Stress Analysis of Cylinder Head Bolt of 4 Strokes SI Engine using FEM

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Abstract— Automobile has become an unavoidable part of our day to day life. Thus looking into its importance in the daily routine its safety needs to be taken into account. The stud connecting the cylinder head and block is a part of concern. The current study deals with the FEM analysis of stud where the analytical calculations are compared with the software results.

Key words: Stud, Automobile

I. INTRODUCTION

The Bolted joints are separable joints held together by means of thread fastening such as bolt and nut. The Internal Combustion engine cylinder head bolt is continuously subjected to high pressure and high temperature. Especially in S.I.engine the variation in pressure is more due to knocking as compared to C.I.engine.

In current decade automotive industries are having more demands for two wheeler in Indian market. Because of low emission and high thermal efficiency 4 stroke engines are preferred than 2 stroke engines and all two wheelers in Indian market are of SI engine, hence 4 stroke S.I.engines are necessary to analyze. It is necessary to analyze the bolted joint in order to contribute to a systematic design of bolted joint to avoid uneven thermal expansion. Recently with development of chemical industry and many automotive industries, the working conditions have become more severe regarding distribution of contact stresses which governs the sealing performance of bolted joint with gasket, so it is necessary to design bolted joints more reasonable

A. Importance of Structural Analysis of Cylinder Head Stud

The design of structural systems involves elements that are connected through bolt, rivets and pins. Joints and fasteners are used to transfer loads from structural element to another. The connecting elements play an important role in overall static and dynamic characteristic such as natural frequency, mode shapes and response characteristic of external excitation the joints do represent a discontinuity in the structure and result in high stresses which often initiate joint failure.

Both the design and the development of the automobile engine are complicated processes. To acquire the best performance of an engine in any operating condition in harsh natural environments, many analytical tools and experimental methods are used to find the optimum parameters for engine design. However, numerous measured results point out that the gas escaping from the engine not only affects the output efficiency of the horsepower substantially, but also pollutes the environment. Therefore, the guarantee that the assembly between the cylinder head, bolts, and gasket is reliable and effective, through proper analytical procedures and tests becomes extremely important. Furthermore, the reduction of time and costs are considered in the development process of a novel engine. The above-mentioned reasons are critically deciding factors whether the goals of a novel engine being developed are achieved or not. For solving these foregoing issues, the structural analysis must be adopted in the engine design to save the time of actual modifications.

The current study emphasis on stress, strain, temperature, heat flux, thermal gradient distributions in the component materials. The study was carried out using the Finite Element Methods Approach. UG and ANSYS software's have been used to carry out this finite element study. UG was used for the solid modeling of engine components and ANSYS was used for the analysis.

The study was carried out on prime components of an internal combustion engine such as cylinder head stud Peak stresses were compared with the strength of the corresponding materials and finally attempts have been made to optimize the component geometry.

B. Problem Definition

Many studies have been carried out with respect to automobile engines up to now, but few reports are concerned with bolts which are important elements to clamp each part. Because connecting rod bolts fail sometimes due to fatigue, several studies about them have published reports dealing bolts to clamp a cylinder head are seldom found. The bolts clamping an aluminum alloy cylinder head and block, which is very popular today, are made of steel, therefore it is said that thermal stress is generated due to difference of coefficient of thermal expansion between two materials and increase in axial force of bolt.

In this project relationship between combustion pressure in the cylinder and increment of axial force of the bolts which causes the deflection of bolt is discussed taking effect of thermal stress and preload on the bolt into consideration, in order to contribute to a systematic design of bolted connection.

II. LITERATURE SURVEY

The design of machine part is concerned with determination of dimension of part. In this process a designer should make sure that the stresses developed in a part, are less than the maximum allowable strength of material. This maximum allowable stress is referred as the design stress and its value depends on many factors, namely the types of load, the service conditions, the life cycle, and the safety considerations.

Chang Chun Lee et.al[9] have presented their paper on analysis of proper prestresing force of bolts and gasket design to avoid the escaping gas from engine, affecting the overall performance of engine during operation .The above analysis is made using contact theory by Lagrange multiplier method and augmented Lagrangian method. The advantage is that they have enhanced sealing capacity of gasket by increasing magnitude of assembly force without exceeding material strength of each component in engine structure. But they have not considered the thermal stresses resulting from temperature distribution in cylinder head. Akira Yamamoto et.al[8] have presented their work related to relationship between ignition pressure and increment in axial force in cylinder head bolts. It is analyzed by equations derived by Yamamoto theoretically and compared results with experimental method. The main advantage is that they have considered thermal stresses while designing the bolt but they have not taken the effect of thermal stress developed in gasket and washer.

Toshiyuki Sawa et.al[11] have proposed their work on the analysis of force ratio of bolted joint with gasket and stiffness of gasket. Force ratio of bolted joint with gasket and effect of gasket stiffness on sealing performance is analyzed by numerical method using Bessel’s Equation. The main advantage is that the distribution of contact stresses on gasket surface is analyzed as elastic three-body problem using three-dimensional theory of elasticity. But they have assumed that stress distribution on bearing surface of gasket is uniform in model for analysis and effect of stress distribution on bearing surface is small on the contact stress of gasket. Jerome Montgomery has presented his work for modeling pretension bolted joints using finite element method with the help of ANSYS 5.7. Modeling is done for different types of bolt i.e. No bolt, coupled bolt, Stud, and Solid bolt etc. using constraint equation approach used in ANSYS 5.7. They provide the above approach to describe pre-stressing force of bolts and shows effect of joint simulation from no bolt to solid bolt, but joint simulation is made by ignoring the effect of thread, friction interaction at contact surface.

The cylinder block head is a part of complicate configuration whose construction and principal dimensions are dependent on the size of the inlet and exhaust valves, spark plugs. Fuel injectors, -cooled automobile and tractor engines the cylinder heads are usually cast in one piece for one cylinder bank. In the air-cooled engines use is made of individual cylinder heads or heads joining two adjacent cylinders.

In this project relationship between combustion pressure in the cylinder and increment of axial force of the bolts which causes the deflection of bolt is discussed taking effect of thermal stress and preload on the bolt into consideration, in order to contribute to a systematic design of bolted connection.

III. ANALYTICAL APPROACH

Case Study of 4 stroke single cylinder petrol Engine of 150 cc is taken for Stud analysis the specification is as follows,

Name	Size
Bore x stroke	58 x 56.4 mm
Engine Displacement	149.01 CC
Compression Ratio(CR)	9.0(+0.5) :1
Maximum Engine 0/p	11.36 kW at 8500RPM
Maximum Torque	12.76 Nm

Table 1: Specification of 150 CC, 4 stroke petrol engine

The complete assembly of cylinder head with stud is shown in the figure.

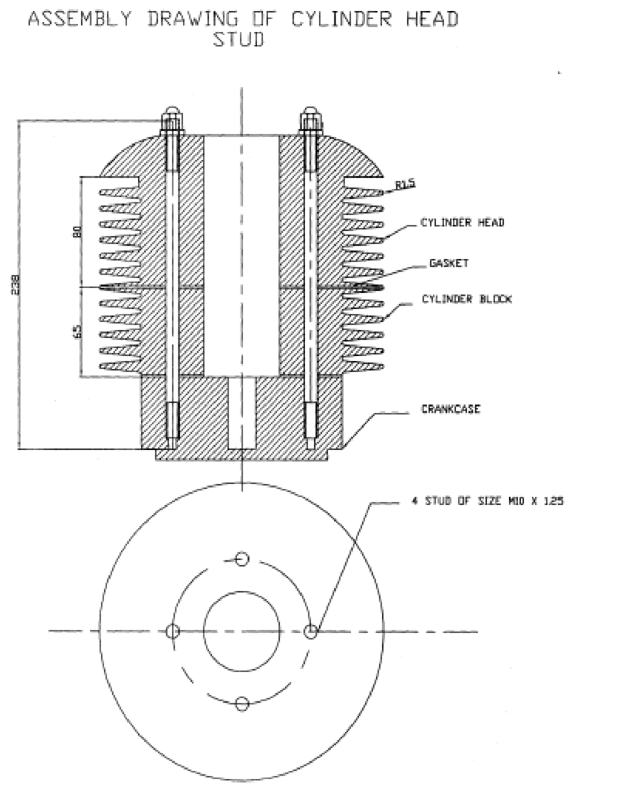

Fig. 1: Assembly Drawing of Cylinder head and stud

The detail drawing of stud is as follows on which the pressure is acting so the analysis is required on this stud.

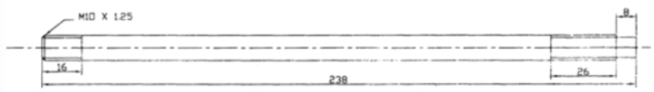

Fig. 2: Detail drawing cylinder head stud

In this project relationship between combustion pressure in the cylinder and increment of axial force of the bolts which causes the deflection of bolt is discussed taking effect of thermal stress and preload on the bolt into consideration, in order to contribute to a systematic design of bolted connection.

A. Maximum and Minimum Stresses Acting on Stud

The stress calculation for the stud is as follows

1) Maximum Stress

σmax = Maximum force on stud /tensile area

Fb = Maximum force on stud

Tensile area of stud as per ISO = 61.2 mm2

σmax = 15044/ 61.2

σmax = 245.82 N/mm^2

2) Minimum Stress

σ_{min}=Minimum force for expanding stud / Tensile area

Fi =Minimum force for expanding stud = 13886.76 N

σ_{min}= 13886.76 /61.2 = 226.9 N/mm^2

3) Elongation of Stud Due To Structural Load

When bolt is tightened with preload the bolt is elongated by an amount δb and the two members head and block with gasket are compressed by an amount of δc, when stresses are within elastic limit. As cylinder put into service that is it is further subjected to and external gas load Fmax then

1) The bolts are further elongated by an amount Δδ and there is corresponding increase in load ΔFi

2) The compression of two flanges and gasket is relieved by a magnitude Δδ and there is corresponding reduction in load.
3) The limiting point is M, where the compression of members becomes zero and the joint is on the verge of opening
4) The elongation of bolt is increased along line OA as operating pressure is gradually increases.

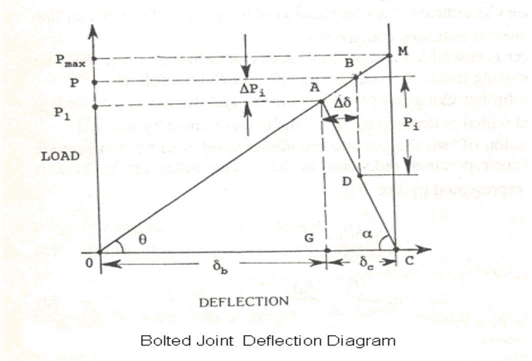

Fig. 3: Load vs. deflection diagram

Change in length = P x Ls / (A x E) = 15044 x 238 / (61.2 x 2.0 x 10^5) = 0.29 mm = 0.3mm

IV. CAD MODELING FOR STUD

A. *Introduction*

In this chapter CAD modeling of stud is described using Uni-Graphics. The Uni-Graphics application is mechanical design automation software that takes advantage of the familiar Microsoft Windows graphical user interface.

B. *Model Created In UG*

The model created in the Uni-Graphics is shown in the figure 4.1

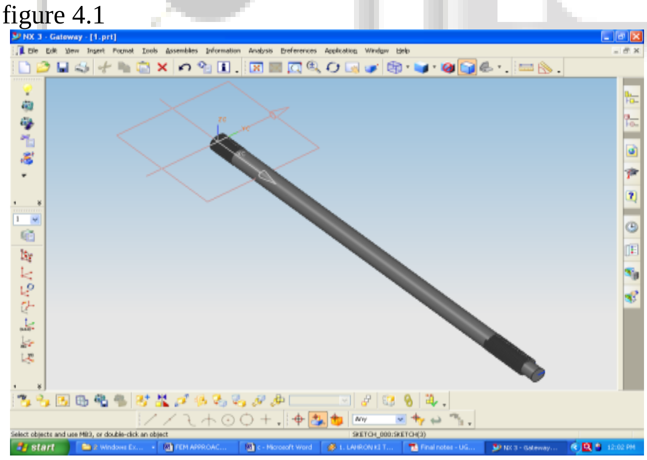

Fig. 4: UG model of cylinder head stud

V. FINITE ELEMENT ANALYSIS OF STUD

A. *FEA of Stud*

In the SI engine the high amount of pressure is generated on the stud which causes change or deformation of the stud. Thus to carry out the analysis of the study is needed to be carried out.

B. *Importing the Model of Cylinder Head Bolt in ANSYS*

Model drawn in Uni-Graphics model software and it is the imported in ANSYS for the purpose of analysis of cylinder bolt

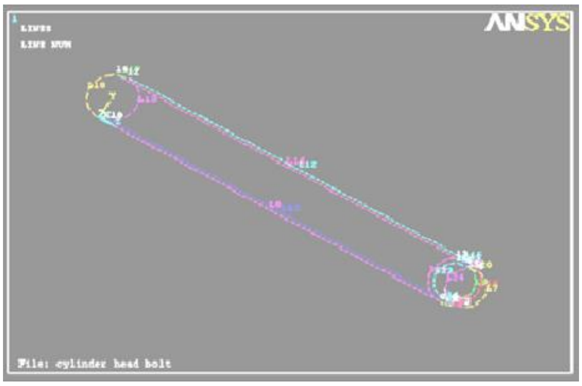

Fig. 5: Importing of UG model in ANSYS

C. *Mesh Generation*

In this module of analysis, the prepared geometric model is meshed. Meshing is nothing but converting a whole geometry into number of elements & these elements are connected by nodes. Meshing is done with following properties meshed model of stud using tetrahedral solid element of ANSYS.

Stud: No. of Elements: 5909,No. of Nodes: 12545

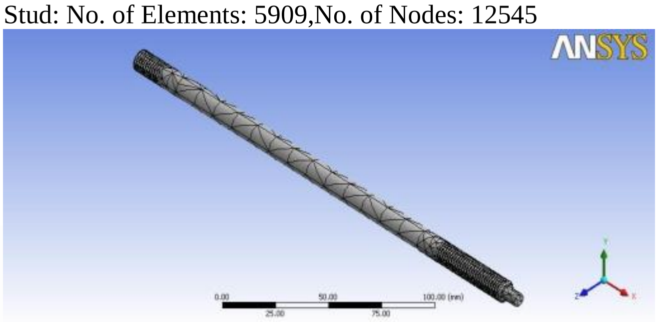

Fig. 5: Meshing of Cylinder head bolt in ANSYS

D. *Material Properties*

Following material properties are used for analysis.

Young's Modulus	200000 MPa
Poisson's ratio	0.3
Yield Limit	940 MPa
Density	8500Kg/m3

Table 2: Input properties

E. *Loads & Boundary Conditions*

Loading: - Uni-axial tensile load is applied. The value of the applied stress is 245.82 MPa. Structural Load acting on the stud is 15044 N

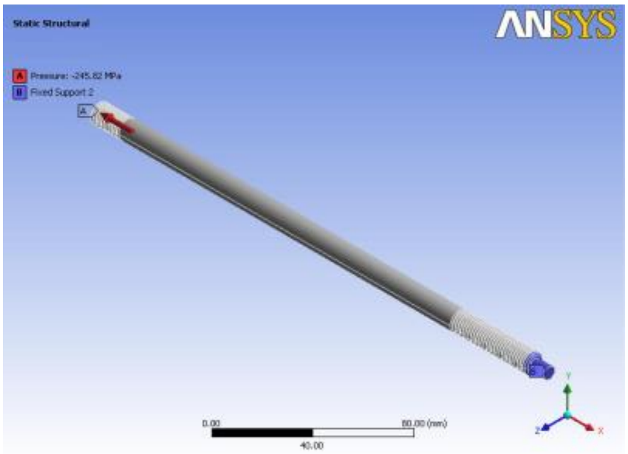

Fig. 6: Loading on cylinder head bolt

F. Solving (Processing)

The given problem is solved for static analysis.

G. Post-Processing

In this effect of load acting on the cylinder head bolt is plotted in the form of deformed shape.

VI. RESULT AND DISCUSSION

The dissertation work deals with 'Determination of Stress and deflection of cylinder head bolt due to the application of uni-axial tensile load.

A. Deformation Due To Loading

Due to the application of load, there will be increase in length of stud in the direction of the applied load. The deformed shape along with the original shape is as shown in the figure 6.1. Deformed shape is shown in the figure. From fig it shows that maximum deflection of stud is 0.27258 mm.

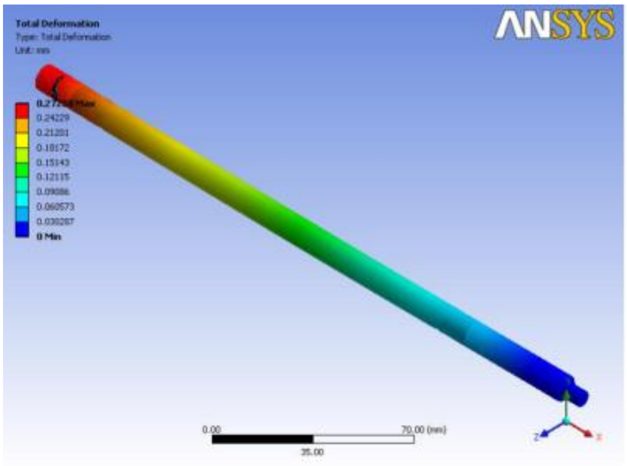

Fig. 7: Deflection of stud in isometric view due to structural load

B. Von Mises Stresses

Von Mises stresses at various points are determined. The same is shown in the figure 6.2 below. It is clear that Von Mises stresses will have highest value at the shank of stud. The same is evident from the exaggerated view of the bolt. From fig it shows that maximum von-mises stresses are developed near threading portion having value of 231 N/mm2.

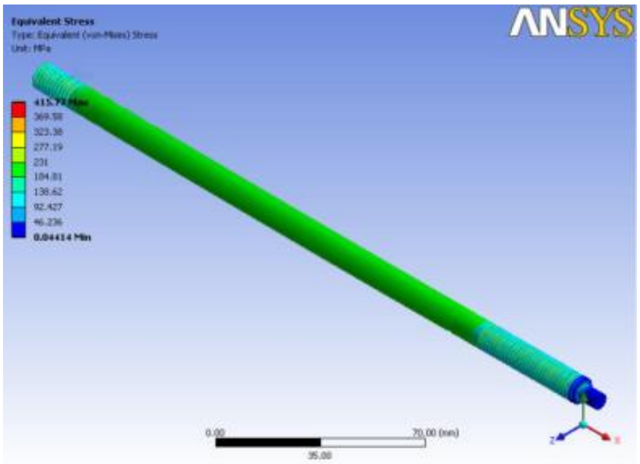

Fig. 7: Von mises stresses in stud in isometric view due to structural load.

C. Deflection Validation

The deflection value obtained by 'ANSYS' software is 0.27258mm

% Error =(δanalytical - δansys) / δ Analytical

= [(0.29 – 0.27258) / 0.29] X 100

= 6.00 %

D. Stress Validation

The stress intensity factor value obtained by 'ANSYS' software is 233 N/ mm2

% Error = (σ Analytical – σ Ansys) / σ Analytical [Tada]

= [(245.82 - 231) / 245.82] X 100

= 6.00 %

The error in solution when compared with analytical solution obtained by using ANSYS is 6.00 % which is very small. So the solution obtained is within acceptable range.

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