Influence of sealing gasket distortion on diesel engine injection pump mounting

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Abstract. Currently, the common-rail injection system is composed from a high-pressure pump, injectors, an electronic control unit and a common rail. Over time, the common-rail system has been simplified and optimized, but it remains that the high-pressure pump can still be affected by distortion which occurs during the pump assembly process and in turn has an effect in mounting the pump to the engine. The main assemblies of the diesel pump are the front plate, housing, driveshaft and hydraulic head. Our paper presents a solution for minimizing the distortion and also any external leaks that may occur due to a change in design of the sealing gasket between the body and front plate. This modification realizes the connection interface with the engine block and facilitates the pump mounting. The tests analysis is performed on high pressure pumps to determine where and when the distortion occurs.

1. Introduction

Most car manufacturers select a common-rail direct injection system for their internal combustion engines rather than a conventional direct or indirect injection system due to many advantages. The features of the injection system as well as the operating mode have a significant impact on pollutant emissions, noise levels and engine performance. Improved design and controls for continued quality assurance are indispensable in this industry and its continued development. Injection systems have proven to be the most important factor contributing to the failure of the diesel engine.

The most affected component from injection system is the diesel pump. The main assemblies of the diesel pump are the front plate, housing, driveshaft and hydraulic head.

As a result of measurements made on an experimental test rig that simulates the actual dimensions and conditions of a pump mounted on the engine, it has been observed that the pump cannot be assembled on it. This is due to the pump front plate nose distortion. Distortion is a deformation/deviation from the initial form of a component under certain conditions. Pump distortion may have a negative effect on the stability, sealing on the engine, [1-4].

Literature presents numerous analyses on the design and sealing of gaskets, [5-7]. The objective of our paper is to create a finite element model (FEM) to replicate the front plate assembly tightening similar to the engine in order to find the main contributor to front plate nose distortion. The front plate is modeled to minimum limit dimensions because the less material it has, the more distortion produced will be greater. The front plate nose distortion shape correlates with the test data and the gasket is identified as one of the main contributors to front plate nose distortion.
Figure 1. The components of an injection pump.

Figure 1 presents the gasket positioning in an injection pump. A gasket is classified as a mechanical seal, filling the space between two or more pair surfaces. Typically, this is done to prevent leakage between the joined surfaces while under compression. There are many applications for gaskets in the automotive industry, including cylinder-head sealing gasket, cooling system gaskets and in the high pressure diesel fuel pump, [8].

In figure 2 is depicted the typical shape of a gasket.

Figure 2. Current gasket shape.

The gasket is subjected to environmental factors such as temperature, pressure differences, and vibration. Literature offers studies concerning gasket materials behavior under these conditions and also their comportment under low load conditions, [9].

The various elastic and elasto-plastic behaviors of the threaded joints with rings subjected to traction force are also studied. Tensile resistances of bolted circular flange connections, stress and displacements of joint bolts are experimental evaluated, [10, 11].
The sealing function of the gasket is achieved under certain conditions involving compressive forces that lead to its deformation by filling the voids between the components. The optimal contact pressure between components leads to deformation of the gasket, thus preventing leakage between them. Since the gasket main role is to maintain surfaces contact and prevent leakage, it is necessary that the forces pressing the gasket be constant and uniformly distributed throughout its surface.

The hydrostatic load must be less than the residual load applied to the gasket. Hydrostatic force is used to separate the flanges by acting on the internal pressure. Different parameters should be taken into account when selecting the sealing gasket to guarantee the customer's requirement. The properties of sealing gaskets, configuration and application of points of interest are very important in determining the used parameters, [12].

Another important issue for sealing gaskets is the choice of material. It must withstand a certain pressure applied to it at a certain temperature but also for a prolonged period. Sealing gaskets are classified and arranged according to the material of which they are composed: metals, non-metals, polymers and hybrids, [13].

An experimental study on the wear and friction mechanism on the interface was conducted in, [14], in order to evaluate the tribological behavior between the spiral gasket and the flange. It is stated that the abrasive and adhesive wear are prevalent and high loads lead to plastic deformation. The gross wear can be observed in friction process mainly on the circumferential direction of small displacement. Large displacement quickly creates a graphite layer on the stainless steel surface and improves the friction coefficient, avoiding the wear risk, [15].

Our paper aim is to experimentally study the influence of gasket design on its sealing performance. Finite element method (FEM) is used to optimize the model and the measurements show the sealing improving. Front plate distortion causing leakage is discussed and the paper results demonstrate that an optimal change in the sealing gasket design influences the mounting of the finished product to the engine.

2. Methodology and materials

The sealing gaskets of the injection pumps are divided into metallic and non-metallic types. As materials for metallic gaskets it can be used stainless steel, aluminum, titanium, monel, copper, gold, rhenium and Inconel. Table 1 presents a synthesis of their characteristics and applications.

| Material       | Characteristics                          | Applications                      |
|----------------|------------------------------------------|-----------------------------------|
| 1 Stainless    | Decent corrosion resistance              | High temperature applications     |
| Steel          | Decent tensile strength                  |                                   |
|                | Can withstand elevated temperatures      |                                   |
| 2 Rhenium      | Less hole deformation                    | High pressure applications        |
|                | Higher sample stability                  |                                   |
| 3 Gold         | High corrosion resistance                | Small area applications           |
| 4 Copper       | Good sealing capacity                    | High temperature application      |
| 5 Inconel      | Good corrosion resistance                | High temperature applications     |
|                | High creep strength                      |                                   |
| 6 Aluminium    | Good corrosion resistance                | Corrosion prone environments      |
| 7 Monel        | Good chemical resistance                 | High pressure applications        |
|                | Good corrosion resistance                |                                   |
| 8 Titanium     | Good corrosion resistance                | High temperature applications     |

The metallic sealing gasket can be made in different shapes, depending on the application area where it is used (high load, pressure, temperatures). These gaskets are manufactured as simple sheets and therefore
they are very light. The sealing gasket between the front and housing is made by stainless steel (a combination of Cr-Ni) because it has high corrosion resistance and good tensile strength, then it is coating.

The measurements of gasket circularity are performed using the Mahr and Zeiss measurement system for diameter and position. The Zeiss measurement system is a machine that uses optical and multi-sensors systems driven by a metrology software to realize measurements with high precision in automotive industry, mechanical engineering, aircraft, medical and plastics technology, [17].

The experimental study is carried out using the Taylor Hobson's measurement system by analyzing the way and process steps for building a pump. This measurement system allows the front plate diameter to be measured on three height sections (figure 3). Also, it is measured the circumference of the seal, starting with assembled pump, until the final stage of its mounting on the engine.

![Figure 3. Front plate diameter measurements on three height sections.](image)

![Figure 4. Front plate with inserted bush.](image)

Measurements are made on fresh front plates and gaskets (received directly from the supplier), prior to assembly, and at different stages of the assembly process. Distortions were observed on two pumps from different injection pump suppliers using the same type of belt for pump rotation.

Figure 4, shows the second step of the process of assembling a front plate having the inserted bush.

![Figure 5. Forces on the front plate and the gasket.](image)
Figure 5 suggests that the force applied to the screws is not uniformly distributed due to the geometry of the components and their dimensions. Literature shows that the deformation of the sealing gasket can be also caused by the uneven distribution of the bolt screwing torque, [18-20]. Therefore, the screwing process influences the gasket distortion. In order to be sure of the conditions that lead to the distortion of the gasket, measurements are made on 50 pumps.

3. Results and discussion
The front plate and sealing gasket analyses were carried out using ANSYS Workbench in a non-linear static domain. The simulation is performed to solve the interference with the bush. The finite element method (FEM) is used in various areas of engineering interest: fluid flow, heat transfer, structural analysis, mass transport and electromagnetic potential.

The finite method of the problem results in a system of algebraic equations that establishes a value close to the unknown function. To solve the problem, large systems are divided into simpler smaller parts called finite elements. The element modeling uses simple equations, which are then grouped into complex equations, resulting in the modeling of the whole problem. FEM approximates the solution to minimize error functions using varied calculation methods, [21, 22].

![Figure 6. Correlation of front plate dimensions (FEM analysis vs. Taylor-Hobson measurements).](image)

The FEM analysis of the assembled front plate provides interfering data of the front plate with the bushing. The bushing is inserted inside the flat front, as in figure 4.

Figure 6, shows the comparison of the front plate dimensions resulting from FEM analysis with results obtained by Taylor-Hobson method and manufacturer admissible data.

Lower and upper interference represent the minimum and maximum diameter, respectively, of the front plate with the inserted bushing. In section 3, the maximum distortion values obtained with the FEM analysis are lower compared with admissible data. This may be explained by front plate cross section thickness. In the other two sections plotted in figure 6 it can be observing a good correlation between the FEM results and admissible data.
Zeiss measurement system gives us the roundness of gaskets. In this regard, figure 7, presents the circularity of the gasket but also a large distortion which leads to the impossibility of mounting the pump on the engine.

![Figure 7](image)

**Figure 7.** Distortion shape in section 3 (FEM analysis compared to data obtained with the Zeiss measurement system).

Figure 7 (Test data-Part 9) presents the sealing gasket measured on the three sections and it is compared the ideal one (red) with the gasket measured on Zeiss system (blue). FEM analysis depicts a simulation of distortions created by the flat front plate after the pump assembling. The simulation is based on the measurements on Zeiss system. The diameter value of the first circle is 24.96 mm and the last diameter value of sixth circle is 25 mm.

As result of the above observations, we have continued our study on a current gasket and an improved to one with a stiffening solution. Figure 8 presents the distortion values for current gaskets from all the 50 tested pumps. There are many differences and the causes of these distortions may be linked to the material thickness and strength and also to the gasket geometry. The maximum distortion observed for the tested current gaskets is 0.0451 mm and the minimum one is 0.0299 mm.

![Figure 8](image)

**Figure 8.** Current gaskets distortions.
To reduce the observed distortions a new solution for the gasket design is proposed. Adding stiffening beads has improved the contact pressure distribution due to reduced distortion on the highlighted region. Contact is seen only on the beads/pads.

The gasket sealing pressure is increased from 17MPa to 24MPa (figure 9). We used this pressure value (24MPa) because we want the pads to improve load distribution on the lining (the output surface). In the FEM analysis it can be observed that we experience lower pressure applied to the gasket across the kidney slot and we note an increase as an indicator of improving the contact pressure, thereby showing a more even distribution of load and reduced distortion. In the FEM analysis we used different values on the surface of the gasket to see which of these values is best suited for improving the contact pressure.

![Figure 9. Gasket contact pressure.](image)

In figure 10, the red contour shows the stress above the yield strength (1200 MPa) of the material. Material yielding will be seen on these regions. For the option 5B, the stiffening bead/pad in the location 2 and 3 can be moved radially outward to improve the stress levels.

![Figure 10. Gasket stress distribution.](image)

The greatest improvement in distortion reducing is observed on the third height section of the front plate measurements (section 3), furthest from the body of the pump.

Modifying the sealing gasket design, its roundness has been improved, with positive effects on the leakage. This is an important step in order to ensure the mounting of the final product on the engine (figure 11).

The maximum distortion value observed for the improved sealing gasket is 0.0311mm and the minimum one is 0.0243mm (figure 12).
The obtained results show differences between the deformations using the current gasket and those resulting after the proposed modification had been implemented.

Figure 11. Improved gasket roundness.

Figure 12. Improved gasket distortions.

4. Conclusions
Due to the fact that the old gasket design, the sealant between the body and the front plate could cause leakage outside the pump, we have analysed it to show the optimal solution against distortion and leakage. The new solution consists in stiffening pads implemented on the gasket. This stiffening pad helps to support bolt load being spread uniformly. The following conclusions are drawn:
1. Gasket is defined as the main contributor to front plate nose distortion. The front plate nose distortion shape co-relates with the test data.
2. The current front plate with the improved gasket has a wider kidney slot which causes uneven load distribution leading to front plate nose distortion.
3. Front plate distortion is sensitive to the design change made on gasket compared to the front plate design.
4. Location of the gasket stiffening bead/pad closer to bolt holes helps in changing the front plate nose distortion pattern.
5. The new gasket design also helps in better sealing and improved clamping load distribution.

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