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Review on Stress Concentration Factor in Eccentrically Loaded Bolt

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Abstract - *An accident in pressure vessels occur due to the structural failure, out of them mostly occurs due to failure in bolted joints due to overloading bolted joints are used to maintain structural integrity of equipment and also to avoid leakage from joints of equipment which avoids accidents in equipment. This paper contains analytical method to find maximum stresses in bolts subjected to eccentric loading. It contains VDI (Verein Deutscher Ingenieure) approach to determine maximum stress in bolts and stress concentration factor in bolts. The bolts are mainly subjected to two types of loads. One is preload which is applied by means of tightening torque at the time of installation. The Preload in bolt should be sufficient to maintain structural integrity and to avoid leakages from joint portion. It should be sufficient to press gasket to avoid leakage. Another load is due to prying action. This paper contains measurement of preload, prestress, maximum stress and stress concentration factor.*

Key Words: Bolt, Preload, Prestress, Eccentric load, Stress Concentration Factor

1. INTRODUCTION

Bolted joint are separable joints between two or more mating components, which are held firmly by means of threaded fasteners like nut and bolt or studs.

Bolted joints are also used to join mating parts to avoid leakage of pressurized liquids or gas by virtue of gaskets between them. In this case the bolts require more efforts to press gaskets between two mating components and also to avoid leakage due to pressure of fluid inside of component.

Bolted joints are generally loaded in to main conditions that are in tension joint and shear joint.

In tension joint the load is applied in axial direction of bolts which tends to deform bolt in longitudinal direction. In the tension joints the mating components are clamped in such a way that the tensile load or separating load should not overcome the clamping force and there will no any relative motion between two mating components and the joint will remain intact [5].

In shear joint shearing load is applied in perpendicular direction to the axis of bolt. It causes shearing of bolt in shank portion. In such joint tensile forces are minor as compared to shearing, as tensile forces are just for tightening to generate prestress.

1.1 Preload

It is a tensile load into the bolt due to the tightening torque applied at the time of installation [6].

Preload in bolt is necessary to avoid leakages from joint and to ensure intact assembly.

Preload should be within limit in such way that it is to avoid leakage not to crush gasket.

1.2 Eccentric load

It occurs due to the prying action in bolt. When external tensile load is applied onto the equipment it results in eccentric load onto the bolts which causes extra tensile and bending load onto the bolts. The eccentricity is distance between radius of gyration of joint and axis of load application [1].

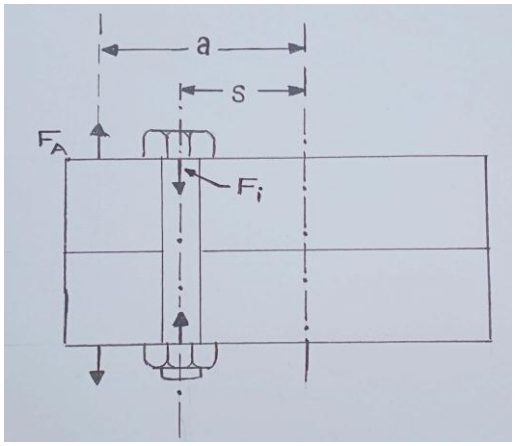

Fig. 1: *Eccentrically Loaded Bolt*

Where,

F_a - External load

F_i - Preload

a - Eccentricity of load

S - Eccentricity of bolt

2. LITERATURE REVIEW

Gauri Shrinivasan, *et al.* [1] reported various approach for stress analysis of bolts subjected to an eccentric loading

was done by using ASME approach, VDI approach and by using finite element analysis using I-DEAS software. In this maximum stresses and stress concentration factor calculated by ASME method and VDI approach. The different models were tested for maximum stresses by taking different bolt circle diameter and outer flange diameter. The F.E.A. analysis was done using I-DEAS software. The results of ASME method, VDI method and F.E.A. method were compared for maximum stresses. The comparison shows that the stresses results by ASME method were more than results by ASME and VDI method.

Nomesh Kumar, *et al.* [3] performed "3D Finite Element Analysis of Bolted Flange Joint of Pressure Vessel" The stresses in bolted joint of Pressure vessel evaluated by theoretical and finite element model. It contains method to find prestress on bolts, tensile and bending load due to prying actions. The 3-dimensional finite element model is constructed on Ansys12.1 to found out stresses, deflection in nut bolts of flange joint. The stress resulting from proof pressure test was less than results of F.E.A. method. This shows that stresses in bolts depend on friction between the flanges of joint. The stresses in bolts decrease with increase in coefficient of friction between flanges.

Khemchand M Kapghate *et al.* [5] conducted extensive review of literature on "Conventional Design and Finite Element Analysis for Bolted Joint" and reported that analysis of bolted joints under shear load, preload, bending load conditions, to found out failure stress, contact pressure, deformation. They evaluated stresses in flange joint of stacked heat exchanger; hence bolted joint will not fail during proof resistance test.

They found out methods for preload and prestress in bolt. They concluded that bolt stiffness factor is considered as a function of coefficient of friction between two surfaces, thread helix angle, thread profile angle. It contains F.E.A. modelling of bolted joint loaded in shear and bending conditions.

Rashtrapal B. Teltumade *et al.* [6] performed "Stress Analysis of Bolted Joints" by experimental and finite element analysis method on bolted joint subjected to shear load. Physical model of bolted joint tested under shear for finding stresses by analytical method. In this analysis was done for various models by changing clearance between plate hole and bolt shank. The resulting stresses by conventional method were closer to results of F.E.A. method. It shows that the thickness of plate should not be greater than nominal diameter of bolt; if it is greater than it results in increase in stresses in bolt. It shows there should be less clearance between hole of plate and bolt shank, if there is more clearance between hole of plate and bolt shank then stresses in bolt also increases.

P. Pimpalkar *et al* [8] Performed Experimental and FE analysis for eccentric loaded bolted joint under symmetric and unsymmetrical bolt system with consider bolt pretension. They compared results from FE analysis and Experimental work was closely agreement. They found that bolt which is nearer to point of loading was heavily loaded and failure of that bolt takes place at the shank of bolt.

3. REVIEW ON MAXIMUM STRESS IN BOLT AND STRESS CONCENTRATION FACTOR

3.1 Bolt pretension and prestress

Bolt pretension is also called as preload. Which results due to the installation torque (T) was applied at the time of installation of bolt. Due to the plane of inclination of thread helix installation torque is converted into the bolt pretension.

It is calculated by [4, 5]

$F_i = T/(K \times d)$

Where

F_i - Preload

T - Installation torque

d - Bolt shank diameter

K - Torque coefficient

Where torque coefficient arises due to the thread geometry, coefficient of friction in thread and coefficient of friction in collar. Value of Torque Coefficient (K) can be obtained by finding coefficient of friction in collar and thread. Following is formula for Torque Coefficient (K) from shigley mechanical engineering design 9th edition M.C. Graw hill. (Equation no. 8-26 page no. 438) [4] [5]

$K = \{[(0.5 \times d_p) \times (\tan\lambda + \mu_t \times \sec\beta)/ (1 - \mu_t \times \tan\lambda \sec\beta)] + [0.625 \times \mu_c \times D]\}/D$

Where

D=bolt shank diameter

β=thread profile half angle

λ=thread helix angle

d_p=bolt pitch diameter

μ_t=thread coefficient of friction

μ_c=collar coefficient of friction

Published value of K is applicable for perfect clean and lubricated surface. In actual case K value is more than published value because of operating conditions value for coefficient of friction for collar and thread.

Bolt prestress is given by

$\sigma_i = F_i/A_t$

From shigley mechanical engineering design 9th edition M.C. Graw hill. [4]

3.2 Stress concentration factor

Stress concentration factor (K_t) is the ratio of maximum stress to the nominal stress in bolt [7]. Due to the surface irregularities in geometry like notches, grooves, stress distribution is non-uniform near the irregularity. Which is called as stress raisors and region of their occurrence is known as area of concentration [1].

The equation for stress concentration factor is,

$K_t = (\sigma_{act})/ (\sigma_{nom})$ [1]

Where

σ_{act}= actual stress in area of stress

σ_{nom}= concentration total stress applied to bolt (nominal stress).

3.3 Nominal stress in bolt

Nominal stress is total stress applied to the bolt and it is sum of the prestress applied to the bolt at the time of installation and part of stress due to axial force because of pressure inside the vessel.

Part of stress due to axial force is related to the term load factor (φe) in case of eccentric loading which results in prying action, the load factor is given by VDI procedure (Equation 340 P.N.17) [2]

$\varphi e = K_b [1 + (a \times s \times Acrs/I_j)]/K_j+KB[1+(s^2 \times Acrs/Ij)]$

Where

Acrs - Substitutional cross sectional area calculated from equation 3.17 of VDI P.N.8

K_b & K_j are bolt and joint stiffness

Respectively where value for K_b and k_j are given by shigley mechanical engineering design, 9th edition. [2, 4]

$K_b = (A_b \times E) / (2t)$

$K_j = \{0.577 \times \pi \times E \times d\} / \{2\ln [(5 \times 0.577 \times 2t+0.5d)/2t]\}$

Where,

I_j - Moment of inertia of joint

A_b - Area of bolt

E - Modulus of elasticity of material

t - Flange thickness

d - Bolt shank diameter

Now the nominal stress in bolt due to eccentric loading is given by VDI method [2].

$\sigma_{nom} = \varphi e (Fa/Ab) + \sigma_i$

Where actual stress is stress generated at stress concentration area which is find by finite element analysis method [1].

4. CONCLUSIONS

The parameters for design of bolted joint i.e. preload, prestress, eccentric load, nominal stress and stress concentration factor are studied for eccentrically loaded bolt. These parameters are used for selection of bolt size and material for bolt, as proper selection of bolt can avoid failure in shank and slipping of bolt head. Bolted Joints has variety of application such as wall Bracket and Pillar Crane which are subjected to eccentric loading conditions apart from that bolted joint is very popular method for fastening components together. So it is useful for industries like ship building, Automobile, Pressure Vessel, Space craft, civil structures & Pipelines

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