# THE EFFECT OF LENGTH OF HIGH PRESSURE PIPES ON INJECTION PROCESS IN COMMON RAIL SYSTEM OF DIESEL ENGINE

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*Abstract*

*The storage supply systems of Common Rail type are characterized by high possibilities in shaping the rate of injection. The possibility to implement multi-injection at high pressure, easiness of adapting the system to the engine, relatively easiness of compensation the arrangement of injector parameters resulting from work tolerance, as well as easiness of making changes in the electronic engine controller enabling the production of engines with various performances, cause that type of these solutions currently are widely used injection systems in diesel engines. Injection system should be characterized above all by high precision fuel dosing into engine cylinders, the accuracy in starts controlling of individual phase of injection, repeatability and reliability and durability, as well as the upkeep of these parameters for long time during operating duration. Fuel injection system works in difficult conditions resulting from high pressure, vibrations, electromagnetic interference affecting electronic executive systems and high temperatures. Especially the injector and injection pipes are open to high temperatures. The dimensions of used elements are also important. The article presents selected results concerning the effect of the length of high-pressure pipes on injection process parameters such as fuel amount, overflow in injector, and the fuel pressure course in injection pipe in front of electromagnetic injector socket. The study was conducted with test stand with electronic measurement system of fuel amount. The tests were made at different pressures in the rail and for different durations of the injector opening.*

*Keywords: common rail, fuel injection, injection control, high-pressure pipe*

## 1. Introduction

The storage injection systems are becoming the most frequently used type of supply system of diesel engines. The main advantage of this type of injection system is the high flexibility of shaping the rate of injection enabling the multi-injection used to improve the ecological parameters of the engine [2, 4, 8]. The possibility of compensation of performances of the injector with electronic way allows for relatively easy exchange of damaged injector as well as adjusting the control parameters to the regeneration injectors [1].

The injection system should be good at high accuracy of fuel dosing, which depends on total fuel amount, the fraction of individual phases (pilot injection, pre-injection, the main injection, and the rest of the injection), the angles at which these phases begin and the parameters of the macro- and microstructures of fuel spray. These quantities mainly depend on basic parameters of the injection system, which are injection duration and pressure in the system, but the effect on these may also have other parameters of the fuel supply system. It should be counted controller parameters and the accuracy of the generated control signal [3, 6, 10, 11], the condition of the solenoid valve and the injector nozzle, the characteristics of sensors ensuring the correct information about the parameters of the adjustment system and the fuel properties (temperature and depending on it density and viscosity) [6, 12]. These parameters may change during the operation duration causing the changes in the fuel dosing. Adaptation of the injection system for engines of different capacities may require the use of another length of high-pressure pipes, which can also cause changes in the process of fuel injection.

This article presents the study concerning the impact of injection pipes length on the basic parameters of fuel injection process using a two-phase injection.

## 2. Test stand and measurement methodology

The aim of experimental studies was to determine the effect of length of high-pressure pipes connecting the rail with electromagnetic injector on process of fuel dosing. In order to determine mentioned effect test stand with test bench Bosch EPS 815 enabling stable drive of high-pressure pump was built. The test stand was equipped with an electronic measurement system of fuel amount type of KMA-822 enabling measurements at steady state of temperature. To make it, heat exchanger being equipment of test bench was used. The fuel was injected into special chamber filled with fuel and the measurements of fuel amount were made at a constant temperature. The temperature was described at fuel outlet from chamber to measurement system. The scheme of test stand is included in following papers [3, 6, 9].

A control of injector was made with the developed controller, which allowed a three-phase fuel injection. The study was conducted at two-phase injection. Diagram of two-phase injection is shown in Fig. 1 and a description of the controller is presented in paper [5].
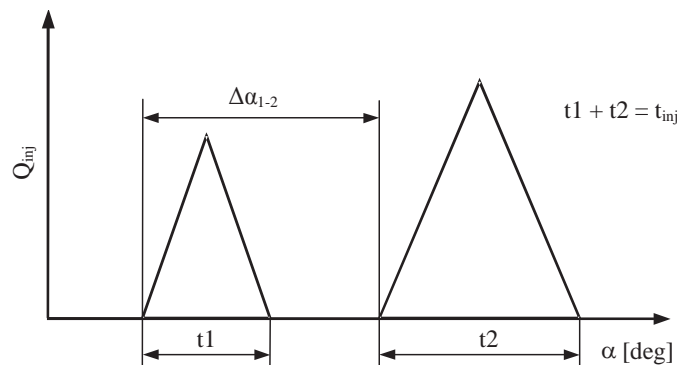


*Fig. 1. Scheme of symbols describing the injection strategy – two-phase injection*

In order to avoid changes in the dosing process resulting from changes in supply voltage [7], the injector control system was powered with the battery cooperating with power pack enabling to keep up an accurate supply voltage amounted to $13 \pm 0.02$ V. The study was conducted for two different injection durations $t_{inj} = 1$ and 3 ms and the pressures in the system of 75, 100 and 125 MPa. The rotational speed of pump was constant and equalled to 1000 rpm.

The signal parameters such as switching duration, the frequency and pulse-width modulation in the feed phase were also determined to reduce their impact on the injection process [10, 11]. In order to keep up high accuracy of injector control signal, for generating the signal about rotational speed, the optical position and rotational speed sensor type of AVL 365C generating 720 pulses per revolution was used. Besides the measurement of fuel amount injected by the injector, there was measured fuel outlet rate from solenoid valve of injector and its temperature. There was recorded high-speed courses i.e. the pressure in the injection pipe behind the rail, in front of injector socket and voltage and current of control signal.

## 3. Analysis of test results

The test results of fuel amount injected by injector into chamber filled with fuel at various work conditions of injection system are presented in Fig. 2. The fuel amount is shown depending on a length of injection pipe connecting the rail with the injector. On the left side of Fig. 2 the fuel amount for the injection duration amounted to $t_{inj} = 1$ ms for consecutive values of rail pressure $p_{rail}$ and on the right side for $t_{inj} = 3$ ms are shown.
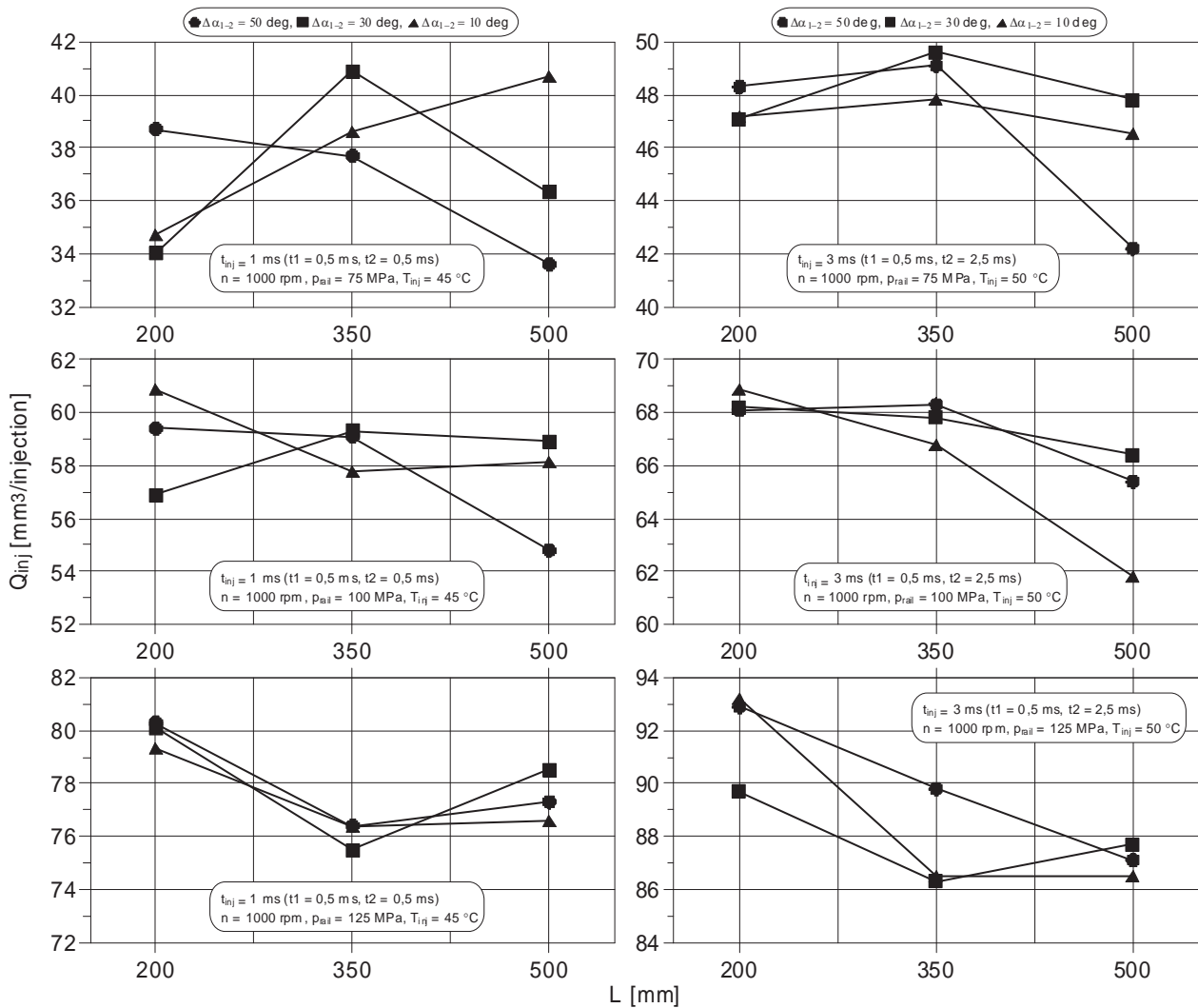
Fig. 2. *The effect of length of injection pipe on fuel amount under different conditions of the injection system and for two-phase injection*

As it is shown, the impact of pipe length is diverse and depends on the angular distance between individual phases of the fuel injection. The biggest changes in fuel amount can be observed for the lowest analyzed pressure in the system amounting to 75 MPa, irrespective of the injection duration. The change of angular distance between pre-injection and main injection causes the biggest change in fuel amount for the longest injection pipe, while the shortest pipe of 200 mm and short injection duration the changes in fuel amount are also considerable. The smallest changes in fuel dosing can be observed for the pipe with length of 350 mm, what is particularly visible for shorter injection duration. For the longest injection duration the smallest changes in fuel amount are for the shortest injection pipe at pressures of 75 and 100 MPa. At higher injection pressure the smallest changes are next for the longest pipe.

The maximum pressure differences in the injection pipe in front of the injector socket are shown in Fig. 3. The general trend of these changes is accordance with the idea of a storage supply system, i.e. the farther from the rail (longer pipe), the fluctuations of pressure measured in front of the injector socket are larger. It is worth noting, that large fluctuations of pressure are observed for a pipe with a length of 350 mm, for which the changes in fuel dosing for most analyzed work points of injection system are the smallest. At the same time, these large changes in pressure are for short angular distances between individual phases of the injection. It can be concluded that fuel amount depends on the pressure fluctuations, the frequency of pressure wave and locations of starts of individual injection phases in relation to mentioned wave.
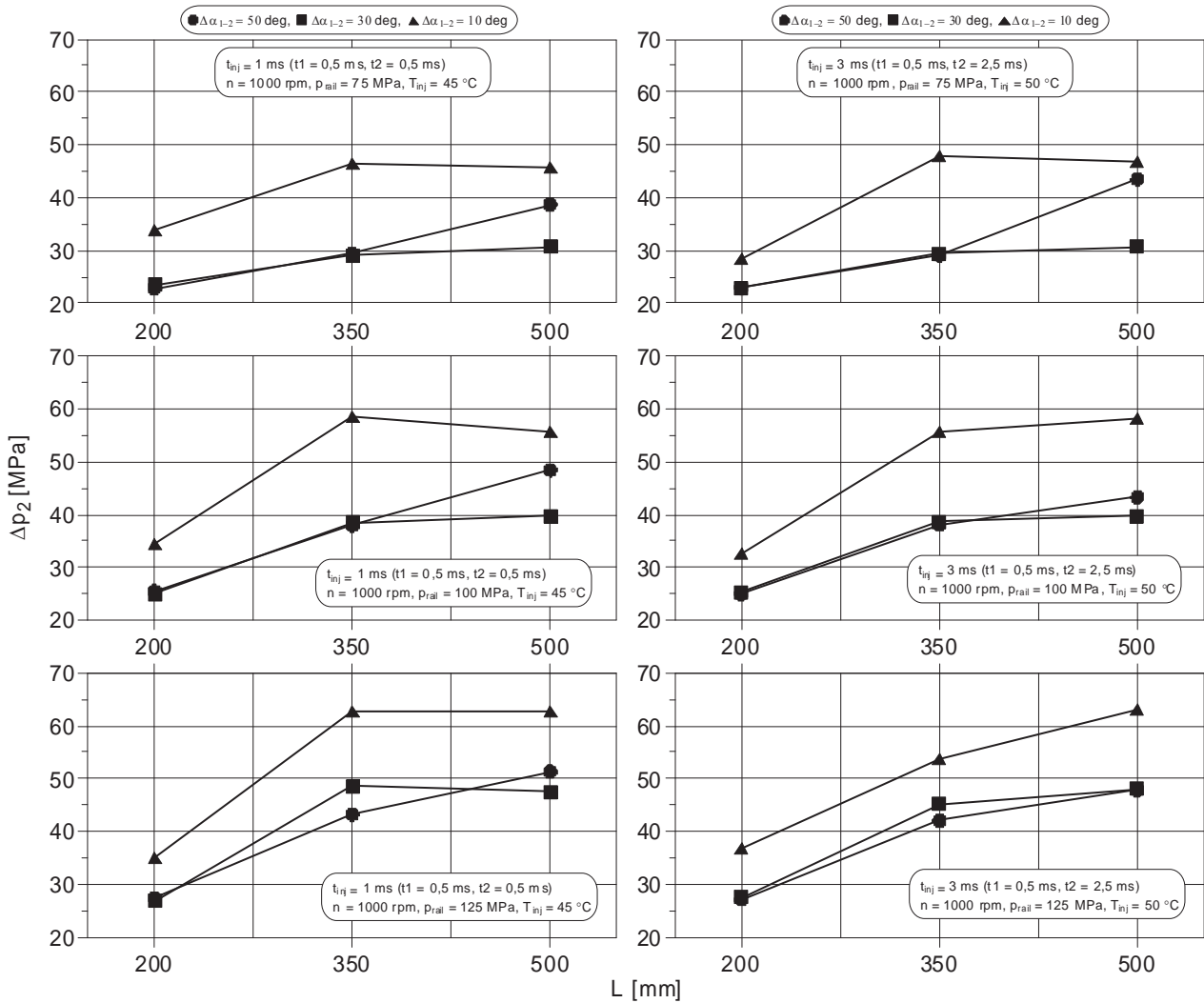
*Fig. 3. The effect of length of injection pipe on fluctuations of pressure measured in injection pipe in front of injector socket*

The demonstration courses of pressure in front of the injector socket for all tested lengths of the injection pipe are shown in Fig. 4. As we can see, at the time of injector controlling during main injection phase, the pressure waves in all three cases, have not only different values, but are shifted in phase. It causes, that at relatively little difference in the observed extremes of pressure, the fuel amount changes significantly (Fig. 2). The opposite situation occurs in Fig. 5, where the main injection begins at the moment when for all three pipes the course of wave is consistent in phase, and the fuel amounts differ from each other only slightly (Fig. 2). It should be noted, that the pressure courses in the chamber of spray nozzle and control chamber may further differ from each other due to an even greater distance from the fuel rail.

## 4. Conclusions

On the basis of conducted tests, we can see, that the length of injection pipe has a significant impact on the fuel dosing, especially for a multi-injection. For single-phase injection this effect is smaller, especially for short injection durations. Changing the length of pipe changes the frequency of pressure wave, which in multi-phase injection causes, that the next injection phase may start at another point of wave, and therefore at a different pressure, which also changes in different way. A scope of changes in pressure in the injection system can range from a maximum of 35 MPa for shortest pipe to over 60 MPa for longer pipe. Such significant fluctuations in pressure cause changes
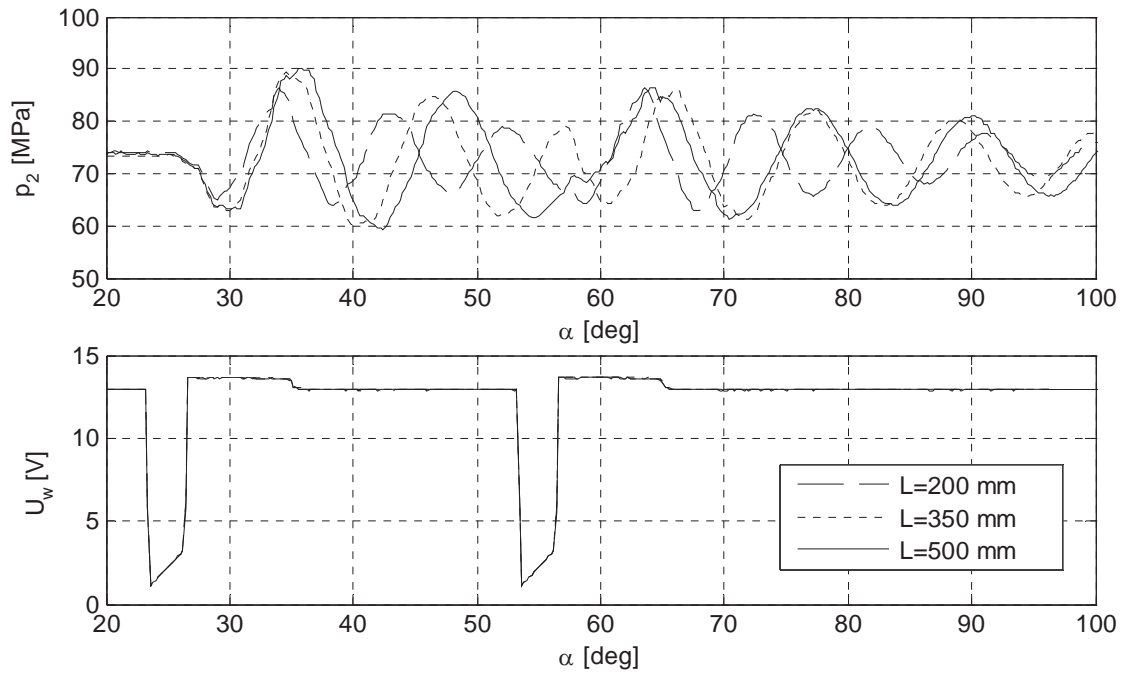
*Fig. 4. The courses of press ure in i njection pipe in front of i njector socket $p_2$ and v oltage of control signal $U_w$ at various lengths of injection pipe (n= 1000 rpm, $t_{inj}$=1 ms, ,$\Delta a_{1-2}$=30 deg, $p_{rail}$=75 MPa)*
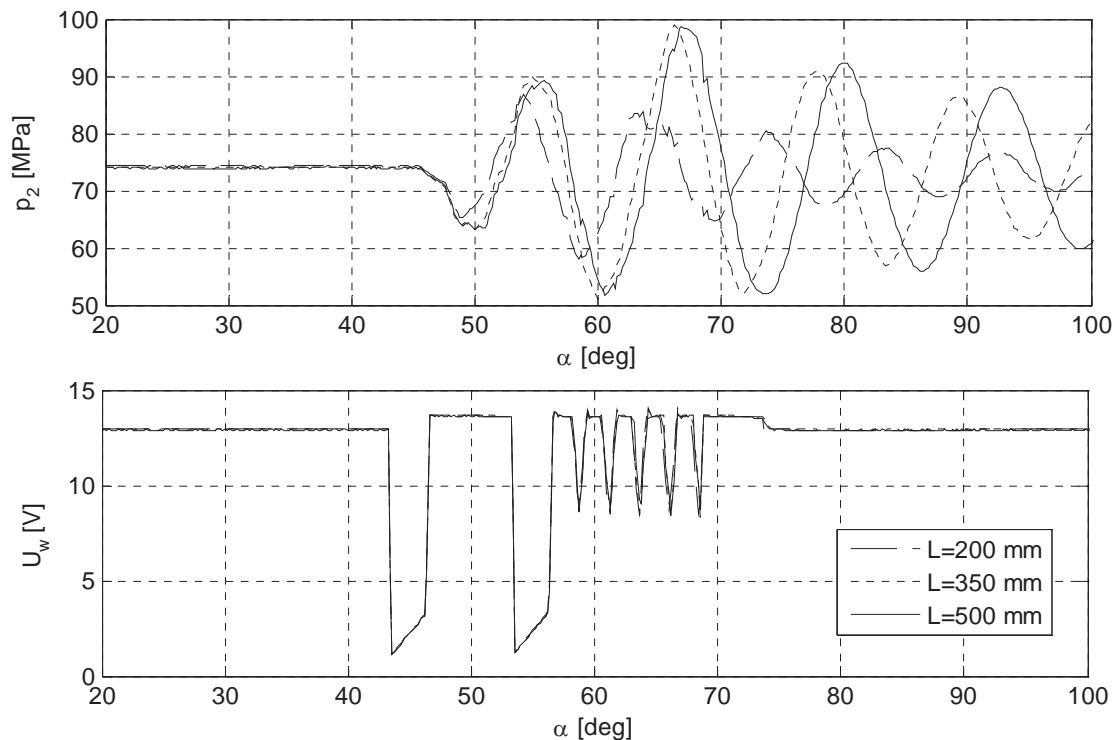


*Fig. 5. The courses of pressure in injection pipe in front of injector socket $p_2$ and voltage of control signal $U_w$ at various lengths of injection pipe (n= 1000 rpm, $t_{inj}$=3 ms, ,$\Delta a_{1-2}$=10 deg, $p_{rail}$=75 MPa)*

in fuel dosing, even by several percent at low values of injection duration. The fluctuations of pressure in the pipe near to the rail are the biggest for the pipe with a length of 200 mm and amount to about 12 MPa at pressure of 125 MPa.

The angular distance between individual phases of the fuel injection have a significant impact on the range of changes in fuel amount and their character. This parameter also determines the point of injection start of next injection phase in relation to point located on pressure wave.

The changes of fuel dosing are the result of changes in the course of wave phenomena in the Common Rail system resulting from the fact that the length of the injection pipe affects the length of pressure wave, its amplitude and maximum values.

The use of short injection pipes causes shortening the pressure wave and reducing its amplitude in front of injector. It is favourable for accuracy of fuel dosing under different conditions of the injection system.

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