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FUEL INJECTION: MODELING OF THE HYDRODYNAMIC COMPORTMENT

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ABSTRACT

The motor with lighting by compression requires an alimentation rigorously measured in fuel, at the precise moment and during a very short time, being located at the end of compression in the cylinder. The main objective of this work is to develop a mathematical simulation of the injection (pump – piping - injector), while being based on the equation of the movement and the equation of the continuity, to arrive finally at differential equations that are solved by Range Kutta method. We developed a code of calculation in FORTRAN language; the results are presented under shapes of curves (pressure, flow and positions).

KEYWORDS: Injection, Injector, Mathematical Simulation, Diesels Motors

1. INTRODUCTION

In the diesel motor injection system, the function of the injector is to introduce in the motor cylinder, at a given instant and during an extremely short time, a determined quantity of fuel, and to distribute this quantity in a finely pulverized state, according to law that function in the space and in the time of an adopted room combustion type, and that must take into consideration the motor speeds and loads variations [1].

The length during which the injection takes place is extremely limited; for a rotating motor about 1500min^{-1} it is the order of 1/300 of seconds, the quantity of the injected fuel to each cycle varying to a full load about 0.3gram and even more following the rate of the motor super charging [2]. The combustion can't be correct only under reserve that the beginning and especially with no transitory regime, even to instantaneous character-said the order of a traction of thousandth of second-so much in the law of the debit than in the pulverization quality [1].

The aim of the system of injection is to assure the introduction of the fuel in the cylinder, it must then:

- Measure the quantity of fuel;
- Drive back this quantity in accordance with a given law, without excessive pressures provoked by this repression;
- Introduce this quantity in the motor cylinder, from a given instant and during a given period of time;
- Distribute this quantity, introduced in a pulverized state, at an extremely short time.

We developed a mathematical model of simulation, from the energy and mass balances relative to the drying process of mint leaves, spread on trays of the drying chamber. This model allows us to determine changes in water content of the product to dry over time taking into account the main aero thermal parameters (temperature, hygrometry and mass flow of drying air).

Initially we will consider a constant temperature and humidity over time in order to validate our model thanks to the measures done with the help of the vein of drying.

2. ELEMENTARY FUNCTION OF THE INJECTOR

With regard to the classic injection systems, the pent-up fuel under pressure by the pump of injection is driven by channels in the room of pressure. Since diameters of the needle and the reach of the seat are different. The fuel exercises on the needle a thrust that has a tendency to raise it of its seat, which effectively, will produce when the pressure of carries-injectors. The needle unveils openings of the injector and the fuel is pulverized in the room of combustion. The pressure of the repression falls, the needle falls again, obstructing holes of injections all over again [3].

The taring pressure can be adjusted previously while acting mechanically on the tension of the spring. If (P) is the taring pressure and (F) is the tension of the spring, one has:

$$F = \frac{\pi}{4}(D^2 - d^2)P \tag{1.1}$$

With: (D): diameter of the needle, [m];

(d): diameter of the reach of the seat.

In the beginning of injection, the pressure of fuel acts on all the section of the needle that rises very quickly; this privileges, of course, the pulverization.

The closing of the injector takes place for a pressure (P_f) as:

$$P_F \cdot \frac{\pi}{4} D^2 = F_1 \tag{1.2}$$

The corresponding tension of the spring (F_1), is practically equal to (F). Indeed, considering the very weak needle levee (less 1mm), the contribution of the stiffness of the spring is negligible. On gets therefore:

$$P_F = P . \frac{D^2 - d^2}{D^2} \tag{1.3}$$

The injected instantaneous volumic huge (Q_v) is written according to Bernoulli law:

$$Q_v = K_S . A_{in} \left(\frac{P_{in} - P_{cy}}{\rho} \right)^{1/2} \tag{1.4}$$

(K_S) - Specific coefficient of an examined injector.

(A_{in}) - Section of openings of the injector, [m²].

(P_{in}) - Pressure in the injector (fuel), [MPa].

(P_{cy}) - Pressure of air in the room of combustion, [MPa].

(ρ) - Mass volumic of fuel, [$Kg.m^{-3}$].

3. THE MATHEMATICAL MODEL OF THE INJECTION

The injection of the fuel, in diesels motors, depends of the organization of the system of the injection it self, as well as of the physical properties of the fuel.

For the choice of the parameters optimum of the system of the injection, it is necessary to use the mathematical models of calculation on computer.

Systems of injection, composed of a pump with piston, a conduct and an injector with holes, are more used in present diesels motors (Figure 1).

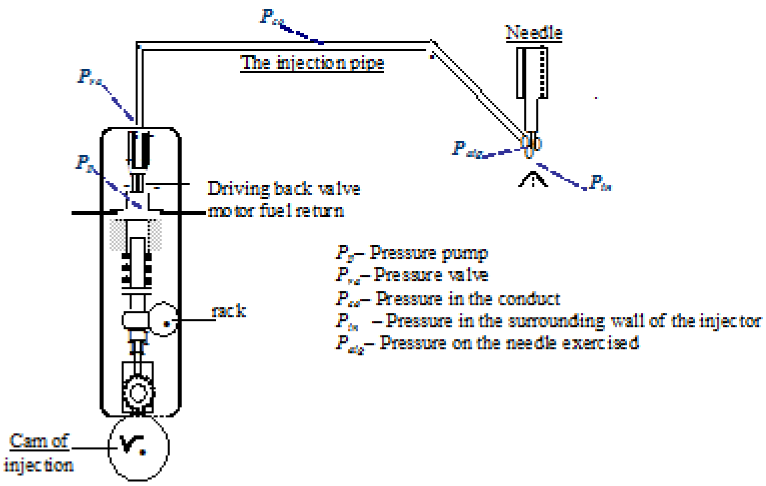

Figure 1: Representation of the Pressure in Different Points of Injection System

4. THE MATHEMATICAL MODEL OF SIMULATION

4.1 The Conduct at High Pressure

A considerable influence is exercised on the process of the injection, by the conduct at high pressure that joins the pump and the injector. The out-flow one-dimensional no permanent of the fuel in the conduct, while holding amount of the hydraulic resistances, can be described by equations of the movement and the continuity [4]

$$\left.\begin{aligned} &\rho\frac{\partial u_{co}}{\partial t}+\frac{\partial P_{co}}{\partial x}+\rho\frac{\lambda}{2d_{co}}|u_{co}|.u_{co}=0 \\ &\rho\frac{\partial u_{co}}{\partial x}+\frac{1}{c^2}\frac{\partial P_{co}}{\partial t}=0 \end{aligned}\right\} \tag{2.1}$$

Where for laminar regime, the hydraulic resistance coefficient, of a length unit (L) of the conduct, is:

$$\lambda_{Lam}=\frac{64}{\mathrm{Re}}=\frac{64.\nu}{|u_{co}|.d_{co}} \tag{2.2}$$

(Re): the number of Reynolds.

And for the turbulent regime:

$$\lambda_{tur} = \frac{1}{\left(1{,}14 + 2.Ln\,\frac{d_{co}}{\delta}\right)^2} \tag{2.3}$$

(δ) - The middle height of irregularities of the surface interns the conduct, [m].

(u_{co}) - The speed of the fuel in the conduct, [m.s^{-1}].

(P_{co}) - The pressure of the fuel in the conduct, [MPa].

(d_{co}) - The diameter of the section of passage of the conduct, [m].

(ν) - The coefficient of the viscosity kinematics, [m².s^{-1}].

(c) - The speed of the sound in the fuel, [m.s^{-1}].

The derivative of the first equation according to (x) and of the second, according to (t) in the system (2.1), after certain transformations, permits to get the following differential equation of the second order:

$$\frac{\partial^2 P_{co}}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 P_{co}}{\partial t^2} - \frac{\lambda}{c^2.d_{co}}\left|u_{co}\right|\frac{\partial P_{co}}{\partial t} = 0 \tag{2.4}$$

The finished differences method is a method adapted for the resolution of this kind of equations, as well as for the programming on computer.

- **The Pump of Injection and the Valve**

The limited conditions, at the entrance of the conduct at a high pressure, are dictated by the construction of the pump itself, and of the regime function.

The limited conditions are the equation of the continuity in the surrounding wall of the pump, the equation of the movement of the repression valve, as well as the equation of the continuity in the surrounding wall of the splice and the valve of repression.

The equation of the continuity in the surrounding wall of the pump, reflect the balance between:

- The quantity of the fuel driven back by the piston of the pump, propertied a surface (A_P) and that displaces itself under the effect of the cam, with a speed $\left(\frac{dh}{dt}\right)$;
- The quantity of fuel that passes in the surrounding wall of the pump, through a variable (A_0) section of openings, under the effect of the pressure difference $(P_P - P_B)$;
- The quantity of the fuel that full the free surrounding wall because of the rise of the section (A_{cl}) valve at a speed $\left(\frac{dy}{dt}\right)$;

- The quantity of fuel that passes through the section (A_{ra}) between the valve and the seat of this one, in the surrounding wall of the splice, under the effect of the pressure gap $(P_P - P_{ra})$;

- The quantity of fuel, to fill the surrounding wall of the pump (V_P) because of the compressibility of the fuel. So:

$$\varepsilon_P.V_P \frac{dP_P}{dt} = A_P.\frac{dh}{dt} - \mu_0.A_0\sqrt{\frac{2}{\rho}}\frac{P_P - P_B}{\sqrt{|P_P - P_B|}} - A_{cl}\frac{dy}{dt} - \mu_{ra}A_{ra}\sqrt{\frac{2}{\rho}}\frac{P_P - P_{ra}}{\sqrt{|P_P - P_{ra}|}} \tag{2.5}$$

From the splice, a part of the fuel arrived; pass in the section of entrance of the conduct (A_{co}) with a speed (U_0), where another part is consumed to fill the volume of the surrounding wall of the splice, free because of the compressibility of the fuel:

$$\varepsilon_{ra}V_{ra}\frac{dP_{ra}}{dt} = \mu_{ra}A_{ra}\sqrt{\frac{2}{\rho}}\frac{P_P - P_{ra}}{\sqrt{|P_P - P_{ra}|}} + A_{cl}\frac{dy}{dt} - U_0A_{co} \tag{2.6}$$

In these equations (ε_P) and (ε_{ra}) represent the middle coefficients of compressibility of the fuel, in surrounding walls of the pump and the splice, and that depend values (P_P) and (P_{ra}).

From equations (2.5) and (2.6), one gets values current of the pressure in the surrounding wall of the pump (P_P) and in the surrounding wall of the valve (P_{ra}).

- **The Valve of Repression**

The valve of repression does a movement under the effect of strengths, of quoted it of the fuel and of quoted it of the spring:

$$m_1\frac{d^2y}{dt^2} = A_{cl}(P_P - P_{ra}) - k(y_0 - y) \tag{2.7}$$

(m_1) - The mass of the valve with the spring, [Kg].

(k) - The stiffness (rigidity) of the spring, [Kg.s-2].

(y_0) - The position to the initial state of the spring, [m].

Surfaces of opening sections in the cylinder of the pump (A_0), as well as sections in the valve (A_{ra}) depend the diver's rise (the piston of the pump) and of the repression valve:

$A_0 = A_0(h)$, $A_{ra} = A_{ra}(y)$

4.2 The Injector

For an injector with holes, conditions to limits, to the exit of the conduct, are composed mainly, of the equation of the continuity in the surrounding wall of the injector (V_{in}) and the equation of the movement of the needle.

The fuel that arrives from the conduct into surrounding wall of the injector with a speed (U_{in}) is consumed:

- To fill the free space at the time of the rise of the needle with a section (A_{aig}) to a speed $\left(\frac{dZ}{dt}\right)$;
- For the injection of a quantity of fuel of the injector, through holes, in the cylinder of the motor, under the effect of the difference pressure $(P_{in} - P_{cy})$;
- To fill the free space, because of the compressibility of the fuel in the volume (V_{in}). So:

$$\varepsilon_{in} V_{in} \frac{dP_{in}}{dt} = A_{co} U_{in} - A_{aig} \frac{dZ}{dt} - \mu_{tr} A_{tr} \sqrt{\frac{2}{\rho}} \frac{P_{in} - P_{cy}}{\sqrt{|P_{in} - P_{cy}|}} \tag{2.8}$$

The equation (2.8) permits to get the pressure (P_{in}) in the surrounding wall of the injector.

The acceleration of the movement of the needle of the injector, results under the effect of the pressure strengths, on the side of the fuel and the strengths of the spring:

$$m_2 \frac{d^2 Z}{dt^2} = (P_{in} - P_0)(A_{aig} - A_k) + P_{aig} . A_k - k_1 Z \tag{2.9}$$

(m_2) - The mass of the needle with the spring, [Kg].

(P_0) - The pressure in the beginning of the rise of the needle, [MPa].

(P_{aig}) - The experienced pressure under the cone of the needle, [MPa].

(A_k) - The section of the cone of the needle, [m²].

(k_1) - The stiffness (rigidity) of the spring, [Kg.s^{-2}].

The value of the section of passage of the atomizer $(\mu_{tr} A_{tr})$ depends on the rise of the needle. In quality of calculation results, it is possible to get the characteristic of the injection:

$\left(\frac{dQ}{d\varphi}\right) = f(\varphi)$, in the form:

$$\frac{dQ}{d\varphi} = \mu_{tr} . A_{tr} . \sqrt{\frac{2}{\rho}} \frac{(P_{in} - P_{cy})}{\sqrt{|P_{in} - P_{cy}|}} . \frac{1}{6.N} \tag{2.10}$$

(N) - The speed of rotation of the pump;

(φ) - The angle of rotation of the pump.

After integration of this equation, one gets the integral characteristic of the injection:

$$Q = Q(\varphi) \tag{2.11}$$

5. RESULTS AND INTERPRETATIONS

To do calculations, it is necessary to have:

- The speed of the rise $\left(\dfrac{dh}{d\varphi}\right)$ of the piston of the pump, according to the angle of rotation of the pump.
- The sections of passage of openings of admission and return, according to the rise (the levee)

$$A_0 = A_0(h) \tag{2.12}$$

- The sections of passage in the valve of repression and in the splice.

On figures 2, one finds the height of the levee of the valve and the height of the levee of the needle, and on the figure 3, the pressure in the surrounding wall of the injector, according to the angle of rotation of the camshaft of the injection pump.

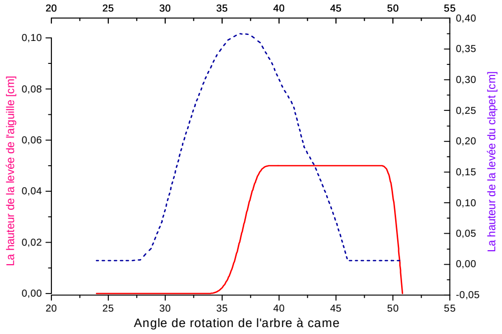

Figure 2: The Height of the Levee of the Valve (Y) and the Height of the Levee of the Needle (Z) in Function of the Rotation Angle

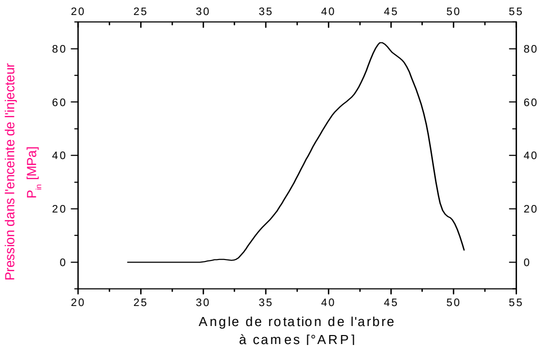

Figure 3: The Pressure inside Injector (P_{in}) in Function of the Rotation Angle

The figures 2, shows indeed, that the valve of repression opens long before the levee of the needle, and closes long before its coming down, all according to the angle of rotation of the camshaft to cams of the pump.

The evolutions of the pressure in the conduct in different positions, the pressure of the splice, according to the angle of rotation of the camshaft to cam of the injection pump, are shown on figures 4 and 5.

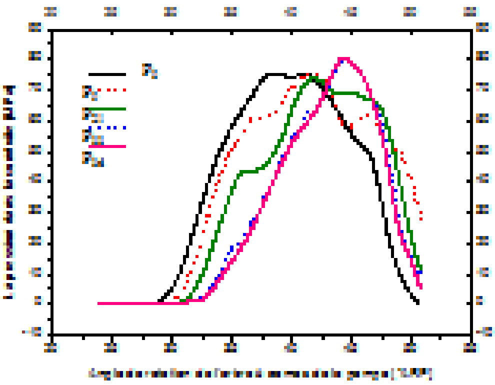

Figure 4: The Evolution of the Pressure in the Injection Pipe, in Different Positions, in Function of the Rotation Angle

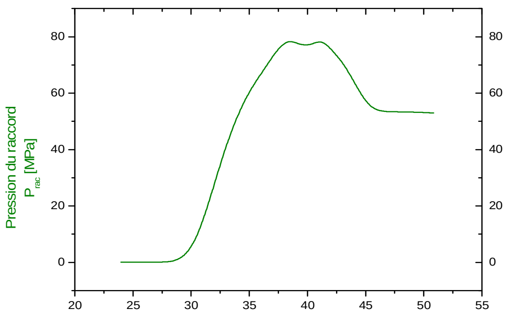

Figure 5: The Pressure in the Valve (P_{ra}) in Function of the Rotation Angle

The curve of the debit of the injected fuel is shown on the figure 6.

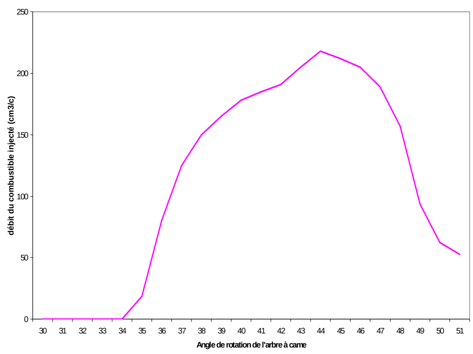

Figure 6: The Injected Debit in Function of the Rotation Angle of the Camshaft

The representative curves of the injection are compliant with their shapes really met in practice, testifying this, that the code of count assures some truthful qualitative results. The following stage will be to verify these results a quantitative manner, by confrontation with the experimental results, and then to deduct the precision that the code can provide.

The influence of the length of the conduct is less considerable. When the volume of the system is big enough, the growth of the length of the conduct can only provoke the displacement of the phases of the injection. The characteristic of the injection herself, don't vary considerably, (figure 7). It moves solely, of somewhat in phase.

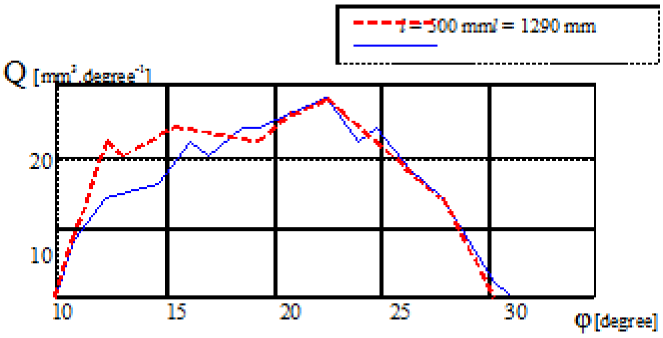

Figure 7: The Effect of the Length of the Conduct on the Characteristic of the Injection

6. CONCLUSIONS

For the choice of parameters injection system, it is necessary to use the mathematical models. Resolution of laws and conservation system of equations permits to develop a calculus code. The code FORTRAN will permit to get all parameters of the injection, such as the pressure in the splice, in the conduct and in the injector, as well as the debit of the injected fuel, the levee of the valve and the needle of the injector, according to the angle of rotation of the camshaft to cams of the pump.

As perspective, the second part will be devoted to the quantitative verification of count results, by comparison with the experimental results, as well as to the survey of the certain factor effects on the parameters of the injection.

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