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Analysis of Distributorless Ignition Systems

***Abstract**. Ignition systems even in its simplest form represent electrical system which produces voltage waveforms in a form of pulses in complex shape. For the diagnosis of these systems is necessary to use such diagnostic systems, which allow to record these waveforms for next analysis. In the presented contribution we deal with possibilities of analysis and investigation of waveforms, primary and secondary circuit fully electronic ignition systems.*

***Streszczenie.** W artykule zaprezentowano system diagnostyczny do badania przebiegów napięciowych w układzie zapłonowym. (**Analiza systemu zapłonowego bez rozrządu mechanicznego**)*

Keywords: EFS ignition systems, diagnostics, LabVIEW system, high-voltage waveforms.
Słowa kluczowe: system zapłonowy, diagnostyka.

Introduction

Distributorless ignition system (DIS) is ignition system which distributes high voltage to each spark plug without using mechanic distributor. High voltage shall be achieved to create a spark at the spark plug igniting the mixture through a high-voltage coil (transformer). High-voltage outlets in distributorless ignition system are directly applied to plugs, thus increasing the number of ignition coils. An immediate flash-over in the cylinders is necessary to determine by a separate switch controlling of transformer primary circuits. In practice are used two solutions which differ in the number of ignition coils.

Basic characteristics of the EFS ignition system

In EFS ignition system (or COP - Coil on Plug) are used coils which are creating only one spark for one spark plug at any given moment, thus that the number of ignition coils is corresponding with the number of engine cylinders Fig.1.

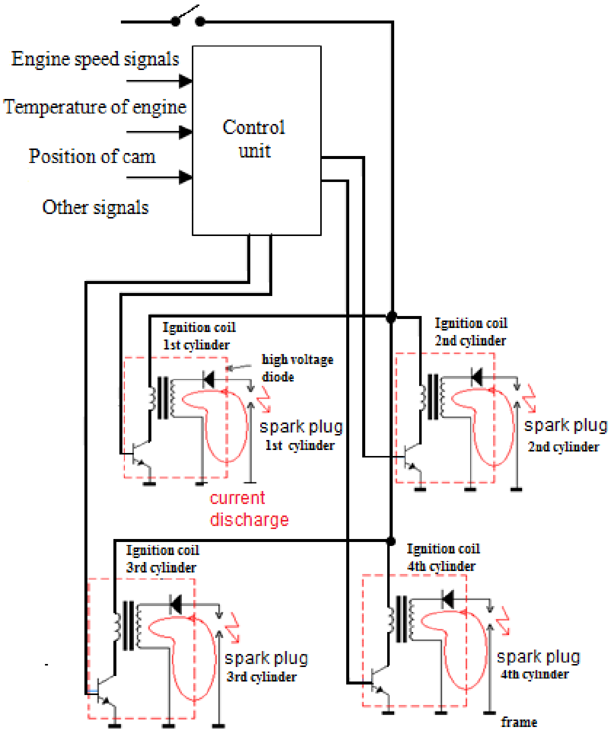

Fig.1. Simplified scheme of the ignition EFS

The engine operating parameter signals input into the control unit. EFS is not sufficient just with crank speed signals because each ignition coil receives one control pulse for two turns of crank but from the signal reference mark the control unit do not know whether the piston of cylinder is at top dead center compression stroke or at exhaust stroke. It is not possible to decide whether the spark-over is conducted in the 1st or 4th cylinder and therefore another synchronization pulse is needed, which is a control pulse cam.

In the Fig.2 is an example of voltage waveforms (pulses) of the primary and secondary winding of the transformer.

The spark has to flash over in cylinder near the top dead center in compression stroke for right engine running.

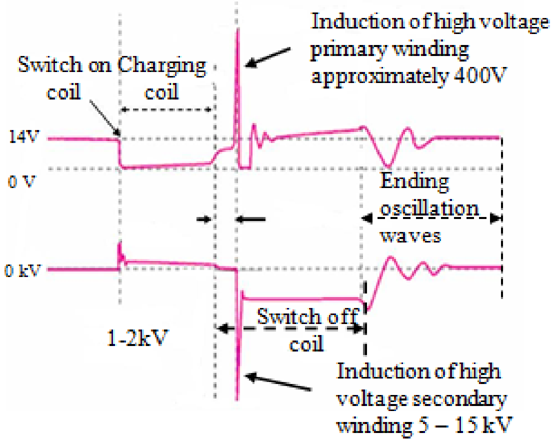

Fig.2. The voltage waveforms of the primary and secondary winding of the transformer

Analysis of equivalent circuit of the ignition system

In analysing the spark plug discharge problem, the spark plug current discharge channel is an overriding factor. As current i shooting through the unshielded centre electrode is the dominant ignition current, the discharge channel and the corresponding circuit model of the spark plug are shown below in Fig.3 [6].

In Fig.3, R_r is the series resistance and its value can be given by the manufacturers; r_g is the air-gap resistance of the spark plug; and C_q, C_r and C_p are the parasitic capacitances between the centre electrode and the shell.

Circuit is getting from the steady state into a new due to active element parameter changes i.e. connecting or disconnecting the voltage source or current.

Fig.4 shows the ignition system circuit model with the following simplifications: 1) the parasitic capacitances between the ignition system's modules are neglected and are finally added to the whole system; 2) the ignition coil circuit model is simplified here, which is expatiated in [7].

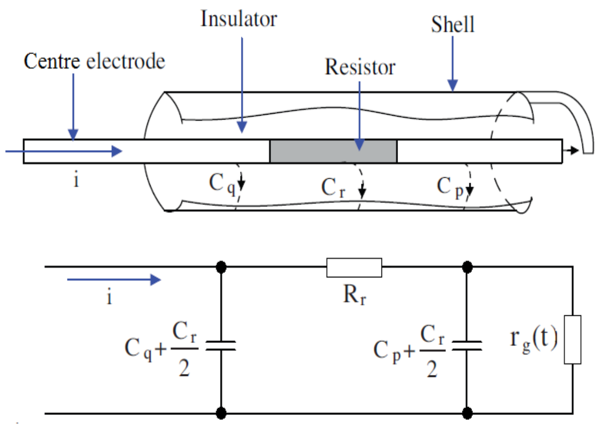

Fig.3. The discharge channel and circuit model of the spark plug

From the equivalent circuit of the ignition on Fig.4 is obvious, that change in steady-state to another is associated with a change of electromagnetic energy $W(t)$ of circuit.

This can be distributed into electric field energy accumulated in the capacitor circuit and magnetic field energy accumulated in inducers

$$W(t)=\sum_{k=1}^{n_1} W_{ek}(t)+\sum_{k=1}^{n_2} W_{mk} \tag{1}$$

where n_1 is the number of capacitors and n_2 is the number of inductors.

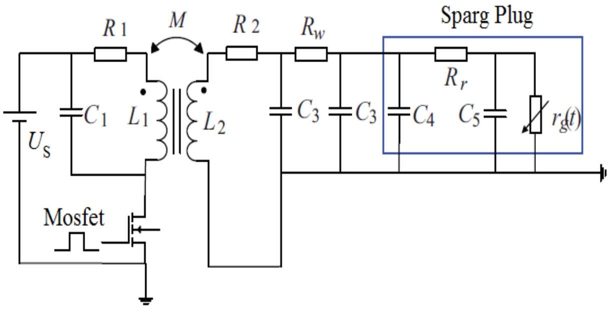

Fig.4. The circuit model of the ignition system EFS

In Fig.4 are valid there equations [5]:

$$C_4=C_q+\frac{C_r}{2},\ C_5=C_p+\frac{C_r}{2},\ C_3=\frac{C_w}{2}, \tag{2}$$

U_S is voltage of the DC power supply, R_1 and R_2 are respectively the resistance of the primary and the secondary winding, L_1 and L_2 are respectively the inductance of the primary and the secondary winding, M is the coefficient of mutual inductance between the primary and the secondary winding, C_w is the parasitic capacitances between the high-voltage wire and the shell, and R_w is the resistance of the high-voltage wire.

Analysis and measurement of high-voltage waveforms of ignition

The sides of primary coils are powered by the pulse voltage and switching by output stages to frame, or the ending degrees are integrated into module of coils. The control unit controls the switching and injection, and each coil is switched once per one cycle of the motor by control pulses Fig.5.

Synchronization of switching is taken away from the crank speed. Obviously for the synchronization are needed another signals for adaptation of the ignition immediate operating conditions (engine load signal, temperature and the intake air quantity, throttle position etc.). [4]

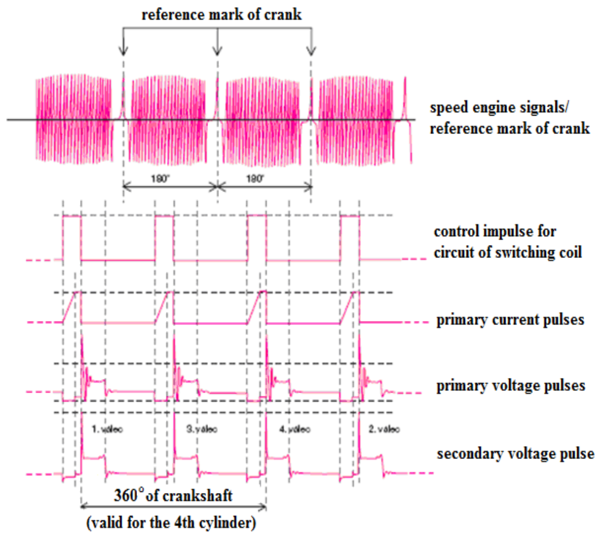

Fig.5. Synchronization of switching and the emergence of high-voltage pulses

To the control unit are entering signals of engine operating variables. Ignition with EFS is not sufficient just with crank speed signals because each ignition coil receives one control pulse for two turns of crank but from the signal reference mark the control unit do not know whether the piston of cylinder is at the top dead center compression stroke or at exhaust stroke. It is not possible to decide whether the spark-over is conducted in the 1st or 4th cylinder and therefore is needed synchronization pulse which is a control pulse cam Fig.6.

On the basis of cam and crank signals the control unit is creating control pulses for final stages of each ignition coil Fig.5

In the secondary circuit coils is high-voltage diode connected. For each of the cylinders in the moment of switching the primary winding on the secondary side there is a high voltage pulse (1-2kV). In ignition systems with distributor and the cylinder located outside circuit is disconnected. This voltage do not shift air gap between the plug electrodes and thus undesirable spark on the spark plug does not skip. [4]

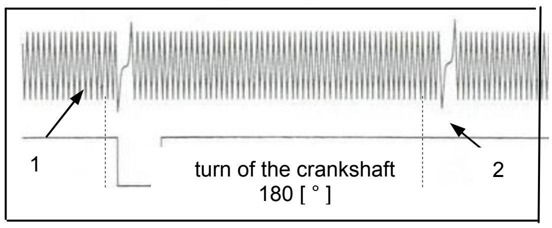

Fig.6. Speed engine signal / reference mark of crank (1) and cam position signal (2).

In DFS system (or DIC – Dual Ignition Coil) high voltage pulse of secondary circuit breaks dielectric area on the distance given by the sum of the distances of the electrodes connected distance given by the sum of the distances of the electrodes connected in series spark plugs in series and therefore there is no discharge. If the primary circuit switch off it incurred substantially higher voltage which breaks through the area between two electrodes of spark plug and that results in a spark.

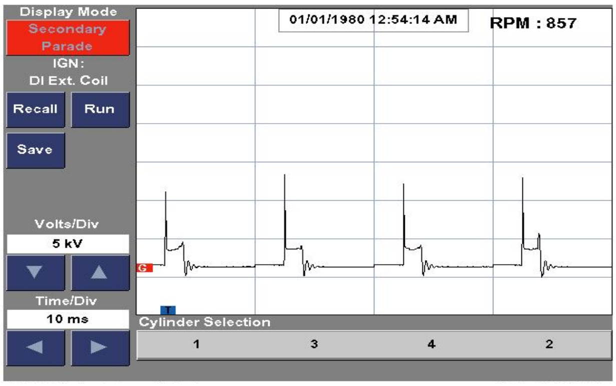

Fig.7. Ignition pulses of cylinders in the DFS system

EFS systems have diode in secondary circuit of ignition coil that prevents creation of unwanted sparks when switching the primary winding and conversely transmits high voltage for the creation of sparks in its disconnection Fig.8.

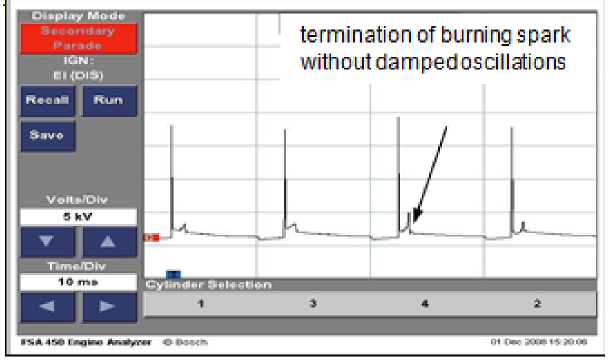

Fig.8. Ignition impulses in EFS

Diagnostic of high-voltage (secondary) circuit of ignition is affected by the presence of high-voltage diode.

In practice are ignition individual coils recessed into the cavity in the cylinder head and there are mounted directly on the spark plug with short cables. By implementing capacitive sensors on these wires it can be obtained waveforms of high-voltage discharges. We scan voltage on these coils just behind the high voltage diode which ultimately distorts the image resulting voltage.

Simulation waveforms

For a deeper analysis can be used simulation by programming environment NI Labview, where you can set up through the mathematical model of such operations during the subsequent simulation of error conditions spark pulses Fig.9.

According to Fig.9 we can be divided into waveform for five periods, which we then mathematically spread (interval t_1 until t_5):

Interval t_1: $u(t) = 0$

Interval t_2: $u(t) = l \cdot \cos(n \cdot t) e^{-d \cdot t}$

l – the voltage in the steady state is voltage constant, *n* - determines the number of amplitudes,
k - amplitude, *d* - specifies the attenuation.

Interval t_3: $u(t) = a \cdot t + c_1$

a - is constant of inclination of the line, c_1 - determines the initial state (final state in the interval t_2).

Interval t_4: $u(t) = \frac{1}{b\sqrt{\pi}} \cdot e^{-t^2/b^2} + c_2$

b - amplitude constant, c_2 - determines the initial state (final state in the interval t_3).

Interval $t_{5\text{-}1}$: $u(t) = -m \cdot t + c_3$

m - is constant of inclination of the line, c_3 - determines the initial state (final state in the interval t_4).

Interval $t_{5\text{-}2}$: $u(t) = k \cdot \cos(n \cdot t - h) e^{-d \cdot t} + c_4$

n - determines the number of amplitude, *d* - specifies the attenuation, *h* –shift of course, c_4 - determines the initial state (final state in the interval t_5).

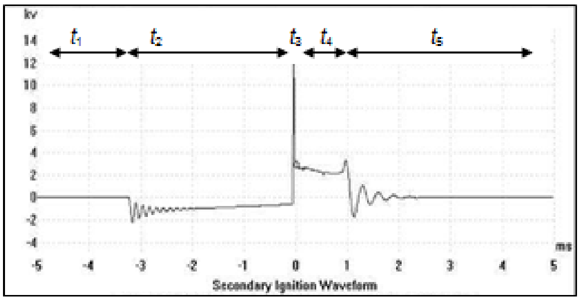

Fig.9. Model of ignition voltage waveform

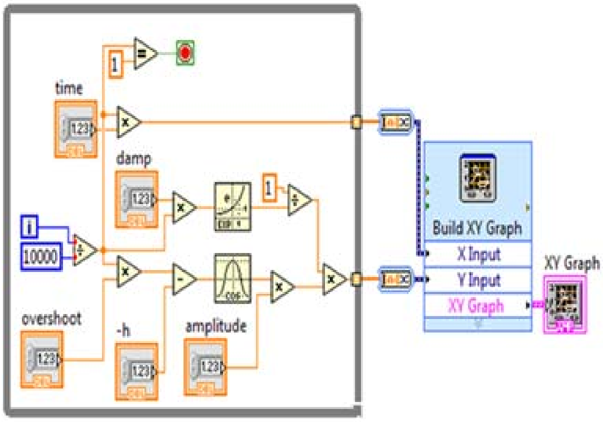

Fig.10. The sequence of program in Labview

In Fig.10 is presented by sequence program of high voltage waveform ignition model EFS with a faulty diode and simulation graph on Fig.11, which shows the comparison of malfunctioning ignition coil – sinusoidal course with decreasing amplitude at switching on primary side of transformer and switching off secondary side of transformer the shut down transformer (faulty diode) and graph with the end of burning sparkle without damped oscillations (correct operation of the ignition coil).

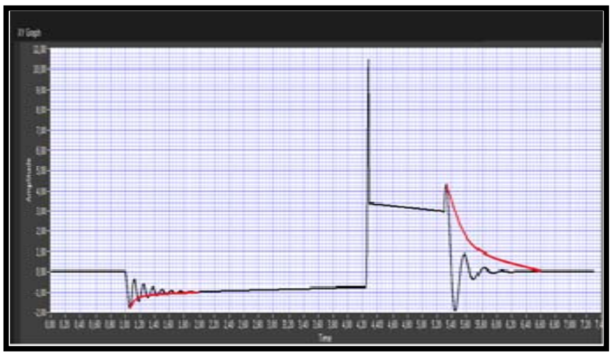

Fig.11. Simulating spark waveforms during correct and incorrect operation

In Fig.13 is presented by sequence program of high voltage waveform ignition model DFS and simulation graph on Fig.14, where ignition system where high voltage is transported directly on spark plugs and flash-over occurs at a certain moment on the two plugs at the same time. Fig.12. shows simplified scheme of the DFS system.

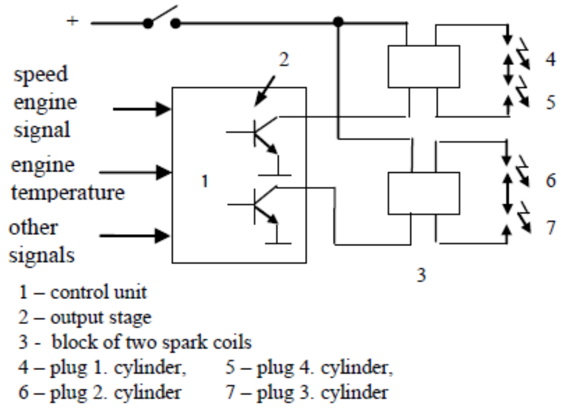

Fig.12. Simplified scheme of the ignition DFS

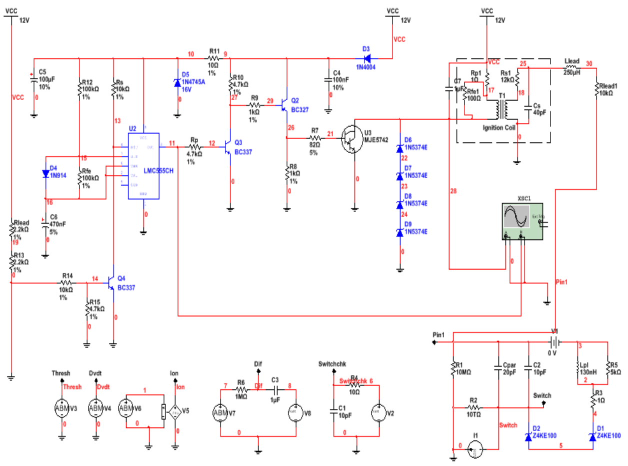

Fig.13. The sequence of program in NI Multisim

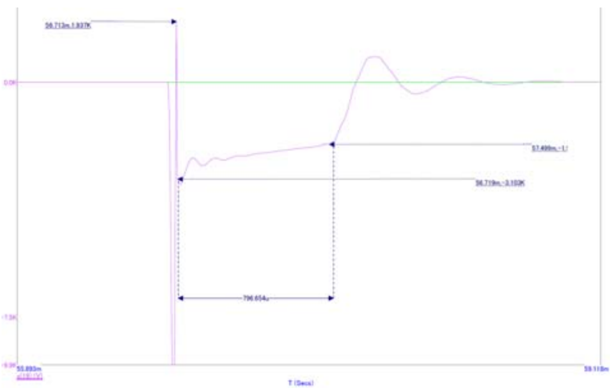

Fig.14. Simulation graph DFS system according to Fig.13

Conclusion

Diagnostics of ignition systems by diagnostic systems allows measurement of primary and secondary high-voltage waveforms. Programming environment of Labview allows adequately evaluate the waveforms to obtain a comprehensive overview of the examined system based on the simulation analysis.

Ignition system with dual spark coils represent simple variant without mechanical distribution of ignition. The negative aspect is the limitation of time adjustment because of exhaust sparks.

High-voltage parts of ignition of two cylinders create serial circuit where in damaged conditions of circuit (high voltage lines), or the 1st plug of cylinder will also affect 4th cylinder. Interruption of high voltage circuit of one coil means failure of two cylinders. Fault in the primary circuit of one coil results in failure of two cylinders. This method is only available for cars with an even number of cylinders.

EFS systems are demanding that every coil is excited by control pulse thus that works only once per two turns, or arise only work sparks and there are no exhaust sparks. In determining the choice we can choose large for inflammation - spark of the expansion time. Operational reliability of EFS ignition systems is greater than in two coil systems because a fail in circuits whether in primary or secondary circuit omits only one cylinder. These systems can be applied even in engines with an odd number of cylinders in the engine.

In the abovementioned analysis voltage waveform when burns out spark are evident that finishing phase of burning sparks is missing and instead of damped oscillations course gradually declined. This effect is caused by high-voltage diode. If a spark goes off the current stops flowing in secondary circuit and diode closes than electrically disconnects section of secondary circuit.

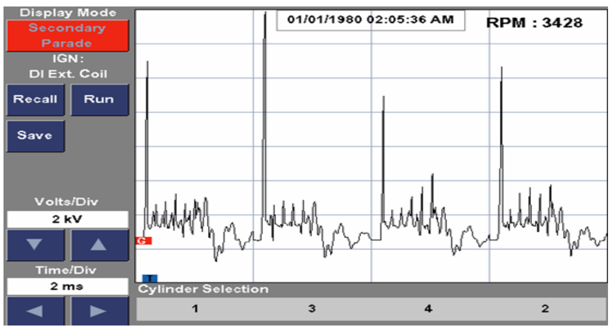

Fig.14 Real waveform with faulty diode in the EFS ignition

In Fig.14 is recorded real and simulated process EFS ignition system with faulty diode.

Simulation of ignition coil waveforms allows us to implement the various states of high voltage ignition coil waveforms based on mathematical analysis and solve problems in the ignition system.

Diode in this manner distorts the course of the measured high voltage. The voltage level can vary above or below the zero level, what can be affected by the accuracy of the analysis and the burning time of flashover voltage sparks. [3]

Pulse section length, burning time of spark, amplitude size of flashover voltage and amplitude of burning are important parameters in the analysis of high-voltage waveforms.

Acknowledgments

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