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Aspects Regarding the Functioning of Electronically Controlled Diesel Engines

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Abstract: The paper presents some considerations regarding the functioning of an electronically controlled Diesel engine, used to equip a motor vehicle. It is highlighted the issue of exhaust gases resulting from combustion of air and fuel. Also, there are presented results obtained from experimental tests, in case of a Diesel engine with common-rail fuel injection system and gas recirculation system. Yet again, it is performed an analysis on electronically controlled gas recirculation system.
Keywords: motor vehicle, common-rail, electronic control, exhaust gas recirculation

I. INTRODUCTION

There has been more than a century since the Diesel engine was first invented, time during which it was recorded a constant improvement on functional and design characteristics. Also, due to latest technologies which include embedded electronics, consisting in sensors, microprocessors and specific laws of control, it was noted an increase in engine performances and a decrease of pollutant emissions, according to nowadays requests [1], [2], [4]. From begining, but especially lately, Diesel engines have always been considered to produce inadmissible levels of pollutant emissions.

To satisfy increasing requirements, today's Diesel engines use design solutions and advanced technologies such as variable geometry turbocharger and common-rail fuel injection. In addition, there have been developed new testing cycles for the analysis of exhaust gases, obtaining more realistic assessments, by eliminating ambiguity.

Also, present Diesel engines benefit by improved control and diagnostic algorithms, as well as more efficient investigative equipments. For example, it was observed an increased usage of fractional control and a more refined control based on artificial intelligence algorithms. In addition, there has been developed software for modeling and simulation of Diesel engine functioning, which allow improving and optimizing performances and reducing pollutant emissions.

II. EXPERIMENTAL TESTS

Experiments were conducted on a Ford Focus motor vehicle, equipped with supercharged Diesel engine and gas recirculation control system. The injection of fuel is made by the common-rail intake system. Data acquisition of functional parameters is possible due to the FoCOM software and interface, which can be used for Ford vehicles. From the data recorded, there were used 100 experimental samples, which were significant for the analysis, because they were recorded during normal functioning of engine. Each experimental sample consists in 1200 values for each parameter and it lasts 120 s; measuring rate is 10 values/s.

For example, in fig. 1a there are presented instantaneous values of engine torque M_e and in fig.1b the values of engine power P_e, both as continuous and discrete values. Regarding the engine torque, from fig. 1a it results that 76.3% of all values are within 100-160 Nm, which is more visible in case of discrete representation.

In fig. 1 there are also shown maximum values indicated by technical specification, namely 15 Nm for engine torque and 66 kW for engine power; from experimental tests there were obtained maximum values of 199.4 Nm and 62.6 kW, respectively.

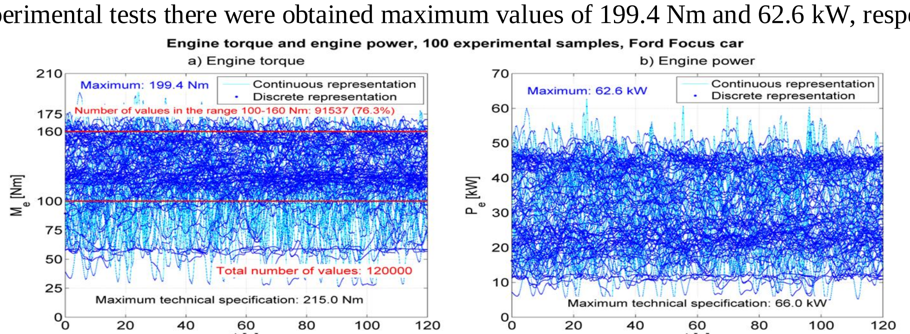

Fig. 1 Engine torque and engine power

In fig. 2 there are presented values of engine speed and accelerator pedal position and in fig. 3 is depicted the variation of air pressure from intake manifold p_a (the supercharged air pressure) and fuel pressure from common-rail system p_c.

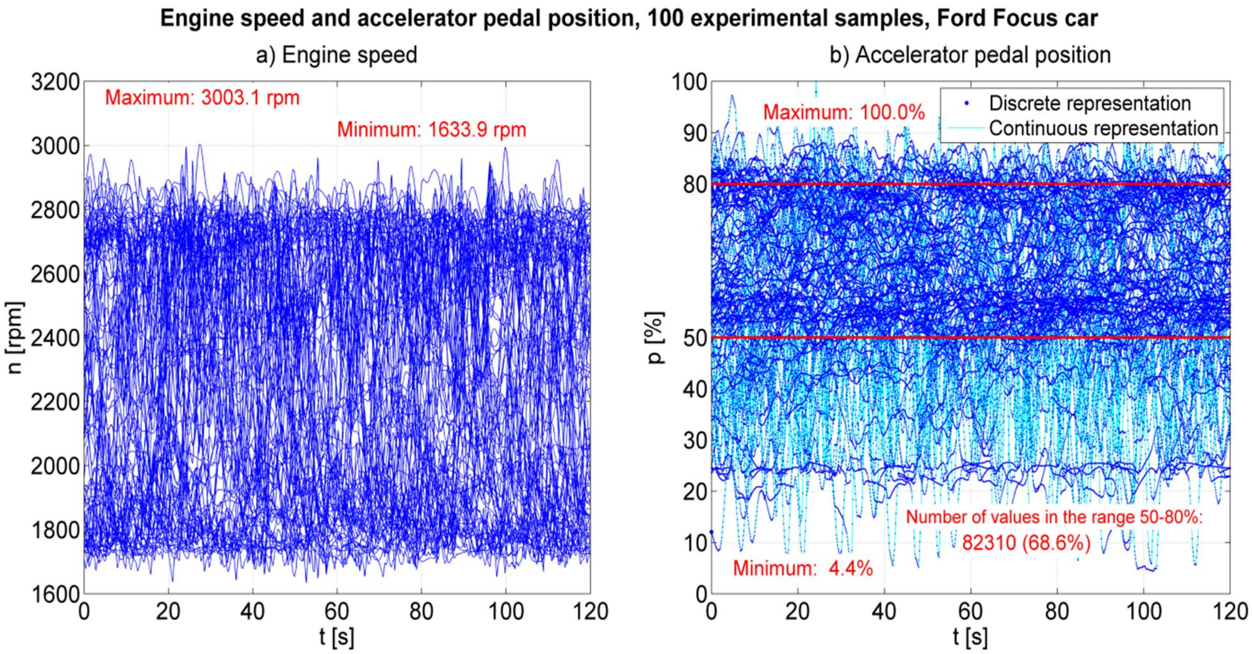

Fig. 2 Engine speed and accelerator pedal position

From fig. 2a results that engine speed varies within the range 1633.9-3003.1 rev/min. From fig. 2b it can be observed that the accelerator pedal position (which indicates the driving style) has 68.6% of values within 50-80%.

From fig. 3a results that the intake air pressure is higher than 100 kPa (ranges between 106-230.7 kPa), which is specific to a turbocharged engine. Also, fig. 3b presents the variation of fuel pressure between 22.7-129.97 MPa (the values are high due to the common-rail injection system).

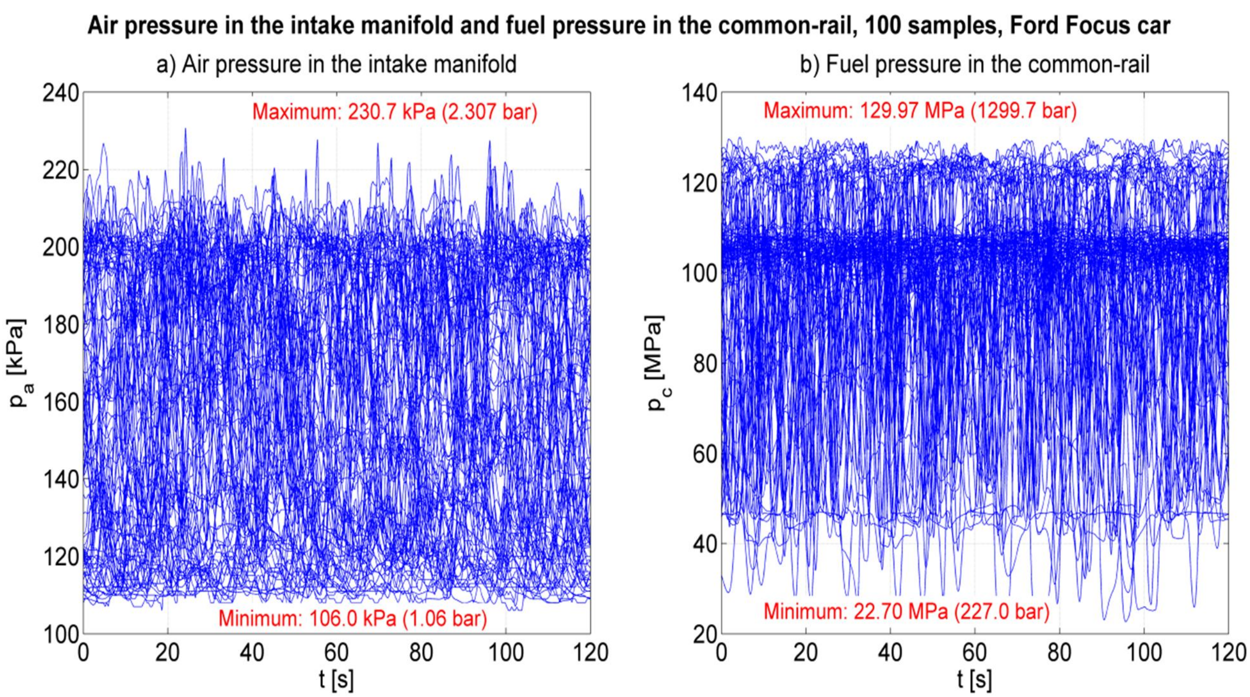

Fig. 3 Air pressure in the intake manifold and fuel pressure in the common-rail

In fig. 4a there are presented instantaneous values of hourly fuel consumption C_a, in fig. 4b the values of hourly exhaust gas recirculation rate C_g, and in fig. 4c are depicted percentages of gas recirculation □□□the latter defined by formula:

$$\gamma = \frac{C_g}{C_a + C_g} \cdot 100\% \qquad (1)$$

The use of discrete representation from fig. 4b and 4c allow a more clear notice of intervals with the most values.

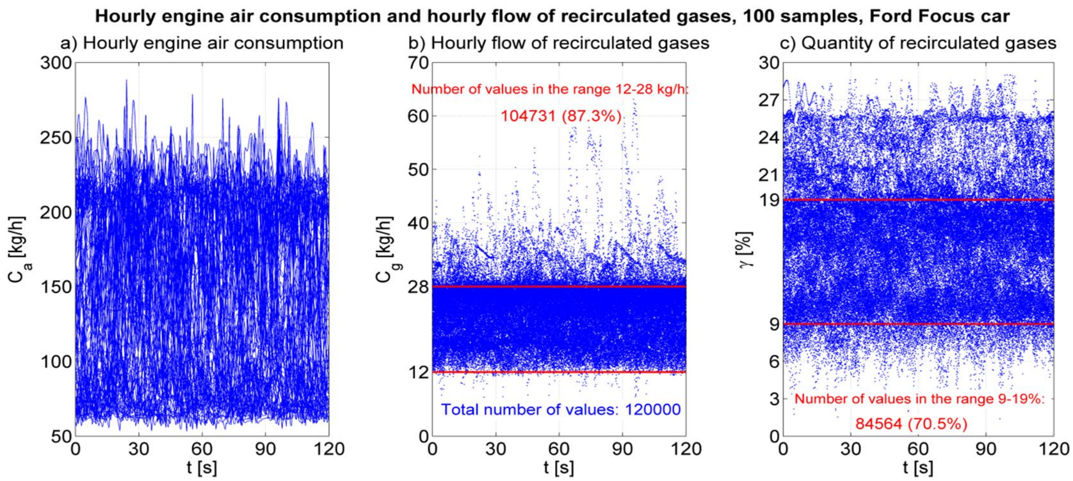

Fig. 4 Hourly engine air consumption and hourly flow of recirculated gases

Therefore, from fig. 4b it can be observed that 87.3% of all values regarding hourly flow of recirculated gases range between 12 kg/h and 28 kg/h. From fig. 4c results that 70.5% of EGR values are within 9-19%. As it can be observed from fig. 4c, one of the term for EGR (Exhaust Gas Recirculation) is associated with formula (1).

Fig. 5a depicts the variation of volumetric efficiency coefficient □$_v$, and 5b the real hourly air consumption C_a, the latter being defined empirically.

Volumetric efficiency coefficient is defined by formula:

$$\eta_v = \frac{C_a}{C_0};\ C_0 = 30\rho_0 V_h z n \qquad (2)$$

In which □$_0$ represents air density in standard environment, V_h piston engine displacement, z number of cylinders, C_a actual/measured hourly air consumption, and C_0 theoretical hourly air consumption.

As it can be observed from 5a, all instantaneous values of volumetric efficiency coefficient are greater than one, which confirms that the analyzed Diesel engine is turbocharged.

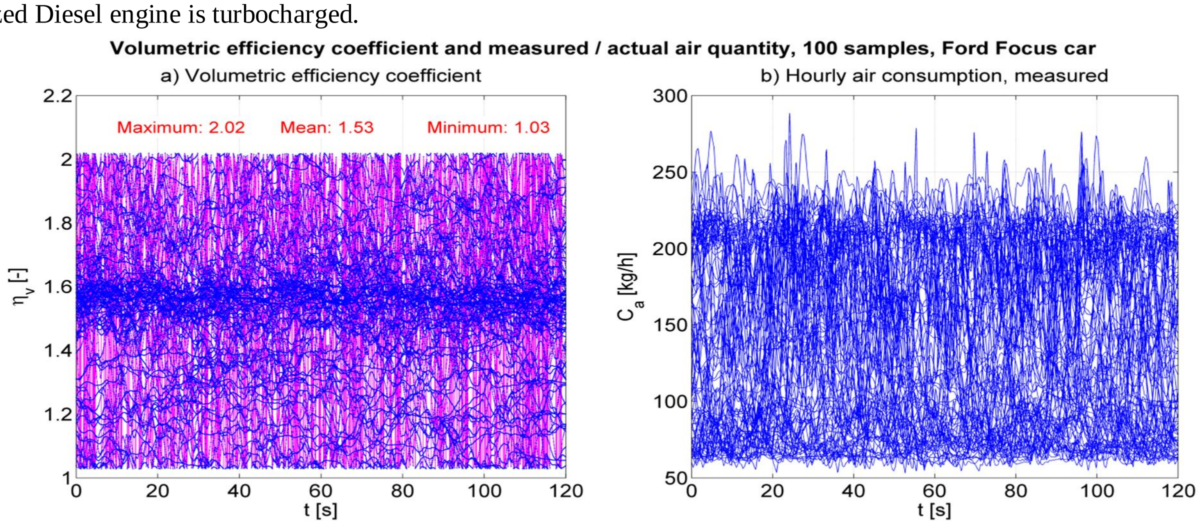

Fig. 5 Volumetric efficiency coefficient and measured/actual air quantity

III. CONTROL OF RECIRCULATED GASES

Nitrogen oxides are part of the pollutant emissions caused by internal combustion engines, with harmful effect on human health. In both cases, of engines running with petrol or diesel fuel, nitrogen oxides are produced as a result of fuel combustion. Due to different operating principles and fuel characteristics in case of the two types of aforementioned engines, the level of NOx is different [2], [5], [6].

Diesel engines operate with lean mixtures and as a consequence, the complete combustion of diesel fuel requires excess air. Also, due to high pressure within engine cylinders, the ignition temperature is higher. High temperatures and excess air are two main causes responsible for the emission of nitrogen oxides. That is why, Diesel engines, compared to those running on petrol, produce higher quantities of nitrogen oxides.

The control system of gas recirculation is used to introduce a part of exhaust gases resulted from combustion, within the intake manifold. The process leads to a decrease of released nitrogen oxides because it modifies the two elements influencing its production. By introducing a certain quantity of exhaust gases inside the intake manifold, a part of the oxygen is replaced by the exhaust gases, thus resulting in a decrease of fresh air. On the other hand, because the gases absorb heat resulted from fuel combustion, it is obtained a decrease of maximum temperature [1].

In case of this system, the EGR valve is the actual actuator. In fig. 6 there can be observed different EGR valves, from several manufacturers [7], [8]. In fig. 6e is presented the EGR valve from Ford Focus vehicle, which was used during experimental tests and in fig. 6f are depicted both the valve and the cooler for recirculated gases.

Because the actuator represents a first order inertial element, the functioning equation of exhaust gas recirculation valve, in dynamic state, is:

$$T\gamma'(t) + \gamma(t) = k\gamma_{st}(n, p) \qquad (3)$$

In which □ represents percentage of recirculated gases, known from tests and $\gamma_{st}(n, p)$ represents static characteristic of actuator (valve), established experimentally for all 100 samples engine speed *n* and accelerator pedal position *p* are known parameters.

In formula (3), *T* represents time constant of recirculation valve and *k* is the static transfer coefficient of valve.

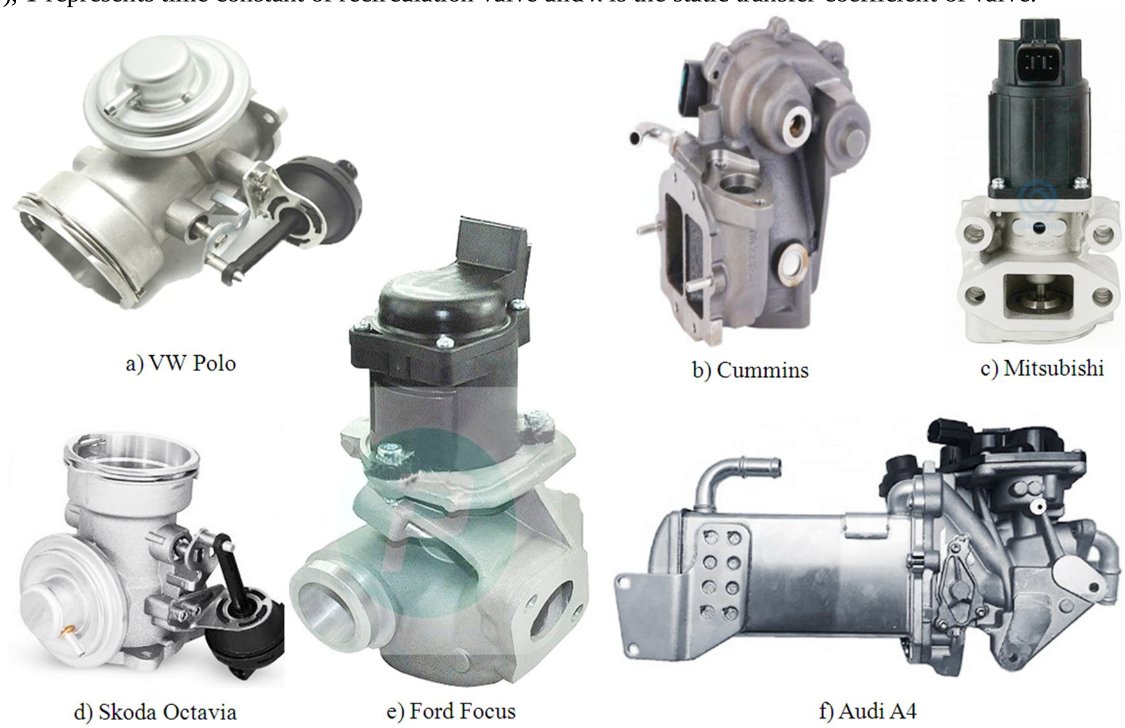

Fig. 6 Exhaust gas recirculation valves

In fig. 7 is presented the spatial distribution of static characteristic $\gamma_{st}(n, p)$ in case of the recirculation valve. The graph contains the commutation surface of static characteristic, defined by formula (1) which is written within the graph, as well as the 120000 values from all 100 experimental tests.

The mathematical expression for static characteristic depicted in fig. 7 is:

$$\gamma_{st} = 0.0277n - 0.1814p - 0.0000063n^2 - 0.000735p^2 \quad (4)$$

Based on these data, it can be applied the ARMAX identification algorithm (Autoregressive-moving-average exogenous), to establish functioning equation in dynamic state, in case of gas recirculation valve, as well as its response, as it can be observed from fig. 8a.

From fig. 8a it results the functioning equation of valve, in dynamic state:

$$\gamma'(t) + 96.91\gamma(t) = 99.11\gamma_{st}(n, p) \quad (5)$$

with transfer function:

$$G(s) = \frac{96.91}{s + 99.11} \quad (6)$$

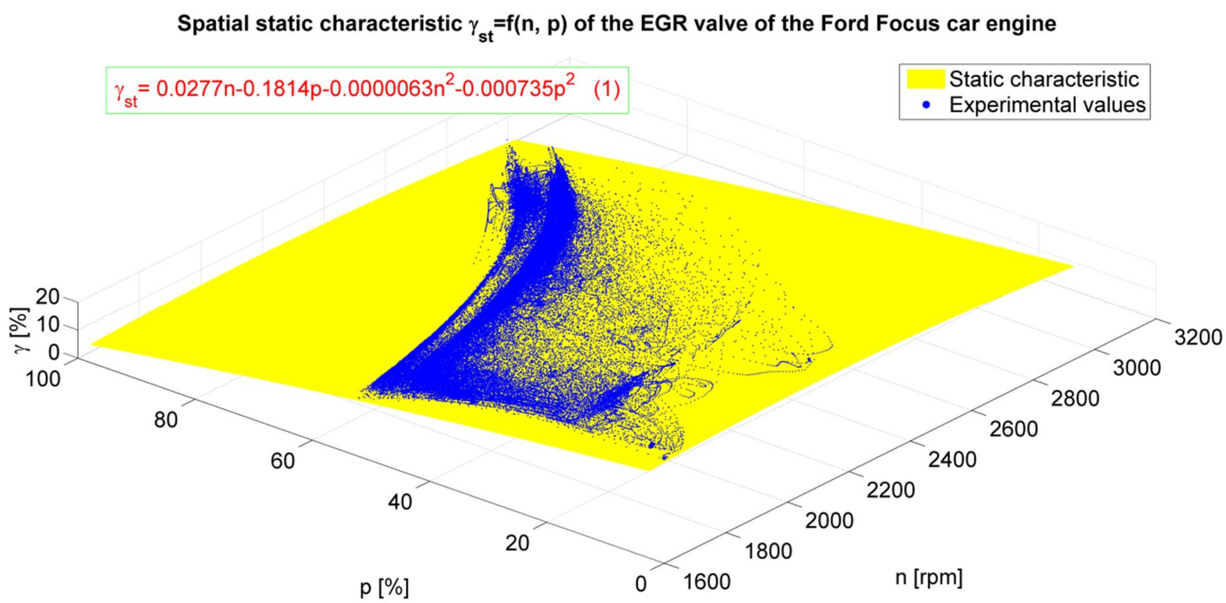

Fig. 7 Spatial static characteristic of the exhaust gas recirculation valve

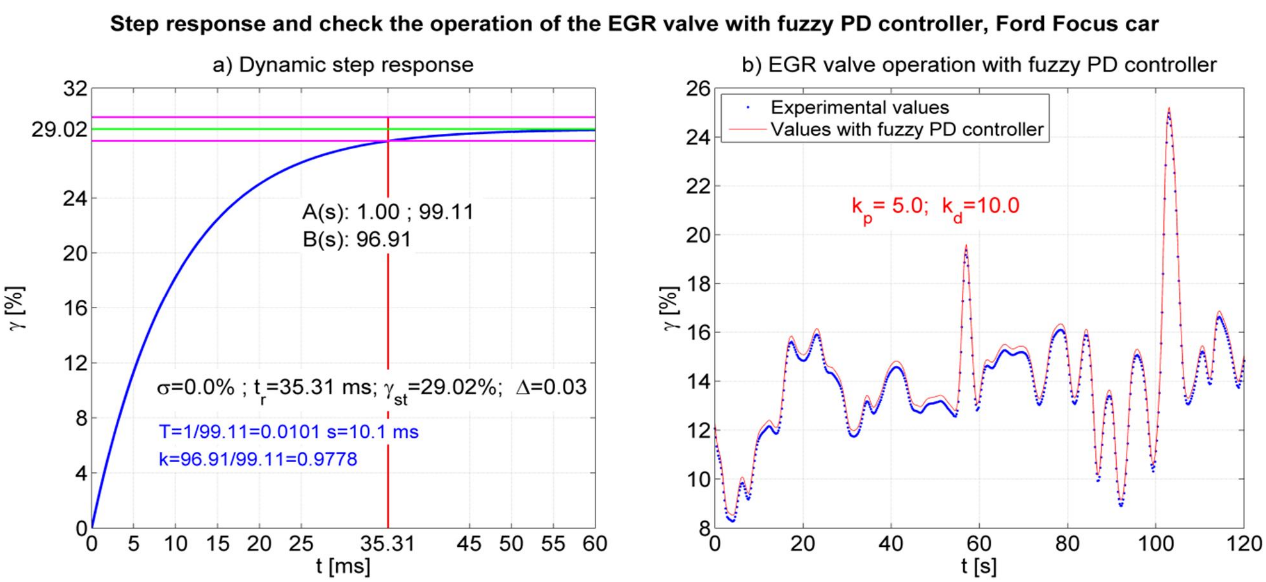

Fig. 8 The step response of the EGR valve using a fuzzy PD controller

Dividing by 99.11 in formula (5) it results:

$$0.0101\gamma'(t)+\gamma(t)=0.9798\gamma_{st}(n,p) \qquad (7)$$

with transfer function:

$$G(s)=\frac{0.9798}{0.0101s+1} \qquad (8)$$

From formulas (3) and (8) there can be obtained both time constant of recirculation valve and static transfer coefficient: T=0.0101 s=10.11 ms; k =0.9798. According to specialty literature, the maximum value of time constant T has to be 25 ms, which is accomplished in this case.

From fig. 8 it also results that dynamical performances in case of a step signal response (as input, it is applied the maximum value of residual gas from 100 samples): time response t_r =35.31 ms; zero override (□ =0); stationary value □$_{st}$=29.02%.

As it can be observed, the response time of recirculation valve is lower than the smallest value of time for engine cycle (25.7 ms<40 ms, the latter was established empirically), which means that the actuator ensures a normal functioning in dynamic state. To that effect it was used a fuzzy PD controller, which was modeled in Matlab (fig. 9). The scheme consists in reference size □$_{st}$ for modeling block 1, element of comparison EC at block 2, fuzzy PD controller at blocks 3, transfer function (6) at block 4, calculated value of cyclic flow □$_c$ at block 5, clock 6 and block 7 of time.

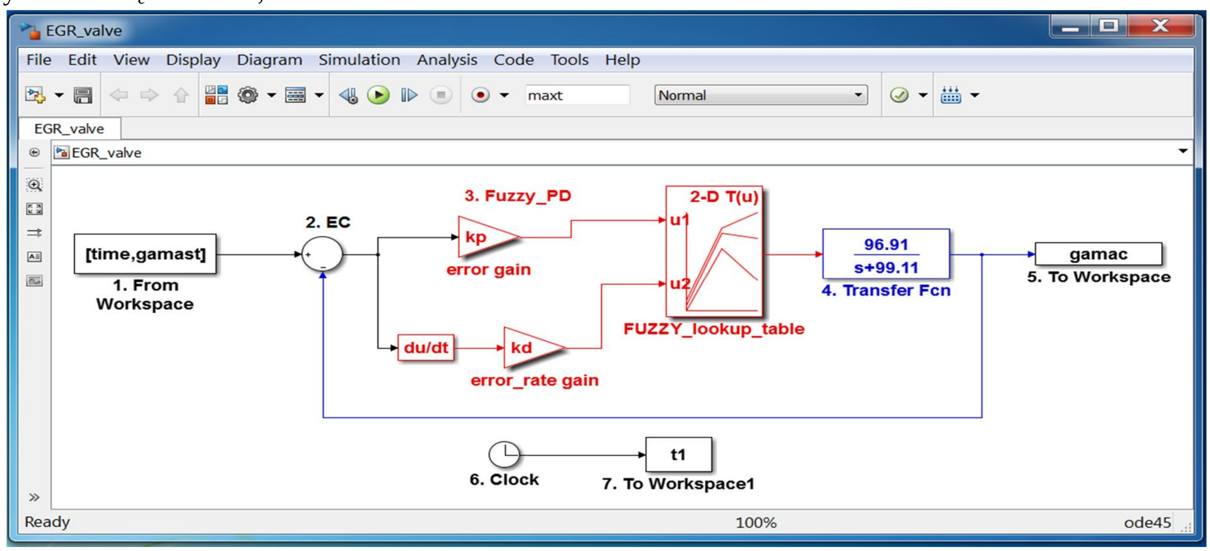

Fig. 9 Recirculated gas control scheme using a fuzzy PD controller

The fuzzy PD controller has the following parameters established by Ziegler-Nichols algorithm (parameters also shown in fig. 8b):

$$k_p=5;\ k_d=10 \qquad (9)$$

In fig. 8b it is verified the Ford Focus engine functioning in case of one experimental sample. By overlaying the two curves, one obtained from experimental tests and one from calculus, and comparing the graph with results from pressure sensor and fuzzy PD controller for percentage of recirculation gases □, the results are the same, indicating that the graphs are correct.

For present analysis, the control was based on fuzzy logic, which nowadays is widely used by itself or in combination with neural networks (called neuro-fuzzy control). This type of control is part of intelligent systems, which uses algorithms inspired from biological networks [3], [4].

IV. CONCLUSIONS

Based on the conducted study, part of which is presented within this paper, it can be concluded that Diesel engines will still be used in the future, mainly for heavy-duty vehicles, but also for passenger cars. To this end, five technological elements are considered to be essential for the use of Diesel engines: common-rail high pressure injection, advanced systems for gas recirculation, variable-geometry turbocharger, exhaust after-treatment systems and electronic control of engine functioning.

A part of the experimental tests was presented within present paper and it showed that Diesel engines have multiple advantages, but also some drawbacks. Main advantage consists in superior efficiency and the main drawback refers to higher values of pollutant emissions, which imply complex and high-cost design solutions.

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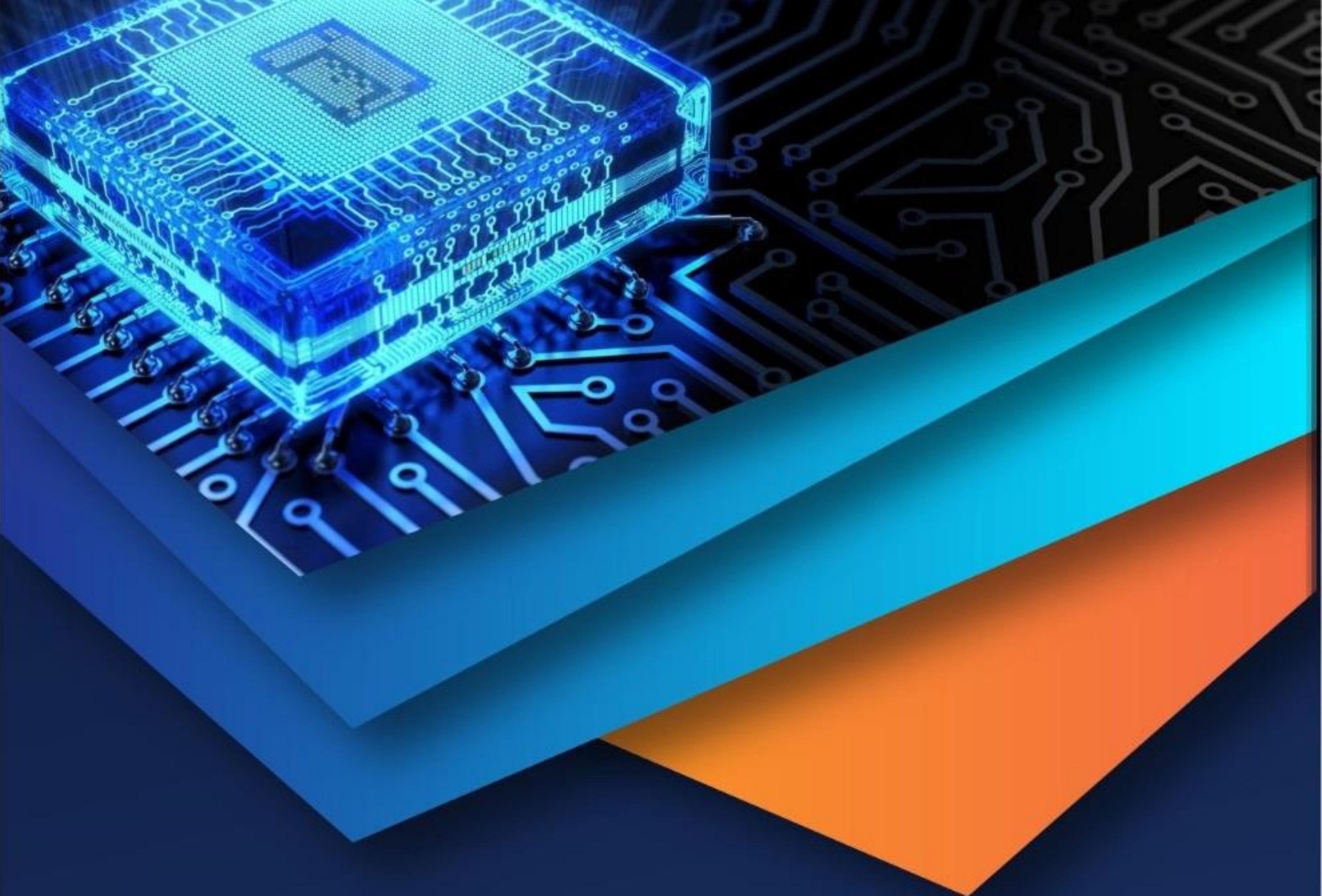

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