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OPTIMIZATION OF INJECTION LAW AT MODERN DIESEL FUEL SUPPLY SYSTEMS

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1. Introduction

Knowing the main advantages of diesel engine that could be recognized through reliability, economy and durability, it is perfectly obvious why a great attention is dedicated to their development for passenger cars, as well as for commercial vehicles. According to this fact, the development of modern diesel engines is based on the following tasks:

- reduction of pollutants emissions in exhaust gases towards world regulations;
- reduction of fuel consumption;
- reduction of external noise;
- improvement of dynamic characteristics of vehicles.

In solving these tasks, it is necessary to obtain a qualitative combustion process in the working chamber of the diesel engine. The most important element for obtaining the qualitative combustion process is atomization process of air/fuel mixture. This atomization exclusively depends from fuel supply system. Thus, the main tasks at modern diesel fuel supply systems are:

- a direct fuel injection into the working chamber of the diesel engine;
- a fuel injection under high pressure;
- a fully flexibility of the fuel supply system according to start and duration of injection as well as injection law for all speed and load regimes;
- an electronic management of complete fuel injection process.

According to the defined tasks, modern fuel supply systems for diesel engines are based on use of direct injection of fuel under high pressure. An important attention has been dedicating to design of injection law, especially at the beginning of injection process. The “designing” of injection law can produce a lower noise, loads and NO_X emission.

2. Optimal injection law

According to [SAE, 2000], [Hwang, Kal, Park, Shenghua, Martychenko, Chae, 1999] and [Kohketsu, Tanable, Mori, 2000], it is recommended a limited injection of small portion of fuel at the beginning of injection process in order to prepare air/fuel mixture convenient for pre-combustion. Furthermore, injection of main fuel portion in this prepared air/fuel mixture is following, that make possible a completely controlled combustion process. An optimal injection law is shown in the figure 1.
Injection of small portion of fuel at the beginning of injection process, so-called “pilot-injection”, achieves better conditions for combustion process during main injection of fuel in working chamber. A smaller pressure gradient and a lower noise are obtained too. On this way, a direct control of combustion process is achieved, that makes possible the reduction of pollutants emissions in exhaust gases, as well as the lower thermal and mechanical loads.

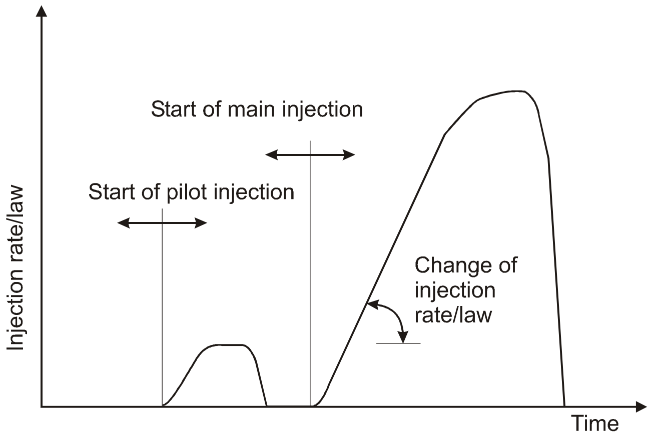


Figure 1. Optimal injection law

3. Possibilities for achievement of optimal injection law

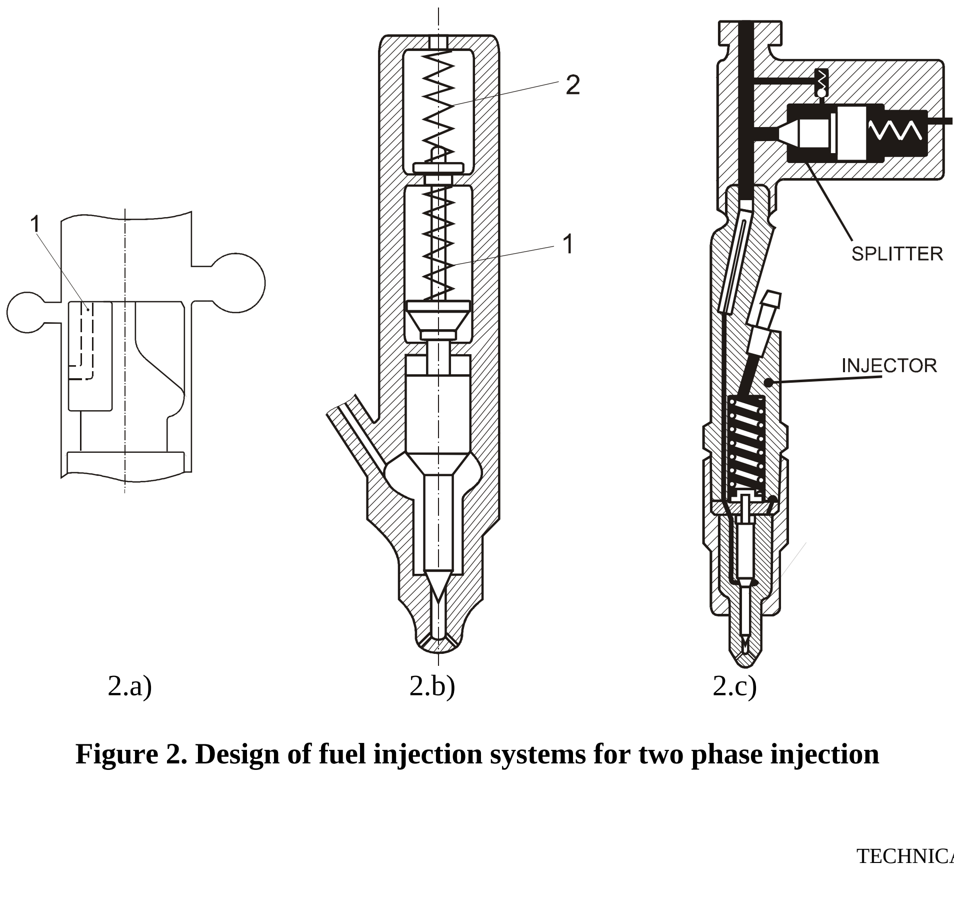
The optimal injection law could be achieved in different ways what directly depends from control of injection process. The known controls of injection process at fuel injection systems are:

- conventional fuel injection systems without electronic control;
- modern fuel injection systems with electronic control.

3.1 Conventional fuel injection systems without electronic control

Conventional fuel injection systems without electronic control of injection process are presented in road transport very often. This is the basic reason why significant attention is dedicated to these systems, especially to introduce of two phase injection. In that way with relatively small costs, it is possible to reduce pollutants emissions, noise emission and loads of piston, connecting rod and crankshaft assembly.

With more or less success, few different conventional fuel injection systems with possibility of two phase injection were made. Some of them are presented in the figure 2.



2.a) 2.b) 2.c)

Figure 2. Design of fuel injection systems for two phase injection

The fuel injection systems with possibility of two phase injection, presented in the figure 2, are based on:

- introduction of additional overflow duct (pos. 1) in the piston and cylinder liner of the high pressure pump, [Liševski, 1981], (fig. 2a);
- introduction of two spring injector (pos. 1 and 2), [Yamauchi, Sakurai, Takamori, 1989], (fig. 2b);
- introduction of injector with splitter, [Monaghan, 1984], (fig. 2c).

A basic disadvantage all of enumerated solutions for two phase injection is the impossibility of optimal injection law during all speed and load regimes. Some of them have unwanted oscillations of characteristic parameters.
The best solution for two phase injection is the introduction of injector with splitter, presented in the figure 2.c). Working principle is based in the following: At the beginning of pressure increasing in the injector, caused by action of high pressure pump, injector needle starts rising from the seat and makes possible a start of injection. However, when pressure in the injector raise enough to overcome the spring force in the splitter, then a valve in the splitter starts moving causing a fuel starts flow through overflow duct. This fuel flow through overflow duct cause decreasing of fuel pressure and needle starts bringing down on the seat. In that way, the phase of pilot-injection is ended. Further pressure increasing, caused by high pressure pump, leads to start of main injection which duration is determinated by the fuel pressure in the injector.
Using own developed computer program, a simulation of processes in the injector was conducted. Certainly, the most interesting is the injector law for different engine speeds and some of them are shown in the figure 3. Based on the results presented in the figure 3, a different two phase injection could be noticed. Also, during each pilot-injection amount of injected fuel is approximately 10 % of total amount of injected fuel per cycle. Amount of injected fuel during pilot-injection is marked by q_c^*.

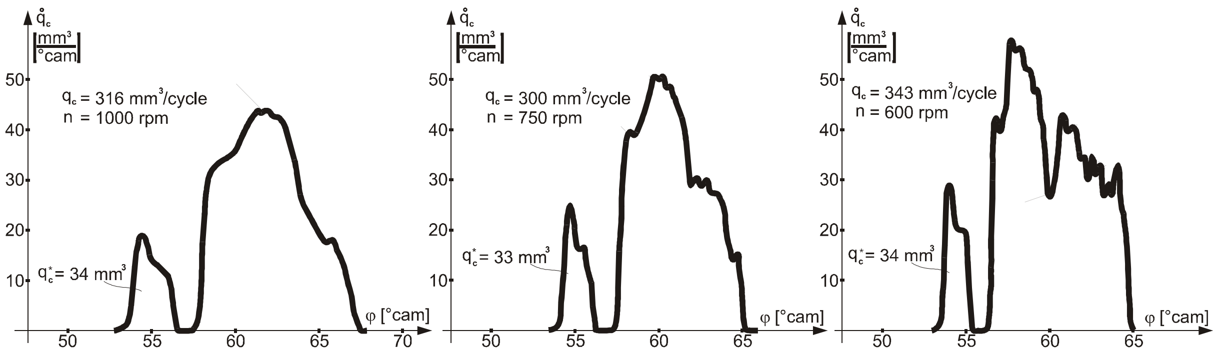


Figure 3. Injection law for different speed regimes

The pilot-injection was realized by use of presented simple way of injection process control. Amount of injected fuel during phase of pilot-injection depends of the characteristics of high pressure pump and design of splitter, as well as the working regime of fuel injection system.

3.2 Modern systems with electronic control

Modern fuel injection systems for diesel engines are mostly based on different solution of unit injector systems and accumulator systems with Common rail. All mentioned systems have an electronic control of injection process. Control of injector process means still presence some kind of "splitter", which activating is determined by engine speed and load regimes. In that way, fully flexibility of designing of injector law is possible, independently from engine speed and load regime, that is shown in the figure 4.

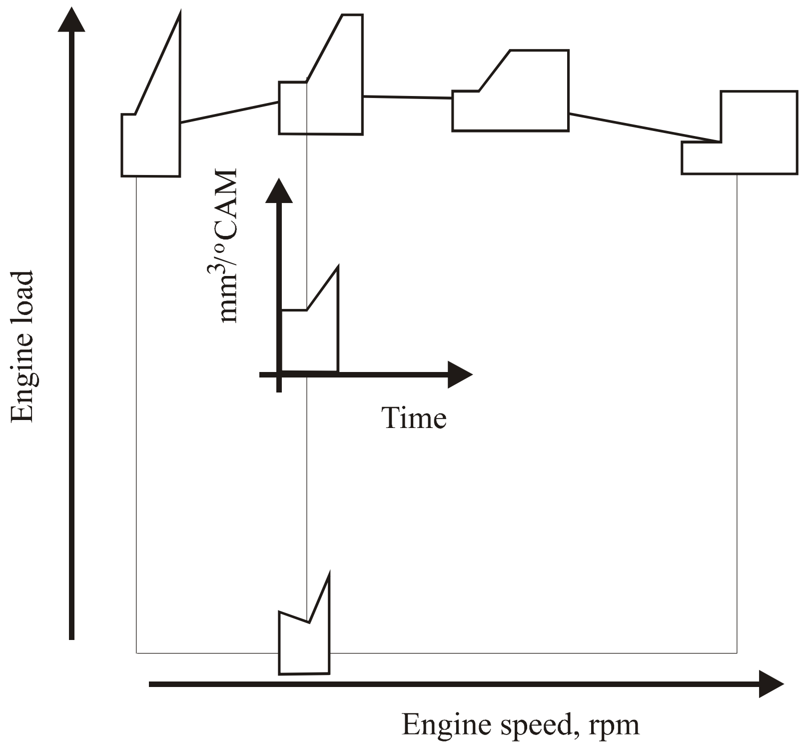
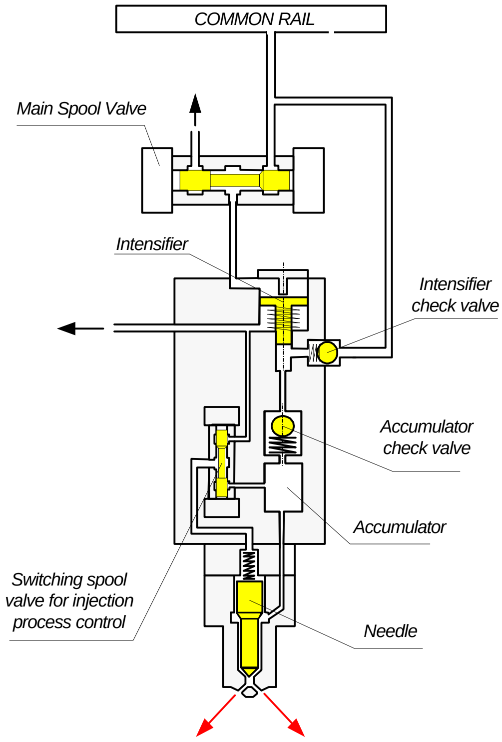


Figure 4. Optimal injection law of modern diesel fuel injection systems for different load and speed regimes

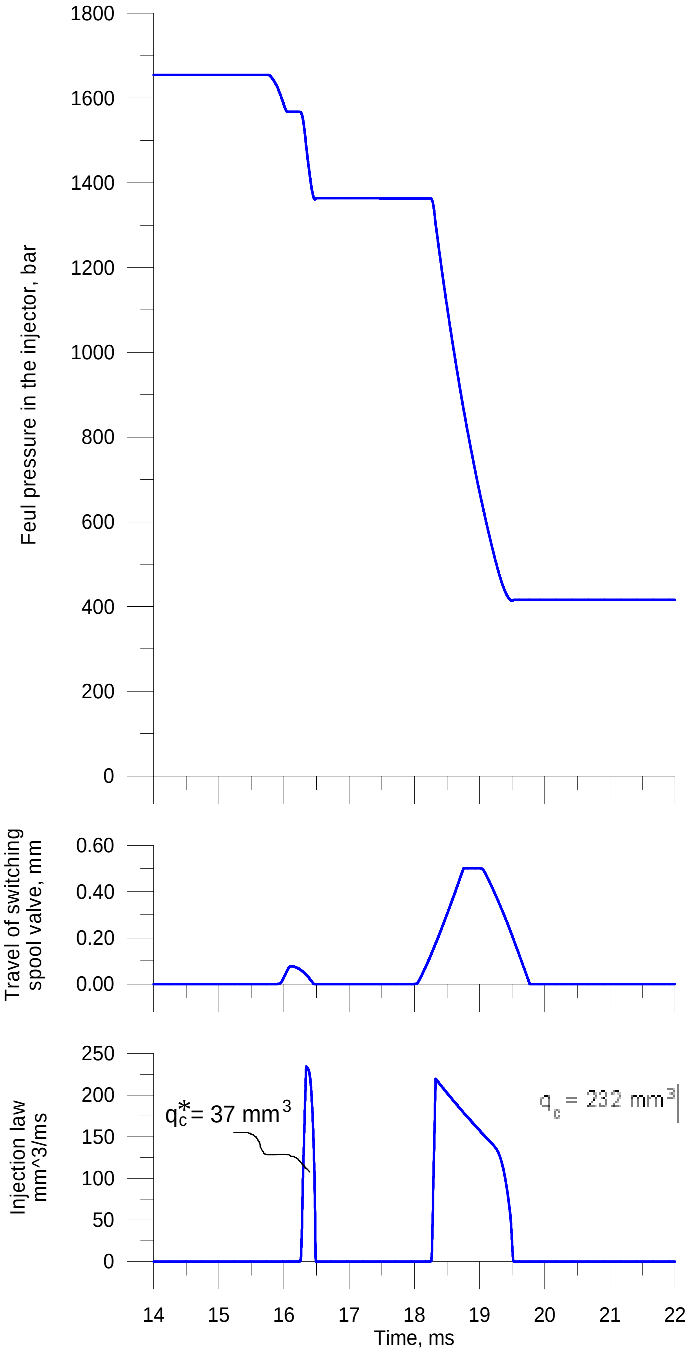
In order to understand problem area of two phase injection at modern fuel injection systems, a fuel injection system presented in the figure 5.a) is chosen. A working principle of this injection system is based in the following: Fuel form the Common rail (accumulator of fuel under low pressure up to 200 bar) is leading to the main spool valve, as well as to the intensifier check valve. In that way, it is possible to make a supplement of working space placed bellow the intensifier with the fuel. When main spool valve is activated, depending of engine speed and load regime, the fuel is pressing the upper side of the intensifier causing intensifier movement and fuel compression. Fuel compression is conducting all the time of main spool valve activating, while maximal possible compression ratio could be 16:1. Compressed fuel flows through the high pressure pipe and it moves a ball of accumulator check valve causing supplying of accumulator of fuel under high pressure placed in the injector. Supply process of accumulator of fuel under high pressure has a same duration as duration of main spool valve activating. During supply process of accumulator under high pressure, injector needle stays at her seat. Process of fuel injection into the working chamber of diesel engines is controlled by activating of switching spool valve placed in the injector. In that way, direct control in designing of injection law could be achieves what is very important for modern diesel engines.

An example of characteristic parameters of injection process is shown in the same figure (figure 5.b). Special attention is dedicated to two phase injection where during pilot-injection is injected about 16 % of fuel, by volume. These results are obtained by simulation of injection process using own developed computer program.

Keeping in mind the results shown in the figure 3 that are characterised for conventional fuel injection systems, designed as unit-injector and unit-pump, injection at the beginning of injection process at accumulator systems is always performing under high fuel pressure. According to this fact, optimisation of amount of injected fuel during pilot-injection requests a very short duration of pilot-injection phase and a very small travel of switching spool valve placed in the injector.



5.a)



5.b)

Figure 5. Modern fuel injection system and corresponding injection law

4. Conclusion

Beside direct injection of fuel under high pressure into the working chamber of diesel engines, special attentions is dedicated a designing of the injection law. Possibilities for designing of the injection law at conventional and modern fuel injection systems are presented in the paper. Keeping in mind the fully flexibility of injection process control, it is perfectly understand why modern fuel injection systems have important share in the world market.

Taking in consideration the fact that accumulator systems have a great share in this market, additional attention should be dedicated to the control of injection process and right selection of elements important for qualitative control. In selection of appropriate parameters of control elements for two-phase injection, important place is reserved for mathematical modelling of processes in injection systems.

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