THE GENERAL ASPECTS OF THEORETICAL CONTRIBUTION MODELING OF GASOLINE INJECTION AT ENGINES WITH SPARK LIGHTING

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Abstract
The author present the general aspects of theoretical modeling of gasoline injection, the principle modeling of some of the elements of gasoline injection, namely the gasoline pump model and the pressure regulator model.
It is presented the general model of a spark engine with gasoline injection.
The modeling of the motor cycles with spark engines and gasoline injection suggested by the authors is realized by executing a computer program for determining the variation of the three-dimensional and bi-dimensional parameters with the sub-programs:
-program for calculating the SIE (dependence according to n and λ at $t_o=-35...+45ºC$ and $p_o=1·10^2$ kPa);
- program for calculating the SIE (dependence according to n and t_o at $λ=1$ and $p_o=1·10^2$ kPa);
-program for calculating the SIE cycle with gasoline injection.

Key words: pressure regulator, valve, pulverization, duration of injection.

INTRODUCTION
1. GENERAL ASPECTS OF THE MODELLING

The theoretical and experimental research of the elements and injection systems of gasoline, represent the fundamental components of the analysis and synthesis for knowing the static and dynamic quality performances. The experimental analysis takes place mainly when the system in known, while the theoretic one when we design the system. The usage of computer in modeling the systems considerably enlarges the possibility for studying a of a great number of models in a short period of time, and then through simulation we can follow the answer when applying different entering signals (Apostolescu and Chiriac, 1998).
In the analysis and the synthesis in dynamic running of the injection systems for gasoline we usually use a series of laws, theorems, fluid mechanic and mathematics which are presented as follows. From theoretical mechanics we use:
   -the fundamental laws of mechanics (Oprean, et al., 1989) (Radcenco, 1994)

$$\overline{F} = m \cdot a; \ \overline{H} = m \cdot \overline{v}; \ \overline{M} = d \cdot \overline{F}; \ P = \overline{F} \cdot \overline{v}; \ \Sigma F = -m \cdot \overline{a}; \ \Sigma \overline{M} = J_z \cdot \overline{\varepsilon} \ \Leftrightarrow$$

$$J_z \frac{\partial \omega}{dt} = \Sigma M;$$

- Second equation of Lagrange:

$$\frac{d}{dt}\left(\frac{\partial E}{\partial g_i}\right) - \frac{\partial E}{\partial g_i} = \Sigma F_i;$$

- Equation of D'Alambert

$$m\frac{d^2 x}{dt^2} + b(x) + c(x) \bullet x = \Sigma F_i;$$

From the mechanics of the fluids, we use:
- Equation of the state of the fluid;

$$V = V_o [1 - \beta_V (p - p_o) + \alpha (T - T_o)];$$

- The characteristic equation;

$$\rho = \rho_0 \cdot e^{\beta v(p - p_0)};$$

- Isothermal compressibility coefficient;

$$\beta_V = - \frac{dV\!/\!V}{dp} = \frac{1}{E_V};$$

- Isobar thermic extension coefficient;

$$\alpha = \left[\frac{dV\!/\!V}{d_T}\right]_{p=ct};$$

- Newton's viscous friction law;

$$dF = -\eta \frac{d\overline{v}}{dn} dS;$$

- The principle of conserving the masses, expressed through the continuity equation;

$$div\left(\overline{v}\right) = 0 \Rightarrow \frac{\partial}{\partial t}\left(\rho S\right) + \frac{\partial}{\partial l}\left(\rho \overline{v} S\right) = 0 \Rightarrow vS = Qv = ct.$$

și $\rho VS = Q_M = ct$;

- The principle of conserving the energy, expressed by Bernoulli's equation, for unsteady flow;

$$\frac{v_1^2}{2g} + \frac{p_1}{\gamma} + h_1 = \frac{v_2^2}{2g} + \frac{p_2}{\gamma} + h_2 = \Sigma h_p + \Sigma h_i;$$

- Equation of hydrodynamic impulse force resulted from the Euler's theorem of impulse and kinetic moment;

$$\frac{d}{dt}\int_V \rho\bar{v}dV = \Sigma\bar{F}_e; \quad \frac{d}{dt}\int_V \bar{r}\times\rho\bar{v}dV = \Sigma\bar{r}_e\times F_e$$

$$\Rightarrow F = \rho\bar{v}Q;$$

- Equation for flows;

$$\Sigma Q_1 - \Sigma Q_2 = \frac{dV}{dt} + \frac{V}{Ev}\frac{dp}{dt};$$

- Kirchoff's law for hydraulic junctions; $\sum_{i=1}^{n}Q_i = ct.$

About the mathematical means, we can say that in the majority of the cases the differential equations systems which describe the phenomena which take place inside the injection systems of the gasoline are non-linear.
 There is no universally applicable methodology for solving these non-linear equations, so we solve them through approximation, which allow the description of the phenomena to the prejudice of the quality of the simulation.

Among the most frequently used methods we can mention:
Linearization of calculating relation around a functioning stationary point; linear analysis on parts; analysis in the plan of phases; analysis with description function.

In order to illustrate the linearization method we will present Taylor's formula for a function with two variables. With the help of this formula we can linearize any of the functions around a point. (Grunwald, 1980).

Being given a function f(x,y), which in the neighborhood of (a,b) has continuous partial derivates of (n+1) order, according to Taylor's formula, can be written:

$$f(x,y) = f(ab) + \frac{1}{1!}\left[f_x'(a,b)\cdot(x-a) + f_y'(a,b)(y-b)\right] +$$

$$+ \frac{1}{2!}[f_{xx}''(a,b)(x-a)^2(y-b) +$$

$$2f_{xy}''(a,b)(x-a)(y-b) + f_{yy}''(a,b)(y-b)^2] + ...$$

$$+\frac{1}{n!}\left[(x-a)\frac{\partial}{\partial x} + (y-b)\frac{\partial}{\partial y}\right]^n f(a,b) +$$

$$+ R_n(x,y); \text{unde}: R_n(x,y) = \frac{1}{(n+1)!}\left[(x-a)\frac{\partial}{\partial x} + (y-b)\frac{\partial}{\partial y}\right]^{n+1} \cdot$$
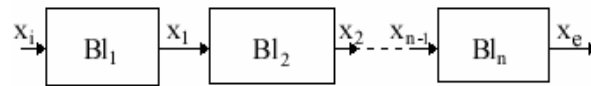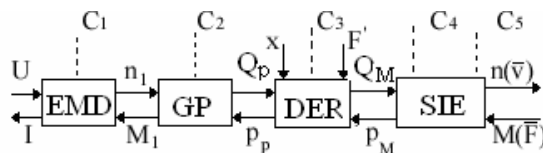
$$\cdot f[a + \theta(x-a), b + \theta(y-b)],$$

$$O\,\pi\,\theta\,\pi\,1$$

Where: in the particular case a=b=0: we obtain Mac Laurin's formula. Structurally, a system of gasoline injection from an engine represents a succession of energy conversions C1,C2,….,C5, figure1. In the figure the blocks represent, in order: the electric motor drive EMD, the gasoline pump PB, control and adjustment equipment ARC, (directional equipment for flow regulation and pressure storage, filtering, injection), usually named the organs of the spark ignition engine ESL.

The electric engine is accumulator driven. It transforms the electric energy into mechanic energy, so here takes place the first conversion C1, and then the gasoline pump transforms the mechanic energy into pressure potential energy, in this way the second conversion takes place C2. The electromagnetic injector pulverizes and doses the gasoline in front of the admission valve realizing in this way the conversion of the pressure potential energy and electromagnetic energy into mechanic energy for moving the needle/indicator of the C3 injector. In the combustion chamber of the engine takes place a double energy conversion. When the fuel mixture burns the chemical energy of the fuel is conversed into thermal energy C4, which is transformed into effective work (mechanic energy) and the C5 conversion takes place.

Compared with other systems in a classical acceptation having an entering amount x_i and an outgoing amount x_e, figure 1. The system of gasoline injection is presented in systemic acceptation, like a multivariable system in which the component elements (blocks 1….n) are quadric-poles or sexa-poles, and the connection lines (poles) represent the information support of the variables, figure 2.

The global driving system supposes the existence of an electric amount (U-voltage, I-intensity), mechanic (n_1- the pump's number of rotations); n (v)- number of rotations of the ESL; M1 – the moment of the pump; M(F)- the moment of the ESL, and hydraulics (Q_p- the pump's flow rate; Q_M the air flow rate at the ESL; pp- pressure of the pump; pM- the pressure at the MAS) ordered in such a way according to the way of transmission of the energy or information. The amounts U, n_1, Q_p, Q_M, and n(v) are called direct variables or movement variables, through which the frequency characteristic of the system is made, while M(F); p_M; p_p; M_1; I – are called effort variables, which supposes the power supply of the system for creating the force or the necessary moment for surmounting of resistant moments or forces from the engine. X and F' are exterior amounts for command. From the global system presented in figure 1 we can distinguish the system made by the 2,3,4, blocks, which are in fact the injection system of the gasoline, having the mechanic connections at entrance n1 and M_1; and n(v) and M(F) with four energy conversions at the exit. This subsystem is analyzed on each of its components.

Fig. 1. The scheme of the energy conversions for an injection system

Fig. 2. The multi variable system for gasoline injection

2. THE MODELLING PRINCIPLE OF SOME ELEMENTS FOR THE GASOLINE INJECTION

The gasoline pump model

For elaborating the mathematical models of analysis on the computer, we start from the equation of equilibrium of the flows, the movement, and dynamic equilibrium of the moments at the level of links between the electric engine and the pump, which have the following form: (Oprean , et al., 1989)

$$Q_p = \frac{q_p}{2\pi} \cdot \omega_p - a_p p - \frac{q_p}{2E} \frac{dp}{dt};$$

$$J \frac{d\omega_p}{dt} + b_p \cdot \omega_p + \frac{q_p}{2\pi} p + \frac{q_p}{2\pi} \cdot c_{fp} \cdot p = K_e \left(\omega_s - \omega_p\right); \qquad (1)$$

Where:

Q_p is the pump's flow rate [m³/s]; q_p- the capacity of the pump(we neglect the non-active liquid quantities) [m³]; ω_p- the angular speed of the pump [rad/s]; a_p- linearised gradient of the flow rate loses [(m³/s)/(N/m²)]; p- the instantaneous pressure in the pump [N/m²]; E- the elasticity module of the liquid [N/m²]; J- accumulated inertia moment of the rotor part of the pump and the rotor of the electric engine [N·m·s²]; b_p- linearised gradient of the loses proportional with the rotative speed [(N·m)/(rad/s)]; K_e- the slant of mechanic characteristic of the electric motor [(N·m)/(rad/s)]; ω_s- the synchronism angular speed of the electric engine [rad/s]; c_{fp}- dry friction coefficient (adimensional).

It is considered the entering amount, the instantaneous pressure p, the exit amount the instantaneous flow rate Q_p, and as a parameter the synchronism angular speed ω_s.

It is considered the pump in systemic acceptation (figure 3) (Apostolescu and Chiriac, 1998). With the relations (1) the model of the gasoline pump is realized.

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The model of pressure regulator

We consider the pressure regulator, figure 4, where we neglect: the mass of the spring, the dependence of the elastic constant of the movement spring and the dependence of the damping factor of movement, so K1 and C are considered constants.

If we have in view the ball valve with conical seat, from the construction of the pressure regulator, the equations which describe the model are: (Oprean, et al.,1989);(Grunwald, 1980):

$$Q_M = Q_p - \Delta Q - \frac{V_1}{E} \cdot \frac{dp}{dt}; \tag{2}$$

$$m_p \cdot \frac{d^2 x}{dt^2} + c \frac{dx}{dt} + K_1(x + x_1) = A_1 p - A_2 p_2 - F_D; \tag{3}$$

$$F_D = \rho v \Delta Q \cos\alpha = \rho \sqrt{2p/\rho}\, \Delta Q \cos\alpha; \tag{4}$$

$$\Delta Q = C_D \cdot \pi \cdot D \sin\alpha \cdot x \sqrt{\frac{2}{\rho}(p - p_2)}; \tag{5}$$

Where:

Q_M is the flow rate transmitted to the consumer [m³/s]; Q_p- is the pump's flow rate [m³/s]; ΔQ- the overflow flow rate [m³/s]; V_1- the liquid volume from the inactive space of the valve [m³];
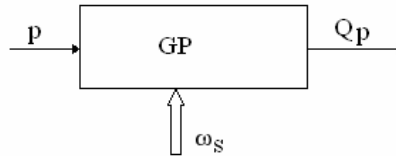

Fig. 3. The systematic scheme of the gasoline pump
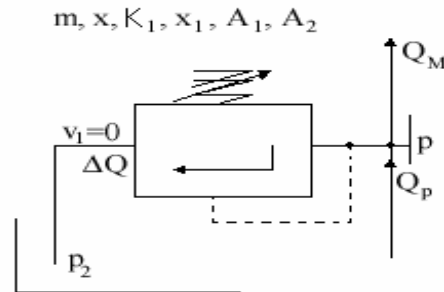

Fig. 4. The systematic scheme of the pressure regulator

m- the mass of the closing element [kg]; x- the movement of the element [m]; x_1- spring's pre-pressing [m]; A_1,A_2- the active surfaces of the closing element [m²]; F_D- hydrostatic force [N]; α- the angle of the valve seat [degree]; v- the flow of liquid through the valve [m/s]; E- the elasticity module of the liquid [N/m²]; K_1- the elastic constant of the spring; p-

instantaneous entering pressure [N/m^2]; c- damping factor; p_2- - pressure from the reservoir [N/m^2]; D- diameter of the valve aperture [m]; C_D- flow rate coefficient when flowing through the valve aperture. When we replace relation (5) in formula (4), it results:

$$F_D = \rho \sqrt{\frac{2p}{\rho}} \cdot \cos\alpha \Delta Q \cdot C_D \cdot \pi \cdot D \sin\alpha \cdot x \sqrt{\frac{2}{\rho}(p - p_2)}$$

And neglecting p_2 pressure we obtain the following final formula.

$$F_D = C_D \cdot \pi \cdot D \cdot x \cdot p \sin 2\alpha ;$$

The hydrostatic force is influenced by the rate flow coefficient through the valve aperture, by the moving of the valve element, the instantaneous pressure of entrance and the angle of the seat valve.

3. THE GENERAL MODEL OF A SPARK IGNITION ENGINE WITH GASOLINE INJECTION

The number of rotations and charge defines the functioning regime of the engine, but besides these, it requires knowing the thermal regime, meaning the temperature of the pieces, the temperature of the cooling fluid, the temperature of the admitted air, the temperature of the evacuated gases, altitude corrections etc. (Bățagă, 1979).

The appreciation of the quality of the mixture is frequently made through the coefficient of air excessλ, defined by the ratio $\lambda = L/L_0$, where L is the available air amount for burning a kg of fuel, and L_0 the minimum quantity of air theoretically necessary for burning a kg of fuel. For a stoechiometric dosage $\lambda = 1$, $\lambda > 1$, for the poor one, $\lambda < 1$ for the rich one.

The block scheme of the general model used for modeling the gasoline injection system of a SIE is presented in figure 5. It consists of a system for correlating the quantity of air sucked in by the engine with the quantity of gasoline injected. The entering amounts in the system are χ- the charge, n- number of rotations, ω- the angular speed, φ_A, – the position of the shutter, and the exits are the effective moment, the effective capacity, the effective consumption, polluting emissions. The processes from the engine are influenced by the thermal regime of the T engine (Blaga 2000).

After the study made at different gasoline injection systems, we can see that each system, whether it is electric or mechanic, have the principle scheme based on the functioning of the fuel burning engine. The mechanic systems have as a basic principle scheme two circuits: the fuel circuit, the air circuit, and the adequate corrections. The electronic systems also contain an electric and ignition circuit, in the case of Motronic system.

The main duty of the injection equipment is to correlate the quantity of the air sucked in by the engine with the quantity of injected gasoline, in

order to obtain the optimal dosage for each functioning regime of the engine. This may be realized by correlating the quantities of air and gasoline and a series of functional parameters of the engine (the air pressure in the admission collector, the position of the obturator, the engine's rotation speed).

The quantity of air sucked in by the engine may be expressed term to the above-mentioned functional parameters. When expressing the quantity of the gasoline term to these parameters we must take into account of the injection pressure, the flow section, through the injector and the length of the injection.

It is mostly preferred that the time length for opening of the electro-magnetic injector to be term to the low depression from the admission collector, because this quantity of injected
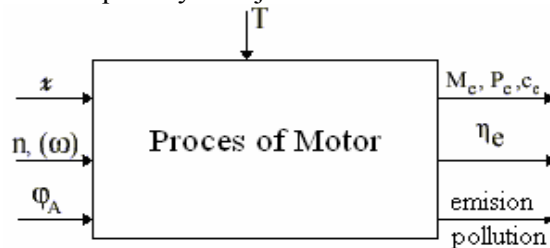
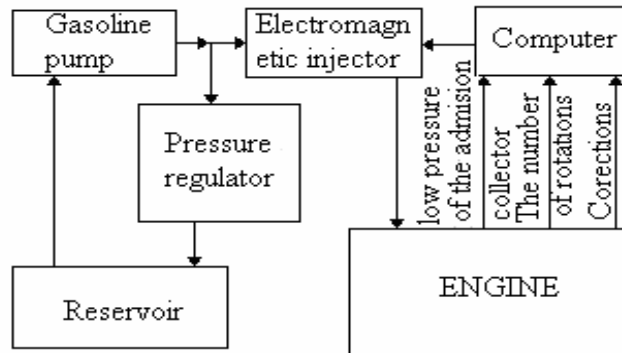Fig. 5. The general model of a SIE with gasoline injection

Fig. 6. The basic principle of the gasoline electronic injection
gasoline is correlated with the quantity of sucked air on each cycle, which is, as we know from the mechanic equipments for injection, is term to the low pressure from the admission collector; the dependence on the number of rotations being small, some corrections are going to be made for the number of rotations in the functioning regimes which ask for these corrections. The corrections of gasoline flow injected in the cylinder are needed because of a series of transitory functioning regimes of the engine, cold start, as well as the temperature of the cooling liquid, the temperature of the admitted air in the cylinder, the temperature of the lubricating oil, atmospheric pressure.

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Considering all these when realizing the injection equipments the basic principle expressed in figure 6 is applied.

A fuel feed pump sucks in the gasoline from the reservoir and drives it back to the electromagnetic injectors. The gasoline pressure upstream the injectors is maintained constant by the use of the pressure regulator which allows the return to the reservoir the extra gasoline driven back by the fuel feed pump.

The electromagnetic injectors associated to each cylinder of the engine, are opened one time for each cycle (at a full rotation of the tumbler shaft), through current impulses which come from a computer. The length of the command impulses depend on the low pressure of the admission collector, the number of rotations of the engine, and on a series of corrections. The mechanic-electric transducers sense these corrections, being transmitted to the computer under the form of electric scales. (Blaga, 2005)

According to this basic principle we can model a great variety of injection equipments with electronic command, which will be able to answer to the request of growing performances of the power of the engines, the reducing of effective fuel consumption and polluting products from the exhaust gases and the need for low costs, liability, long life and adaptability.

CONCLUSIONS

a. It was devised a personal model for calculating the pressure for the admission gallery pga and for the pressure at the end of admission pa.

b. It was devised the model for calculating the pressure regulator and the electromagnetic injector. It was made the calculus model for the length of the injection ti with the charge and number of rotations, which represents the model proposed by the author.

c. It was devised the model for calculating the SIE parameters with the gasoline injection with the sub-programs: program for calculus of MAS parameters (dependence after n and λ at t_o=-35...+45ºC and p_o=$1 \cdot 10^2$ kPa);

The program for calculating the parameters of the SIE (dependence on n and t_0 at λ =1 and p_0= $1 \cdot 10^2$ Pa); the program calculating the SIE cycle at the gasoline engine;

d. With the help of the calculus program, we figured the three-dimensional of the adiabatic and polytrophic coefficients, temperatures and pressure in the characteristic points of the cycle, the filling coefficient, the dosage, the heat supply of the capacity of the engine, the pressure growth ratio in the isochoric burning, the volume growth ratio in post burning, the technical-economical parameters of the engine and the length of the injection.

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