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EFFECT OF SUPPLY VOLTAGE ON THE DOSAGE OF FUEL IN INJECTION SYSTEM THE COMMON RAIL TYPE

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Summary

Common Rail systems are most frequently used solution to the fuel supply system of Diesel engines. This is due to due to their high potential to shape the characteristics of fuel injection. One of the important requirements for each injection system is precision dose control and its onset, that is, as a consequence of the start of the combustion process. The most important parameters affecting the accuracy of dosing injection systems are, of course injection time, pressure of fuel in the rail and the fuel temperature. Influence on the size of the dose but also other factors, which include the supply voltage, which may be subject to significant change during the start-up of engine. The issue of start-up is becoming of interest to EURO standards, as the processes occurring in the course have a significant impact on the level of pollutants in the exhaust of internal combustion engine. Increased in this period, emissions of toxic compounds results from the unstable processes in the engine cylinder, as well as dynamic changes in the parameters of injection and in the start-up system, in particular, changes in voltage resulting from a large collection of current from the battery. Thus, the article attempted to determine the impact of voltage supply on the dosage of fuel in different operation conditions of the injection system. In particular attention was paid to the size of the dose and the actual changes at the beginning of fuel injection voltage changes. The study was conducted on a test stand, which were the main components of the test bench Bosch EPS-815 with electronic measurement of fuel dose and the visualization system AVL Visioscope. Control of the injector was performed using the self-developed controller.

Key words: *Common rail, fuel injection, control injection, precision dosing of fuel*

1. Introduction

Common Rail fuel supply systems have high potential in shaping the fuel injection characteristics. For that reason, they are now widely used systems of fuel injection for diesel engines [3, 7, 8]. Diesel injection system is expected to provide a high precision metering of fuel amount injected into the cylinder, accuracy in injection start timing control and repeatability of that. Many factors contribute to above capacities including, inter alia, accurate control of injection duration and timing, which depends on the electronic control unit design and the kind of input signals that it uses, the injection pressure, the fuel parameters [4, 5, 10, 11], and the power supply voltage. On the accuracy of injected fuel amount, the factors related to the injection process progressing have also a significant impact, especially when multi-split injection is implemented. Pressure pulsations triggered by pilot injection, the amplitude of which may reach even 60 MPa, change the fuel quantity of main injection and its start angle position as well [9]. The changes in voltage, especially during the engine start-up, can be so considerable, that in effect they may cause the changes of the injector coil current value and emerged magnetic stream. Fluctuations of this stream will affect the magnetic force lifting the injector control valve, so the entire range of injector operation.

In this article the impact of supply voltage on the injected fuel quantity and the actual start of fuel injection are studied.

2. Test stand and measurement methodology

To determine the effect of voltage variations on the dosage of fuel, the test stand was built, which consist of a few key devices like: the test bench Bosch EPS-815 joined to the fuel delivery electronic measurement device Bosch KMA-822 with heat exchanger, and the module for testing the Common Rail system CRS-845. The fuel was injected into the special transparent chamber filled with the fuel, that enables the observation of injected fuel sprays. Fuel propagation inside the measuring chamber was recorded with use of visualization system AVL Visioscope. It was captured at every 0.1° of pump shaft angle. The layout of the test stand is shown on Fig. 1.

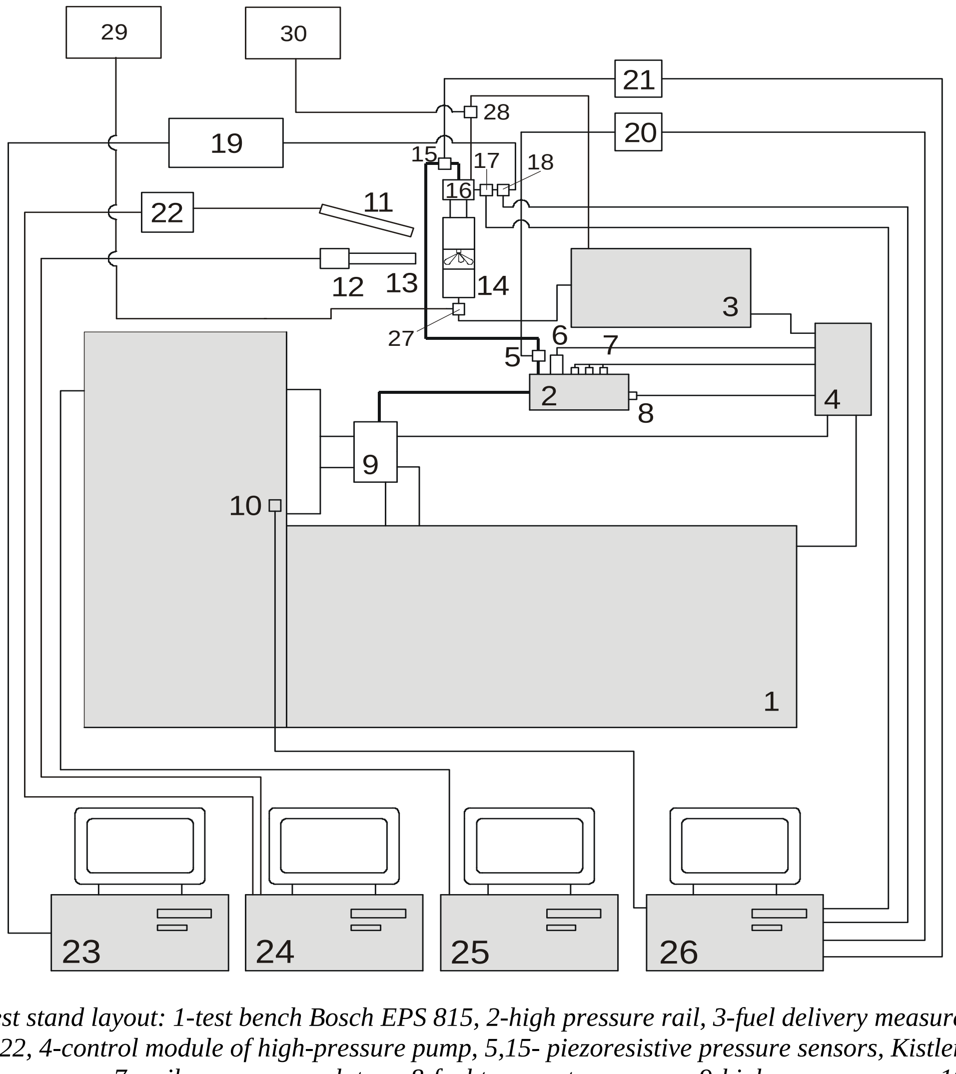

Fig. 1. The test stand layout: 1-test bench Bosch EPS 815, 2-high pressure rail, 3-fuel delivery measurement device Bosch KMA 822, 4-control module of high-pressure pump, 5,15- piezoresistive pressure sensors, Kistler 4067A2000, 6- rail pressure sensor, 7- rail pressure regulators, 8-fuel temperature sensor, 9-high pressure pump 10-pump shaft position and rotational speed optical sensor of AVL 365C, 11-light pipe, 12-digital camera PixelFly VGA, 13-endoscope, 14-visualization chamber, 16-tested injector, 17-measurement connector of injector control voltage, 18-injector current sensor PA-55, 19- microprocessor controller of injector, 20, 21-charge amplifiers Kistler 4618A0, 22-light unit, 23-computer with control software of injector,24-visualisation system AVL Visioscope, 25-computer with software for test bench controlling and for measuring of fuel delivery, 26-computer with data acquisition devices for high-speed parameters recording, 27,28-temperature sensors, 29,30-termometers EMT 101

Research in each measurement series were carried out at a fixed temperature of the injected fuel, which was measured in outlet pipe of the measuring chamber. The temperature of the fuel in the tank was stabilized at around 40 ± 1ºC. As the testing device the Bosch injector from the engine Fiat Multijet 1.3 (marked 445 010 083) was used. For injector operation control the electronic unit developed in Department of Automotive Vehicles and Internal Combustion Engines of Rzeszów University of Technology was used. Detailed description of the controller is presented in the work [1].

The primary purpose of the study was to determine the injected fuel amount and actual start of fuel injection depending on supplying voltage. The study was conducted for single injection strategy in order to avoid the changes in injection delivery that may arise from variations of pressure due to implementation of multi-split injection [2,6]. In order to determine precisely the actual start of injection, the progress of fuel spray was recorded by visualization system AVL Visioscope with an angular resolution of 0.1° of pump shaft revolution. That accuracy level was possible to obtain owing to use of pulse angle encoder AVL 365C mounted on the shaft of test bench. Pulses generated by the transmitter were also used as the input signal for the electronic injector controller. In this case, the angular resolution of 720 pulses per revolution was available, what gives a very high precision of controlling the start of fuel injection.

For recording the progress of injection process a digital VGA camera and the endoscope of AVL Visioscope system were used. Figure 2 presents the photographs of fuel sprays in the measuring chamber that were captured in the same angle position of pump shaft but for different values of supply voltage.

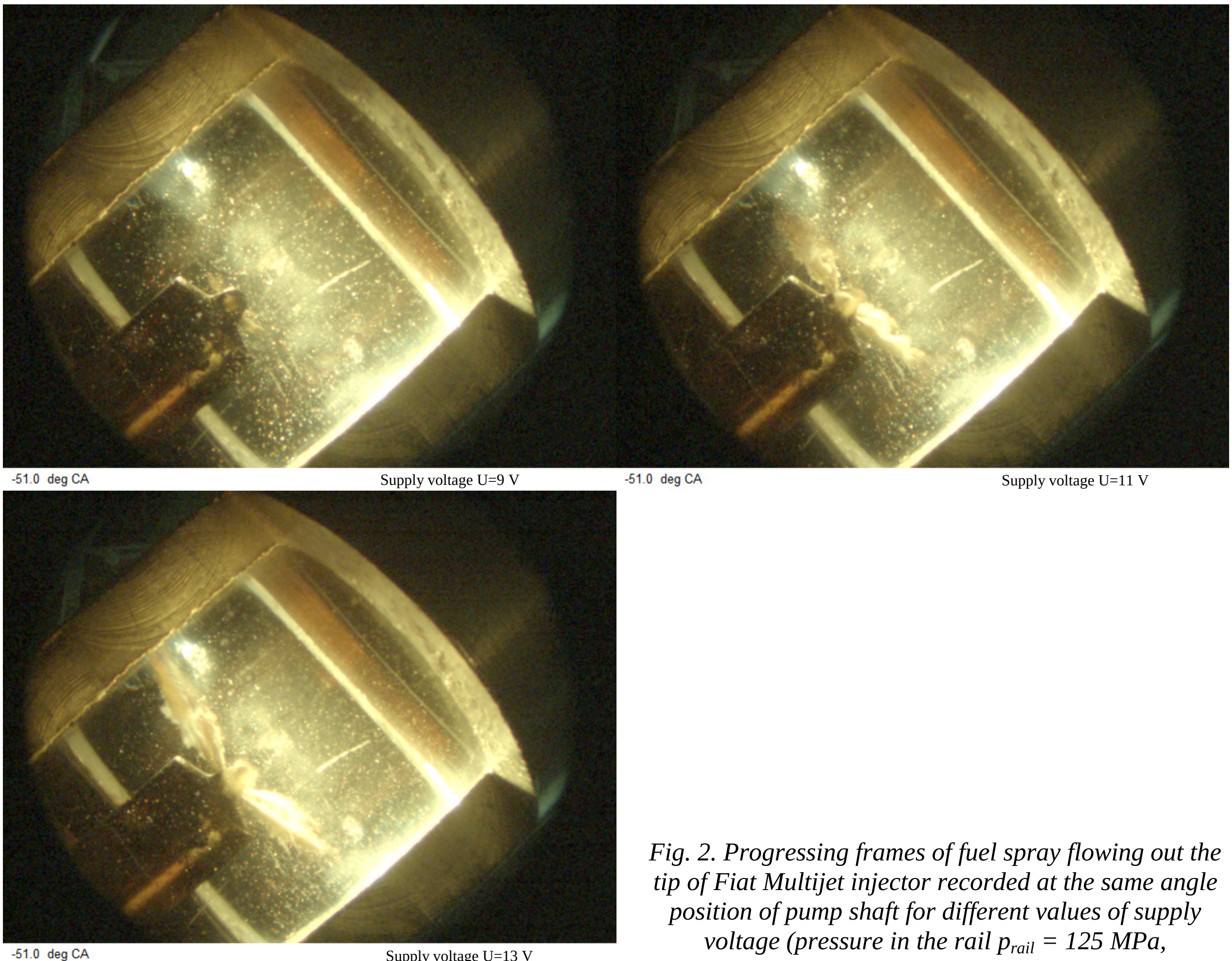

Fig. 2. Progressing frames of fuel spray flowing out the tip of Fiat Multijet injector recorded at the same angle position of pump shaft for different values of supply voltage (pressure in the rail p_{rail} = 125 MPa, injection time t_{inj} = 1 ms, n = 1000 rpm)

As can be noticed, at the supply voltage of 9 V the fuel sprays there are at the initial phase of their progress, while at the supply voltage of 13 V they are already in mid-expanded stage.

The injector control system was powered from a battery, which was also connected to the charger with a free and precise adjustment of supplying voltage and current feature. It allows for the voltage power supply to stay highly stable and reliable. The research were conducted for the voltage varied from 9 to 13 V, beginning from lower value. In order to perform it, the battery was partially discharged and loaded by an additional resistance increasing current consumption. Since the study was conducted at different durations of the injection, which causes the changes in the injector input current, each time after changing the injection time the supply voltage was re-adjusted. The tests were made for injection durations changed in the range of 1 to 3 ms, for three values of fuel pressure in the whole system equals 75, 100, and 125 MPa and at rotational speed of 1,000 rpm. In addition, for specific values of injection time and pressure some studies on the impact of supply voltage on the fuel injected quantity at different pump shaft speeds changed from 600 to 2000 rpm have been carried out.

3. Test results

Fig. 3 presents the volume of fuel injected versus the time of injection for different values of voltage U and fixed rotational speed n = 1000 rpm and pressure in the rail 75 MPa. For the voltage below 11 V this relationship ceases to be linear, and further, for the voltage below 9.5 V, the amount of fuel injected becomes a random, and increasing the time of injection does not make it higher. Thus, these results are not included in the figure. Reducing supply voltage results in a delay in opening the electromagnetic valve and thereby the start of injection delays also (Fig. 4). For the change in supply voltage from 13 V to 9.5 V, the delay at this rotational speed is exceeds 1ºof pump shaft angle.

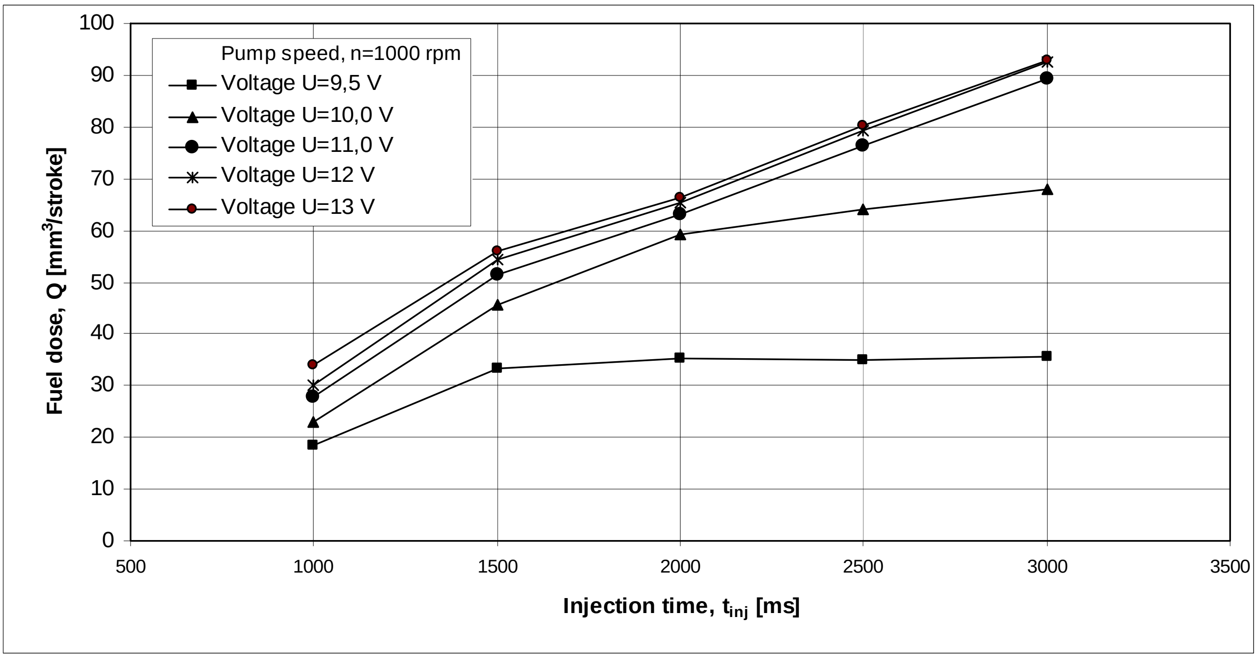

Fig. 3. The fuel dose quantity Q versus the injection time t_{inj} at different values of voltage U (the pressure in the rail p_{rail} = 75 MPa, n = 1000 rpm)

Fig. 5 presents the changes of the value of fuel dose quantity Q depending on the supply voltage for different values of fuel pressure in the rail and for fixed injection time of 1 ms. The temperature of the fuel flowing out the chamber was 90ºC for the injection pressure of 100 and

125 MPa, but 75ºC for the injection pressure of 75 MPa due to the fact, that attainment 90ºC of fuel temperature at this value of injection pressure was not possible.

As can be seen, the variation range of injected fuel quantity is very wide; it changes about 5 mm^3/stroke per each 1 V of drop, where at the voltage less than 10 V this value still increases. For longer injection time of 3 ms, these changes fit in the exponential curve; in this case a significant reduction in the injected fuel amount is already noticed at a voltage of 11 V (Fig. 6). Minor changes of fuel amount at shorter injection time can be explained by the influence of capacitor, whose stabilizing action becomes little at increasing injection time.

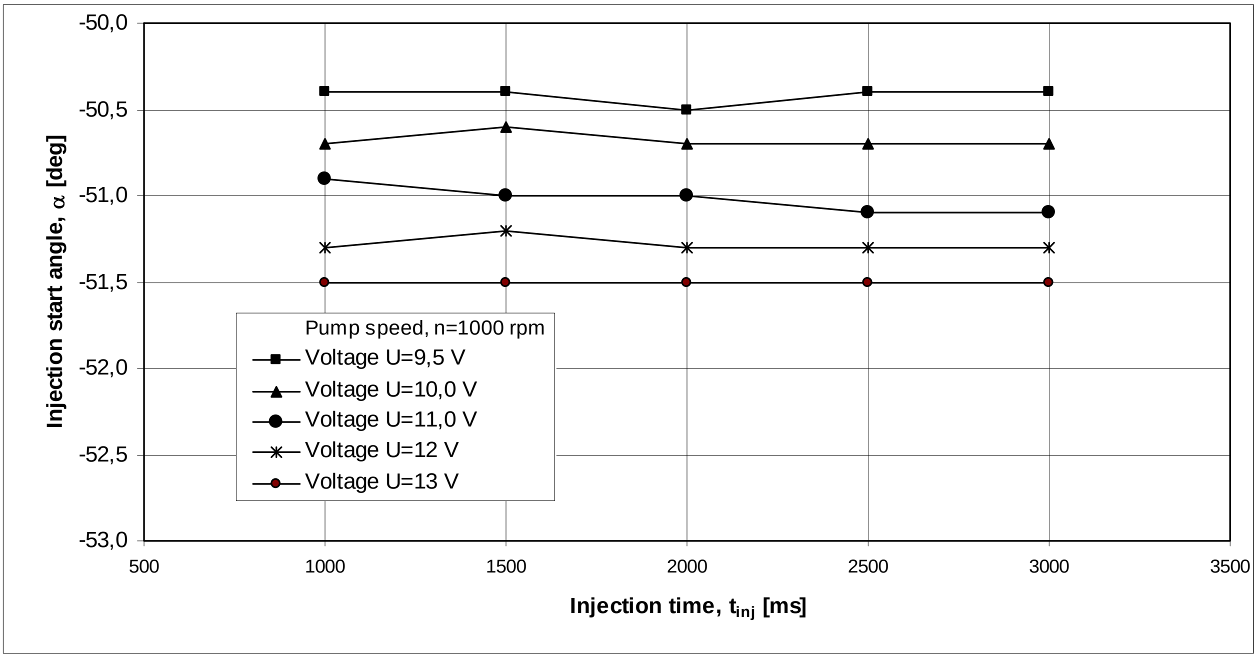

Fig. 4. Changes in the actual start of injection α versus the injection time t_{inj} for different values of voltage U (the pressure in the rail p_{rail} = 75 MPa, n = 1000 rpm)

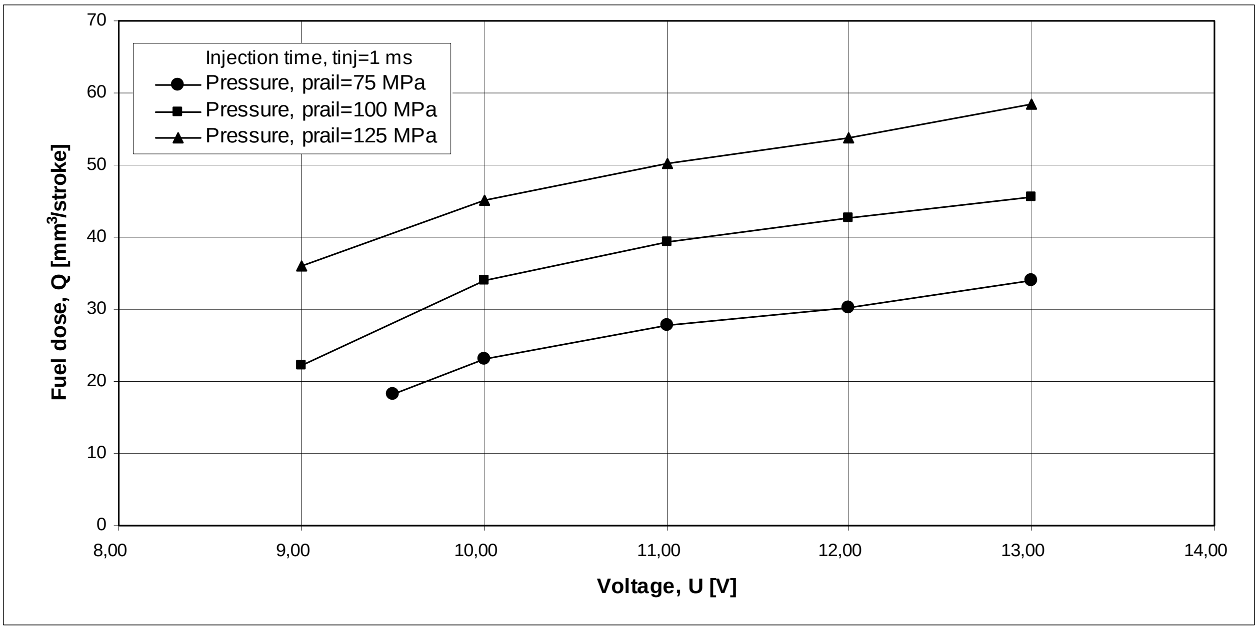

Fig. 5. Effect of supply voltage U on the fuel injected quantityQ for different values of pressure in the rail p_{rail} (injection time t_{inj} = 1 ms, n = 1000 rpm)

In Fig. 7 the relationship between injected fuel amount Q and pump shaft speed n for three different values of supply voltage of 9, 11, and 13 V, injection time of 3 ms and the fuel pressure of 75 MPa is presented. At 9 V, the injected fuel amount corresponds to only about 15% of the amount at higher voltage values. In principle, the injected fuel quantity does not dependent on the speed, although for larger values of supply voltage a slight increase of injected fuel volume at higher rotational speeds can be observed.

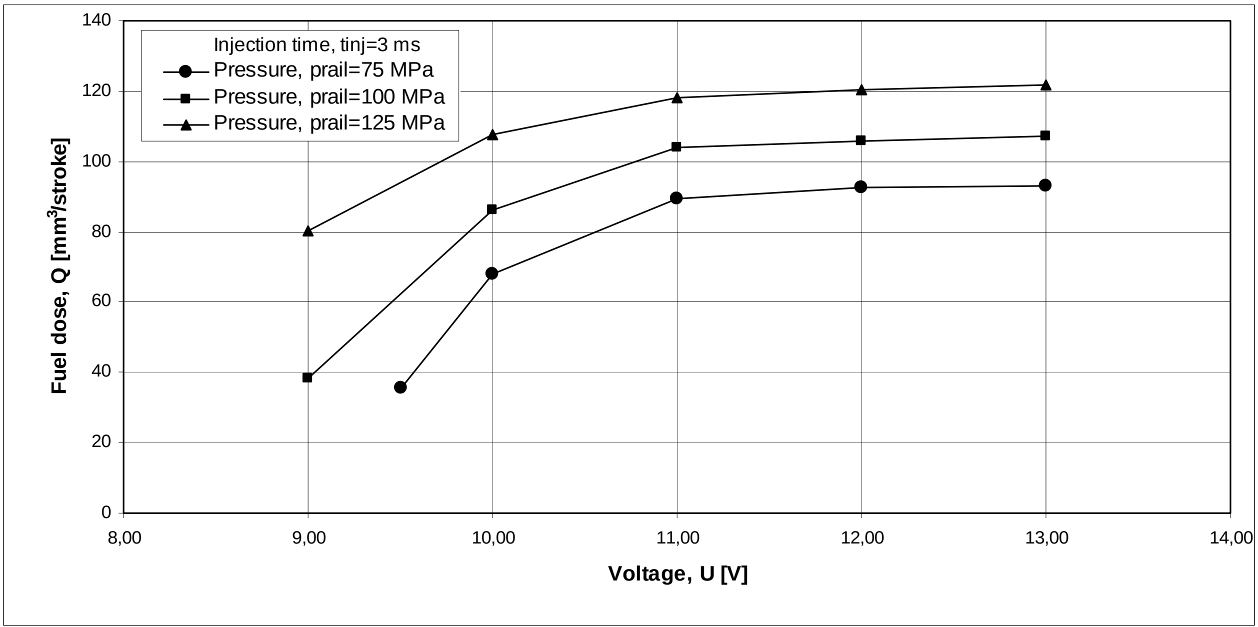

Fig. 6. Effect of supply voltage U on the injected fuel amount Q for different values of pressure in the rail p_{rail} (injection time t_{inj} = 3 ms, n = 1000 rpm)

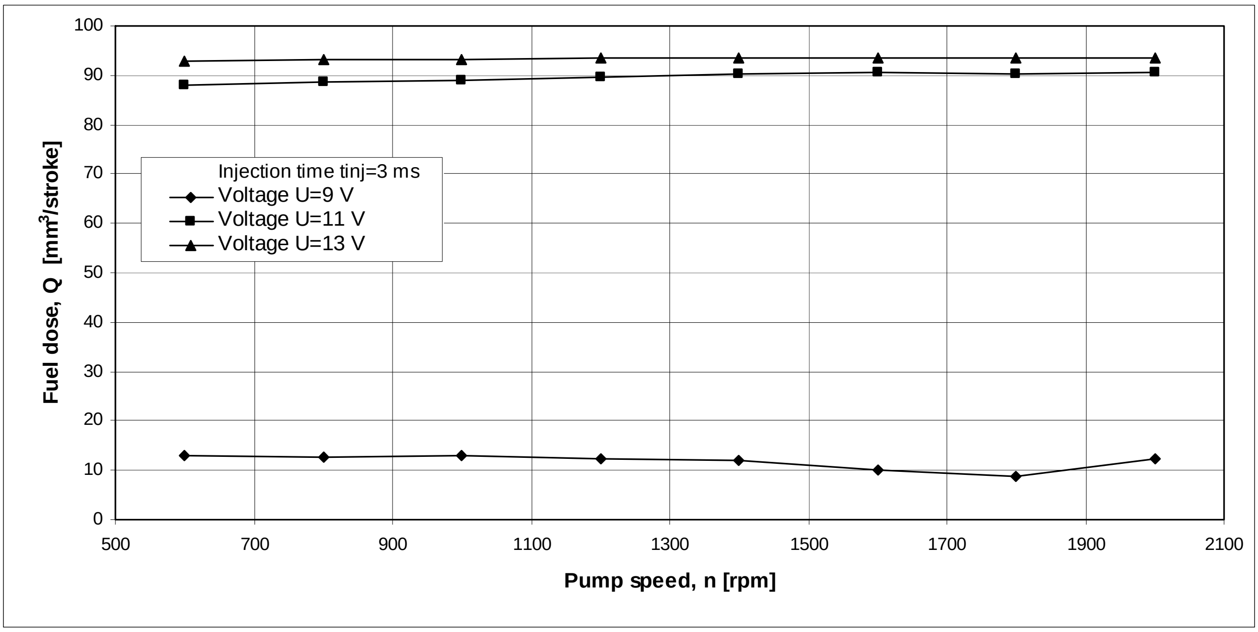

Fig. 7. The injected fuel amount Q versus the pump shaft speed n for different values of voltage U (injection time t_{inj} = 3.0 ms, the pressure in the rail p_{rail} = 75 MPa)

Figure 8 presents the changes in the start of injection angle position depending on the pump shaft speed. As can be seen, the time delay of needle lift associated with a reduction of voltage value is constant, what results in increasing the value of changes in injection beginning angle position at increasing pump shaft speed. However, throughout the whole analysis range the change of voltage from 11 V to 9 V causes greater differences in the injection beginning angle position than as for the change from 13 to 11 V. In the same conditions of system operation, similar changes occur for a longer injection time.

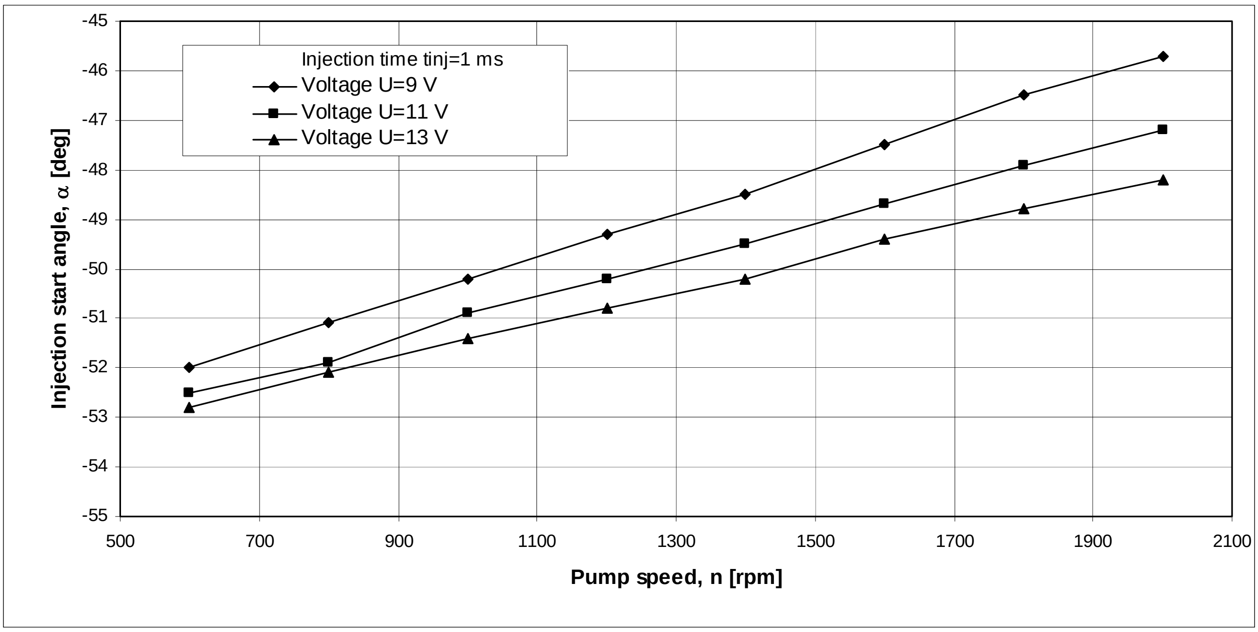

Fig. 8. Changes of the injection start angle position α depending on the pump shaft speed n for different values of the voltage U (injection time t_{inj} = 1 ms, n = 1000 rpm)

4. Conclusions

Analyzing the results obtained, it should be noted that the change in supply voltage significantly affects the injected fuel quantity. The lower injection pressure, the more significant the relative changes of that are. It may further affect the injected fuel amount, especially at low engine speeds. Changes in the angle position of the injection start for low speeds are negligible, and taking into account that at high speeds and alternator order working, the voltage fluctuations are smooth and should not be large, so their impact on this parameter can be neglected..

However, the injector may not open at all, if the voltage would be to low, especially at low fuel temperature. The injector operation principle at low values of voltage depends to a large extent on the kind of capacitor used in the controller. The boundary values of voltage, at which the injector will still work, also depend on the parameters of the injector coil, and so, also on the coil temperature, that may change due to the temperature of the fuel, as well as working time of the injector.

In conclusion, the voltage fluctuations can significantly affect the value of fuel quantity injected by the Common Rail system into the engine cylinders, which may adversely affect the emissions of pollutants in the engine exhaust. The elimination of these changes can be obtained by applying an additional electricity storage device e.g. by placing the suitably selected capacitor in the controller or by the use of a separate power source for the injectors, so that the change of the battery voltage during engine start-up and immediately after does not affect the accuracy and quality of injection control in the meaning of fuel dosing in these phases of Diesel engine work.

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