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ASPECTS REGARDING THE DIAGNOSIS OF A GASOLINE INJECTION ENGINE

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ABSTRACT

The paper presents some considerations regarding the diagnosis of a gasoline injection engine that equips an electronically controlled vehicle. Some results obtained from the tests of an Audi A6 car equipped with a gasoline injection engine are presented. Some engine faults are targeted. It comparatively addresses the issues related to energy efficiency and the influence of functional factors in the case without faults and in the situation of their existence. It is possible to detect faults by using time analysis, frequency analysis and time-frequency analysis, the latter by using the Born-Jordan transform of the Cohen class.

KEYWORDS: motor vehicle, model-based diagnosis, signal-based diagnosis, variance analysis, sensitivity analysis, informational analysis.

1. INTRODUCTION

Diagnosis consists of a series of operations that assess the state of a system through a non-invasive action, so without disassembly or forced penetration inside it. Thus, electronically controlled systems have been developed, for which the adjustments are made through a computerized management system which includes: sensors, actuators, electronic control units [6]. Having all the components integrated through the construction of the vehicle, the electronically controlled systems have the possibility to ensure the self-diagnostic function as well. For this purpose, through the permanent monitoring of the measured parameters, the system signals in real time the occurrence of the faults produced both at the level of the components (ECU, sensors, actuators) and at the level of the functional control parts. For this reason, the real-time diagnosis system is currently the most efficient method for detecting faults from the very beginning phase of their implementation, which is the reason for their current role in the solution. in the greatest process of diagnosis. Thus, the control solution of the system appeared in the presence of faults. According to this control strategy, the existence of faults is tolerated, and the electronic control unit transmits the command signals to the executors in close compliance with the report. In this way, the capacity of the system to fulfill its specified functions in the conditions of the existence of faults is ensured [1][2][4][5].

2. EXPERIMENTAL RESEARCH

The experimental tests were performed with an Audi A6 3.0 TFSI Quattro equipped with a gasoline injection engine and the functional variables were recorded using the specialized Ross-Tech VCDS tester and software for the VAG group. During the experiments, the functional variables were measured for 30 fault-free samples (marked A1-A30). With the help of these tests, mathematical models of engine operation without faults were established, which allowed the comparison with the cases in which faults were caused. Also, experimental research was carried out (30 samples marked D1-D30) with the challenge from the beginning of the tests (at time t = 0 s) and simultaneously of 4 defects mentioned in table 1, to the constructive elements in figure 1: in fig.1a the air filter, in fig.1b at the air flow sensor through the air filter, in fig.1c at the actuator of the throttle position, and in fig.1d at the pressure sensor in the intake manifold.

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Table 1. Faults caused simultaneously at the engine of the Audi A6 car

Notation	Description	Effect	Type
f_{pf}	pressure loss in the air filter	pressure drop	abruptly
f_{ymf}	air flow sensor fault through the air filter	measurement error	abruptly
f_{xco}	throttle position actuator fault	leading fault at flow error	abruptly
f_{ypa}	pressure sensor fault in the intake manifold	measurement error	abruptly

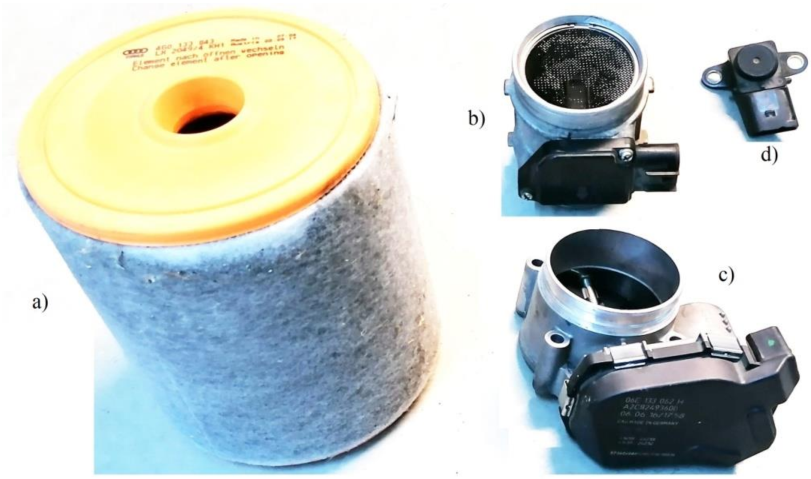

Figure 1. Constructive elements with faults caused simultaneously, the engine of the Audi A6 car

For example, Figure 2 shows the result of establishing the static characteristic P_e = f (n, ξ) of the engine of the Audi A6 car, where P_e represents the engine power, n its speed, and ξ the position of the throttle (engine load). The graph shows the switching surface of the static characteristic, its analytical expression (1), as well as the values of the 30 experimental tests without faults.

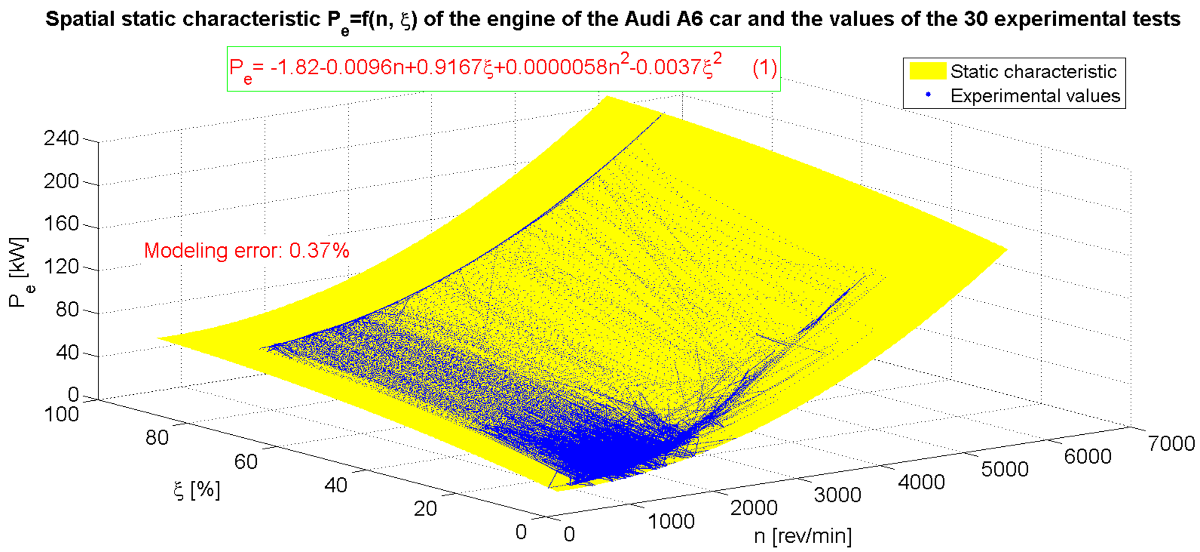

Figure 2. Spatial static characteristic Pe=f(n, x) of the Audi A6 car engine, and 30 experimental tests

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Figure 2 shows the analytical expression of the static characteristic:

$$P_e(n,\xi) = -1.82 - 0.0096n + 0.9167\xi + 0.0000058n^2 - 0.0037\xi^2 \qquad (1)$$

mathematical modeling ensuring an acceptable error of 0.37%.

3. COMPARATIVE ENERGY EFFICIENCY

It is of interest to highlight the impairment of engine performance in the event of engine fault [7]; in this sense, the performances of power, fuel consumption and energy efficiency are targeted (simultaneously the first two).

For example, Figure 3 shows the engine torque M_e and the engine power P_e at test D19 in case of pressure loss in the air filter (f_{pf} fault). For this test, figure 4 shows the values of hourly fuel consumption C_h.

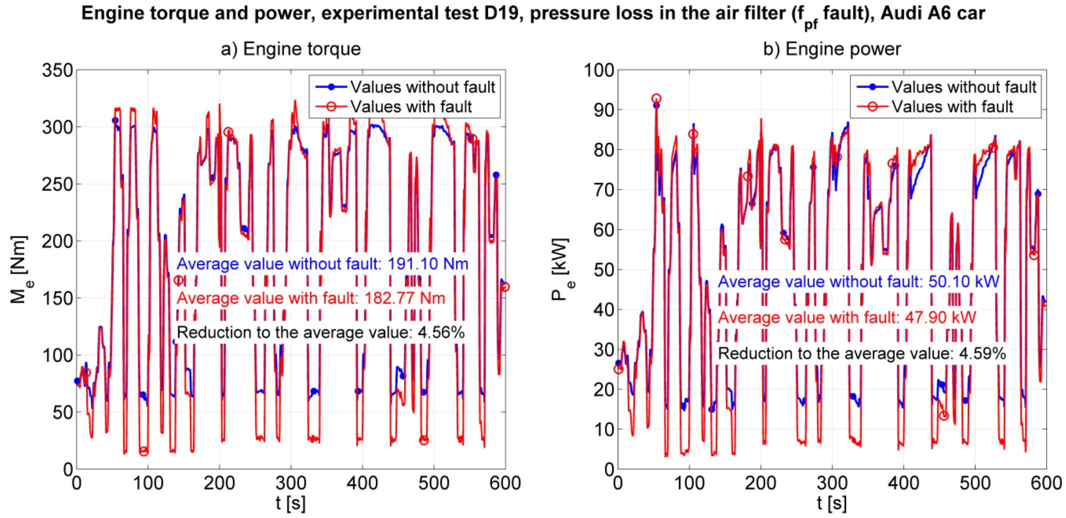

Figure 3. Torque and engine power, f_{pf} fault, test D19, Audi A6 car

Figure 3 shows a decrease in engine performance in the case of f_{pf} fault, by 4.56% at the moment and 4.59% at power. The top graph in Figure 4 shows a 4% reduction in fuel consumption in the event of a fault. The lower graph in Figure 4 shows the experimental validation with an acceptable modeling error of 2.18%.

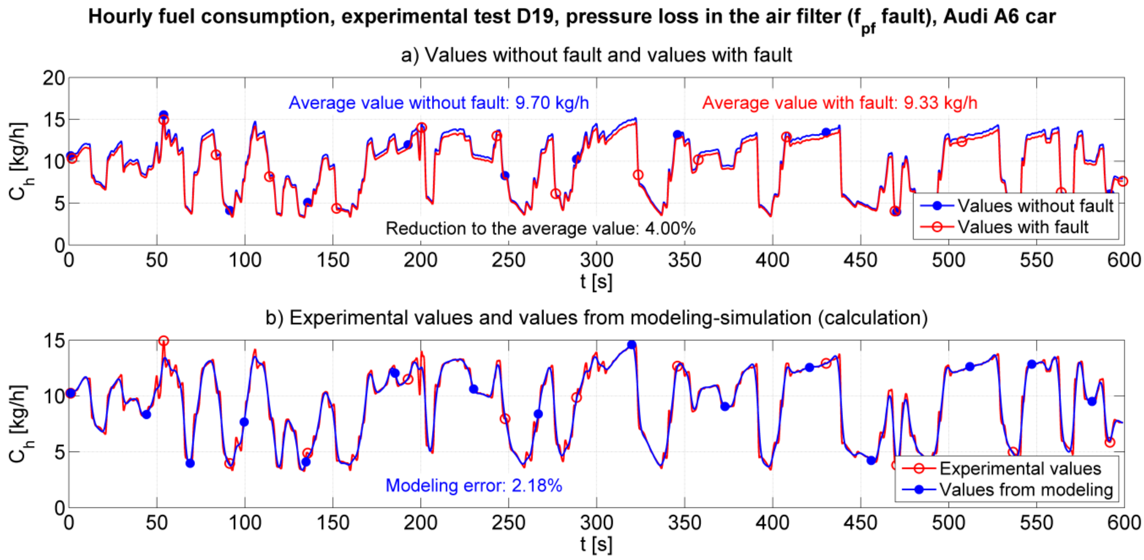

Figure 4. Hourly fuel consumption, f_{pf} fault, test D19, Audi A6 car

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Based on the values in figure 3 and figure 4, in figure 5 the energy ratios torque/fuel consumption and power/fuel consumption are established; these ratios mean how many Nm and how many kW are developed with 1 hourly consumption of 1 kg/h and are established with the relations:

$$k_1 = \frac{M_e}{C_h} \quad (2)$$

and respectively:

$$k_2 = \frac{P_e}{C_h} \quad (3)$$

As can be seen from Figure 5, the existence of the f_{pf} fault (pressure loss in the air filter) led to a decrease in the energy efficiency of the engine, by 11.27% at the ratio k_1 and by 11.09% at the ratio k_2.

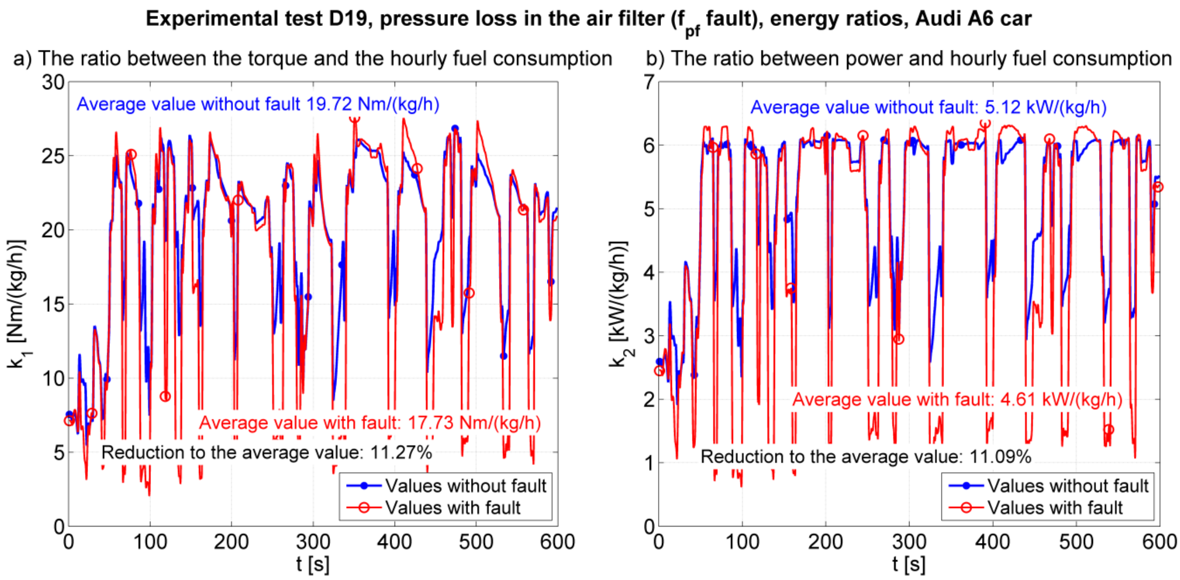

Figure 5. Energy ratios, f_{pf} fault, test D19, Audi A6 car

Figure 6 shows the values on the 30 experimental tests of the reductions of the energy ratios torque/fuel consumption and power/fuel consumption ratios that belong to the f_{pf} fault (pressure loss in the air filter). The graphs also show the minimum, average and maximum values for all 30 tests D1-D30; thus, the overall average is 12.44% at the torque/consumption ratio and 12.07 at the power/consumption ratio, values that mean decreases in energy efficiency.

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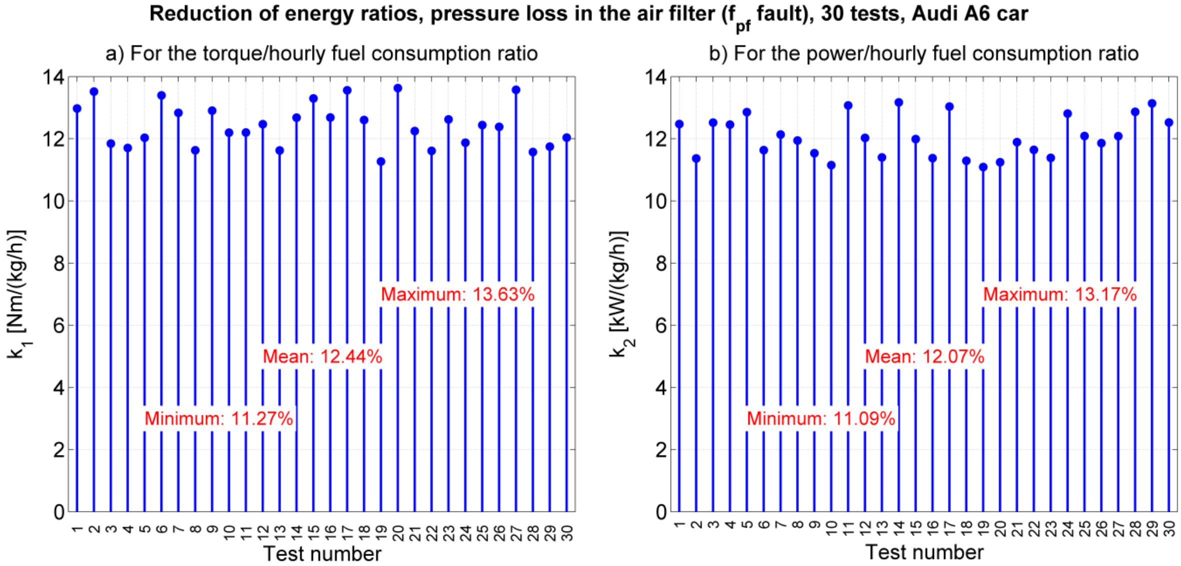

Figure 6. Reduction of energy ratios, f_{pf} fault, 30 tests, Audi A6 car

4. THE INFLUENCE OF FUNCTIONAL FACTORS ON PERFORMANCE

The following is the influence of the main functional factors on power performance and fuel consumption, so on the dynamism and fuel economy of the engine in the absence and presence of faults. As functional factors will be considered the engine speed n, the position of the throttle ξ (engine load), the position of the accelerator pedal p, the air pressure in the intake manifold p_a, the coefficient of excess air λ (hence the quality of the air-fuel mixture) and the ignition advance β. Influenced quantities will be considered the engine power P_e and the hourly fuel consumption C_h. In order to establish the influence of the functional factors, the multivariable variance analysis, the informational analysis and the sensitivity analysis can be applied [3][8]. Because studies have shown that there are interdependencies between all functional variables, it is recommended to use the global sensitivity analysis, whose quantitative quantification is given by the Sobol indices that verify the relationship:

$$\sum_{i} S_i + \sum_{i}\sum_{j>i} S_{ij} + \sum_{i}\sum_{j>i}\sum_{k>j} S_{ijk} + ... = 1 \qquad (4)$$

in which for a factor i, S_i constitutes the first-order Sobol index (or the main Sobol index), for factors i and j is the 2nd order Sobol index, and so on.

Thus, figure 7-figure 10 shows the values of the main Sobol index (first order index) in the case of the 4 faults concerned, with the 6 influencing factors mentioned above and the two influential quantities (engine power and fuel consumption).

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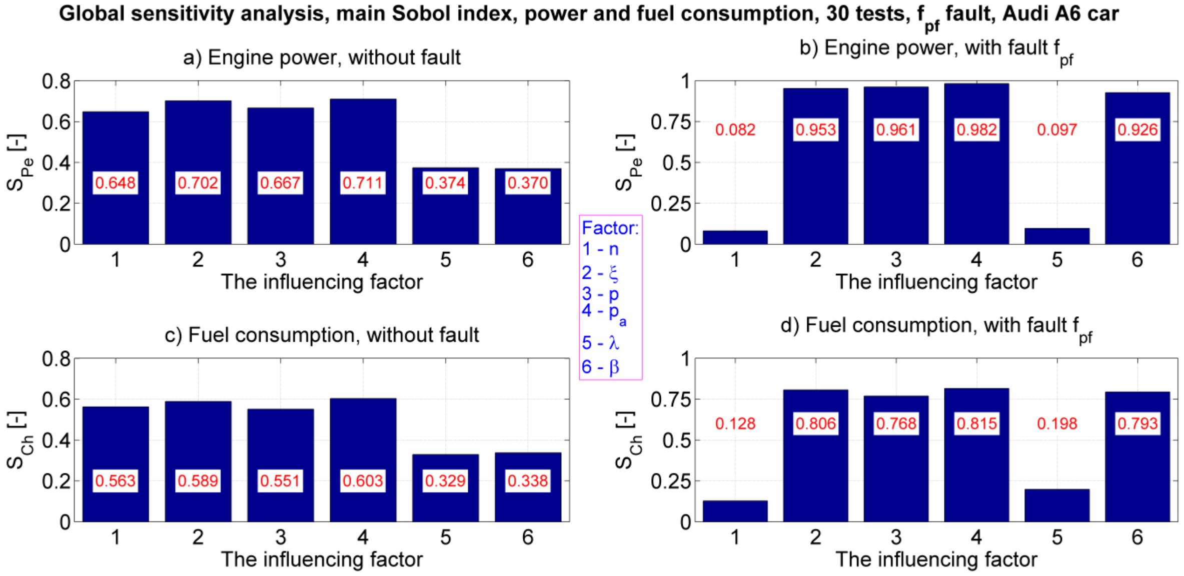

Figure 7. Global sensitivity analysis, f_{pf} fault, Audi A6 car

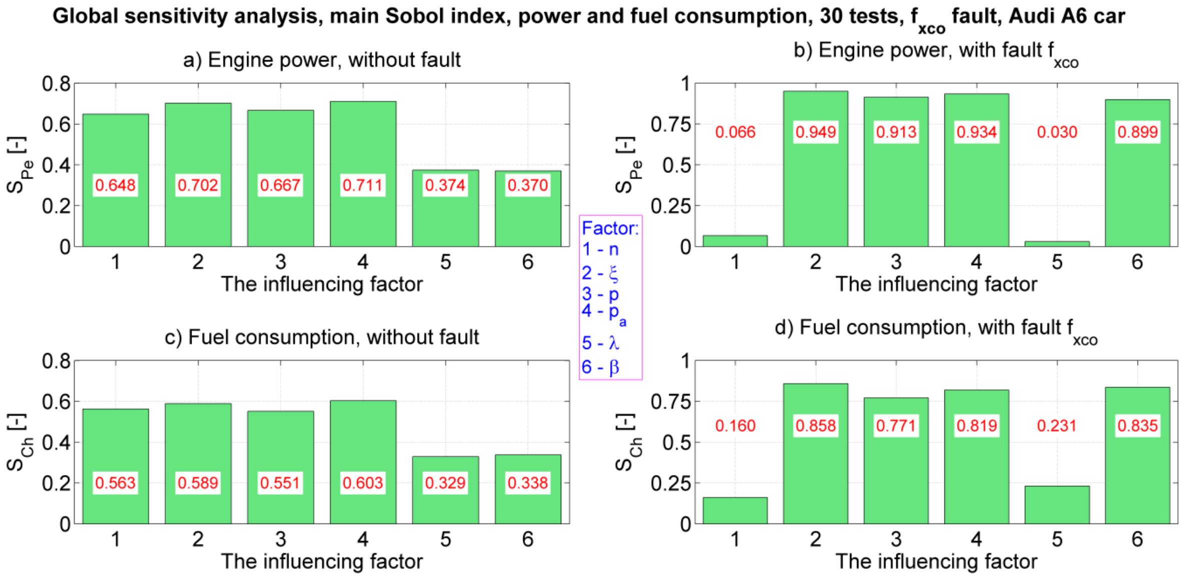

Figure 8. Global sensitivity analysis, f_{xco} fault, Audi A6 car

These graphs show, among other things:

- in all situations the motor load ξ influences more than its speed *n*;

- the influence mentioned above is much higher in the case of any fault (graphs on the right) than in the situation without fault (graphs on the left);

- for all 4 faults (graphs on the right), the smallest influences on power and fuel consumption have the engine speed and the quality of the air-fuel mixture;

- when operating without faults (graphs on the left), the smallest influences on power and fuel consumption have their advance on ignition and the quality of the air-fuel mixture.

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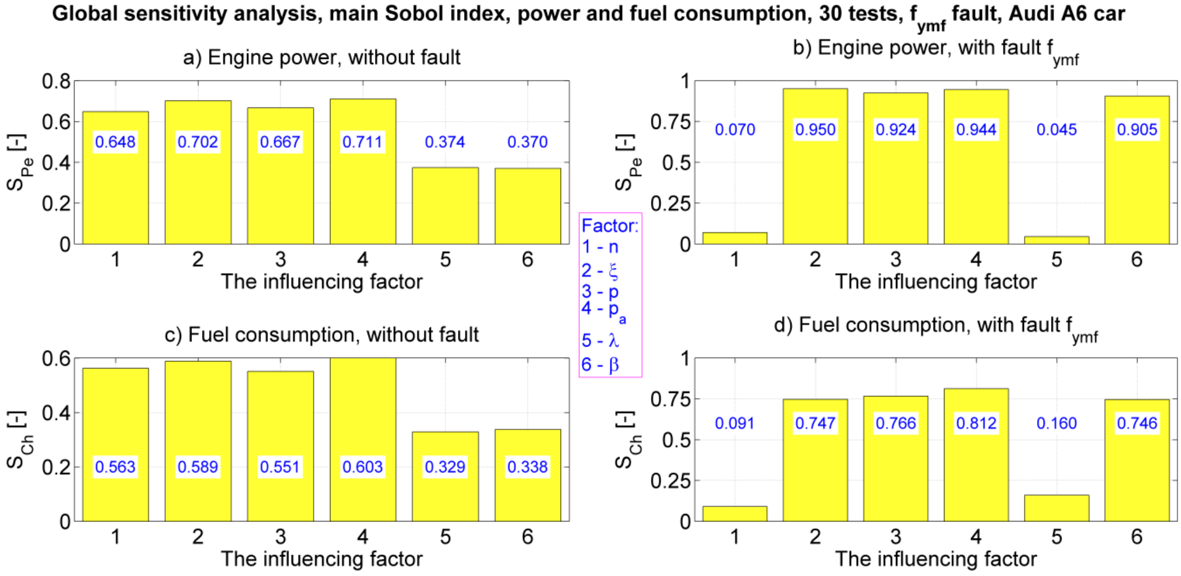

Figure 9. Global sensitivity analysis, fymf fault, Audi A6 car

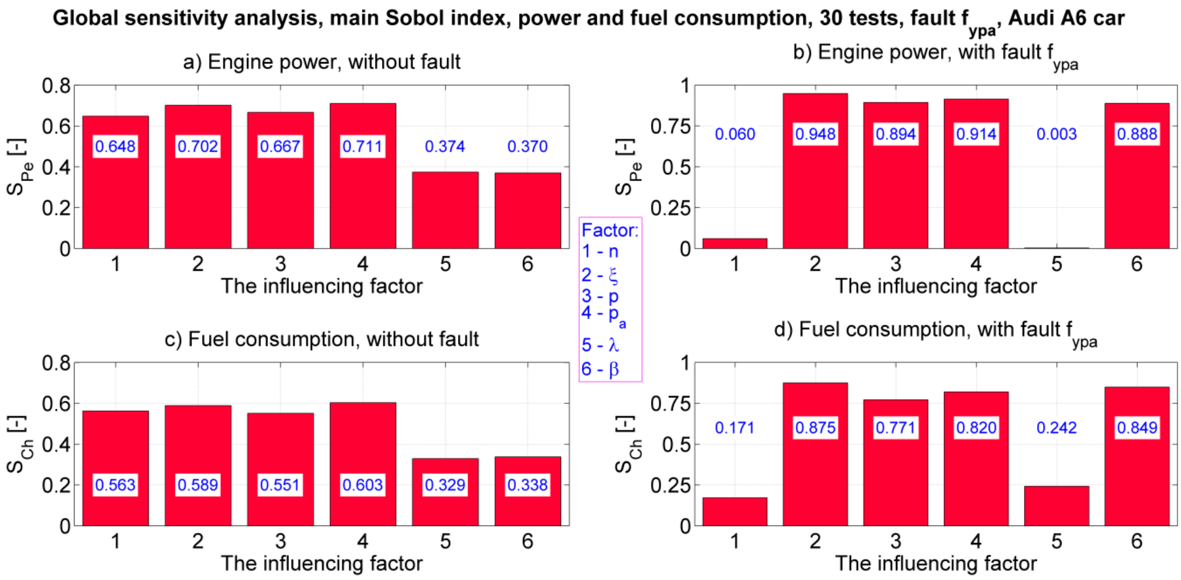

Figure 10. Global sensitivity analysis, f_{ypa} fault, Audi A6 car

5. FAULTS DETECTION

Several methods and various calculation algorithms can be applied to detect a certain fault. One of these possibilities is the use of signal detection, in which case time analysis, frequency analysis and time-frequency analysis are used [9].

For example, it is considered that at time t =190 s a fault occurs at an engine injector, which results in a decrease in the cyclic fuel flow, as shown in Fig.12a.

In figure 11 and figure 12 we use all three types of analysis: in time, in frequency (by applying the classical Fourier transform) and in time-frequency (by applying the Born-Jordan transform). As can be seen from fig.12, only the time representation (TR) and the time-frequency representation (TFR) detect the appearance of the fault at a certain point in time, in the latter case by changing the image in area A (fig.12c) where decreases the amplitude of the Born-Jordan transform.

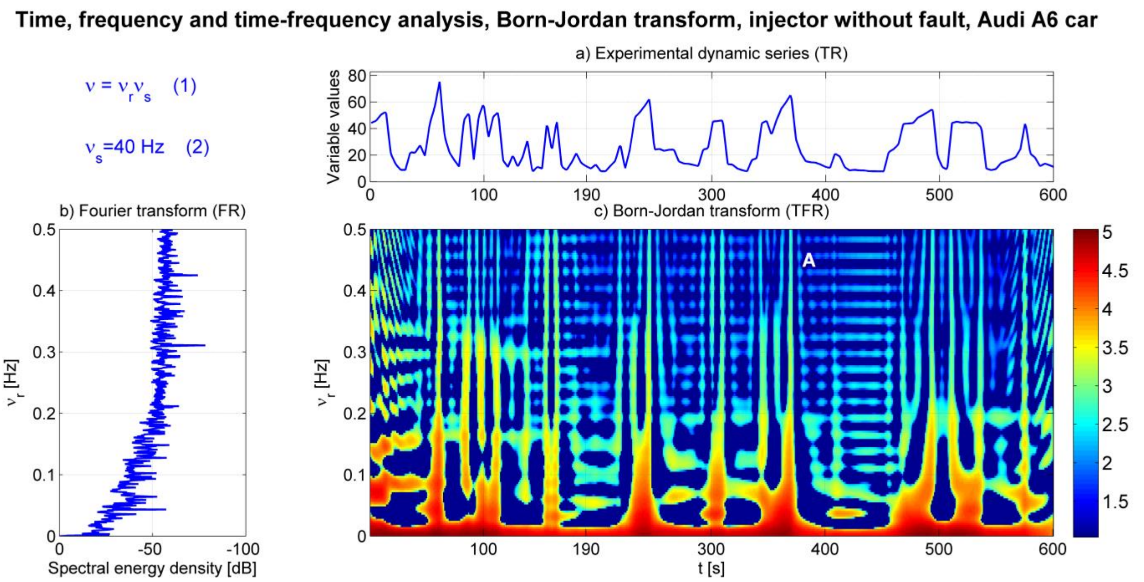

Figure 11. Time, frequency and time-frequency analysis, injector without fault, Audi A6 car

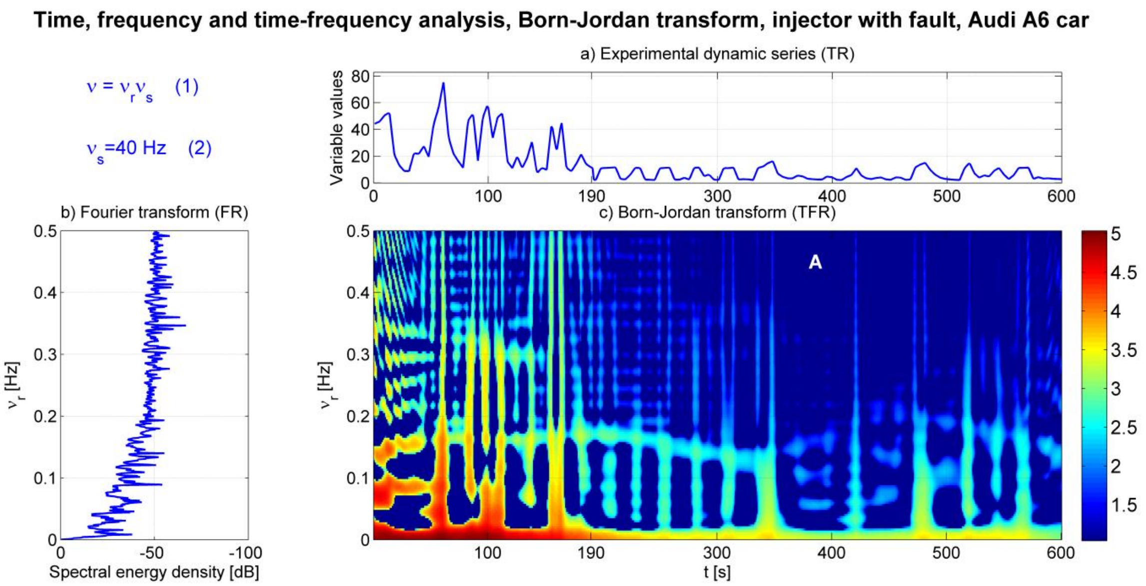

Figure 12. Time, frequency and time-frequency analysis, injector with fault, Audi A6 car

The Born-Jordan transform of any complex variable y with the conjugate y^* is defined by the expression:

$$Y(\tau, j\upsilon) = \int_{-\infty}^{\infty} \left[\frac{1}{|\tau|} \int_{t-|\tau|/2}^{t+|\tau|/2} y\left(s+\frac{\tau}{2}\right) y^{*}\left(s+\frac{\tau}{2}\right) \mathrm{d}\, s \right] \mathrm{e}^{-j2\pi\upsilon\tau} \, \mathrm{d}\,\tau \qquad (5)$$

where t, τ and s it's time, and ν frequency.

In the graphs from fig.11c and 12c, on the ordinate axis was represented the normalized frequency, or the relative frequency ν_r (Nyquist frequency being 0.5 Hz); the time *t* is rendered on the abscissa axis. The absolute frequency is obtained by multiplying the number on the ordinate axis in fig.11c and 12c with the sampling frequency ν_s according to relation (1); the axis of the ordinates in fig.11c and fig.12c is the same as the axis of the abscissas in fig.11b and fig.12b, where the graph is arranged rotated to the left by 90^0.

6. CONCLUSION

Real-time operation diagnosis and control is the most efficient solution, as malfunctions can occur at any time during actual operation. In this sense, it must be remembered that a defect is an impermissible deviation of at least one characteristic property/variable of the system from the acceptable/usual/standard/nominal behavior. In addition, a failure means a fault that involves a permanent interruption of the system's ability to perform a required function under specified operating conditions; the fall can therefore be considered as a total fault.

Based on the study, part of which is presented in this paper, it can be concluded that the existence of any fault during engine operation leads to a decrease in its energy efficiency. In addition, other criteria for assessing the energy efficiency of the engine may be adopted; as it turned out, energy efficiency simultaneously targets the dynamics and fuel economy of the engine.

For the study of the influence of functional factors must be considered a simultaneous variation of all of them, the practice proving that none remains constant during engine operation

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