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Wear's issues on high-pressure common rail pumps

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Abstract. High-pressure pumps are the most important components of modern fuel injection systems. A modern system is the common rail one, equipping vehicles with a diesel or a gasoline engine. Depending on the fuel type, the design of the pumps is completely different, and it is more complex for diesel engines that are more prone to wear. The components subjected to wear are those in contact and continuous motion like drive shaft with roller and shoe, plunger and hydraulic head assembly with valves. Wear is initiated as a result of a process and product deviations or inadequate exploitation of the high-pressure pump. The factors influencing the wear can be improper material hardness, improper coating, incomplete or wrong machining, wrong clearance or misalignment between components, inadequate surface finish, dimensions out of tolerances, wrong assembly process, poor lubrication, contamination or running at high loads and temperatures. Our paper aims to identify, describe and discuss the types of wear encountered at common rail high-pressure pumps, highlighting the effects on their functionality. The wear occurrence can be prevented by paying more attention to the design details, manufacturing processes and correct exploitation of the high-pressure pumps.

1. Introduction

The high-pressure common-rail system is a modern fuel injection system which equips most of the nowadays combustion engines. It is composed of a high-pressure pump, injectors, a high-pressure accumulator (rail) and the electronic control unit (ECU) which controls the whole system for a good performance of the engine and low emissions [1]. The pump is a complex mechanism that can deliver high-pressure fuel to the high-pressure accumulator. Pump components are subjected to high loads by compressing the fuel at high pressures. The most stressed subassemblies of the pump are the drivetrain components and the hydraulic head assembly.

The drivetrain components are the drive shaft, roller and shoe, which acts the plunger in order to compress the fuel in the compression chamber. These components are in permanent contact, and also they are lubricated with fuel. When the pump is operating, in some cases the parts may lose the fuel film and are subject to very high friction, resulting in high working temperatures. Obviously, this behaviour leads to a wear process.

The hydraulic head assembly with valves and plunger has the role in transforming the low pressure in high-pressure fuel. These valves have simple designs, and the outlet valve is composed of a spring, a ball with a spherical seat and the inlet valve is composed of a spring, a stem and a conical seat [2]. The valves are subjected to cyclic loads due to plunger's motion by compressing the fuel and are more prone to fatigue.

Figure 1 depicts the main possible types of wear that we have identified for each pump component.

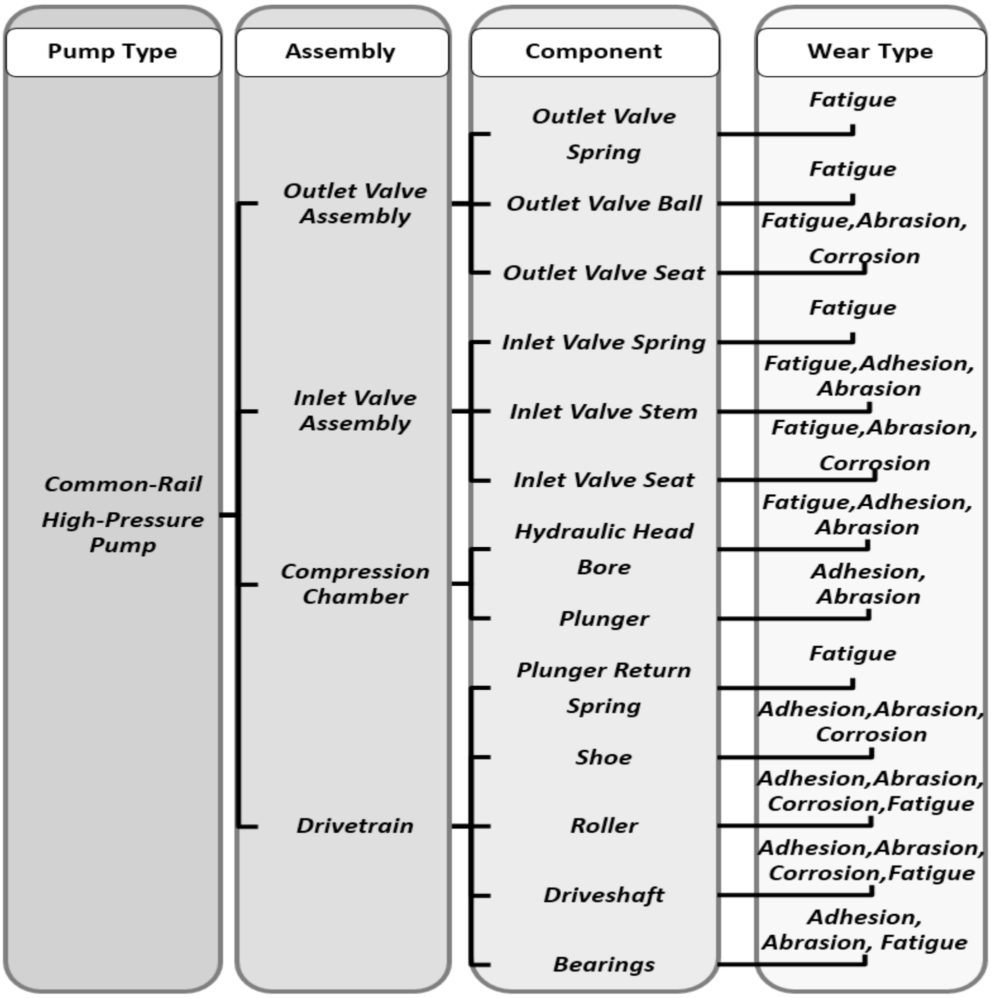

Figure 1. Wear types for common-rail high-pressure pump components.

2. Wear of the drivetrain components

Transmission of motion into the high-pressure pumps is achieved via the drive-shaft. It is driven directly by the camshaft or crankshaft indirectly via transmission belts, chains or gears. This rotating motion of the drive shaft is transformed into a translation one. The cam comes into direct contact with the roller and makes possible this movement transformation. The lubrication is carried out with the fuel flowing through the pump. The drive shaft is made of high-strength steel. The roller is a rolling element with a logarithmic profile made of steel [3]. The shoe is made of a material that has excellent compatibility with the roller material. In order to have high wear resistance, it is covered with DLC (Diamond Like Carbon). Considering that these elements are in permanent contact and the fluid used for lubrication is a fuel with limited lubrication properties, the appearance of wear is inevitable. Working conditions, surface irregularities, components clearance, improper dimensions, load distribution, vibration, or surface condition facilitate wear appearance. The main types of wear in this mechanism are adhesion, DLC removal, abrasion and corrosion. The working parameters to which the pump is directly subjected can influence the fuel properties and the contact between the components. According to a previous study [4], a high-pressure pump was subjected to an aggravated test, the Low Sommerfeld Number. This type of experiment was performed under critical conditions of speed, temperature and pressure. It has been shown that these parameters adapted to aggravate the test correlated with low clearance between components lead to the occurrence of scuffing (figure 2). During the run, because of the critical conditions, the surface of the roller adheres to the surface of the shoe, which leads in blocking the pump components.

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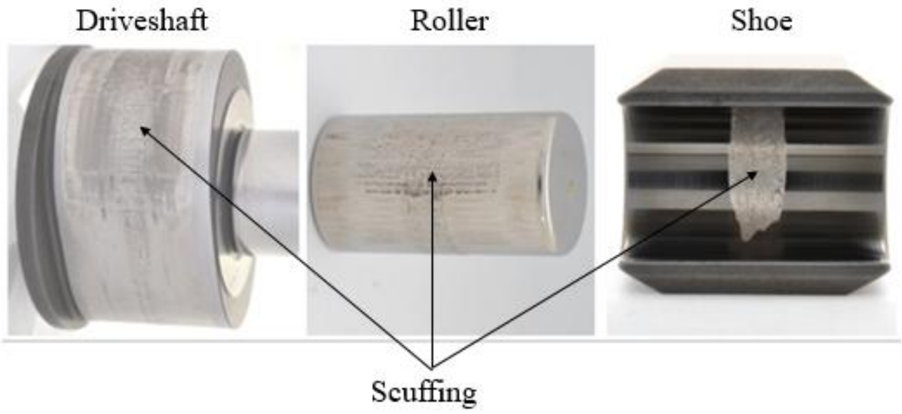


Figure 2. Roller, shoe and drive-shaft with scuffing after an aggressive test [4].

Mirror polishing (figure 3) is another important type of wear found in high pressure pumps and it appears on the drive shaft cam surface. This is not often seen because it is characterized as an effect due to the poor fuel properties. Over time, it leads to fatigue (figure 4).

Figure 3. Mirror polish.

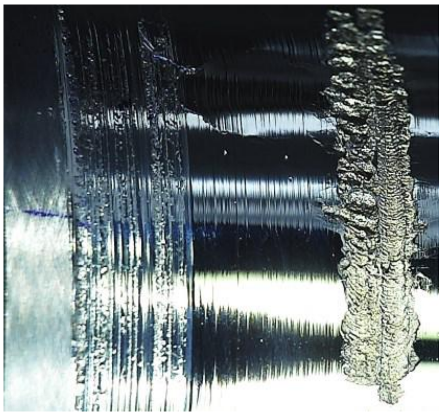


Figure 4. Fatigue on drive-shaft.

The shoe internal diameter area is the most sensitive for removal of DLC. Depending on the roller rotation direction, the pressure on the shoe edges is uneven (figure 5). Thus, DLC removal may occur (figure 6).

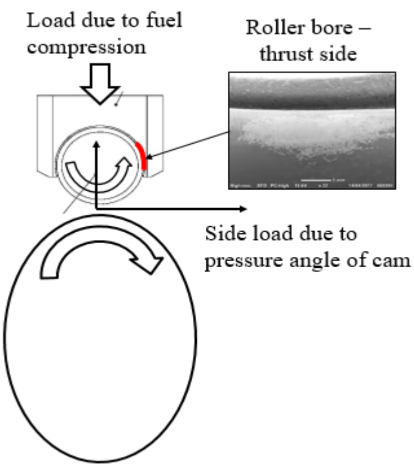


Figure 5. Shoe – load distribution.

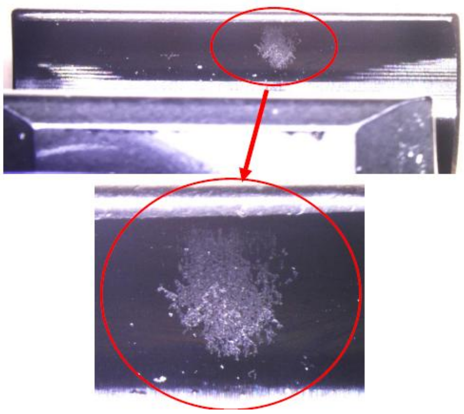
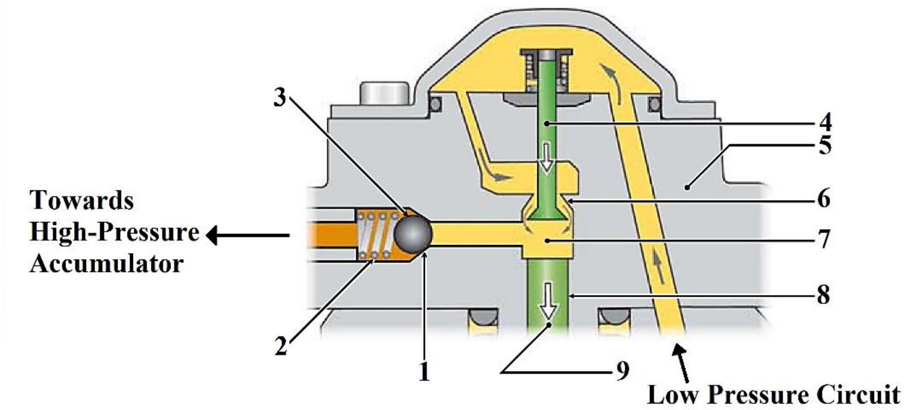


Figure 6. DLC Removal.

3. Wear of the hydraulic head components

The inlet valve with the outlet valve and the plunger assembled on the hydraulic head body, together form the hydraulic head assembly of the common-rail pump (figure 7). The hydraulic head is one of the most stressed parts of the pump, its role being to compress the fuel at pressures of over 2000 bar.



1 – Outlet Valve Seat; 2 – Outlet Valve Spring; 3 – Outlet Valve Ball; 4 – Inlet Valve Stem; 5 – Hydraulic Head Body; 6 – Inlet Valve Seat; 7 – Compression Chamber; 8 – Plunger Bore; 9 – Plunger

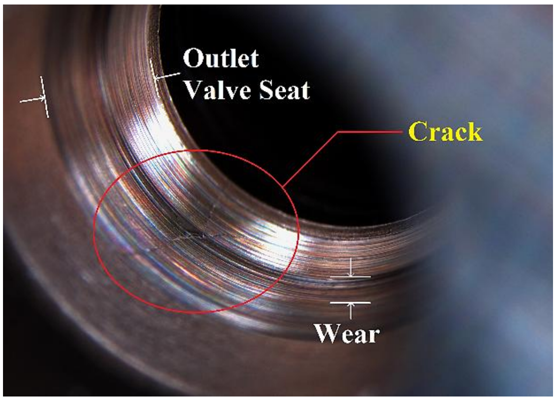
Figure 7. Hydraulic head assembly with valves and plunger [6].

3.1. Outlet valve

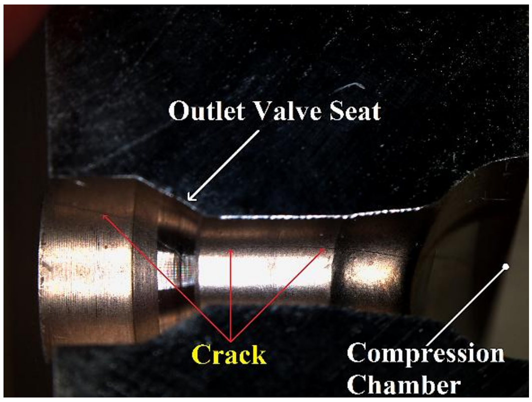
The outlet valve assembly is composed of a spring, a steel ball and a machined spherical seat, which is prone to impact wear and fatigue. The wear appears due to the opening and closing of the valve in which the ball hits the seat with high velocity and high force due to the high pressure from the high-pressure accumulator.

In figures 8 a, b (in a hydraulic head section) a crack on the outlet valve seat can be observed. During pump operation, this crack leads to high-pressure external leakage. By opening the fracture, the initiation point and the fracture pattern can be viewed in detail (figure 8 c). The crack initiation point is exactly on the machined spherical seat, in the worn area where the most considerable contact stress is due to the ball.

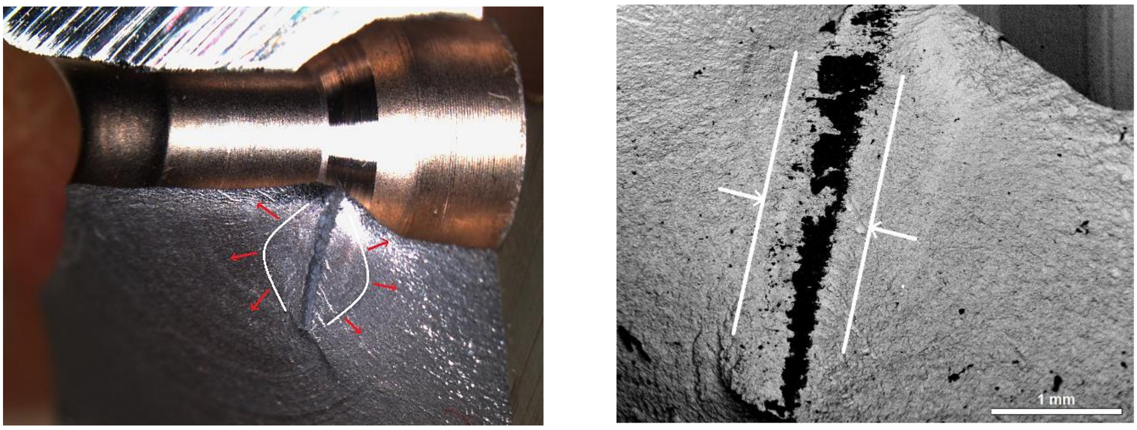
As a result of the analysis performed on the scanning electron microscope (SEM) in figure 8 d, an inclusion has been observed. It has a chemical composition different from that of the base steel which has an enormous influence on the mechanical properties of the material, mainly under high cyclic load conditions, resulting in a high dispersion of the fatigue life [7]. The main elements present in the inclusion are calcium (Ca), magnesium (Mg), aluminium (Al) and oxygen (O) and are suitable for a spinel inclusion, most likely formed during the steel manufacturing process.



(a)



(b)



(c) (d)

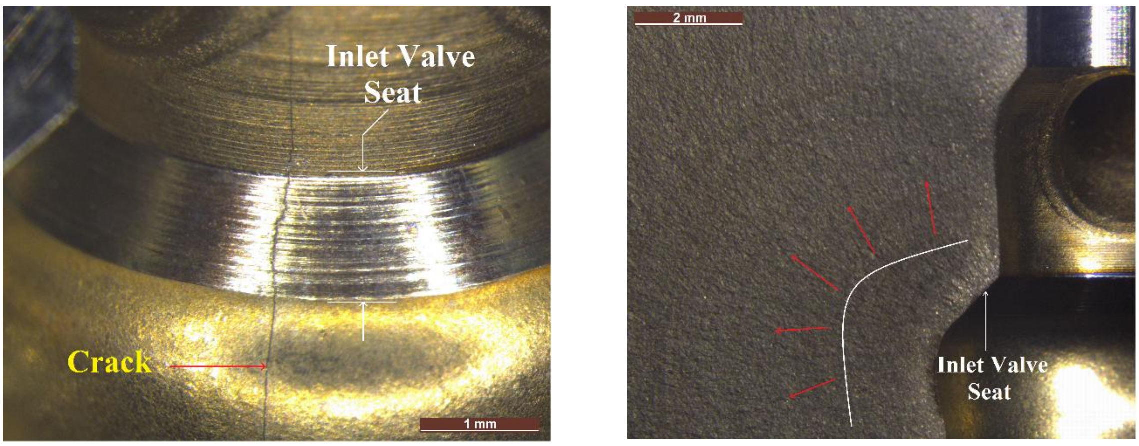
Figure 8. Hydraulic head outlet valve failure due to material inclusion.

3.2. Inlet valve seat

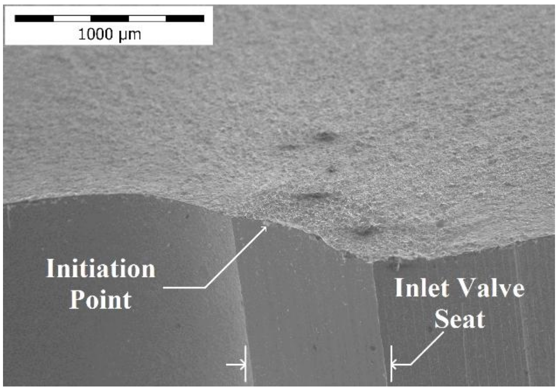
The inlet valve assembly consists of a spring, a stem and a conical machined seat (figure 9 a) in which the components are more prone to abrasive wear, impact wear and fatigue. During operation of the pump, the stem moves up and down, making a translational movement. This movement can lead to abrasive wear due to a very small clearance with the guide, impact wear and fatigue due to the high-pressure cyclic pulsations in the compression chamber [8].

In figure 9 a, a crack on the inlet valve seat can be observed, which leads to external leakage during the pump compression stroke. The crack has been opened (one half in figure 9 b) and the fracture initiation point was identified on the inlet valve seat. At the scanning electron microscope, it was analyzed the fracture area in the region of the initiation point where a thin layer of material was observed (figure 9 c). This layer has a very fine fracture morphology indicating high hardness and high brittleness. Also, it has been found in the surrounding area signs of higher ductility due to over tempered martensite.

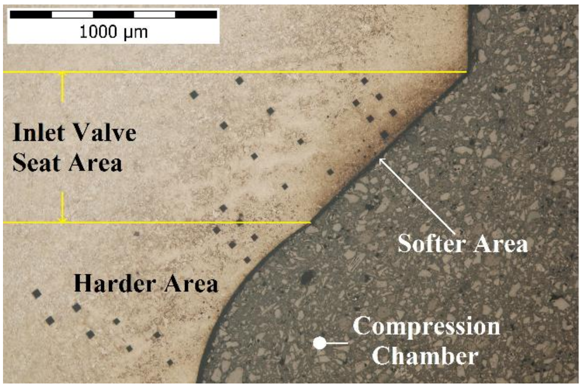
Half of the fracture was cut, polished and 2% Nital Etch Solution was used to reveal the microstructure (figure 9 d). A hardness check was performed, where the surface of the inlet valve, recognized on the image as a darker area, the material is much softer compared to other areas. The darker surface of the inlet valve seat is specific to the over tempered martensite which occurred during the machining process. The grinding process produces a very high temperature on the surface of the inlet valve seat in a short time that can change the metallurgical structure of the material and is called grinding burn [9, 10].



(a) (b)



(c)



d)

Figure 9. Hydraulic head failure due to inlet valve machining burn.

4. Conclusions

The high-pressure common-rail injection system pump must have components with excellent wear resistance and cyclic loads because almost all components are mechanically driven and stressed by high-pressure fuel. Even so, after a certain period of operation, wear is inevitable. High pressures and load, incorrectly set of fuel injection parameters, heat transfer between components lead to overheating and geometry changes of common rail pumps. They are factors influencing decisively the pumps wear. The paper presents particular cases of wear and defects of the pump components, in which wear can take many forms for the drivetrain ones, such as the drive shaft, the roller and the shoe. For the hydraulic head components as the outlet valve and the inlet valve, wear is most often caused by several openings and closures where the high pressure acts with enormous force on the components. In some cases, as presented in this paper, the process of valve seat machining or material composition play an essential role in the life of the hydraulic head, and also, another role in terms of safety as these defects can lead in time to cracks and further to external leakage. Due to the tight clearance between hydraulic head bore and plunger, the components are susceptible to adhesion and abrasion wear. Therefore, the plunger is DLC coated in order to reduce friction during pump operation, but if the components are running in a system with poor lubrication fuel quality as low viscosity or contaminated with fine particles, the wear is accentuated, and the components will be out of use very quickly. The same issue can also occur for DLC coated shoe. To improve the wear resistance and hence the lifetime of the high-pressure pump, should be paid more attention to manufacturing processes of components or detection of the defects, but not least the assembly process of the pump, where there should be a controlled environment in terms of cleanliness. Our future work will focus on the theoretical study of some components (valves and roller-shoe) in order to quantitative estimate the wear rate.

5. References

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