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Considerations Regarding to Supercharging Air Control on an Electronically Controlled Diesel Engine

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ABSTRACT: The paper presents some considerations regarding the operation of an electronically controlled diesel engine that equips a vehicle. The problem of noxious substances emitted at the evacuation is highlighted. Some results obtained from the tests of a vehicle equipped with a diesel engine, with a common-rail fuel system and with a gas recirculation system are presented. The electronic control system of recirculated gases is analyzed.

KEYWORDS: Diesel engine, motor vehicle, common-rail, electronic control, intake air pressure.

I. INTRODUCTION

The current diesel engine uses advanced solutions and advanced technologies such as the use of a variable geometry turbine to control the supercharging air pressure. The turbine is composed of rotating blades with variable inclination, which ensures the flow of a smaller amount (darker blades) or larger (lighter blades) of flue gases (fig.1). The opening of these blades is controlled by an electropneumatic actuator by means of a lever system [6, 8]. Depending on the engine speed, its computer adjusts the air pressure in the air actuator, which closes or opens the blades. In this way, less or more flue gases pass through the turbine rotor; as a result, the turbine rotor speed decreases or increases, which results in a decrease or increase in the compressor rotor speed. This results in a lower or higher boost air pressure, so an electronic control of it [3, 5, 7, 9].

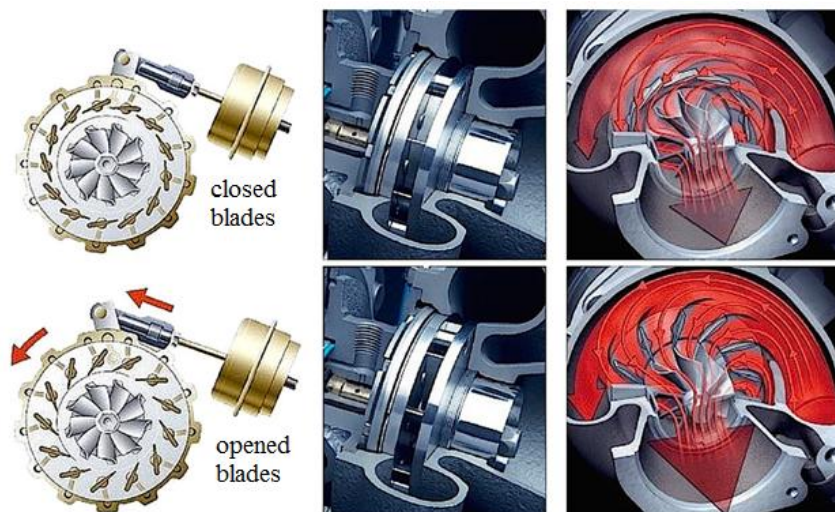


Fig.1. Variable Geometry Turbocharger

II. EXPERIMENTAL RESEARCH

The experiments were carried out with a Ford Focus car equipped with a turbocharged diesel engine. The acquisition of the functional parameters was made using Ford's FoCOM interface and software. From the data obtained,

100 more significant experimental samples were retained for the purposes pursued, which mark a normal movement during operation.

Fig. 2 shows the instantaneous values of the air pressure in the intake manifold p_a and of the hourly air consumption C_a of the engine.

Fig. 3 shows the instantaneous values of the inclination angle of the turbine blades α and of the volumetric efficiency coefficient η_v . These graphs also show the minimum and maximum values of the respective parameters.

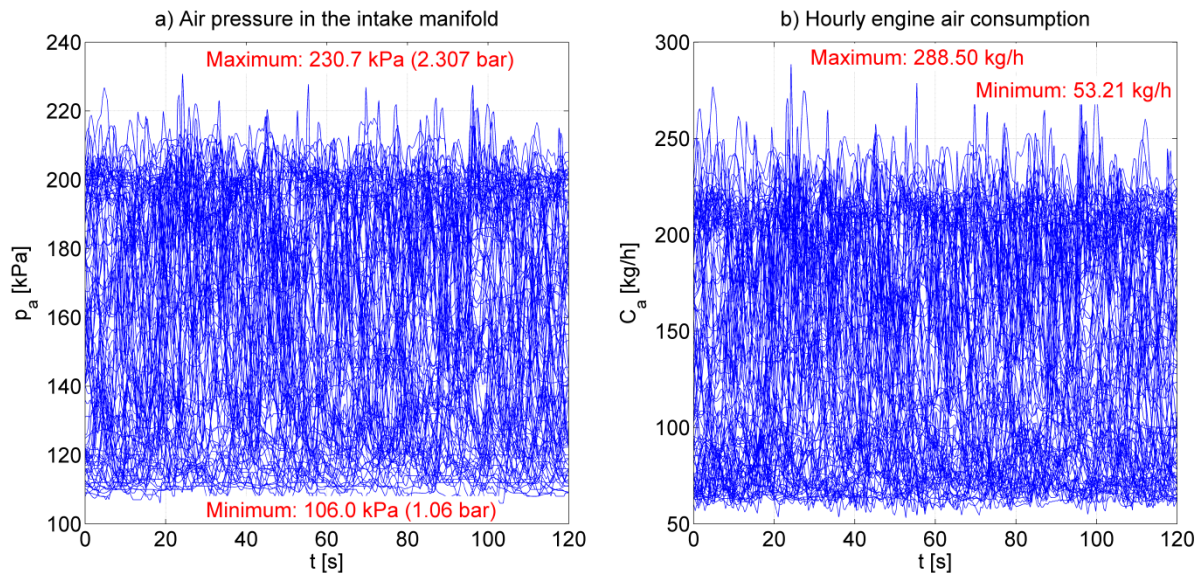


Fig.2. Air pressure in the intake manifold and hourly air consumption

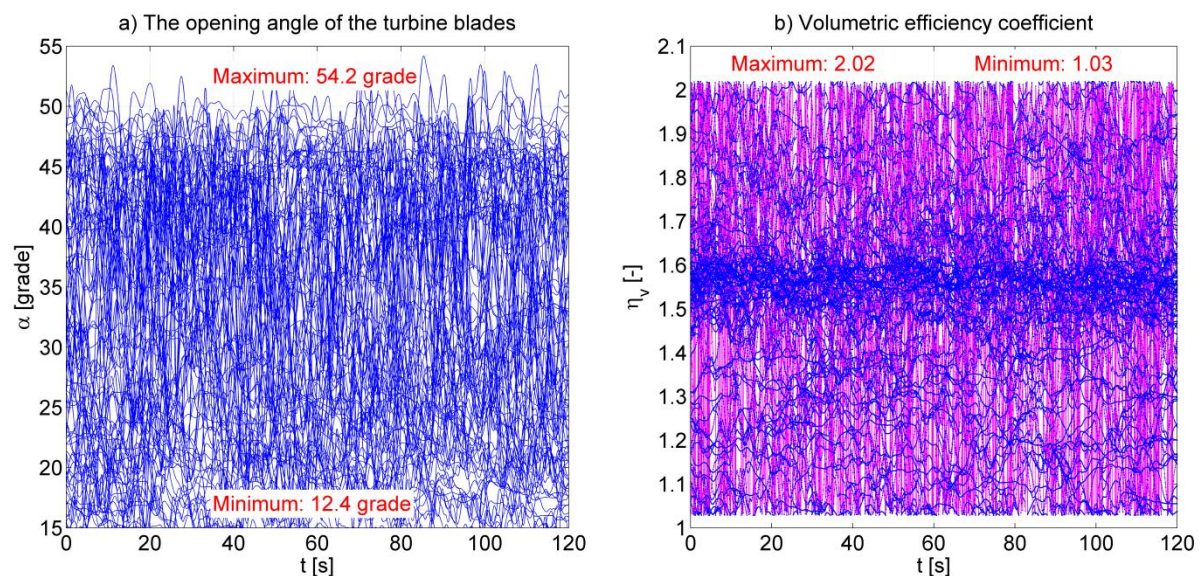


Fig.3. The opening angle of the turbine blades and volumetric efficiency coefficient

The volumetric efficiency coefficient is established with the relation:

$$\eta_v = \frac{C_a}{C_0}; C_0 = 30\rho_0 V_h z n \tag{1}$$

where ρ_0 represents the density of the air under reference conditions of the environment, C_0 the theoretical hourly air consumption, V_h - the unit cylinder displacement, z - the number of cylinders, n - the engine speed. As can be seen from Fig. 3b, all the instantaneous values of the volumetric efficiency coefficient are superunitary, which confirms that the motor is supercharged. In fig.3b there is a continuous representation and a discrete representation of the data, the latter highlighting the area with a high concentration of values.

III. SUPERCHARGING AIR PRESSURE CONTROL

The study of this control system concerns the intake manifold, the compressor and implicitly the turbocharger group through the turbine with variable geometry VGT (fig.4a, part 3), its electropneumatic actuator (fig.4a, parts 1 and 2), as well as the air pressure sensor supercharger (fig.4b). In Fig. 4, the actuator assembly is the EPC electropneumatic pressure converter (part 1), the PA pressure actuator being shown separately (part 2). In addition, Fig. 4a shows the mode of operation of the VGT turbine with variable inclination blades (part 3). It was also denoted by x the stroke of the rod of the pressure actuator PA, at part 2 distinguishing including the chamber, the spring and its diaphragm. Finally, reference 1 also showed the application of the EPC supply voltage [6].

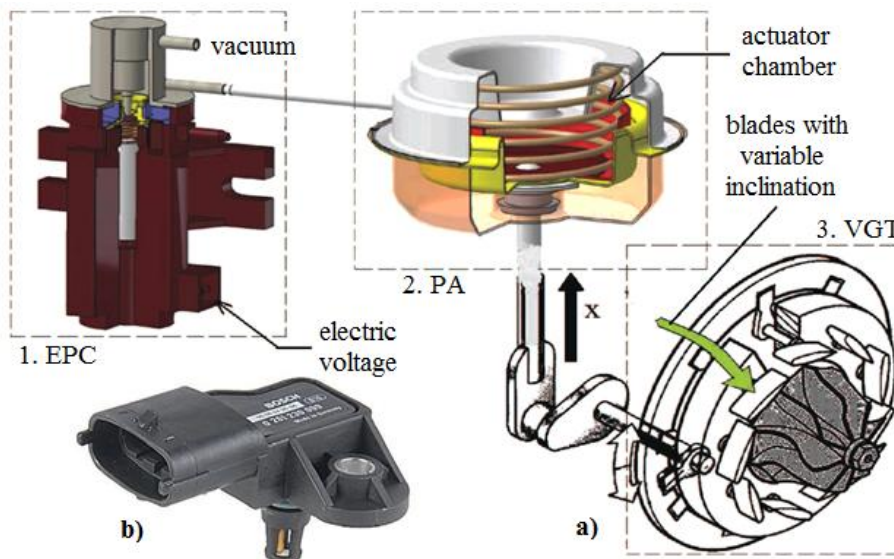


Fig.4. Turbocharger electropneumatic actuator and pressure sensor

It is now considered *the sensor* that measures the air pressure and shown in fig.4b. In the literature, sensors and actuators of electronic control systems are considered to be first-order inertial elements, in which case the differential equation of operation in dynamic regime is first-order [1, 2, 4, 10].

It turns out that the dynamic operation equation of the pressure sensor is:

$$T p'_a(t) + p_a(t) = k p_{a_{st}}(n, p) \tag{2}$$

where p_a is the air pressure known from the experiments, and $p_{a_{st}}(n, p)$ represents the static characteristic of the sensor, established experimentally for all 100 tests at which the engine speed n and the position of the accelerator pedal p are known (fig.5).

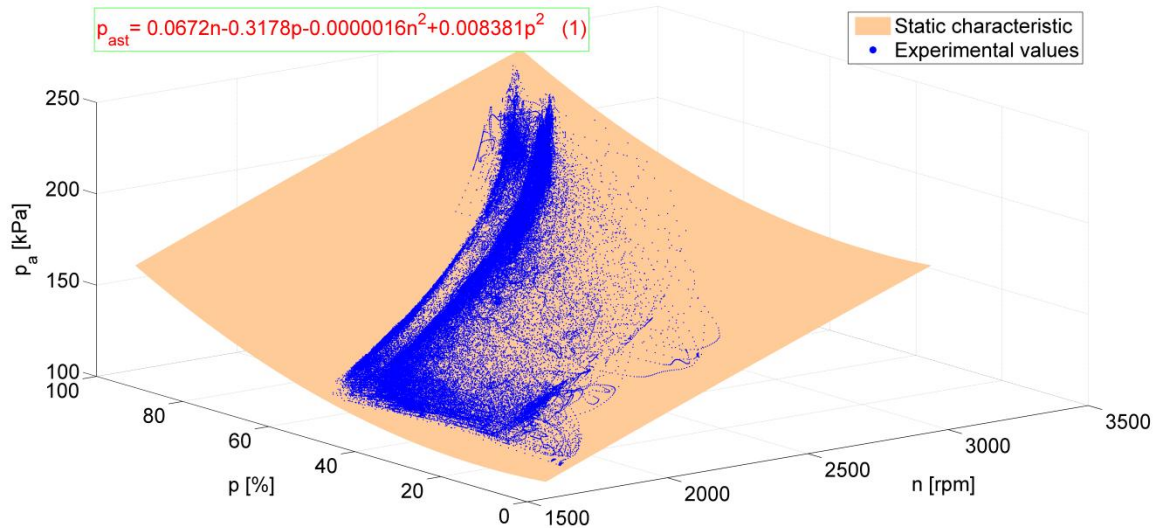


Fig.5. Spatial static characteristic of the pressure sensor

In relation (2), T is the time constant of the pressure sensor, k being the static transfer coefficient.

Fig.5 contains both the switching surface of the static characteristic, which has the analytical expression (1) in the graph, and 120,000 values of the 100 experimental tests.

The expression of the static characteristic in fig.5 is:

$$p_{ast} = 0,0672n - 0,3178p - 0,0000016n^2 + 0,008381p^2 \quad (3)$$

Based on these data, an identification algorithm is applied, for example ARMAX and the dynamic operation equation of the pressure sensor is established, as well as its response, as shown in fig.6.

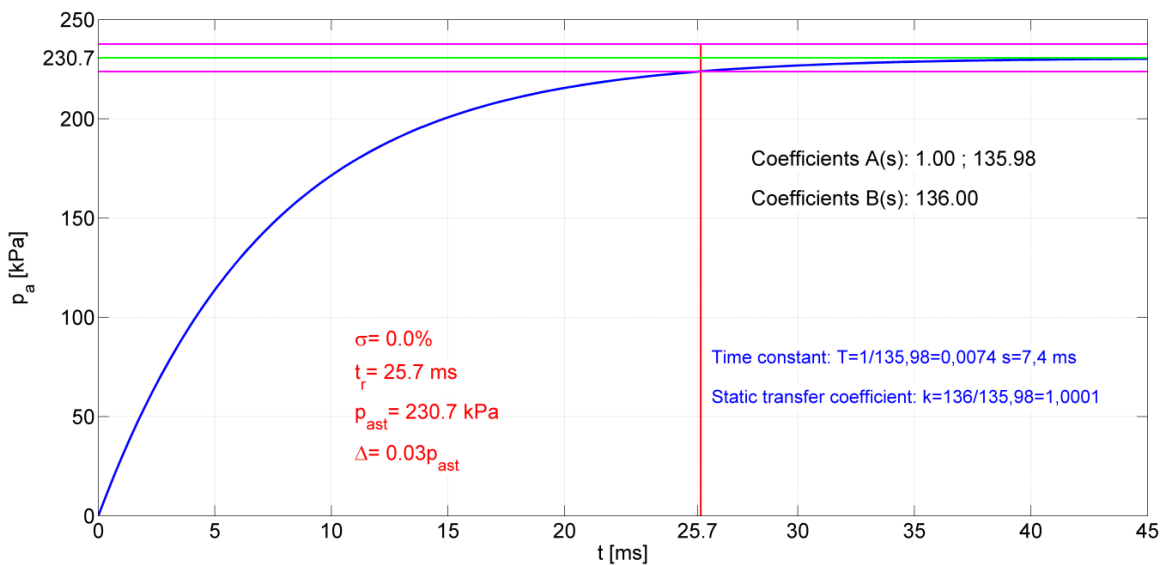


Fig.6. Dynamic step type response of the air pressure sensor

Fig. 6 shows the equation of operation of the sensor in dynamic regime:

$$p'_a(t) + 135,99p_a(t) = 136p_{a_{st}}(n, p) \tag{4}$$

and so the transfer function is:

$$G(s) = \frac{136}{s + 135,98} \tag{5}$$

Dividing by 135.98 in expression (5) results:

$$0,0074p'_a(t) + p_a(t) = 1,0001p_{a_{st}}(n, p) \tag{6}$$

with transfer function:

$$G(s) = \frac{1,0001}{0,0074s + 1} \tag{7}$$

The sensor time constant and the static transfer coefficient are thus obtained: $T = 0.0074 \text{ s} = 7.4 \text{ ms}$; $k = 1,0001$. In the literature it is considered that the maximum value of the time constant of the pressure sensor must be 15 ms, a condition that is met in this case.

Fig. 6 also shows the dynamic performances in the case of a step-type response (the maximum value of the boost pressure from the 100 samples is applied at the input): response time $t_r = 25.7 \text{ ms}$; zero override ($\sigma = 0\%$); stationary value $p_{a_{st}} = 230.7 \text{ kPa}$.

The *electropneumatic actuator* that ensures the rotation of the turbine blades with variable geometry, both shown in fig.4a, is still considered. In this case, too, the actuator is considered to be a first-order inertial element. It follows that the equation of operation of the actuator in dynamic regime is:

$$T\alpha'(t) + \alpha(t) = k\alpha_{st}(n, p) \tag{8}$$

where α is the known blade inclination angle from experiments, and $\alpha_{st}(n, p)$ represents the static characteristic of the actuator, established experimentally for all 100 tests at which the engine speed n and the position of the accelerator pedal p are known.

In relation (8), T is the time constant of the electropneumatic actuator, k being the static transfer coefficient.

Fig. 7 shows the spatial static characteristic $\alpha_{st}(n, p)$ of the electropneumatic actuator. The graph contains both the switching surface of the static characteristic, which has the analytical expression (1), and 120000 values of the 100 experimental samples.

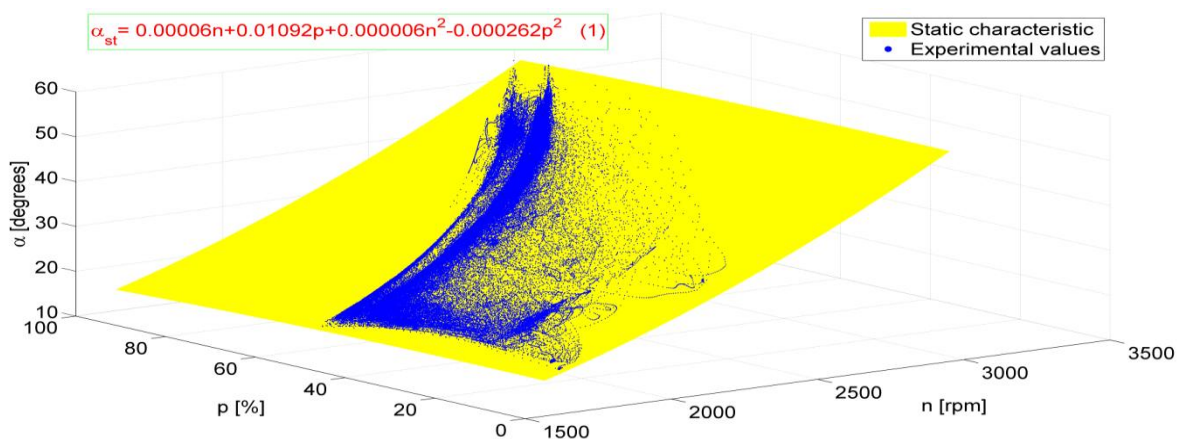


Fig.7. Spatial static characteristic of the electropneumatic actuator



The formula of static characteristic from fig.7 is:

$$\alpha_{st} = 0,00006n + 0,01092p + 0,000006n^2 - 0,000262p^2 \tag{9}$$

Based on these data, it is applied an identification algorithm and it is established the functioning equation of actuator turbine blades in dynamic regime, as well as its response, according to fig. 8.

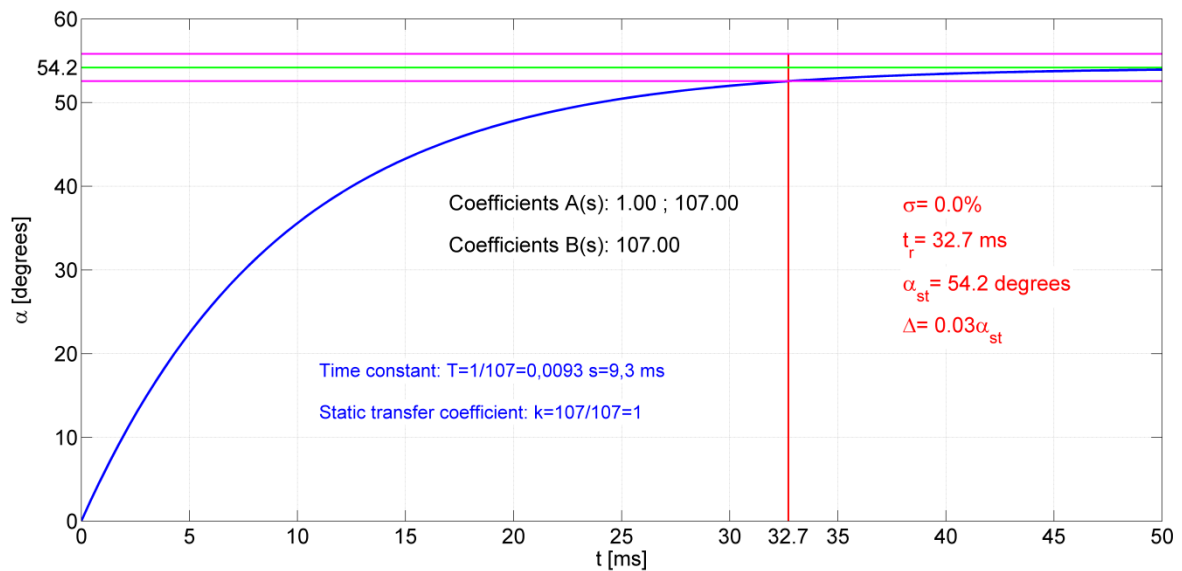


Fig.8. Dynamic step type response of the electropneumatic actuator

Fig. 8 shows the equation of operation of the actuator in dynamic regime:

$$\alpha'(t) + 107\alpha(t) = 107\alpha_{st}(n, p) \tag{10}$$

and so the transfer function is:

$$G(s) = \frac{107}{s + 107} \tag{11}$$

Dividing by 107 in expression (10) results:

$$0,0093\alpha'(t) + \alpha(t) = \alpha_{st}(n, p) \tag{12}$$

with transfer function:

$$G(s) = \frac{1}{0,0093s + 1} \tag{13}$$

From this relation are obtained the time constant of the actuator and its static transfer coefficient: $T = 0.0093 \text{ s} = 9.3 \text{ ms}; k = 1$.

Fig. 8 also shows the dynamic performances in case of a step type response (the maximum value of the inclination angle of the blades from the 100 tests is applied at the input, ie. 54.2 degrees in fig.3a): response time $t_r = 32.7 \text{ ms}$; zero override ($\sigma = 0\%$); stationary value $\alpha_{st} = 54.2 \text{ degrees}$.

IV. CONCLUSIONS

For the study of the supercharging air pressure control system, including for the establishment of dynamic performances, it is necessary to know the spatial static characteristics of the components.

The values set for the response time of the sensors and actuators of the control system are lower than the times of a motor cycle, which ensures fast dynamic responses with short delay times.

In addition to those presented, issues related to the compressor, turbine and turbocharger group can also be addressed.

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