Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2021, 8(7):96-99

Research Article ISSN: 2394 - 658X

Optimizing Cap Screw Performance in Fuel Injector Pilot Valves: A Finite Element Analysis

Aneesh Kaliyanda

Email: aneeshkr99@gmail.com

ABSTRACT

In this study, stress distribution was computed at the caps screws of the of the fuel injector's pilot valve assembly. A detailed CAD model of the assembly followed by finite element analysis (FEA) was done. This study applied a preload of 4.4kN (corresponds to 2.7 Nm torque) on M3x0.5 cap screws (grade 12.9). The results determined that screws will yield but not fracture at the applied torque. A 30% safety factor was further considered. Accordingly, a higher preload of 5.72kN was applied. Under both loading conditions, maximum stresses were below the true fracture stress of 1481 MPa.

Keywords: caps screw, torque-preload relation, fuel injector, pilot valve assembly, finite element analysis

INTRODUCTION

Determining the appropriate torque and grade for cap screws in fuel injector pilot valves is vital for ensuring structural integrity and operational efficiency [1]. The relationship between torque and preload has been extensively studied, as preload is crucial for maintaining the clamping force necessary for the integrity of assemblies [2]. Ludman and Waterland (2009) provide a foundational understanding of mechanical design principles, emphasizing the importance of preload in fastener applications [3]. However, these studies often rely on idealized assumptions that may not hold in practical scenarios. Material properties of cap screws play a significant role in determining their performance under various loads. The selection of appropriate cap screw grades, especially for high-precision applications like fuel injector pilot valves, is crucial. Mahlem et al. (2014) discuss the mechanical properties of different grades of fasteners and their suitability for specific applications [4]. While valuable, these works lack specific guidelines for M3x0.5 cap screws in high-precision assemblies.

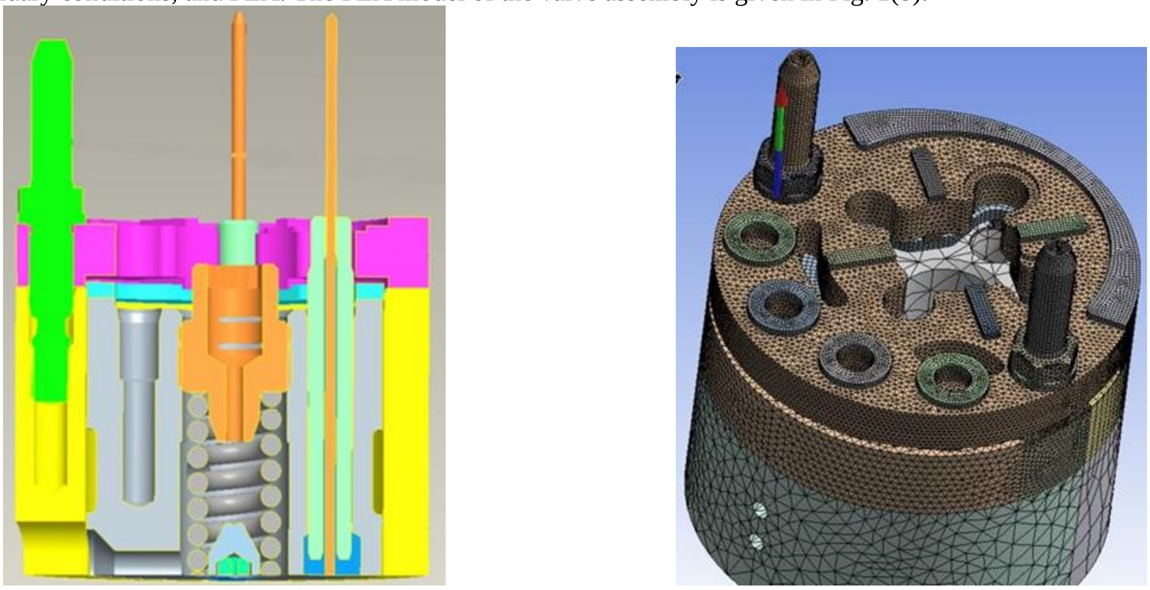
Empirical methods for validating theoretical calculations of torque and preload are essential for ensuring the reliability of fastener assemblies. Fransplass (2015) highlighted the importance of experimental testing to complement theoretical models, but their focus is primarily on larger fasteners [5]. Similarly, Nassar et al. (2005) emphasize the need for empirical validation but do not address the specific challenges associated with small cap screws [6]. Fuel injector assemblies require precise control of preload to ensure optimal performance. Krogerus et al. (2016) investigated the mechanical behavior of fuel injector components under various loads, underscoring the critical nature of proper fastening [7]. However, this study does not delve into the specifics of cap screw selection and torque optimization.

ISO 898-1 (2004) [8] Standards provide guidelines for the mechanical properties of fasteners. However, these standards often lack specific recommendations for the torque and preload requirements of small-cap screws in precision assemblies. Similarly, the VDI 2230 [9] (1998) guideline offers insights into the systematic calculation of high-duty bolted joints but does not address the nuances of M3x0.5 cap screws. Recent advances in measurement techniques have improved the accuracy of preload determination in fasteners. Ultrasonic measurement methods offer a non-destructive way to measure preload in situ, providing valuable data for validating theoretical models. However, these techniques are not always applicable to small cap screws. Several fastener failures have occurred due to improper torque application, lubrication, or friction [10,11]. These studies reinforce the importance of the comprehensive approach adopted in this research.

Current literature and practices in the field overlook the intricate balance between achieving the desired preload and avoiding the risk of screw failure due to overload. The primary objective of this study is to determine stress distribution at the M3x0.5 cap screws for a fuel injector's pilot valve assembly optimal torque subjected to a preload varying between 4.4-5.72kN. This study employed FEA to determine stress distribution. The findings of this study have significant implications in mechanical engineering. This research enhances the reliability and efficiency of the fuel injector's pilot valve assemblies. The methodology can be applied to other high-precision assemblies, offering a robust solution to a common engineering challenge.

METHODOLOGY

A 3-dimensional CAD model of a fuel injector's pilot valve assembly was developed using Dassault Systèmes Solidworks software. A sectional view of the CAD model with different components is shown in Fig. 1(a). The CAD model was exported to Altair Hypermesh as a STEP file for meshing. Four-nodded tetrahedral elements were generated to develop the finite element (FE) model. In all, 3,21,500 elements and 4,21,822 nodes were created. The FE model was exported to the Ansys Mechanical 14.0 software package for assigning material properties, loading and boundary conditions, and FEA. The FEA model of the valve assembly is given in Fig. 1(b).



(a) (b)

Fig. 1 *(a) Mid-sectional view of the CAD and (b) 3D isometric view finite element model of the fuel injector's pilot valve assembly*

The material property of each component was defined within the elastic region. Young's modulus of 191GPa and Poisson's ratio of 0.29 was assigned to the spacer, spring disc, stator, and cap screws. PV housing was assigned Young's modulus and Poisson's ratio of 192GPa and 0.3, respectively. To determine the preload on the screw, the spring disc was given a displacement until yielding occurs. It was noticed that the spring did not yield until a displacement of 0.32mm corresponds to a 4.4kN load, as shown in Fig. 2. This corresponds to the torque value of 2.7Nm.

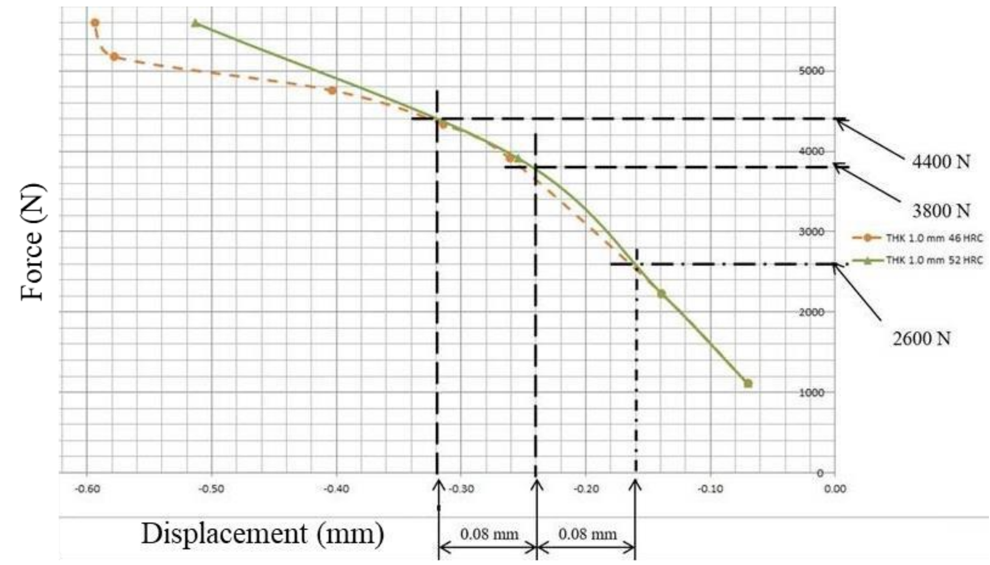


Fig. 2 *Force versus displacement of spring discs of 1mm thickness and 46 or 52HRC hardness*

Two load cases were considered: (1) nominal preload of 4.4kN and (2) preload considering the factor of safety of 30% (4.4 *1.3=5.72kN). Stator has been given an upward displacement of 0.32mm (equal to the considered deflection of the spring disc) in both load cases. Effective stress distribution was computed for both cases.

RESULT

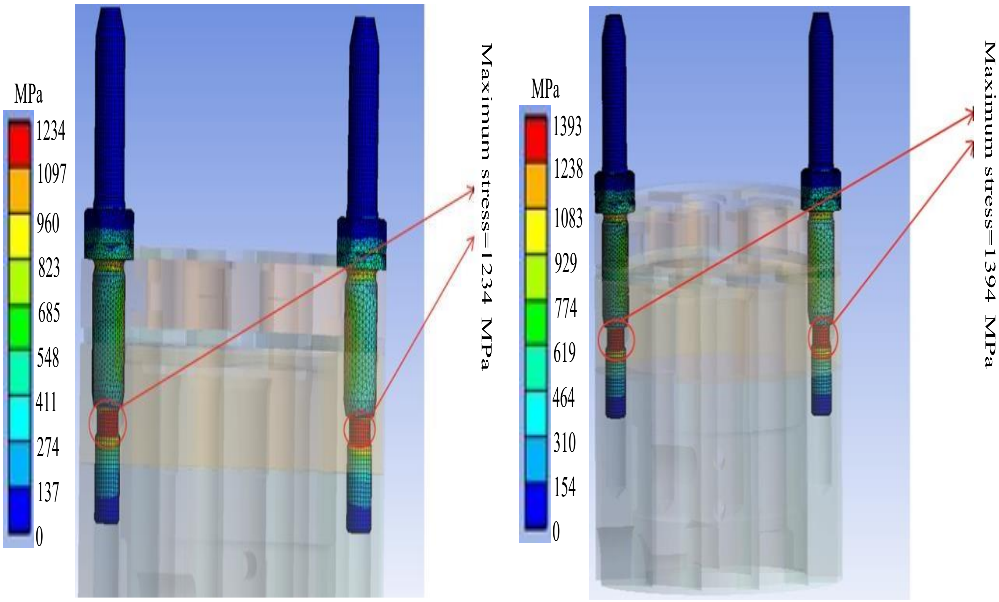


Fig. 3 *Effective stress distribution at caps screws of the assembly for load case 1 (a) and case 2 (b).*

Effective stress distribution at caps screws of the assembly for load case 1 and case 2 is given in Fig. 3. Maximum effective stress in load case 1 and case 2 were 1234 MPa and 1394 MPa, respectively. These values are less than the bolt's true fracture stress of 1481N. However, in both cases, yielding will occur. Yield stress of grade 12.9 caps screw is 1100 MPa. Accordingly, the grade 12.9 caps screw was suitable to withstand preload of up to 5.72kN.

DISCUSSION

The primary objective of this study was to evaluate the stress distribution in Grade 12.9 M3x0.5 cap screws used in a fuel injector's pilot valve assembly under different preloads, using finite element analysis (FEA). This section discusses the implications of the findings, compares them with existing literature, and addresses the relevance of the study's methodology and results in practical engineering applications.

The FEA results illustrated in Fig. 3(a) and (b) depict the effective stress distribution at the cap screws under two preload conditions: 4.4kN and 5.72kN, corresponding to torque values of 2.7

Nm and 3.51 Nm, respectively. Maximum effective stresses were 1234 MPa and 1394 MPa for the two preload cases. These stresses were well below the true fracture stress of the cap screws, which is 1481 MPa, indicating that the screws will not fracture under the applied loads. However, yielding of the screws is expected due to stresses exceeding the yield strength of 1100 MPa for Grade 12.9 cap screws.

Literature review reveals that while general principles of preload and torque relationship are well-established, specific guidance for small-cap screws like M3x0.5 in high-precision applications such as fuel injector pilot valves is limited. Standards such as ISO 898-1 provide mechanical properties of fasteners but lack detailed recommendations for torque and preload in small-cap screws. This study bridges this gap by providing empirical data on stress distribution and yield analysis specific to Grade 12.9 M3x0.5 cap screws under practical preload conditions.

The methodology employed in this study, utilizing CAD modeling, FEA using ANSYS Mechanical, and consideration of material properties within the elastic region, offers a robust framework for analyzing the structural integrity of fastener assemblies. Using a 30% safety factor in determining the higher preload (5.72kN) underscores the practical application of engineering principles to ensure reliability without compromising safety margins.

The findings of this study have significant implications for mechanical engineering practices, particularly in optimizing the design and assembly of critical components like fuel injector pilot valves. By demonstrating the suitability of Grade 12.9 M3x0.5 cap screws for withstanding preloads up to 5.72kN, this research enhances the understanding of fastener performance under high precision and high load conditions. Future research could further validate these findings through experimental testing and extend the analysis to include factors such as thermal effects and dynamic loading scenarios.

CONCLUSION

This study determined the optimal torque (2.7Nm) and preload (4.4kN) for M3x0.5 cap screws in fuel injector pilot valve assemblies, ensuring structural integrity without overloading the screws. The analysis confirmed that grade 12.9 cap screws are suitable for withstanding the required preload, even with a safety factor of 30%, maintaining effective stress below the true fracture stress.

REFERENCES

[1]. Jadhav, A.K.; Joshi, D.S.G.; Maskar, P.D.; Patil, S.V. Design a New Pressure Regulating Valve for Fuel Injection Pump of Diesel Engine. Int. J. Eng. Res. Technol. 2020, 9, doi:10.17577/IJERTV9IS090089.

[2]. Yu, Q.; Yang, X.; Zhou, H. An Experimental Study on the Relationship between Torque and Preload of Threaded Connections. Adv. Mech. Eng. 2018, 10, 1687814018797033, doi:10.1177/1687814018797033.

[3]. Ludman, J.; Waterland, A.F. Practical Application of Fastener Preload Guidance Research. In Proceedings of the Pressure Vessels and Piping Conference; The American Society of Mechanical Engineers, 2009; pp. 163–170.

[4]. Melhem; Bandyopadhyay; Sorrell Use of Aerospace Fasteners in Mechanical and Structural Applications. Ann. Mater. Sci. Eng. Austin Publ. Group 2014, 1, 1–5.

[5]. Fransplass, H.; Langseth, M.; Hopperstad, O.S. Experimental and Numerical Study of Threaded Steel Fasteners under Combined Tension and Shear at Elevated Loading Rates. Int. J. Impact Eng. 2015, 76, 118–125, doi:10.1016/j.ijimpeng.2014.08.004.

[6]. Nassar, S.A.; El-Khiamy, H.; Barber, G.C.; Zou, Q.; Sun, T.S. An Experimental Study of Bearing and Thread Friction in Fasteners. J. Tribol. 2005, 127, 263–272, doi:10.1115/1.1843167.

[7]. Krogerus, T.R.; Hyvönen, M.P.; Huhtala, K.J. A Survey of Analysis, Modeling, and Diagnostics of Diesel Fuel Injection Systems. J. Eng. Gas Turbines Power 2016, 138, doi:10.1115/1.4032417.

[8]. PN-EN ISO 898-1, Mechanical Properties of Fasteners Made of Carbon Steel and Alloy Steel – Part 1: Screws, Screws and Studs with Specified Property Classes – Coarse Thread and Fine Pitch Thread.

[9]. Heston, A.W. VDI Joint Design Procedures. In Handbook of Bolts and Bolted Joints; CRC Press, 1998 ISBN 978-0-429-15357-0.

[10]. Croccolo, D.; De Agostinis, M.; Vincenzi, N. Failure Analysis of Bolted Joints: Effect of Friction Coefficients in Torque–Preloading Relationship. Eng. Fail. Anal. 2011, 18, 364– 373, doi:10.1016/j.engfailanal.2010.09.015.

[11]. Eliaz, N.; Gheorghiu, G.; Sheinkopf, H.; Levi, O.; Shemesh, G.; Ben-Mordechai, A.; Artzi, H. Failures of Bolts in Helicopter Main Rotor Drive Plate Assembly Due to Improper Application of Lubricant. Eng. Fail. Anal. 2003, 10, 443–451, doi:10.1016/S13506307(03)00018-9.