THE USE of the ELECTROMAGNETIC ACTUATORS in DIESEL FUEL INJECTION SYSTEMS WHICH Are EURO 2 and EURO 3 NORM with COMPLIANCE

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Lately, significant progresses have been produced in the injection field. By using electromagnetic actuators and principle of Pulse Width Modulation we can be optimizing the burning process in the burning chamber of the Diesel engine. The accepted modern solution is to modulate the pressure of injection. The common rail system opens up new possibilities for reducing consumption of fuel and gas emission. This is achieved by the double command of a rapid electromagnetic actuator that an electromagnetic command injector has. The fuel for each cylinder comes from a common reservoir under high pressure up to 1800 bar. The electronic command part gives impulses in a well defined moment to the electromagnetic actuator of the injector in order to initiate the injection. The flow of fuel is determined by the flow section of the injector, by time the electromagnetic actuator is opened and by the pressure in the common rail.

The principle of Pulse Width Modulation can be used in achieving the electronic command, part of the electromagnetic actuators. At the conventional injection systems such as in line injection pumps and the injection pumps with distributor, the injection takes place exclusively as a main injection, without preinjection and post injection. However, the peak pressure is the most important measure for the quality of the forming the mixture air/fuel in the burning chamber. By using electromagnetic actuators at the common rail systems, pressure forming and injection are separate allowed a preinjection and a postinjection. These facts have the following consequences, such as diminishes the emission of gasses, Euro - 3 norm with compliance and propagation of the noise.

For the conventional in line injection pumps, a general characteristic is that the flow regulators which are exclusively mechanical display a large time constants due to

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the inertia induced by the masses in movement. These determines a high response time of the flow regulator. By using electromagnetic actuators at the in line injection pumps with electronic control of the flow is obtaining an optimal time constants, and this equipment are Euro - 2 norms with compliance.

Keywords: electromagnetic actuators, injection, pulse width modulation

1. Introduction

The electromagnetic actuators can be used in Diesel fuel injection systems which are Euro – 2 and Euro – 3 norms with compliance. The balance realized in every moment between the actuator electromagnetic force, and the elastic force of the opposing spring, determines the movement. However, the electromagnetic force and the elastic force actuates in the same direction, but have opposite. The activation of these electromagnetic actuators is done using a specific power source. These, built within the INCDIE ICPE – CA , provide an adequate activation voltage. So, the actuator mobile equipment to make a linear and proportional movement.

2. Electromagnetic actuator for Diesel injection equipment Euro - 2

The PWM principle it is used for the construction of the electronic control system of the electromagnetic actuators. The modern Diesel injection system with electronic control uses electromagnetic actuators which have the role of performing elements of the automatic loop control. The control signal is PWM. This is a rectangular waveform with a constant frequency and a pulse variable duration. The RMS value of the current that goes trough the actuator, for a fixed frequency of the PWM voltage, depends mainly on the pulse duty factor [1], [2]. In this way, the excursion of the mobile device of the electromagnetic actuator depends on the ratio between impulse duration and PWM signal period [4]. So, a short duration impulse determines a low current through the actuator, respective a short excursion of the mobile device, while a long duration impulse determines a higher current as well as a movement in direct ratio to its value. The main characteristics are: the rectangular waveform, the constant frequency of the output voltage (f = 24 kHz), the possibility of variation of the pulse duty factor between 10% - 90% and maximal amplitude of $U_{max} = 24\ V_{cc}$.

In Fig. 1.,Fig. 2., Fig. 3. and Fig. 4., there is presented the output PWM rectangular pulse form, for a pulse duty factor of 30%, 36%, 40%, and 66%. The PWM generator discharges on the electromagnetic actuator impedance. In parallel with this there is mounted a probe of the FLUKE 190 oscilloscope. The used oscilloscope has digital capabilities, being connected through an optical isolated serial port RS 232 with the computer. The computer runs the Fluke View for

Fluke Scope Meter, software which allows the user to transfer the resulted waveforms to a computer. Also, the archiving of waveform, the analyzing and the performing of different calculations, like RMS value in the studied case are possible. Therefore, the following experimental results are synthesized in Table 1.

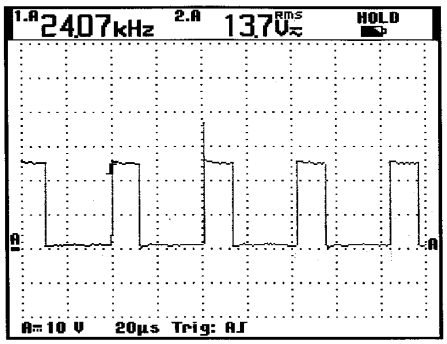

Fig. 1., Wave form for a pulse duty factor of K_u=30%.

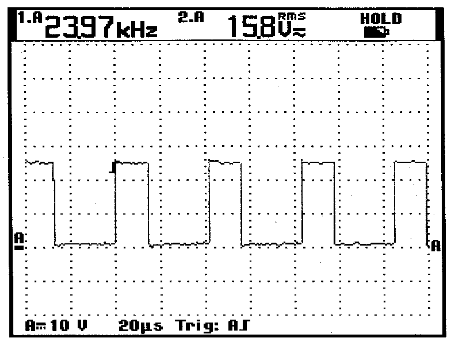

Fig. 2. Wave form for a pulse duty factor of K_u=36%.

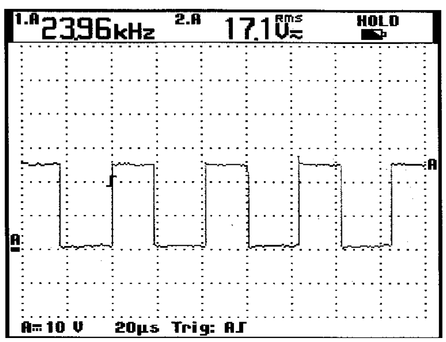

Fig. 3. Wave form for a pulse duty factor of K_u=40%.

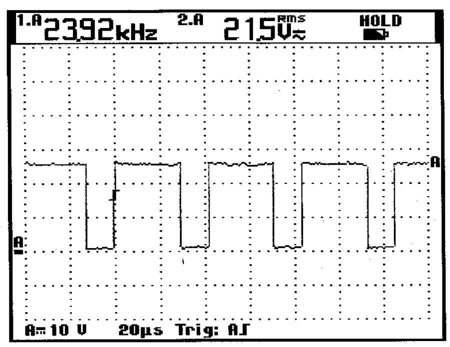

Fig. 4. Wave form for a pulse duty factor of K_u=66%.

Table 1

The PWM generator output RMS value [V] for different values of the pulse duty factor.

Frequency [kHz]	Pulse duty factor [%]	Average value RMS [V]
24 kHz, relative to a pulse maximal amplitude U_{max} = 24 V	30	13.7
	36	15.8
	40	17.1
	66	21.5

The values of the pulse duty factor K_u [%] are automatic calculated and displayed for every waveform. From all presented so far, it is visible that the cog rack controlled linear movement is possible trough the PWM rectangular impulse duty factor variation. This has the immediate consequence the possibility of the realization the injection pomp control by using an electromagnetic actuator. The INCDIE ICPE – CA research collective, we realized a debit electromagnetic actuator, having as a final purpose the injection pomp electronic regulator technical equipment. In Fig. 5., the actuator is presented in the maximum debit position, and in Fig. 6., the actuator is presented in the minimum debit position.

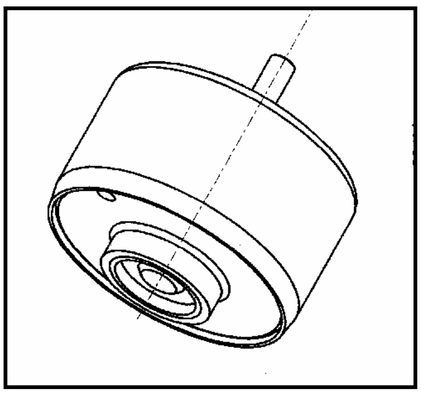

Fig. 5., The actuator in the maximum debit position.

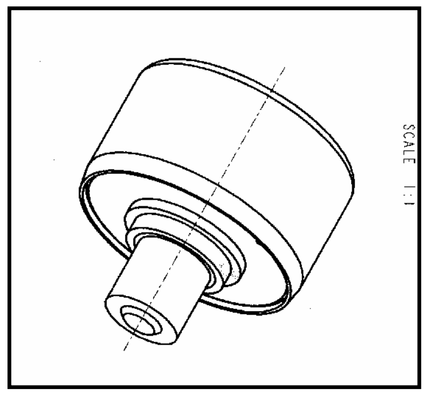

Fig. 6., The actuator in the minimum debit position.

Experimental verification and validation of the electromagnetic actuator linearity as well as the PWM electronic power modulator, [4], represents a maximal importance objective. Practically, it was done in the following way: first the power electronic module having as the operating principle of the pulse width modulation (PWM) was designed and constructed. The pulse duty factor of the output voltage which commands the electromagnetic actuator, k [%], is adjustable depending on the input voltage, U_c. Then it was designed and constructed the electromagnetic actuator which has a linear characteristic of the mobile device movement depending on the same input voltage, U_c. In the Table 2, there are presented the experimental values. In Fig. 7., there is presented the diagram of the pulse duty factor depending on the input cue voltage U_c, and in Fig. 8., the diagram of the cog rack, [1], [2], depending on the same voltage U_c. It is observed a linear dependence on both characteristics throughout the whole domain. The movement of the cog rack must be between 0 mm, relative to a minimal debit, and 14 mm, relative to a maximal debit. The range of the cue voltage results from the Table 2., and it is between 0.75 V and 3.4 V.

Table 2

Experimental values

Uc[V]	*k*[%]	*d*[mm]
0.75	86	0
1	80	0
1.2	74	0.2
1.3	70	1.2
1.4	68	2.1
1.5	67	2.9
1.6	65	3.8
1.7	63	4.7
1.8	60	5.25
1.9	57	5.8
2	54.3	6.75
2.1	53	7.4
2.2	51.5	8.1
2.3	48.5	8.7
2.4	46	9.5
2.5	43	10.3
2.6	40	11
2.7	38.5	11.5
2.8	37	12.05
2.9	35.7	12.45
3	32.86	12.9
3.1	30	13.2
3.2	28.5	13.4
3.3	25.7	13.6
3.4	22.8	14
3.5	20	14.5
3.6	17	14.7
3.7	12.85	15.1
3.75	8.6	15.5

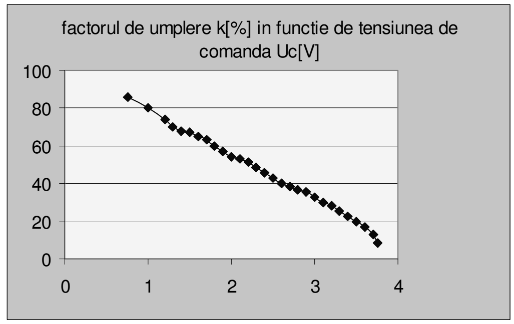

Fig. 7. Diagram of the duty factor *k*[%], depending on the input voltage U_c.

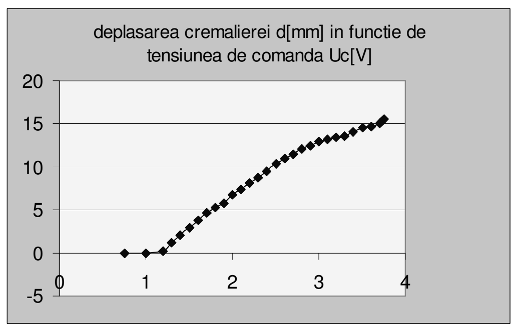

Fig. 8. Diagram of the cog rack movement *d*[mm], depending on the input voltage U_c.

The electromagnetic force developed by the actuator and implicitly the movement of the cog rack, depends mainly on the coil excitation voltage pulse duty factor

$k[\%]$. The frequency of the PWM rectangular impulses is constant, $f = 24$ kHz. Also, the maximum amplitude of the excitation voltage is constant, $U_{max} = 24$ V.

3. Electromagnetic actuator for Diesel injection equipment Euro-3

The Diesel Common-Rail injection equipment uses injectors electronic controlled by electromagnetic actuators. In Fig. 9. and Fig. 10. is presented one of the practical realizations for the electromagnetic actuator that equips this type of injector, as a subassembly and then in expanded form, [1].

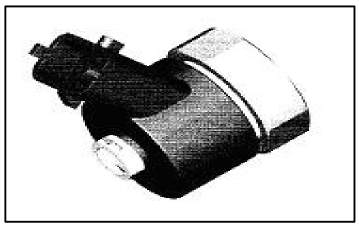

Fig. 9. The electromagnetic actuator used for the Euro-3 electronic controlled injector.

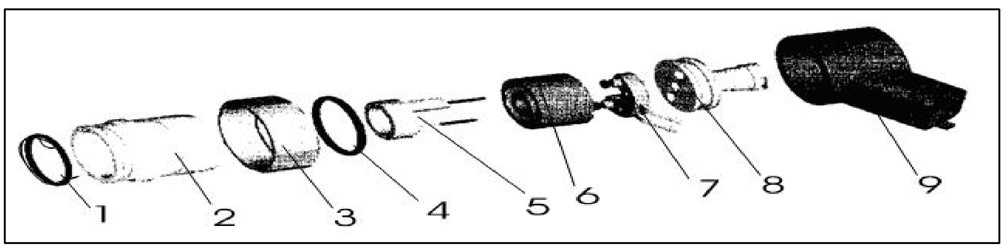

Fig. 10. The electromagnetic actuator used for the Euro-3 electronic controlled injector, in expanded form.

The component elements of the actuator can be identified in the expanded form:

1. The gasket 1, type Oring;
2. The montage magnet limb 1 of the subassembly;
3. The fixation ring;
4. The gasket 2, type Oring;
5. The coil - actuator assembly;
6. The sintered magnetic block;
7. The electric connections plate;
8. The magnetic limb 2;
9. The actuator case.

The electromagnetic actuator coil, position 5, Fig. 10., has 30 turns made of Cu - enamel with a diameter of 0.4 mm and a cc resistance of R_{act} = 2.5 Ω. The fixed part of the actuator magnetic circuit is compounded of a sintered magnetic block, position 6, a magnetic limb 1 of the assembly, position 2, and a magnetic limb 2, position 8 Fig. 10. The electrical connections of the actuator are fixed on an isolated plate, position 7, Fig. 10., being conducted towards the exterior of the case. The magnetic block is made of a special material, with very low hysteretic losses. The magnetic limbs 2 that are part of the actuator have a very high content of Cr, 17.79%, Ni, 8.09% and Si, 0,44%, as it results from the laboratory analysis report that is presented hereunder, Fig. 11.

FE-01		Orientation Fe-alloys				8534/97		07/12/01 13:15	
	C	Si	Mn	P	S	Cr	Mo	Ni	Al
1	0.04	0.44	1.66	0.048	>0.300	17.79	0.25	8.09	0.0057
	Co	Cu	Nb	Ti	V	W	Pb	Sn	Mg
1	0.11	0.62	0.01	0.0040	0.08	0.05	0.004	0.195	0.0047
	As	Zr	B	Zn	N	Fe			
1	≈0.119	0.0064	≈0.0102	0.0453	0.0714	70.04			

Fig. 11. Laboratory analysis report for the magnetic limbs.

The control of the actuator coil, component of the Euro-3 injector, is made with an electric impulse train with adjustable frequency and period. The tests have been made at an adjustable control pulse frequency, f = (1 ÷ 10) Hz. The period of the control pulse is also adjustable between Δt = (0.2 ÷ 5) ms, the tests being done at Δt = (0.4 ÷ 3) ms. This actually represents the time while the injector remains open, introducing in the Diesel motor cylinder a precise dozed fuel quantity (a few mm^3), after a variation in time. The resulted diagrams, Fig. 12., and Fig. 13., for the testing of the electronic controlled injector Euro-3.

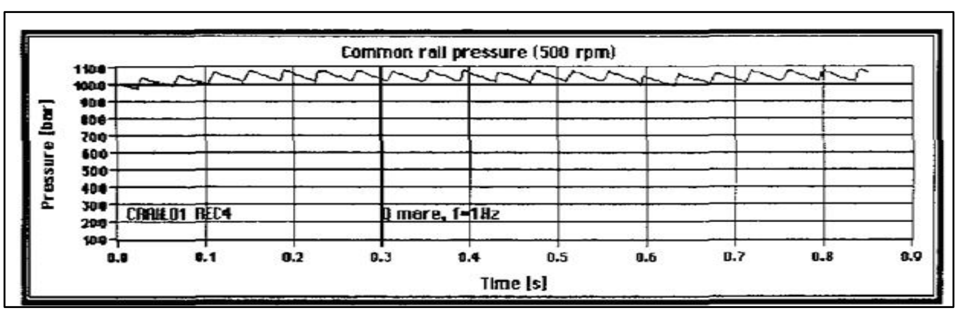

Fig. 12. Common rail pressure, for the rotation of the high pressure pomp axle of n = 500 rpm, control frequency f = 1 Hz and pulse period Δt = 3 ms.

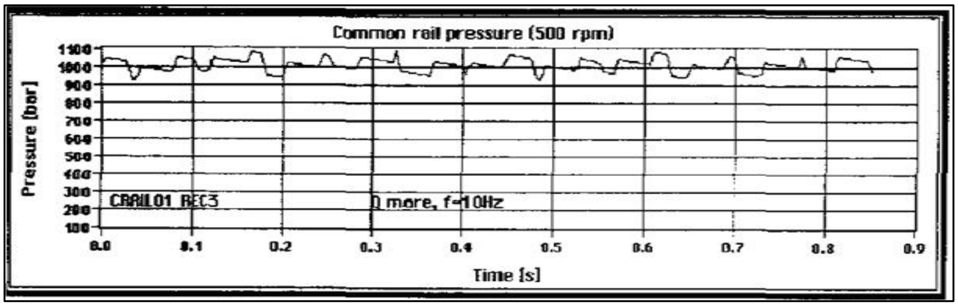

Fig.13. Common rail pressure, for the rotation of the high pressure pomp axle of n = 500 rpm, control frequency f = 10 Hz and pulse period Δt = 3 ms.

4. Conclusions

The optimization criteria which lead to choosing the model for Euro – 2 electromagnetic actuator, [3], [4] are: minimization of the value of the current, in DEC functioning (electromagnetic device for fuel enrichment at start up), in which case the actuator coil is excited with a continuous voltage U_{max} = 24V_{cc}, maximization of the value of the current, in PWM functioning, having the pulse duty factor k_u = 90%. Also, minimization of the temperature value in permanent operating conditions, measured after 2h of functioning in the permanent operating conditions. These criteria are very antagonistic.

Comparing Fig. 12. and Fig. 13., it is observed a larger deviation of the pressure values in case of the control frequency rising to f = 10 Hz. From the resulted diagrams, it is observed that the two in line pumping sections P, [2], can produce a pressure up to 1100 bar. This working pressure was considered relevant for the testing of the electronic controlled injector Bosch Euro-3. By using a pump in line P with three pumping sections a pressure up to 1600 bar can be reached, large enough for the trucks motors applications, up to 600 hp.

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