Changes in fuel supply parameters of Common Rail nozzle after major service intervals

Trifon Uzuntonev$^{1,2}$ and Sergey Belchev$^1$

$^1$Department of Transport Engineering and Technologies, Technical University - city of Varna, 1 Studentska Str., city of Varna, Bulgaria

$^2$E-mail: uzuntonev_trifon@abv.bg

Abstract In a number of countries of the European Union the average age of vehicle fleet is over 15 years, and in the entire European Union vehicles are on average 11.1 years old. This means that the environmental parameters are largely determined by the technical condition of the current vehicle fleet and in particular by the condition of fuel systems operated over extended periods of time. The article examines the changes in the behaviour of electromagnetic nozzles of Common Rail fuel system as a result of irreversible wear and deformation, which in turn affects the hydraulic characteristics and controllable fuel supply parameters. The influence of the changes in the electromagnetic nozzle’s adjustable geometric clearances on the injected fuel and the dephasing of this process in relation to the moment of transmission of the control pulse are examined. An analysis of the impact of these phenomena on the work process development in terms of deterioration of the vehicle’s environmental characteristics is made.

1. Introduction

In a number of developed European countries, the average age of the vehicle fleet is 11.1 years according to data taken from European Automobile Manufacturers' Association (ACEA). The top three positions are held by Luxembourg (6.4 years), followed by Austria (8.2 years) and Ireland (8.2 years). This stands in contrast to countries like Poland, Romania, Bulgaria, Lithuania, Estonia, etc. In Bulgaria, the average age of vehicle fleet is over 18 years. These important statistics determine the approaches of the individual governments to the introduction of restrictive measures to reduce ambient air pollution. Apparently, the introduction of restrictions on the movement of vehicles that do not meet certain eco-standards in certain urban areas for countries listed in the second half of this list is discriminatory. In this case it is more important to pay attention to the changes in the environmental performance of vehicles after major service intervals, the reasons for its deterioration, and the measures needed to bring them into service.

The prolonged operation of electromagnetic nozzles of Common Rail battery fuel system leads to irreversible wear and deformation, which in turn affects the hydraulic characteristics and controllable fuel supply parameters. They in turn lead to negative impact on the work process organisation, with all the accompanying negative consequences.

The aim of the presented work is to determine the level of influence of wear and deformation in electromagnetic nozzles CRI1 on the adjustable geometric clearances AH (Ankerhub) and RLS (Restluftspalt), fig.1. The changes in these clearances may lead to any possible changes in the amount of injected fuel and nozzle speed, which is expressed as extension of the response time RT (Response
Time out). These deviations from the standard adjustments cause deterioration of the power and economic performance of the engine, and of its environmental performance.

2. Prerequisites and Basic Concepts

The quantity of injected fuel and its time of injection into the engine cylinder in the Common Rail electromagnetic nozzles is controlled by an electronic pulse of a certain nature and duration. It is controlled by a card inserted in the computer and remains unchanged under the same operating conditions during the entire operation of the vehicle. The injected fuel quantity is a function of both the nature of this pulse and the physical phenomena occurring in the structure of the nozzle itself, figure 1.

![Figure 1. Fuel supply control of electromagnetic nozzle](image)

Despite the construction features of the different generations of Common Rail electromagnetic nozzles, they all follow similar principle of operation and have common adjustable geometric clearances. CRI1 nozzle of the company Bosch 0 445 110 076, designed for Puegeot 2.0 HDI, is subject to analysis in the article. It largely corresponds to the idea of the article - establishing changes in its work after major service intervals comparable to the average statistical age of the vehicle fleet. Figure 2 shows a detailed section of the electromagnetic part of the nozzle with the most important geometric clearances AH and RLS. They are regulated during the initial production of the nozzle and their values largely determine the basic fuel supply parameters. Ball valve lift AH determines the choking of fuel as it flows out of the nozzle control chamber. The increased AH lift leads to increased portion of injected fuel. The occurrence of preconditions for more intensive wear and tear in this group should be taken into account as a negative consequence of such an increase. The strength of interaction between the armature and electromagnet is determined by the size of residual air gap RLS and obeys Coulomb's law:

\[ F = k \times \left( \frac{q_1 \times q_2}{r^2} \right) \]

where

- \( q_1 \) and \( q_2 \) are fixed point electric charges
- \( R \) is the distance between charges, in this case the residual air gap RLS
- \( K \) is a coefficient depending on the measurement system

In this dependence, the distance \( r = RLS \) is an adjustable value and has a second-degree influence on the magnitude of interaction force. In the actual structure, this force overcomes the pre-adjusted spring tension and determines in this sense the system speed. This means that, for example, the
increased value of adjustable geometric parameter RLS and the maintained duration of control pulse will result in delayed opening of ball valve and change in the time of fuel supply, figure 2.

![Figure 2. Adjustable geometric parameters of the electromagnetic nozzle](image)

During prolonged operation of an electromagnetic nozzle, numerous closures of the control ball valve are made in its conical seat. This causes deformations in this structural element and "sinking" of the ball, figure 3.

![Figure 3. "Sinking" of the ball in the conical seat](image)

This deteriorates the sealing condition, since the contact is now made on the surface and not on the line, as it was at the beginning of operation. The emphasis in this case is placed on the fact that the ball "sinking" automatically affects the values of the most important geometric clearances AH and RLS. In this case, the two parameters increase their values. The accuracy of their adjustment is up to 2 microns, and the actions are performed in a specific environment. This implies a noticeable impact of relatively small deformations on the main fuel supply parameters, such as injected fuel quantity and actual beginning of fuel injection. The simultaneous increase of the two adjustable parameters AH and RLS causes different effect on injected fuel quantity. Higher AH values suggest fuel increase, but at the same time, higher RLS values cause a delay in the response time of RT nozzle. As a result of the wide-ranging effect on fuel supply process due to the increased geometrical parameters AH and RLS, the injected fuel quantity changes insignificantly. The main fuel supply parameters, being the beginning of fuel supply process and its differential characteristics, will be negatively affected. This means that injected fuel quantity during continuous operation of the nozzle must be objectively measured after checking and adjusting the main adjustable geometric parameters that change during operation.
3. Experimental Studies

Standard CMX 3000 test bench for Common Rail nozzles was used to establish quantitative relationship between the level of wear and tear in the valve group of the examined electromagnetic nozzle and the basic fuel supply parameters. The accuracy of measurement of injected fuel quantity is 0.1 mm³. The bench has an additional option to measure the response time RT of the electromagnetic nozzle. For this purpose, the fuel is injected into additional measuring chamber before being led to the flow meter. Piezoelectric sensor, which detects the time of pressure increase as a result of fuel injection, is installed in the chamber. This is considered to be the beginning of fuel supply. Despite certain conditions mainly related to the fact that the fuel is fed into a laboratory chamber rather than into the engine cylinder, the present case concerns comparative studies. Therefore, factors that are not taken into account have the same disturbing effect in all experiments. The RT parameter is read in μs and is displayed on the bench.

The different levels of wear and tear in the nozzle valve group are simulated by setting AH and RLS values in advance with the help of standard adjusting washers. Based on a preliminary analysis of the physical wear and tear process, the clearances were planned to be increased at regular intervals.

The quantities of injected fuel Q and the response time of RT nozzle were measured. The physical meaning of RT parameter is the delay of actual fuel injection, relative to the time of supply of the control pulse, figure 1. The aim of the experiment is to establish the quantitative dependence of this parameter on the time-varying air gap RLS and valve lift AH. To perform the experiment, standard programme set in the bench database for implementation of characteristic modes for the specific nozzle was used.

Tables 1, 2 and 3 show the results of the experiment with variation of RLS parameter at AH = 0.052mm = const. The value of AH parameter corresponds to the standard initial setting.

| Table 1. Experiment results AH=0.052mm RLS= 0.100 mm |
|------------------|------------------|------------------|------------------|
|                  | p Common Rail   | t              | RT              | Q                |
|                  | bar             | μs             | μs              | mm³              |
| TEST 0           | 1350            | 1000           | 345             | 51.1             |
| TEST 1           | 800             | 500            | 378             | 16.7             |
| TEST 2           | 250             | 600            | 458             | 4.9              |
| TEST 3           | 800             | 160            | 372             | 2.3              |

| Table 2. Experiment results AH=0.052mm RLS=0.080 mm |
|------------------|------------------|------------------|------------------|
|                  | p Common Rail   | t              | RT              | Q                |
|                  | bar             | μs             | μs              | mm³              |
| TEST 0           | 1350            | 1000           | 335             | 51.7             |
| TEST 1           | 800             | 500            | 372             | 17.0             |
| TEST 2           | 250             | 600            | 448             | 5.1              |
| TEST 3           | 800             | 160            | 365             | 2.4              |
Table 3. Experiment results AH=0.052mm RLS= 0.060 mm

| pCommon Rail | t  | RT | Q   |
|--------------|----|----|-----|
| bar          | μs | μs | mm³ |
| TEST 0       | 1350 | 1000 | 323 | 52.3 |
| TEST 1       | 800  | 500  | 356 | 18.6 |
| TEST 2       | 250  | 600  | 430 | 6.2  |
| TEST 3       | 800  | 160  | 348 | 3.0  |

4. Analysis of the Experimental Results

The attached tables containing simulations of different operating modes (combinations of pressures in the fuel battery and duration of the control pulse) set in the test bench database show reduction of the nozzle’s response time RT at increased pressures in the fuel battery $p_{\text{Common Rail}}$. This is normal, given the fact that the pressure in the nozzle’s control chamber is proportional to that in the fuel battery and differs slightly due to the chocking in the inlet. The higher pressure helps control valve to open faster. Therefore, in all experiments where RLS has different values, the response time for TEST0 ($p_{\text{Common Rail}}=1350$ bar $t=1000$μs) is the smallest. The analysis made shows that the smaller air gap RLS contributes to the greater speed of the nozzle, which is expressed in reduction of the response time RT. This applies to all operating modes for which the tests have been conducted, figure 4.

Simultaneously with the experiments, tests were conducted to establish the influence of the different values of control valve AH lift on the injected fuel quantity. In this case, the relationship is unequivocally defined. As the valve lift increases, with the air gap being maintained, fuel quantity increases as a result of the faster pressure drop in the control chamber. This applies to all operating modes involved in the tests. The increased lift AH in TEST3, which is identified as a pre-portion of fuel before the main fuel portion, has the most negative effect. In absolute terms, this quantity is smaller and even any insignificant change in the increase leads to the possibility of implementing a work process with great advance of release and with all resulting negative consequences for the environmental characteristics and power and economic indicators of the engine.

The article does not present the results of these experiments due to the known influence of AH on the quantitative characteristics of injected fuel quantity.

![Figure 4. Relationship between RLS and RT in different operating modes](image-url)
5. Conclusion

The prolonged operation of electromagnetic nozzles Common Rail leads to wear in the control valve movable elements. This leads to deterioration of its sealing capabilities and changes in important adjustable clearances. They, in turn, have negative impact on the injected fuel quantity and change the actual injection process beginning. Deteriorated organisation of the work process affects negatively the power and economic performance of the engine, and its environmental performance. The article analyses the mechanism of this process and makes a quantitative assessment of the relationship between the level of wear and tear and the level of deterioration of the nozzle's hydraulic characteristics.

In the presence of standard Common Rail nozzle test bench, deviations in the electromagnetic nozzle’s operation can be determined with sufficient accuracy. The accumulation of sufficient database allows for assessment of the RT values based on the level of wear and tear and deviation from the nozzle's normal operation.

If the control valve’s sealing is preserved within the permissible limits, it is possible to restore the initial adjustments of the nozzle and to maintain its operability for a further period.

6. References

[1] Robert Bosch GmbH 2004 Diesel-Engine Management, 4th Edition (Stuttgart) p504
[2] Xiong J and Gu H 2017 An Intelligent Dual-Voltage Driving Method and Circuit For a Common Rail Injector for Heavy-Duty Diesel Engines J. IEEE Access 5 27681-27689
[3] Dongiovanni C and Coppo M 2012 Accurate Modelling of an Injector for Common Rail Systems Fuel Injection Siano D (Rijeka: InTech) p262
[4] J.Hammer, A.Binder Einspritztechnik Teil 1 IVK Universität Stuttgart
[5] Klaus Krieger Diesel-Einspritztechnik für Pkw-Motoren Überblick über Verfahren und Ergebnisse, MTZ Motortechnische Zeitschrift 60 (1999)
[6] Rolf Leonhard, Johann Warga, Thomas Pauer, Mrkus Rückle, Matthias Schnell Magnetventil Common-Rail-Injector mit 1800 bar MTZ 02/2010 Jahrgang 71
[7] Rolf Leonhard, Johann Warga Common Rail System von Bosch mit 2000 bar Einspritzdruck für Pkw MTZ 10/2008 Jahrgang 69