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Stainless Steel Crush Washer Sealing and Fretting Finite Element Analysis

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ABSTRACT

This study employs Finite Element Analysis to evaluate the effectiveness of sealing and fretting on crush washers, which are critical to ensure that the washer is correctly installed and in good condition for the proper functioning of the fuel pump. Ineffective sealing can lead to fretting damage, which in turn can cause fuel leakage, misalignment of components, and reduced performance or even damage to the fuel pump. Regular maintenance and inspection of the fuel pump components, including the washer, can help identify potential issues early and maintain the efficiency and reliability of the diesel engine.

Keywords: Finite Element Analysis (FEA), Stainless Steel Crush Washer, Sealing Effectiveness, Fretting Damage, High-Pressure Fuel Pump, Diesel Engine Reliability

INTRODUCTION

A major failure mode in modern combustion engines is the leakage of the cylinder-head sealing system, which is induced by fretting damage on the engine head and block deck surfaces [1]. High static and fluctuating pressures in high-pressure fuel systems necessitate leak-proof joints for proper engine operation and safety. Sealing pressure, length of the sealing width and retaining capability of joint preload over time are used to evaluate the sealing capability of a joint [2].

In a typical diesel engine fuel pump, the pump head, barrel and crush washers are critical components involved in the high-pressure fuel delivery system. The pump head delivers high pressure fuel to the injectors [3]. The barrel is a cylindrical component in which the plunger moves up and down within the fuel pump. A high-pressure chamber is created as the barrel forms a precision fit with the plunger.

In many diesel engine fuel pumps, there is often a stainless-steel washer or shim between the barrel and the pump head. This washer serves several important purposes such as wear protection, sealing, alignment and thermal insulation. Corrosion and wear resistance are inherent properties of stainless steel, and this helps protect the surfaces of the pump head and barrel from wear caused by the high-pressure fuel. Creating a high-pressure seal between the surfaces of the pump head and barrel is critical to ensure that there is no fuel leakage and high- pressure fuel for injection is delivered. The washer also reduces the heat transfer between the pump head and barrel and acts like a barrier providing thermal insulation of the interface. Precise alignment between the plunger and barrel is also ensured by controlling the internal diameter of the washer.

Sealing and fretting are crucial parameters that need to be controlled in high-pressure fuel injection systems due to several important reasons:

1. Sealing:

Fuel leakage should be prevented at all costs and a robust sealing strategy is needed to prevent fuel leaks. A good seal guarantees precise fuel delivery and efficient combustion without any losses in the combustion chamber. Fuel leakage can lead to increased fuel consumption and reduced overall engine performance.

Sealing system failures can lead to significant safety risks since engines typically operate at extremely high pressures. A fuel leak can result in hazardous situations which may include explosions, fires and risk to human life.

2. Fretting:

Small scale relative motion which occurs between 2 surfaces is referred to as fretting and this can build up over time to result in wear and damage. The integrity of seals and other components can be compromised even if a minor amount of fretting is present in high pressure fuel systems, leading to premature failure

Downtime and maintenance costs can be reduced by minimizing fretting wear. The longevity of seals, washer and other critical components can also be enhanced by reducing fretting.

Sealing and fretting are interdependent parameters. A loss in sealing will lead to fretting, which in turn can lead to fatigue failure. The fretting damage process is a synergistic competition among wear, corrosive and fatigue phenomena driven by both the microslip at the contact surface and cyclic fretting contact stresses [4]. Understanding the root cause of sealing failures will eventually lead to prevention of fatigue failure.

METHODOLOGY

This analysis aimed to evaluate the sealing and fretting margin at the sealing interfaces on the top and bottom of the crush washer.

FEA model

A 3-dimensional CAD model of a fuel pump head, barrel, and crush washer was developed using Dassault Systèmes SolidWorks software. A 2D geometry that represents the cross-section of an axisymmetric model was also developed and imported into Ansys Mechanical 14.0 software package. The 2D surface geometry is in the XY-plane with the Y-axis representing the axis of symmetry. For axisymmetric analysis, you typically only need to model one-half or one-quarter of the cross-section. In the "Model" tab of Ansys Mechanical, the type of analysis is defined as static, and the model is defined as axisymmetric. A mesh is generated for the 2D geometry, and the mesh consists of 66500 elements and 203000 nodes. Loading and boundary conditions are assigned to the mesh model as shown in Figures 1 and 2. Symmetry boundary conditions are applied along the axis of symmetry Material properties are also assigned as shown in Table 1. The base of the pump head was fixed in all directions (denoted by “Constraint” in Figure 1). A bolt pretension load of 57 KN was applied at the pump head to simulate the clamp load from the barrel that will compress the crush washer. A uniform pressure and pressure gradient were applied along the inner edge of the barrel to simulate the dynamic pressure during pumping.

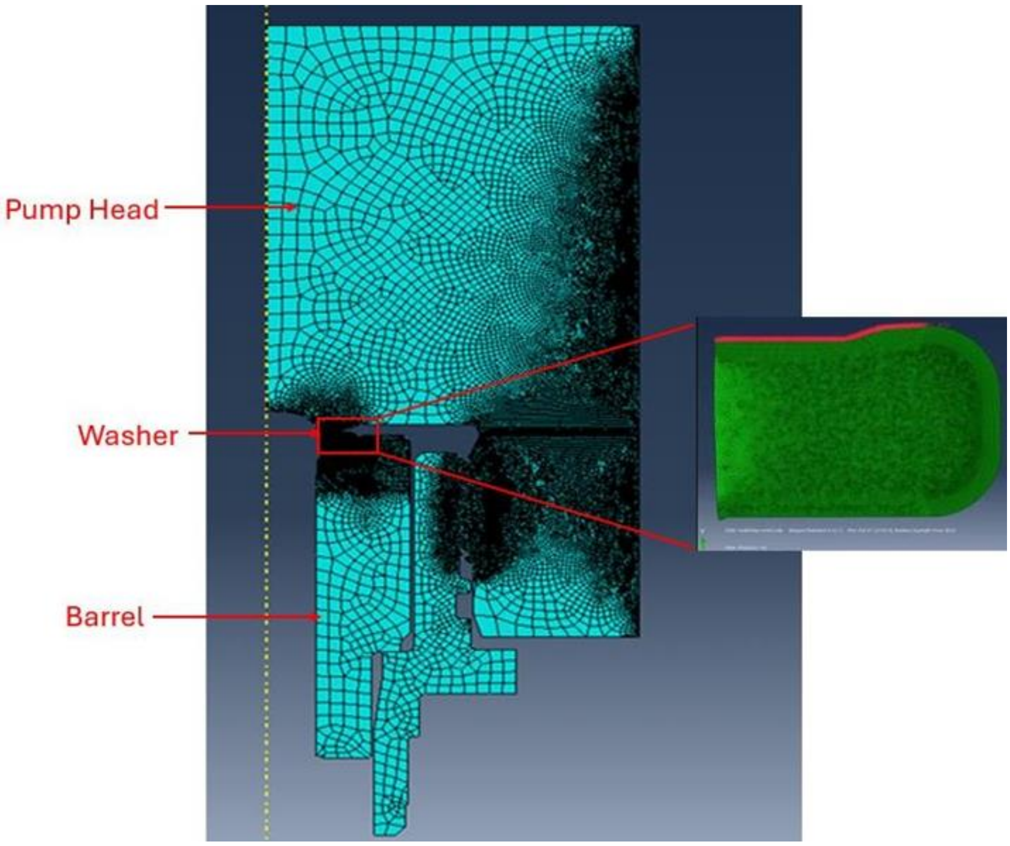


Figure 1: 2D Axisymmetric mesh of the model.

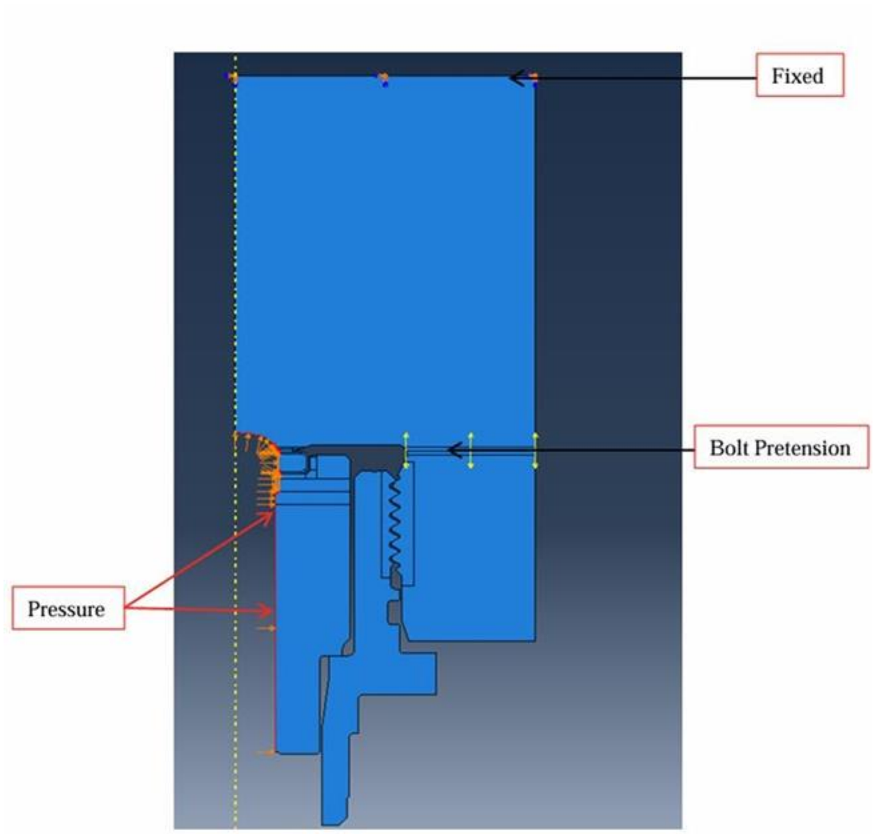


Figure 2: A 2D FEA model of the pump assembly with boundary and loading condition

Table 1: Material properties of different components of the pump model.

Component	Material Used	Modulus (MPa)×10^5	Poisson's Ratio
Pump Head	4140	1.930	0.29
Barrel	4140	1.930	0.29
Crush Washer	SS	1.902	0.30

RESULTS AND DISCUSSION

Figure 3 shows the contact pressure distribution at the upper and lower surfaces of the crush washer. The passing criterion for sealing is to ensure that the contact pressure is more than 50% of the max pressure for at least 1mm along the length of the sealing interface. The surface length exposed to 450 MPa contact pressure or more at both surfaces is more than 1mm. A fretting threshold of 0.25 microns was established, and both the upper and lower surfaces of the crushwasher exhibited fretting levels below this threshold. This indicates that the relative movement between the washer and the pump head, as well as between the washer and the barrel, will not cause wear on the sealing interface over time, thereby preventing the formation of a potential leak path for fuel.

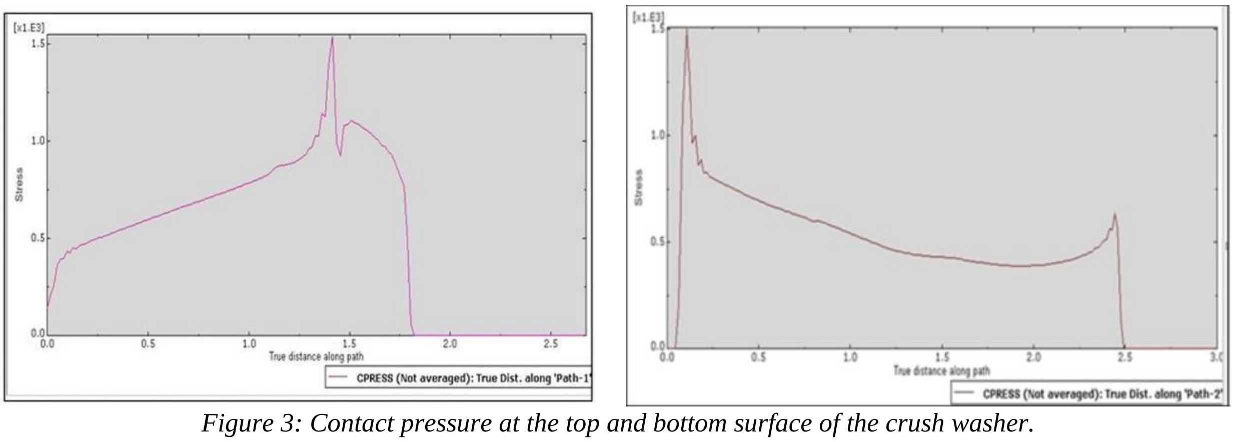
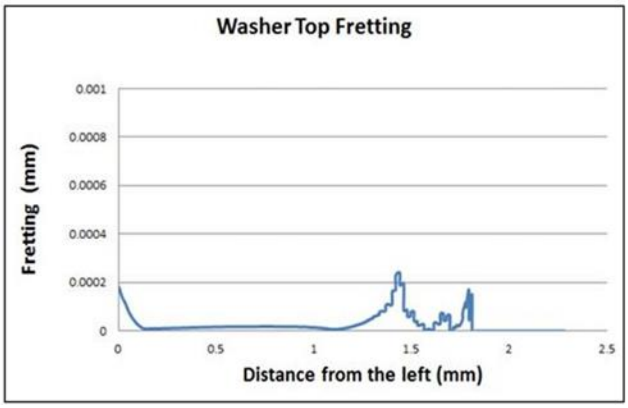


Figure 3: Contact pressure at the top and bottom surface of the crush washer.



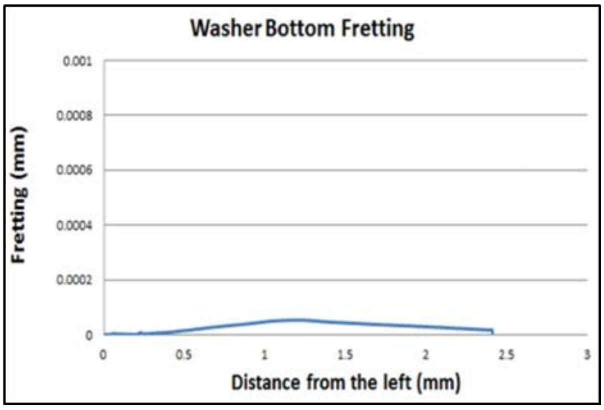


Figure 4: Fretting at top surface of the crush washer.

CONCLUSION

The study used finite element analysis (FEA) to assess the sealing and fretting experienced by a crush washer in a high-pressure fuel pump. To prevent fuel leakage, the pressure distribution should be greater than 450 MPa contact pressure over an acceptable surface length of 1mm from all sides. The paper emphasizes the significance of ensuring sufficient crush along the washer and efficient axial load transfer to generate a high contact pressure. By ensuring effective sealing and minimizing fretting, high-pressure fuel injection systems can operate more efficiently, safely, and with greater reliability, leading to better overall engine performance and reduced operational costs. Future work can include exploring the impact of sealing under high and low temperatures, considering potential problems such as aging at high temperatures and brittle fracture at low temperatures, which can cause failure. It is also crucial to investigate the dynamic performance of combined sealing structures under extreme working conditions.

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