Simulation of high-pressure pump behaviour after running in urban regime

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Abstract. The wear of the high-pressure pump is directly proportional with the engine operating mode of the vehicle. Due to the urban areas congestion, the engine assembly components can be affected and they can lose their reliability. The engine operation can be described as a cyclical model, reaching all the operating points: idle, cranking, maximum torque and maximum power. Thus, the discontinuous operation (proportional with car engine cycles) of the high pressure pump can create different types of wear for its components. Our paper presents an experimental test that simulates the behaviour of the pump after the operation of the vehicle in urban regime with a cyclical type in a course of 10,000 km. It aims to achieve the most important engine operating points. In order to do this, an electronic control unit is installed on the test machine, which has the role of controlling the electronic pump valve. All data (pressure, speed, temperature) are recorded in real time and stored in the memory unit of the test machine. The obtained data are analyzed and the pump is disassembled. Wear is observed on the main components (roller, shoe and driveshaft), but this does not lead to pump malfunction. After this analysis, the main components of the tested pump are compared with new components in order to evaluate the wear level.

1. Introduction

Light vehicles have a very important role nowadays regardless of the propulsion or the fuels used. Because of the need to save as much time as possible, people tend to use the cars constantly, even if their distances to be travelled are very short. This is one of the main factors which are leading to the urban traffic congestion [1]. A lot of studies have been carried out on this topic, based on theories related to air or noise pollution and implicitly their negative effects on the population [2]. In the same time, an important issue that deserves to be studied is the behaviour of vehicle and its subassemblies, during running in mentioned conditions. The vehicles performances have a very important role in their acquisition process. The bases of these performances are practical and theoretical studies on different types of fuel. The most used fuels in the world are diesel and gasoline [3]. Even if the operating principles are similar, the engines may be constructively different, having miscellaneous subassemblies. The construction of the diesel engine assembly is more complex than a gasoline engine. This is why diesel vehicles have high power and torque, and also reduced fuel consumption. The use of the high pressure fuel injection system helps to achieve these performances. In the same time, the wear of this system is visible and can lead to the total malfunction of the engine. The common rail injection system consists of high pressure pump, injectors, common rail, electronic control unit (ECU) and connecting pipes. The most important component of this system can be
considered the high pressure pump. Its role is to provide the high pressure fuel to the injectors, after which they will spray it into the engine cylinders. This process is very well defined and calculated by the electronic control unit, taking into account the engine operating regime [4]. The running mode in the city leads to the exploitation of the engine in all stages of its operation. Thus, it covers all important points of their performance, such as cranking, idle or operating in the parking mode and reaching in maximum torque or power.

Various studies have been carried out regarding the driving mode of vehicles in urban areas. As mentioned above, some of these were done due to pollution considerations. From a technical point of view, there are researches which have the main purpose to expose the light vehicle behaviour in urban regime and the influence of this regarding to the fuel consumption. Thus, the traffic of the vehicles was closely monitored in various cities and statistical data were collected with professional devices.

The following of them help to understand the driving mode in the urban environment. For instance, this type of study was carried out on a heavy duty vehicle, on a bus, and evaluates how the driving cycles can influence the fuel consumption [5]. Another research is based on the pollutant emissions analysis, fuel consumption and travel speed with the help of four instrumented vehicles [6]. Thus, data were obtained regarding the most polluting driving sequences which have the higher fuel consumption inside or outside urban regime [7]. The researchers from the Laboratory of Fuel Technology and Lubricants (NTUA) conducted a study of emissions and fuel consumption using traffic statistical data from Athens. They did a comparative analysis between cars and motorcycles, concluding in favour of the latter [8]. According to various researches it has resulted that the diesel engine running in urban conditions can be harmful for its subassemblies.

The experimental test presented in our paper monitors the high pressure pump behaviour regarding the noise level emitted by the valves, as pump components. Being a cyclic test, it was possible to perform the repeated opening of the valves and to follow their behaviour.

The purpose of this paper is to analyse the evolution of the high-pressure pump and its wear, following a cyclical test, which simulates approximately 10,000 km travelled in urban regime.

2. High-pressure pump description
The high-pressure pumps have different constructive solutions. The most used on diesel vehicles are the ones with the roller-shoe transmission mechanism. This pump type has two main subassemblies: the movement transmission mechanism and the hydraulic head (figure 1).

![Figure 1. High-pressure pump – main components [10].](image)
The most common issue which can lead to the total malfunction of the pump is the roller-shoe mechanism wear. This subassembly has very well defined dimensions. The cam, roller and shoe are in direct contact, the movement being transmitted from one to the other. The cam and the roller are well integrated in this system; they have very well calculated profiles, so that the contact between them is accurate and safe. They are made of hard steel, thus contributing to the robustness of the pump. For example, to increase the service life of the components and to reduce the coefficient of friction between them, coatings are used.

Our test is performed on a pump type with the shoe that has steel as base material, but its surface is covered with Diamond Like Carbon [4]. The hydraulic head has two types of valves, as main constructive elements. The inlet valve allows the low pressure fuel to penetrate into the hydraulic head. The outlet valve has the role of evacuating the fuel with high pressure, as result of the pumping action of the piston [9].

3. Test details and test bench description

Our experimental test is of cyclical type and simulates the behaviour of the pump in all four performance points of the vehicle (figure 2). These points can be easily reached when the vehicle is driven in urban traffic conditions.

The first point is the one where the car starts, which are easy to reach for cars equipped with the start-stop system.

The second point is the one where the car is running outside the gears (static mode) or more precisely on neutral or parking (valid for automatic gearboxes), with the engine started.

The last two points are the maximum torque and power that the car can reach.

A high pressure pump is built so that the supplied fuel can create a balance in the engine in all these four points.

![Figure 2. Test cycle – general view.](image)

The test is performed on a specially designed test bench so that all the above conditions can be met. Also, for the test’s veracity, the electronic control unit and the injectors were mounted on the test
bench. Figure 3 presents the functional scheme of the test bench which is equipped with sensors and acquisition boards to be able to track and save data in real time [4].

![Test bench functional scheme](image)

**Figure 3.** Test bench – functional scheme [4].

The test fluid used is one with diesel similar properties [4]. Its temperature is set to 90 degrees, like the engine normal operation when is mounted on a vehicle. Considering the high resources consumption for such a test, these are only realized during 100 hours, which would mean approximately 10,000 km of running.

4. **Test results and discussion**

The test was successfully completed, without further intervention on the pump or on the test bench.

The pump behaviour is normal during the test, adapting to the conditions initially imposed. The main parameters followed were: the rail pressure, the engine speed and the fluid temperature on the pump return circuit. Considering the low frequency of data acquisition, operating cycles are not visible
in a single graph. Therefore, to easier observe their architecture, two cycles were extracted from the middle of the test: for rail pressure and for motor speed. In the below graphs from figures 4 and 5 there are presented simulations of the different operating regimes and the supply of the high pressure related to the engine speed.

![Rail Pressure - cycle](image)

**Figure 4.** Rail pressure – cycle view.

![Motor Speed - cycle](image)

**Figure 5.** Motor speed evolution – cycle view.

The fluid temperature from the pump return circuit is an important parameter because, through it, we can evaluate the friction of the components. In the case of this test, it is observed that the temperature exceeds by a few degrees the initially imposed value, but is considered acceptable (figure 6).
Figure 6. Temperature evolution during the test.

| Component   | Before Test | After test |
|-------------|-------------|------------|
| Driveshaft Cam | ![Image](image1.png) | ![Image](image2.png) |
| Roller      | ![Image](image3.png) | ![Image](image4.png) |
| Shoe        | ![Image](image5.png) | ![Image](image6.png) |

Figure 7. Driveshaft cam, shoe and roller before and after test.
After the results analysis, there are no deficiencies in the pump functionality. The pressure provided by the pump, following the operating regimes imposed by the electronic control unit, maintained the necessary values for the car operation. In order to carry out a detailed analysis of the subassemblies inside the pump, we proceeded to disassembled it. The components most prone to wear are the shaft, roller and shoe. These are in good condition, no traces of hits or lack of material. Visually, some warmer areas can be observed on the cam and roller surfaces. Thus, we can correlate the temperature rise observation in data analysis with colored surfaces due to heating. Before starting the test, photos with interest components were done, in order to can realize a comparison (figure 7).

Except the different visual appearance, the roller and driveshaft cam profiles were also measured before and after test. For roller is measured logarithmic profile in order to see if there are changes. The important areas for driveshaft are the cam lobs, because these are in direct contact with the roller (figure 8).

| Measurement | Cam Profile |
|-------------|-------------|
| Before Test | ![Before Test Cam Profile](image1) |
| After Test  | ![After Test Cam Profile](image2) |

**Figure 8.** Driveshaft cam profiles.

| Measurement | Cam Profile |
|-------------|-------------|
| Before Test | ![Before Test Cam Profile – zoom view](image3) |
| After Test  | ![After Test Cam Profile – zoom view](image4) |

**Figure 9.** Driveshaft cam profiles – zoom view.
For driveshaft measurement, were taken in consideration the areas with maximum points (figure 9). The difference before and after is approximately 0, 6 microns, which can be considered very small.

| Measurement | Roller Profile |
|-------------|----------------|
| Before Test | ![Before Test](image1) |
| After Test  | ![After Test](image2) |

**Figure 10.** Roller profiles.

The roller profile (figure 10) complies with manufacturer instructions for both pumps. The only one difference is the roughness. Before the test more asperities are visible than after the test; that is the result of the contact with the driveshaft. The results obtained in the previous test are comparable with results from a pump tested during 1400 hours.

**Figure 11.** Visual appearance after 1400 hours of testing.
It is visible that the components are more heated after 1400 hours than after 100 hours. The roller profile was also measured and the result shows us that the central area was flattened due to continuous contact with driveshaft (figure 12).

![Figure 12. Roller profiles after 1400 hours.](image)

Except the components visual appearance and the roller profile, the pump behaviour is the same. This fact confirms the pumps robustness in urban regime.

5. Conclusions
The service life of a high pressure pump depends very much on the operating regime of the vehicle, but also on its manufacturing process. The high-pressure pumps manufacturers can establish an approximate service life of them in various operating conditions. Considering that the manufacturing processes depend on the human factor, there can be various deviations. As an example, another type of test with a high-pressure pump can be taken in consideration. As a result, it has been observed that a manufacturing defect such as inadequate clearance between the roller and the shoe correlated with a marginal value of the shoe's coating adhesion can lead to pump malfunction. This time, our paper showed that the test performed was successfully completed, the pump performing this functional role. The transmission components wear is minimal, which can predict a long life of the high pressure pump. Thus, after approximately 10,000 km running in urban traffic, the high-pressure pump components do not have structural, dimensional or functional changes.

6. References

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