

CAR'S IGNITION SYSTEM DIAGNOSTICS USING CONTINUOUS WAVELET TRANSFORM

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Abstract – The paper describes an unusual approach to diagnose standard ignition subsystem of fuel engines. All the information about real state conditions of the ignition coils and sparks is taken from simple measurement of power consumption transient of the electric control systems of engine. The transient is processed by continuous wavelet transformation (CWT). Result of the CWT is used for a classifier. Classifier is supposed to work in learning and diagnostic modes. The main output of the classifier is two disjoint states meaning correct and incorrect functional work of the engine ignition system. The described method is going to be used as a part of standard information equipment of vehicles. The method could bring saving the costs for automobile manufacturer.

Keywords: Car diagnostics, ignition, sparks, wavelet

1. INTRODUCTION

Most of the diagnostic systems of electric devices used in today's cars are based on a decentralized concept. The decentralization is characteristic by the configuration of probes and classifiers systems that are directly related to particular device that is supposed to be diagnosed. The method introduced in this paper intends to cover more devices based on the same principle by one structure of probe, acquisition chain, data processing and classifier. See Fig. 1. for illustration the difference.

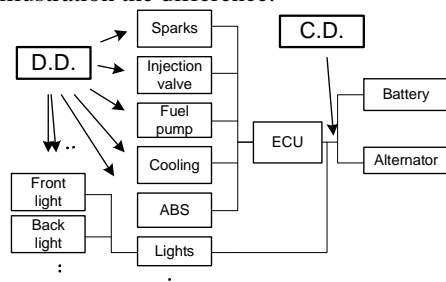


Fig. 1. Centralised and Decentralised diagnostic concept illustration in vehicle system power distribution hierarchy. (D.D. – Decentralised Diagnostic, C.D. – Centralised Diagnostic, ECU – Engine Control Unit, ABS – Anti Blocking System)

The method is designed to coexist with other proposed methods of centralized concept of car's electrical devices diagnostic also. See [2,3]. The mentioned centralized concept has got the fundamental idea to use only one set of

current and voltage probes to measure overall electric consumption of the vehicle. Afterwards the consumption transient is supposed to be processed and all the significant footprints of signal of devices are separated and classified.

Ignition system diagnostic technique design as the one section of the centralized concept has got basics in a modeling relevant relations between all the basic parts in it's equivalent circuit diagram. Changing the parameters of all the basic devices in the model can completely simulate the electrical behavior of the ignition system corresponding to real work conditions of it. Simulating a fault state "unplugged spark" or any similar worst discharging of accumulated charge in the ignition transformer causes a phenomena of propagation of accumulated electrical energy pulse back to the power supply net. This back-propagation is measurable and able to be processed respect to the centralized diagnostic system.

2. IGNITION SYSTEM

Common principle of the car's ignition systems is based on configuration power source, switch, transformer, high-voltage cables and spark gap. Other approaches as piezo-based principles [5] are not still applied in mass production. Let call the common technique as coil ignition system.

The generally known fundamental idea is to accumulate electric energy to the transformer core and produce high voltage peak on secondary winding by fast change of input voltage on the primary winding by opening the control switch. This idea is used in some variations in all ignition-like engines. The variations are different only in the physical configuration of the switches, transformers and high-voltage cables.

Generally could be said, that the switches can be divided to mechanical or electrical, the transformers single coil and multiple coil and the cables long cables and short cables. The proposed diagnostic method finally does not care about the differences in the transformers and cables for the correct function. Only the switches are supposed to be electrical. Especially conventional FET structure based is expected. The fact, that the switches should be semiconductor-based, is not restrictive for present-day manufacturer trends because the mechanical has got much more significant disadvantages for using in new engines.

The important knowledge for the technique is describing the electric behavior of the configuration source transformer and spark gap. See figure 2 and 3.

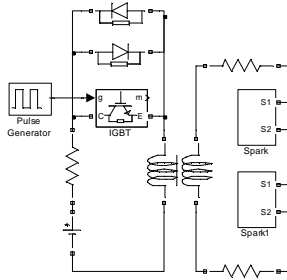


Fig. 2. Typical configuration of ignition systems – Double Coil Ignition system. (IGBT – FET based switch, Spark1,2 – block of the spark gaps)

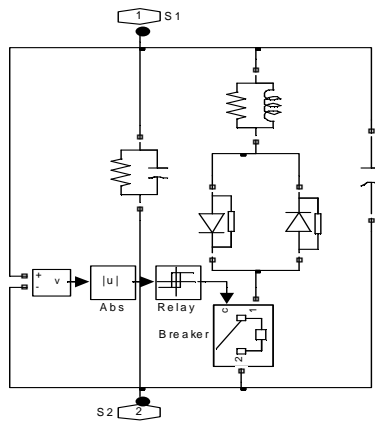


Fig. 3. Electrical model of spark gap. (Relay – hysteresis controlling block, Breaker – controlled switch)

A detailed explanation of the model could be found in [1,3,4]. The spark gap model works as a switch. The switch-on state is controlled by voltage on the contacts. It corresponds to the dielectric breakdown voltage of the environment in between to the gap contacts. It is a parameter of the air and fuel mixture in case of the engine. The switch-off state of the model is controlled by level of the current. The level corresponds to the sustaining value in manner similar to thyristor.

The model of the switching part consists of two diodes also. Those diodes with different threshold voltage allow dissipate the energy in primary circuit accumulated in the transformer when the flashing of the sparks does not consume it all. Just this primary current dissipation can be detected and used as the sign source for the system faults diagnose.

All the detectable faults have to have a relation to the worst discharging the energy in the secondary winding of the transformer. The basic faults can be “unplugged spark”, “broken high voltage cable”, “dirty discharger” and so on character. The typical simulated primary winding current transient of the “no faults” state and “fault state” can be seen at Figure 4.

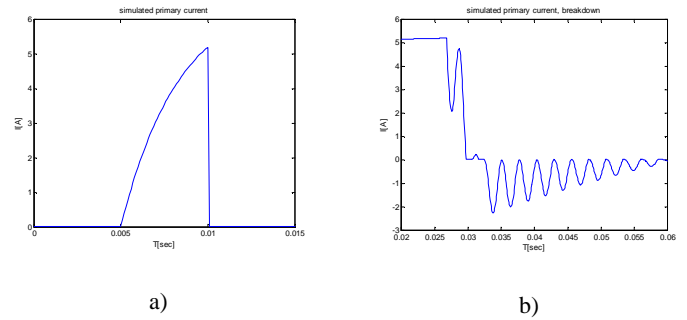


Fig. 4. Simulation of typical “non-faults” transient of primary current a) and magnification to the significant part of typical “fault” transient b)

The signal of transformer primary current transient when the system is working properly has very similar shape to first order system step response. All the energy accumulated in transformer is dissipated in flashing and real transformer windings parameters.

Worst discharging conditions in the sparks i.e. the higher glow voltage value in spark gap in the model causes the whole energy accumulated in transformer can’t dissipate in transformer winding and spark gaps fast enough and the voltage on primary coil grows over the protection voltage thresholds of semiconductor switch. Those thresholds are set up by anti-parallel set of diodes in the model. It results in the damped oscillation added to the first order step response of the primary current in transformer.

3. SIGNAL PROCESSING

The task of the project demands using only the information services available in the subject car or engine without any other intervention to the car’s systems. The data buses using a communication standard and the probes set are used as the information source for the signs obtaining. First state of the diagnostic system is supposed to work in a learning mode. All types of the ignition systems can have behavioral differences. The system has to learn to classify the transients as the “OK” state and remember its profile. The system is supposed to work in the learning mode first amount of engine working hours when the operator installed the system to the car.

Afterwards the diagnostics should be switched to the diagnostic mode. It could happen either automatically or by hand by the operator. The small real conditions changing during the work time of the engine has to adjust the learned OK transient sign profile. Only the significant differences of the profile should be classified as the “FAULT” state.

The proposed technique needs to find the time of maximum load the transformer at first. Then the next time window of hundreds microseconds length is captured to the memory. The transient in this time window equals to the discharging the energy in the spark and the real ignition system. The time window length is set experimentally. It should cover all the potential signs of faults.

The preliminary measurement shows two extremes of behavior the damped sine transient equal to real states of the spark. The one presents unplugged spark where the flash breaks the air around connector electrodes. It means higher glow voltage of the spark gap model and low switch off current level. The other one presents insulator breakdown. The glow voltage need not be higher but the switch off current level grows in this case. It causes longer transient of the damped wave because more accumulated energy needs to be dissipated in the circuits instead of flashing. See Fig.5.

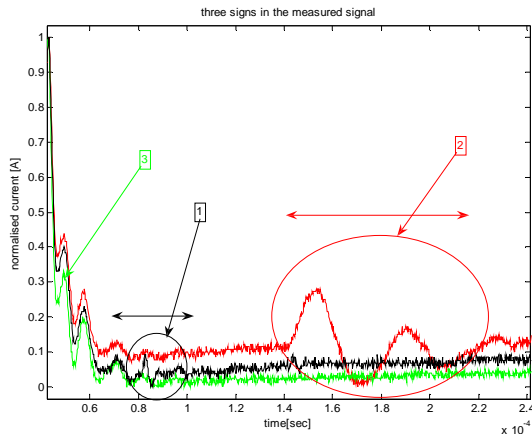


Fig.5. Examples of discharging the energy in the ignition transformer. Double arrows show the possible shifts of the waves (1 – sign of the unplugged spark and air breakdown, 2 – unplugged spark and insulator breakdown, 3 – proper work of the spark gap)

Generally the time position of damped waves can move. The time changes character can be called as random because of all the significant influences to the air or insulators electric breakdown are not measurable in this project.

The main task of the ignition system diagnostics is to find and classify those waves in the current in primary winding of the ignition coils. The centralized concept demands to choose a point where all the primary coils are connected. It could be on one of the battery poles. However all the measurements that were done for this paper are carried out by current probes placed to point where all the engine electric parts are grounded to vehicle case. It means that all primary ignition coils windings are grounded to the same point. Consequently the probe at this point covers all the transformers and some other electric devices such as valves or fuel pumps that are interesting to diagnose. If there would be probe at the battery poles, there would have the devices as air conditions, radios, etc. influenced.

The easier way to implement a diagnostic system capable to recognize proper work of the ignition system could be just simple RMS (Root-Mean-Square) value of the signal. All the additional waves to the “OK” transient cause a higher RMS value of the signal.

The current transient at the grounding point is the superposition of many signal sources. See Fig.6. There are important just the parts around the relatively short and high peaks they correspond to the sparking transformers primary current. Even the sparking transients has got at least 10times higher basic frequency in the spectrum, the other devices

superposing signals can significantly influenced the sparking signal element by their fast edges and they can change markedly the RMS value also.

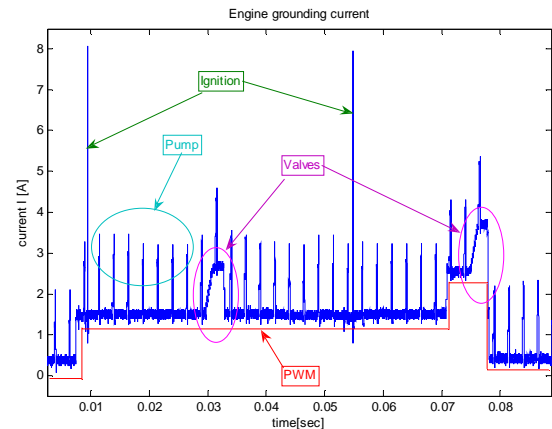


Fig. 6. Typical current engine transient consisted of more signal sources. (Ignition – transient addition from ignition coils, Pump – periodic signal profile from fuel pump based on standard electric motor, Valves – first order system step response like signal of solenoid injection valves, PWM – Pulse Width Modulated preheating of lambda probes system fuel consistency regulation)

There is better to use some integral transformation such as STFT (Short Time Fourier Transform) or CWT (Continuous Wavelet Transform) [7] for higher robustness of the diagnostic algorithm. There is supposed to use a frequency – time window in range of computed coefficients related to the damped waves. The paper prefers to use CWT instead of STFT for better time localization of the breakdown respecting the analogy of the Heisenberg (3.1) uncertainty principle as a side effect [6]. The precise time localization can be useful for diagnostics of ignition control versus power of engine held by other projects.

$$\Delta f \cdot \Delta t = const. \quad (3.1)$$

The proposed algorithm stores to a memory a profile of maximums of coefficients in the frequency – time window during the learning phase. The real conditions of engine are supposed to be fully work during this phase. Let call those coefficients maximums as “learned profile”. Gaussian mother wavelets are used to compute all the coefficients. After statistical amount of measurements the algorithm switch to a “background measurement” mode where it starts to compare all new incoming “OK” measured CWT coefficients to the learned profile. All the coefficients higher than the learned are summarized and stored. The sums could be called as “background”. Afterwards the algorithm switches to the detection phase. There are the unknown real states CWT results hardly thresholded by learned profile. The result is summarized and compared with background.

The comparison the detected coefficient sum with background can be done by different ways. It depends on the demanded diagnose reliability of the system. If the classifier uses the maximum of the background as the threshold value, the “fault” diagnose when the real condition really fault may not be able to be correct in 100percents of samples. But the

error caused by “fault” diagnose when the real condition is OK is minimized. If there is used either mean value or any kind of median of the background sums, the correct “fault” diagnose grows but the wrong one also.

4.RESULTS

The algorithm was tested on five engines in cars from Skoda manufacturer. All the engines worked on single ignition coil ignition system. Two of them were four-cylinders and three three-cylinders. Overall seventeen cylinders i.e. seventeen sparks were tested. The time – frequency CWT coefficients window was set the same for all the measurement. The numbers of transient samples for learning mode were five thousand for learning phase, one thousand for background, five thousand for known fault state and five thousand for known ok state. All the measurements were done in laboratory conditions i.e. 20 degrees of Celsius of environment, normal operating temperature of all the engines.

The algorithm Step by Step

The algorithm illustrated in this subsection is only on the case of detection the “unplugged spark, insulator breakdown” fault (Fig. 5. signal nr. 2). The other faults are similar, but only the positions of CWT coefficients in time – frequency window are different.

The learned profile shows Fig. 7.

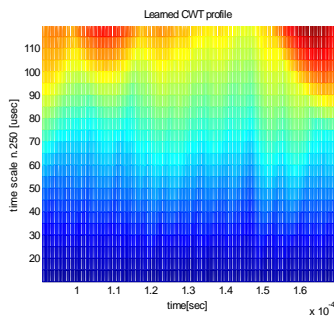


Fig.7. Learned coefficients profile. Proper work of ignition system

The background coefficients and their sums are shown at Fig. 8.

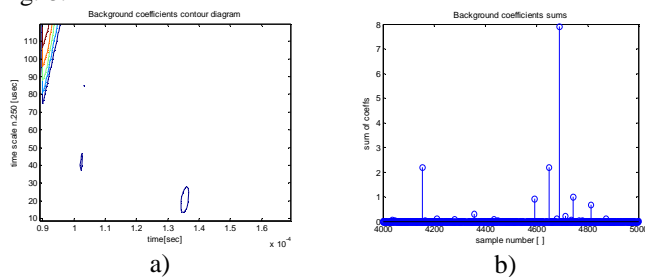


Fig. 8. Background coefficients a) and the sums of the coefficients related to sample numbers b)

The coefficients of “fault” diagnose and the sums as the classifier inputs are shown at Fig. 9.

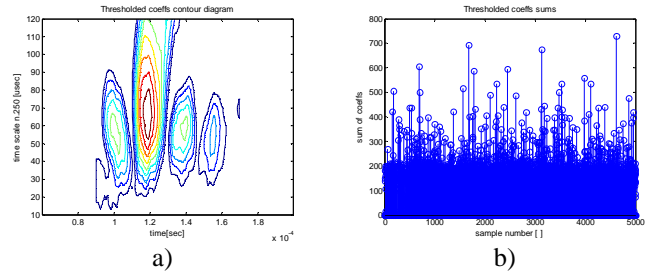


Fig. 9. Thresholded coefficients contour diagram a) and the sums of the coefficients related to sample numbers b)

The reliability for maximum background comparison was around sixty percent with less than one percent of wrong diagnose. There were ninety five percent hits for faults and less than ten percent wrong diagnoses for using the mean value of background for classifier thresholding. See table 1.

| Statistical results table (different engines) | | | | | | |
|---|---------------------------------|--------------------------------|-----|-----|-----|-----|
| Spark nr. | | Percentage of "Fault" diagnose | | | | |
| | | 1 | 2 | 3 | 4 | 5 |
| Real state | Classifier background threshold | | | | | |
| | Fault | | | | | |
| Fault | max | 55 | 62 | 75 | 72 | 77 |
| | mean | 99 | 98 | 100 | 97 | 100 |
| OK | max | 0 | 0,1 | 0,2 | 0,3 | 0,2 |
| | mean | 3 | 5,5 | 7,8 | 6,3 | 9,2 |

Table 1. Results comparison table

FUTURE RESEARCH

The next step of developing the diagnostic technique should be detail ignition system model extension for better understanding time dependencies of damped waves as the diagnostic signs. It could be useful for dynamic settings of the time – frequency window for CWT analysis. Also the statistical measurement taken in higher amount of engines could bring better confidence to the algorithm

CONCLUSIONS

The centralised concept of car’s diagnostic as a possibility of saving costs for automobile producers was introduced. The algorithm for conventional ignition system of combustion engines using Continuous Wavelet Transform coefficients hard – thresholding was described. There were also presented first results of statistical technique quality measurement. All the results show possibility of usefulness the technique for real diagnostic systems.

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REFERENCES

- [1] Jakub Král, Petr Jezdík, *Analýza chování zapalovacího ústrojí v automobilu Škoda (in Czech), study independent thesis*, November 2006
- [2] Jezdík, P.: Centralised diagnostic of electronic and electric equipment in vehicles, *proceeding of IMAPS 2006 conference Brno 14.-15.9.2006* ISBN 80-214-3246-2
- [3] Jezdík, P.-Novák, J.: Centralised diagnostic of electronic and electric equipment in vehicles - engine lighting equipment testing, *International Scientific Journal of Computing*. 2008, vol. 7, issue. 2 p.p.30-34, ISSN 1727-6209
- [4] Intusoft Newsletter, *Personal Computer Circuit & System Design Tools*, Issue#50 Sept. 1997pp.9-12
- [5] Williamson, T.L.: Ignition System Requirements and Their Application to the Design of Capacitor Discharge Ignition System, Thesis, *Naval Postgraduate School Monterey, California*, December 1971, pp.31-33
- [6] Doc. Marcel Kreidl a kolektiv: "Diagnostické systémy", *Vydavatelství ČVUT, Žitkova 4, 16635 Praha 6*, 2001 pp.120-128
- [7] Akansu, A.A.,Smith.M.J.T.: *Subband and wavelet transforms. Design and Applications*. Kluwer Academic Publishers, USA, 1996