Study on the sealing defects impact on high pressure pump

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Abstract. The sealing of the high-pressure pump is carried out by means of a seal between the pump drive shaft and the front plate to keep the fuel inside them. The literature presents numerous studies carried out on how these seals last in time and on their composition. Due to the fact that during assembly or during the mounting of the pump on the engine may occur accidental defects on the sealing area, our interest in this paper is to investigate their impact on pump operation. The damages were explored on a test bench a certain number of kilometres and later analysed their impact on the pump using an ultraviolet chamber in a dark room. The experimental analyses were carried out using the EvoCam optical microscope, but also with the help of computer tomography procedure.

1. Introduction

The world's automotive market has seen a growing increase in the number of cars in recent years. Therefore, the most significant car manufacturers have opted for continuous improvement of injection systems using the common internal combustion direct injection system in the detriment of the conventional direct or indirect injection system. We can say that the mode of operation and the characteristics of the injection system have a major impact on engine performance, pollutant emissions as well as noise levels. Continuous quality assurance, attractive design are indispensable in the continuous development of the automotive industry [1].

Numerous analyses were made on the design, analysis and sealing of the components of a pump around the world [2-4]. The factors that influence the life of a pump sealing are given by certain losses: critical wear, surface degradation, mechanical wear (fatigue, adhesion, erosion and abrasion) [5-6].

A study conducted of Massachusetts Institute of Technology shows that 70% of the replacements of the component parts or „loss of useful capacity” are due to surface degradation [7]. In hydraulic and lubrication systems, 20% of these replacements results is rusting, and 50% as a mechanical effect.

Another study says that since 1950, mechanical seals almost entirely replaced those previously used in process pumps because they were more resistant to compression and had easier maintenance [8].

Figure 1 presents the order of the components from which is built a high pressure pump [1]. According to the classification of the European Sealing Association, the sealing is made with gaskets or seal. They are metallic and non-metallic (also called soft seals) manufactured by the compaction process in which the mixture, a wide variety of fibres (carbon, cellulose, glass and lyts) are compressed between two cylindrical drums. This non-metallic seal made from an elastomer supported
by a metallic o-ring on the internal diameter is used to ensure the sealing between the driveshaft, front plate and other components that require insulation between the inside and the outside environment [9-10].

Figure 1. The components of an injection pump [1].

Figure 2 presents a seal used to prevent fuel leakage from inside the pump.

This seal was created by Austrian inventor Walther Simmer, becoming the trademark of the German Company Freudenberg & Co. KG. The Freudenberg Sealing Technologies (FST) and Freudenberg Technology Innovation (FTI) have managed to develop a layer that forms a flexible connection with the elastomer of a seal [11].

Figure 2. Current production seal.

The objective of our paper is to evidence the loss of seal useful capacity for which it was designed and to identify the conditions withstand these seals.

2. Constructive considerations

The sealing function is valued under certain conditions when subjected to compression forces that lead to its deformation fills the voids between the components [11]. Improper installation is a common cause of seal damage and leads to wear occurrence on the seal area.
The most critical condition that have to be respected for the gasket to fulfil its main role (maintaining the contact between surfaces to prevent leaks) is that the forces pressing the gasket must be constant and evenly distributed over the entire surface [1].

The choice of the material from which is made the seal is another important factor because many aspects must be taken into account: pressure applied, thermal resistance and durability time.

Over time, the material from which the seal is made becomes old, dry and can break. If the seal between driveshaft and the front plate has defects of fabrication it can lead to fuel or oil leakage. It’s the most common issue [12].

The seal can be realized in different forms, depending on the application area in which it is used (weight/pressure/high temperatures). The seal with defects can cause great damage, most of the time the failure of the seal leads to the loss of liquid (oil) of that component, and requires its change to prevent complete loss of fluid and destruction of the parts [13-14].

Moreover, the prices of seal used for cars are low in relation to the damage caused. Car experts say changing it can be a simple or more difficult operation and can take from a few minutes to even a few hours. Everything depends on the location of this piece. Incorrect assembly of the seal, inadequate composition and operation can lead to external fuel leakage [15-22].

Figure 3 shows how the components are assembled and the position of the seal in the pump.

3. Experimental investigation
We have assembled several pumps with different seal types in order to demonstrate that certain characteristics, such as seal composition, its correct assembly, the choice of the right type of seal influence the resistance over time. Our investigation is oriented on the seals defects influence on the assembled high-pressure pump.

Consequently, at some seals we have generated particular defects to observe their aggravation over time and over the test. Figure 4 shows a defect created with a straight screwdriver on a assembled pump.

The pump with particular defect (figure 5) was scanned with the help of computed tomography (CT scan) highlighting the defect on the seal. A CT scan is a imaging procedure that uses computer-processed combinations, X-ray measurements that are taken from different angles. The scan procedure
was initiated, before assembling the pump, to detect if we talk about of surface or depth defect. It has been evidenced the sealing area and the conclusion states that is a surface defect (figure 5).

**Figure 4.** Particular defect created on the seal.

**Figure 5.** Tomography of a seal with particular defect.

To evaluate the impact that we realized on the pump, we tested the pump on a test bench for several hundred hours.

**Figure 6.** Pump confirmed with leaks.
The test bench is designed to simulate the high-pressure pump functional parameters on engine in various working conditions, in order to determine the pump capabilities. As the result, in figure 6 it can be observed how the leaks occurred from the inside of the pump after a certain number of kilometers. Therefore, even if in a first approach the defect is of surface one, a major malfunction of the pump occurs. The leaks are highlighted by green color. The picture was taken after testing the pump on the workbench using a professional camera. To better highlight the area where the leaks from the pump occur we used a dark room and a UV (ultraviolet) lamp. The ultraviolet lamp highlights the green color of the liquid test. We used test fluid and not fuel because the room in which it is located the test bench is relatively small and it is necessary to prevent a future accident due to leaks from the pump.

We have disassembled the pump and we have performed a visual inspection. We compared the seal having the defect with a fresh seal. Figure 7 demonstrates the differences between the two seals. The area seal from figure 7(b) presents extensive signs of wear, which indicates that during the operation of the pump on which it is mounted, its surface was seriously damaged, thus losing its sealing qualities. This obviously explains the fluid losses noticed in the operation of the pump, as seen in figure 6.

![Figure 7](image_url). Differences between the two seals.

Moreover, using the EvoCam Microscope, the most affected area of the seal was detailed and significant wear marks are observed (figure 8). It can be seen how the seal lip, the one that ensures the perfect sealing between the components, is almost non-existent on the respective surface. Therefore, the minor surface defect on the seal had an aggravant evolution which led to the fluid leakage from the pump.

![Figure 8](image_url). Seal studied at EvoCam optical microscope.
We also investigated another defective seal including molten material on the sealing area, this area presenting visible deformations of the material.

Figure 9 depicts the gasket with molten material, the defect being highlighted in the upper right (denoted on the figure). The EvoCam optical microscope is also, in this case, the investigation tool. Thus we managed to capture the area of interest.

![Figure 9. Seal with molten material.](image)

The assembled pump which includes the defective seal (with the molten material and corresponding deformations) is tested on the test bench and the area with massive leaks is captured. Figure 10 shows the image of pump leaks, much more pronounced in the area with molten material.

![Figure 10. Pronounced pump leaks in the molten material area.](image)
4. Conclusions
Due to the fact that during the assembly and also during the mounting of the pump on the engine may occur accidental defects, we thought, in a qualitative investigation, to observe the evolution of some sealing defects and their influence on the amount of fuel leaks from the pump during the tests. The pumps with these particular defects were tested on a test bench a certain number of kilometers and after the end of the tests we highlight the flow area of the pumps using dark camera and UV lamp. The impact of these defects created on the seal has a devastating long-term effect because the pumps lose significant fuel. Another point to note is that car manufacturers put another seal on the outside of the pump to protect the customer and so the pump arrives safety. Future work will focus on quantitative estimation on lost fuel related to defective sealing and the pump assembly to ensure a proper operation.

5. References
[1] Bistrițeanu D P and Bujoreanu C 2019 Influence of sealing gasket distortion on diesel engine injection pump mountability ModTech IOP Conf Ser Mater Sci Eng 591
[2] Meher K K and Rao A R 2006 Optimal foundation design of a vertical pump assembly Journal of Sound and Vibration 291 pp 1269-1277
[3] Speck A J 2015 Mechanical Fastening Joining and Assembly
[4] Hayes J B and Bond S 2007 Sealing Technology 8 pp 11-14
[5] Bistrițeanu D P and Bujoreanu C 2019 Experimental Analysis on High Pressure Pump Sealing Gasket Buletinul Institutului Politehnic Din Iasi 65 pp 17-26
[6] Jiaa C L and Dornfeld D A 1990 Wear 2 pp 403-424
[7] Rabinowicz E 1981 American Society of Lubrication Engineers Bearing Workshop
[8] Heinz P Bloch P E 2018 Mechanical Sealing Options for Long Pump Life Empowering Pumps
[9] Gasket Handbook 2017 Fluid Sealing Association FSA 1000 1st Edition pp 138
[10] Toshibyuki S and Ogata N 2002 ASME Pressure Vessels and Piping Conference pp 115-127
[11] Varouitis S, Igitkhanov Y, Day C, Strobel H and Wenninger R 2018 Effect of neutral leaks on pumping efficiency in 3D DEMO divertor configuration Fusion Engineering and Design 136 pp 1135-1139
[12] Li S, Qian C, Li S, Li Q and Liao H 2020 Study of sealing mechanism of gas-liquid miscible backflow pumping seal Tribology International 142
[13] Drago J 2008 World Pumps Publisher European Committee of Pump Manufacturers Elsevier 498 pp 25-27
[14] Zhang Z, Wang D and Guo Y 2019 Tribology International: Elsevier 133 pp 236-245
[15] http://www.flexitallic.eu/upload/brochures/Gasket_Design_Criteria.pdf
[16] Aibada N, Manickam R, Gupta K K and Raichurkar P 2017 Review on Various Gaskets Based on the Materials their Characteristics and Applications International Journal on Textile Engineering and Processe 3
[17] Voitik R M 1993 Realizing Bench Test Solutions to Field Tribology Problems Tribology Wear Test Selection for Design and Application pp 45-59
[18] Park S J, Park S D, Kim K S and Hyun Cho J H 2006 Reliability evaluation for the pump assembly using an accelerated test International Journal of Pressure Vessels and Piping 83 pp 283-286
[19] Bayer R G 2002 Wear Analysis for Engineers HNB Publishing New York
[20] Blau P J 1992 Friction Lubrication and Wear Technology ASM Handbook ASM International 18
[21] Lutynski C, Simansky G and McEvily A J 1982 Fretting Fatigue of Ti-6Al-4V Alloy Materials Evaluation Under Fretting Conditions pp 150-164
[22] Ciornei F C and Alaci S 2016 Characterization of rubbers from spherical punch - plate indentation tests Robotica & Management 21 pp 10-14