitude and the time between a timing signal and ignition). The results present 3 different engines. All the engines were tested under the same conditions; the same engine speed and without load. Engine 1 is presented in figures 6a & 6b, engine 2 is presented in figures 7a & 7b, engine 3 is presented in figures 8a & 8b.

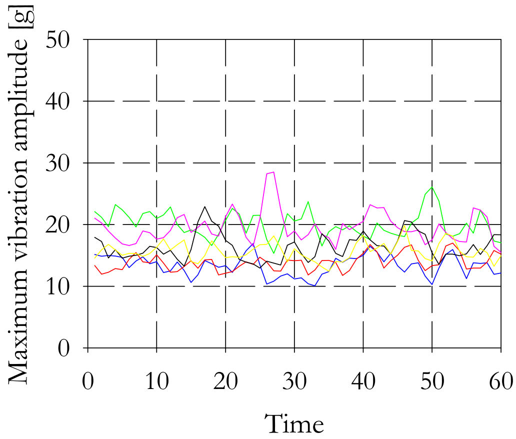

Figure 6a. Maximum vibration amplitude.

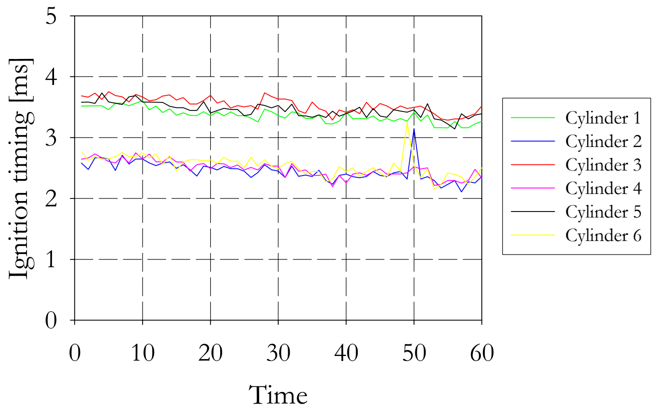

Figure 6b. Ignition timing.

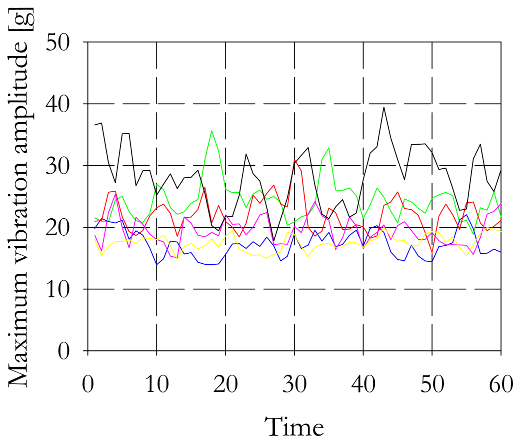

Figure 7a. Maximum vibration amplitude.

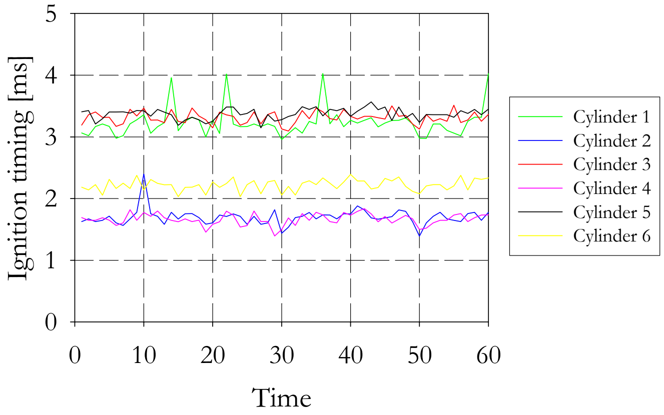

Figure 7b. Ignition timing.

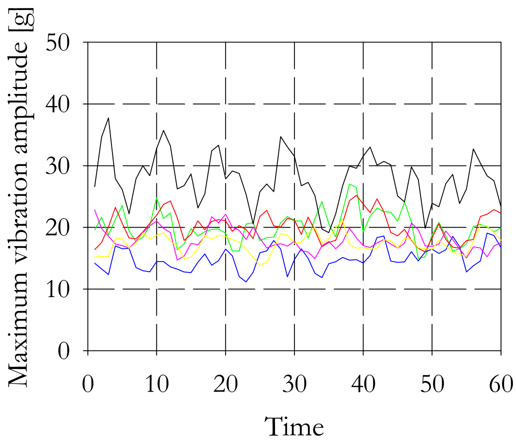

Figure 8a. Maximum vibration amplitude.

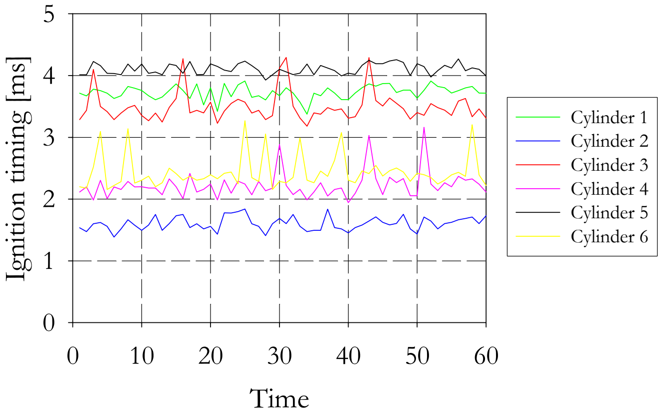

Figure 8b. Ignition timing.

DISCUSSION

The ignition timing defines the period of time that passes before the first flame appears in the cylinder. Under normal operation, the ignition timing will be similar for the different cylinders and there will be a coherent connection between the injection timing and the ignition timing. In the occasion of a fault, the ignition timing may change for a specific cylinder and may correspond differently to the ignition timing.

The "maximum vibration amplitude" is connected to the rate of pressure change and the maximum pressure in the cylinder during ignition. The typical ticking noise of diesel engines comes from the ignition. When the rate of pressure change in the cylinder increases the "maximum vibration amplitude" increases. We may refer to the "maximum vibration amplitude" by means of ignition smoothness. When the "maximum vibration amplitude" is smaller the ignition is smoother and the engine noise is moderate.

The tested engines have different injection timing for each engine side (V shape engine).

The results for engine 1 (figures 6a & 6b) clearly demonstrate that the ignition timing for each side of the engine (cylinders 1,3,5 and cylinders 2,4,6) is uniform. The "maximum vibration amplitude" is moderate which means that the ignition is relatively smooth.

The results for engine 2 (figures 7a & 7b) demonstrate that there is a problem with the ignition timing in cylinder 6; this cylinder ignition lags after cylinders 2 and 4 meaning that the engine is working at a non-balanced mode. Comparison between the "maximum vibration amplitude" of engine 1 and engine 2 shows that the ignition at engine 2 is less smooth than the ignition at engine 1. This parameter may also indicate malfunction of the engine.

The results for engine 3 (figures 8a & 8b) demonstrate that the state of the engine status is poor. The ignition in each cylinder is different and the ignition in cylinder 5 is rough. This engine is working at a non-balanced mode.

CONCLUSIONS

The purpose of this research was to create a system that is capable of identifying non-balanced modes of diesel engine operation and the causes of imbalance. The main demands from the system were that it will work without a database, under all engine conditions and that it will be possible to use it for analyzing a variety of different engines. An additional demand was that the measurement process would not be intrusive. The chosen measurement technique was based on vibration signature analysis. The sensors are attached to the engine by a magnet without an intrusive approach. The experiments that were done showed that there is a fundamental connection between the combustion process and the vibration signature. From this connection it is possible to assess the quality of the combustion at each cylinder separately.

The results show that the system is capable of identifying fault engine operation and can direct the user to the source of the problem. The results presented in this paper are for engines working without load under steady engine speed but this technique works for a variety of engines speeds and loads, under steady operation conditions or under varying operation conditions.

This method may be implemented as a test system for an engine, or as a feedback to an injection system.

References

(1) Dinu Taraza, Naeim A.Henein and Walter Bryzik. Diesel engine diagnosis based on analysis of the cranckshaft's speed variation. SAE paper 982540.

(2) Markus Willimowski and Rolf Isermann. A time domain based diagnostic system for misfire detection in spark-ignition engines by exhaust-gas pressure analysis. SAE paper 2000-01-0366.

(3) Mark C.Sellnau, Frederic A.Matekunas, Paul A.Battiston, Chen-Fang Chang and David R.Lancaster. Cylinder pressure based engine control using pressure ratio management and low cost non intrusive cylinder pressure sensors. SAE paper 2000-01-0932.

(4) V.Macian, M J.Lerma and D.Barila. Condition monitoring of thermal reciprocating engines through analysis of rolling block oscillations. SAE paper 980116.

(5) F.Gu, W.Li, A.D.Ball and A.Y.T.Leung. The condition monitoring of diesel engines using acoustic measurements part 1:acoustic characteristics of the engine and representation of the acoustic signals. SAE paper 2000-01-0730.

(6) A.D.Ball, F.Gu and W.Li. The condition monitoring of diesel engines using acoustic measurements part 2: fault detection and diagnosis.

(7) Anderton, D. and Ghazy, M. R. (1987) "Dynamic response of heavy duty diesel engine structures" SAE technical paper 871669.

(8] Griffiths, W. J. and Skorecki, J. (1964) "Some aspects of vibration of a single cylinder diesel engine", J. Sound Vib., Vol. 4, 345-364.