Determination of the Course of Pressure in an Internal Combustion Engine Cylinder with the Use of Vibration Effects and Radial Basis Function – Preliminary Research

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Abstract. A huge development of new technologies applied in the automotive industry has been observed in recent years. It is visible both in designing, manufacturing and operating new means of transport. All over the world, a number of research institutions deal with such issues. Currently, there are many tests in progress on the development of internal combustion engines which are all mainly conditioned by ecological aspects. All that is aimed at designs which are the most eco-friendly and at the same time which have the best technological parameters. To maintain a proper functioning the presently produced engines are controlled with a lot of electronic sensors installed in the vehicle. In the test, an attempt was made to determine the course of internal combustion pressure in a cylinder on the basis of registered vibration signals. Radial neural networks taught using the data achieved from the decomposition with the application of a discrete wavelet transform were used in this test.

Keywords: internal combustion engines, pressure, vibration, artificial neural networks, diagnostics.

1 Introduction

An intense development of technologies connected with electronics, information technology and related fields which has been observed in recent years has led to a significant increase in their practical applications in the automotive industry. The vehicles of today are full of most modern systems which serve to increase safety and comfort and to reduce the negative impact on the environment. At the same time the work is continued on further development of such technologies, which can be noticed in various scientific papers – such as [7, 8, 9]. The development of branches connected with state-of-the-art technologies does not limit the performance of basic research work leading to similar measurable effects such as, for example, the increase in safety by increasing the durability of the power transmission system elements [2, 4].

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Modern internal combustion engines of cars use integrated ignition-injection systems. By choosing the right value of the ignition advance angle the criterion of maximum turning moment should be taken into account together with a simultaneous low level of harmful substances emission in the car exhaust gas. The value of the ignition advance angle has direct influence on the course of fuel blend peak firing pressure in cylinder.

A correct process of combustion in ZI engines starts at the moment of fuel-air blend ignition. It is initiated with an ignition spark which is formed between the electrodes of an ignition plug. The created flame disperses on the whole charge. The process begins in a laminar way and then continues in a turbulent way. The speed of flame dispersion is dependent on the type of fuel, its composition, temperature and the speed of blend movement.

Three stages can be distinguished during the process:

- stage one – from the moment the ignition spark appears to the moment of pressure increase caused by the reaction of oxidation;
- stage two – from the moment of pressure increase as a result of combustion to the moment when the maximum pressure value in a cylinder occurs;
- stage three – from the moment of maximum pressure value occurrence to the termination of giving off the heat energy.

The first stage includes the ignition delay and the creation of the flame range area. Next the process of fuel oxidation may develop without the input of energy from the outside. The time length of this stage depends strictly on the properties of the blend. It is longer with the decrease of compression degree and ignition energy.

In the second stage the heat is created rapidly and in the form of a flame spreading all over the combustible blend. The time length of this stage depends mainly on:

- ingredients of the blend;
- ignition advance angle;
- degree of compression,
- geometry of the combustion chamber;
- location of the ignition plug;
- rotational speed of the engine;
- degree of blend swirl.

In the third stage, at a high temperature, the fuel after-burns in the combustion chamber.

Detailed information connected with the combustion process in internal combustion can be found in [3, 5, 13, 14].

The heat, created as a result of combustion of a part of blend, fed to the not burned part may lead to creation of next ignition centres. From the created centres the flame may spread with a speed much higher than that in normal conditions (20-40 m/s).

The effect of this is the occurrence of a disadvantageous phenomenon called engine knocking (pinging).

The reason of such phenomenon is:

- too high compression degree;
- too soon ignition of the blend;
- too low octane number of the fuel;
- overheating of the engine;
- too small degree of blend swirl in the combustion chamber;
- too big filling of the cylinder.

The intensity of engine knocking (pinging) depends on:

- degree of compression;
- shape of the compression chamber;
- location of the ignition plug;
- ignition advance angle;
- engine load.

The tendency for engine knocking (pinging) increases particularly with the increase in the engine walls temperature.

It results from the fact that such process occurs mainly during a rapid acceleration of the engine and by big loads of the engine. The engine knocking (pinging) causes an increase in dynamic loads of crankshaft system. Such loads may eventually lead to a damage of bearings. An increased heat exchange between the working gas and the walls of the combustion chamber causes the increase in the temperature of head, valves and pistons which leads to shortening of the life of the whole internal combustion engine.

The limitation of the ignition advance angle is applied to prevent the engine knocking (pinging). To limit the probability of engine knocking occurrence the following methods are used:

- use of fuel with the right octane number;
- properly chosen compression degree;
- properly designed shape of the combustion chamber.

In practice two different methods are used to identify the process of combustion. The first of them assumes a direct measurement of the pressure in a cylinder. However, this method is expensive and requires changes in the construction of the motor head. Also in this case a proper shape of the sensor tip is required as well as the choice of the location of the sensor and the maintenance of the combustion chamber geometry. A direct measurement of the pressure is the advantage of this method allowing an easy identification of the combustion process occurring in the engine.

The second method assumes the use of the vibroacoustic effects, which occur during engine knocking and which are transmitted by the engine elements. In this case the vibration signals measured on the head or on the engine frame may be used and on their basis the occurrence of engine knocking identification. The method, in which the signals are measured is easier and cheaper here, but requires the use of complicated mathematical analyses to detect the engine knocking. Undoubtedly, a huge signal deformation occurs here together with the influence of other engine parts on the shape of the registered signal.

The description of the notions connected with the identification of engine knocking in internal combustion engines can be found in [3, 5, 7, 14].

2 Description of Experiment

In the experiment an attempt was made to determine initially the course of pressure in the combustion process on the basis of registered vibration signals.

The object of test was a 4-cylinder internal combustion engine ZI (installed in a vehicle) with capacity of 1.6 dm^3 fuelled with the LPG gas.

Tests were conducted on a Bosch FLA 203 engine test bench, which made testing of vehicles with a single axle drive possible.

The following aspects were registered during tests:

- signal of vibration acceleration in a direction parallel to the cylinder axis;
- signal of vibration acceleration in a direction perpendicular to the cylinder axis;
- signal of the combustion pressure;
- signal of the crankshaft rotation angle with a marker of upper dead centre of piston position.

Vibration signals were registered with the use of piezoelectric sensors placed on the frame in the area of the fourth cylinder.

The signal of combustion pressure was measured on the fourth cylinder. To perform this a piezoelectric quartz pressure sensor type 6121 was used with a Kisler 5011 charge amplifier. The applied converter enables the measurements in particularly difficult conditions, which are to be found in the combustion chamber. It has a measurement range from 0-25MPa and may work in a temperature range from -50 do +350°C without the need of additional cooling application.

Signals were registered with the use of multi-channel measuring device which enabled synchronous sampling with high frequency. The device worked with an application created in the LabView environment.

Tests were conducted for the engine rotational speed of 1500 rpm at full load.

The registered vibration signals were decomposed with the use of a discrete wavelet transform. Tests were conducted for ten levels of decomposition.

The wavelet analysis consists of the signal decomposition and presenting it in the form of a linear combination of basic functions, called wavelets. The feature which distinguishes this method of signal analysis from other methods is a multi-stage signal decomposition, a variable resolution in time and frequency domain and a possibility to use basic functions other than harmonic functions [6, 11].

A Discrete Wavelet Transform of the signal $x(t)$ is marked as a scalar product $x(t)$ and sequence of basic functions $\psi(t)$:

$$DWT = \int_{-\infty}^{+\infty} \psi(t) \cdot x(t) dt \tag{1}$$

As a result of multi-level signal decomposition, the signal approximation is achieved on a given level a_k and a detail sum on the next levels d_l:

$$x(t) = a_k(t) + \sum_{l=1}^{k} d_l(t) \tag{2}$$

where:

d_l – a detail of signal, a high-frequency signal element,
a_k – the signal approximation, a low-frequency signal representation.

Together with the increase in the signal decomposition level the participation of details decreases, which causes that with the decrease of resolution, the contents of details in the signal approximation decrease.

A Discrete Wavelet Transform gives an opportunity of decomposition and selective reconstruction (synthesis) of the signal in the whole range of the analysis. It can be equalled to a signal filtration with a constant relative bandwidth [6, 11].

The tests assumed that the signal of combustion pressure will be determined with the use of signals achieved from vibration signals decomposition on ten levels. However, because the tests registered combustion pressure only for one cylinder the attempt of combustion process identification was performed only in a chosen range of the crankshaft angle corresponding with the occurrence of the combustion process in a given cylinder.

The tests assumed to use the neural networks taught on the data originating from vibration signals to determine the combustion pressure. Therefore, the registered signals were properly processed with the use of normalisation and scaling processes.

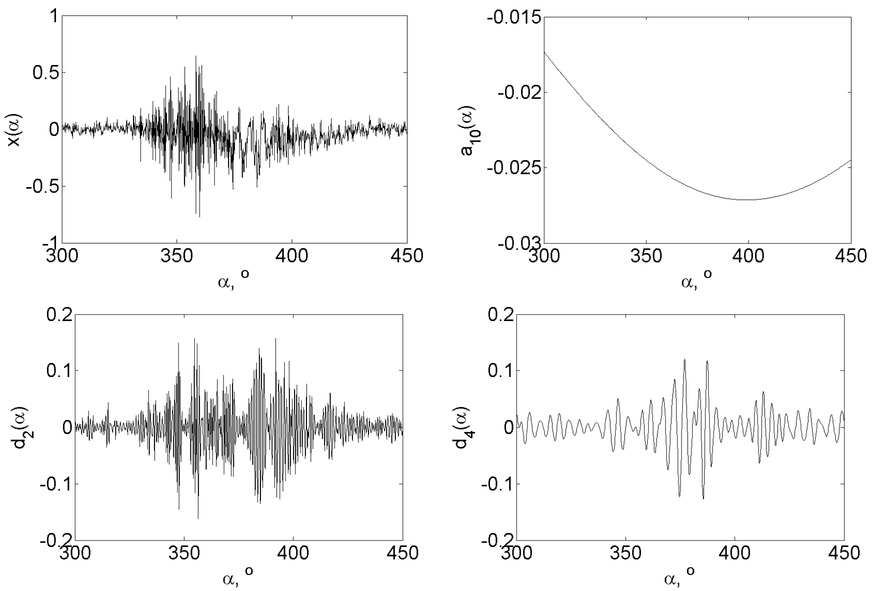

Fig. 1. The course of vibration signal decomposed with the use of discrete wavelet transform

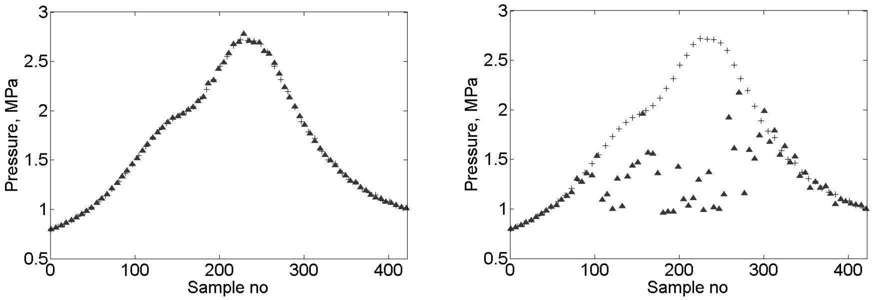

Fig. 2. Influence of coefficient γ on the identified combustion pressure value, the value chosen a) correctly b) incorrectly

An example of vibration signal which was decomposed with the use of discrete wavelet transform is shown in Fig. 1.

Signal values achieved for ten decomposition levels were the input data for the neural networks (radial basis function). The values of combustion pressure were expected to be achieved on the network output.

While using such network type, proper smoothening coefficient γ should be selected. It represents the radial deviation of Gauss functions and is a measure of the range of neurons in the hidden layer. This value, when too low, causes the loss of knowledge generalizing property by the network and if too high, prevents the correct description of details. Similarly to the radial networks, the value of γ coefficient is determined experimentally [1, 10, 12]. The performance of the network for 86 various values of γ coefficient was checked in the experiments.

Example influence of the parameter γ values on the correctness of combustion pressure determination is shown in Fig. 2.

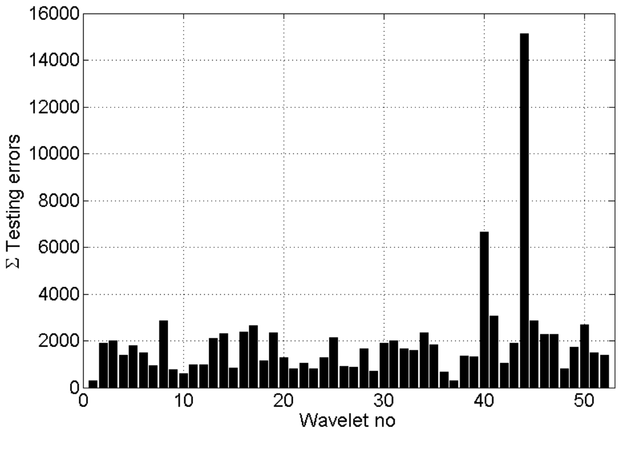

Fig. 3. Influence of basic wavelet on the correctness of the combustion pressure value for the vibration signal measured in a direction parallel to the cylinder axis

Experiments were conducted for vibration signals measured in a direction parallel and perpendicular to the cylinder axis and for 52 basic wavelets. The influence of basic wavelet choice on the correctness of combustion pressure value determination for the signal measured in a direction parallel (a_x) and perpendicular (a_y) to the cylinder axis is shown in Fig. 3 and 4.

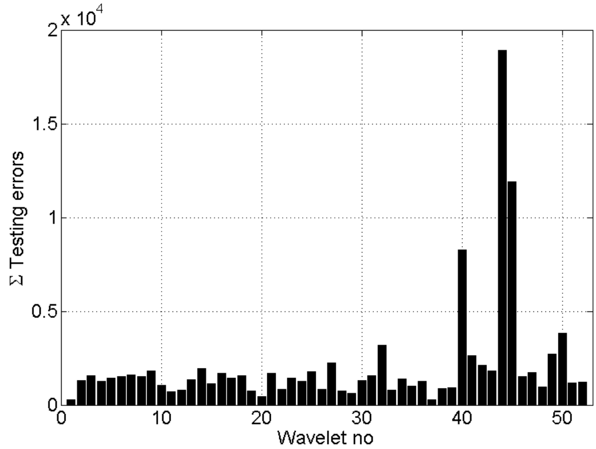

Fig. 4. Influence of basic wavelet on the correctness of the combustion pressure value for the vibration signal measured in a direction perpendicular to the cylinder axis

3 Conclusion

The article presents the results of preliminary tests aimed at the determination of combustion pressure in a cylinder of internal combustion engine with the use of neural networks, which were taught on the data coming from measured vibration signals. The results achieved in the experiment are on a satisfactory level and are the basis to continue further experiments.

The conducted experiments have shown a huge dependence of correct identification of combustion pressure on the choice of the coefficient γ for the radial neural network (radial basis function).

It was also noticed during the tests that the choice of the right basic wavelet used during the signal decomposition with the use of a discrete wavelet transform has a big influence on the determined value of combustion pressure. The best results were achieved for basic wavelets of haar and reverse biorthogonal type.

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