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Investigation and Examination of the Impact of Minor Variations in Pitch on the Endurance Capacity of Bolts

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ABSTRACT: This research investigates how introducing small pitch variations between bolts and nuts affects fatigue failure in their connections. To improve fatigue resistance, three types of minor pitch variations are applied to test specimens, and their effects are analyzed using Finite Element Method (FEM) analysis. Comparing results with standard connections having zero pitch difference ($\alpha = 0 \mu\text{m}$), the study reveals that introducing slight pitch differences of $\alpha = 5 \mu\text{m}$ or $\alpha = 15 \mu\text{m}$ prevents bolt fractures at the No. 1 thread. Moreover, it is observed that incorporating these slight pitch differences can extend the fatigue life of the bolt. The study underscores the significance of minor pitch differences in bolt-nut connections concerning fatigue failure.

KEYWORDS: fatigue failure, bolt-nut connections, pitch difference, specimens, FEM analysis.

I. INTRODUCTION

Bolt and nut connections are widely used in mechanical systems, offering benefits such as easy assembly and disassembly, precise adjustment, and secure fastening of thick components. Despite their advantages, they are prone to fatigue failure, especially under repeated loading, potentially causing premature failure. Factors like root radius, thread pitch, material composition, and thread angle significantly affect bolt performance and lifespan. Bolts and nuts are available in various types, including fine and coarse threads. A crucial consideration is determining the optimal thread pitch to enhance fatigue life and load-bearing capacity for standard steel bolts with standard nut dimensions. This decision is vital as other parameters like fillet radius and thread depth are linked to the pitch. Fatigue failure in bolts poses a serious risk, exemplified by the 1975 incident in Japan involving a large bolt (a tie rod) whose failure stemmed from fatigue-induced crack initiation at the thread root, leading to propagation and eventual failure. Uneven load distribution among threads exacerbates this issue, with the first loaded thread experiencing more stress than subsequent ones, causing high stress concentrations at the thread roots.

Problem Statement



Figure 1: Failure of Bolt

Currently fatigue failure in bolt is observed due to effect of pitch difference in nut and bolt connection. Find the solution to increase the fatigue life of bolt to avoid the crack in first engagement of thread by using suitable pitch difference.

Objectives

This study systematically explores how varying the pitch of bolts affects fatigue life improvement. The primary aim of this seminar is to devise a bolt-nut connection that enhances fatigue strength without inflating costs. The specific objectives include:

Utilizing Finite Element Analysis to Examine How Pitch Differences Impact the Stress Distribution Across Bolt Threads.

Identifying Pitch Variations Conducive to Extending Fatigue Life.

II. LITERATURE REVIEW

A review of literature pertaining to the analysis of bolts to determine their fatigue life, in the context of the present study, is provided and referenced. Nao-Aki et al. discuss the impact of slight variations in pitch difference between bolts and nuts on fatigue failure. They conducted fatigue testing using three different pitch differences at varied stress amplitudes and observed that considering certain pitch differences can increase the fatigue life of bolts. They elaborate on the criteria for fatigue failure concerning pitch difference variations and underscore the significance of this factor in influencing fatigue limits.

Nao-Aki et.al introduces that pitch difference having slight variation between a bolt and nut is affecting on fatigue failure. Fatigue testing is done using three pitch differences by varied stress amplitudes. It is found that the life of fatigue for the bolt can be increase while some pitch difference is taken in the account. Here the criteria for fatigue failure are discussed in terms of variation of pitch difference. They also showed that how importance of pitch difference affecting fatigue limits. They show that the fatigue life can be increase while some pitch difference is considered.

Dragoni found that slight pitch on the fatigue value of strength of ISO steel bolts which are used for analysis. It can have studied boundary element analysis and cross- comparison with theory and photo elasticity, the load capacity of the bolt is ultimately related to a comprehensive stress concentration dependencies. In the work of plotting the function of nominal diameter verses the thread pitch of bolt for the steel bolts. It concludes endurance phenomenon for load lightly increases if the value of pitch is decreased for small diameter bolts of low value of grade steel. Conversely, the value of endurance load increases with the pitch large bolts of high value of grade steel.

Chen et.al has focused on fatigue failure, for bolt and nut connections, while pitch difference is introduced between the connection of bolt and nut. For improvement the fatigue life, there are three types of pitch difference are produced on the specimens which are compared with experimental results and discussed in terms of FEM analysis. The analysis results shows that it can improve the fatigue life of bolt.

Wahabb et.al introduces the slight pitch difference between the bolt and nut engagement in order to study its effect on the fatigue performance. They considered that the pitch of nut was some microns greater than the pitch of the bolt. Fatigue experiment was done for three types of specimens with different measurement of pitch differences. The plot of S-N curves for the fatigue life shows that it was extended by 1.5 times which compare with the standard connection.

On the work done by them to increase the fatigue life of nut and bolt is considered by having pitch differences.

Sano et.al focused on the work done by them to increase the fatigue life of nut and bolt, they can varies the some pitch differences. They also discussed the loosening experiment and relation between the prevailing torque and clamping force.

Chae-Ho Lee shows, reduction mechanism of the stress concentration in bolt-nut connectors was investigated by performing shape optimization using finite element method implementing PQRS- Progressive Quadratic Response Surface Modeling and the GSM- growth-strain method. The reduction mechanism for stress concentration is achieved by these methods. It was found that stress concentration can be reduced by uniformly over the entire threads as far as possible.

Majzoubi found the stress, various factor of stress concentration in the bolt and fatigue strength / endurance limit by analytically and correlate with the experimentally. They compared results standard of ISO having coarse threaded bolts and with the comparatively fine dimension threaded bolts. Which shows have coarse thread are preferred. Here the reason for preferring coarse thread is that the value of pitch difference is more compare to fine

threads. The condition of loading is same for both type of coarse and also fine threads. For the comparison which is made on the basis of parameter of core diameter. The conclusion that for the same stress, which the fatigue life for both ISO as well as unified bolts, for 100 unified bolts, comes low as the nominal bolt diameter increases within the range tested.

Shin-ichi Nishida et.al introduces new method for improve the fatigue strength value of bolts is developed. The new method CD for fracture stands for "Critical Design for Fracture". Improved profile of thread greatly minimizes the peak stresses. The new profile doubles the fatigue strength of bolts as compared to conventional profiles. For both the pre-stressed and non-pre-stressed conditions has improved strength.

D. G. Sopwith et. al stated that for improving the load distribution, discussed differential tapered threads, pitch, and the use of a soft material for nut. Distribution of load along the length of a nut isn't uniform owing to the strains set up in the bolt and nut under load. In the ordinary bolt and nut case the maximum intensity of loading happens at the bearing face of the nut, and may be from two or more extents the mean, depending on the thread form, the proportions of the members, and the degree of lubrication; the maximum intensity is nearly independent of the length of nut (except yielding happens). These strains are analysed and the load distribution across the thread helix reduced lowered.

E.A. Patterson et. al introduces Modifying Sopwith's theory for the load distribution along the threads of a nut and bolt by incorporating modelling of the thread runout in the nut, and by the use of finite element analysis to determine the deflection factor for the thread. Then, it is observe that the stress reduction is noticeable, that the height of bolt threads is reduced near the bolt head and the nut is closer to the bolt head. The outcome of this theory compare with from three-dimensional photoelastic analyses of the loads in the threads of two bolts fitted with conventional nuts.

A. Chhaban et. al investigate the stress field in threaded closures of thick wall in high pressure vessels with the help of the finite element method. A set of elastic analyses of vessels with 5, 8, 11, 15, 20 and 25 standard Buttress threads was used for predicting distribution of load along length of the thread. The index factors for root stress in the region of the first three threads are introduced. The result of this work is to the development in new division of the ASME Pressure Vessel Code for thick walled high pressure vessels.

Jien-Jong Chen et. al. stated distribution of load on every thread in axisymmetric model and three-dimensional model are provided. In the observation of three-dimensional finite element analysis of bolt joint with sliding contact has studied, the friction effect on load distribution of each thread is analyzed. It shows the analytical method by Yamamoto's method produces a minimum value of load ratio than the numerical method (FE analysis) at the first thread. Hence, increasing the frictional coefficient and decreasing the lead angle may increase the load distribution slightly, for 1-inch in 16 UNF bolt joints, the 12 % error of load ratio at the first thread in axisymmetric finite element model with respect to three-dimensional analysis.

Noda, N. A., said in study, the bolted joints with tapered threads are analyzed with the finite element method, and stress reduction effect of CD bolts is observed with different geometrical conditions. The reduction of the stress concentration is observed by tapering threads. Then, found that the reduction of stress is in view when the height of threads is lower significantly near head of bolt and the nut is closer to bolt head. It is found that the maximum stress reduced by 20% with compared to the cases of standard connection of bolts and nuts.

III. EXPERIMENTAL SETUP

Analytical Method

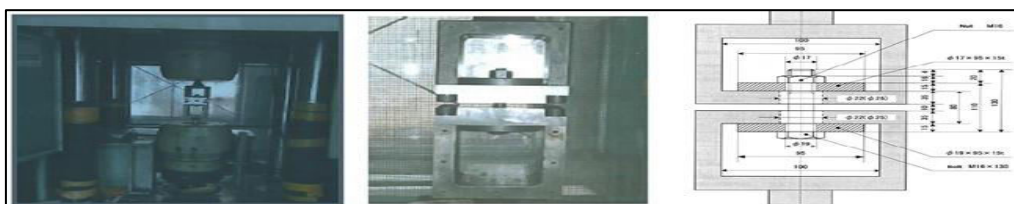


Figure 2: Experimental Setup

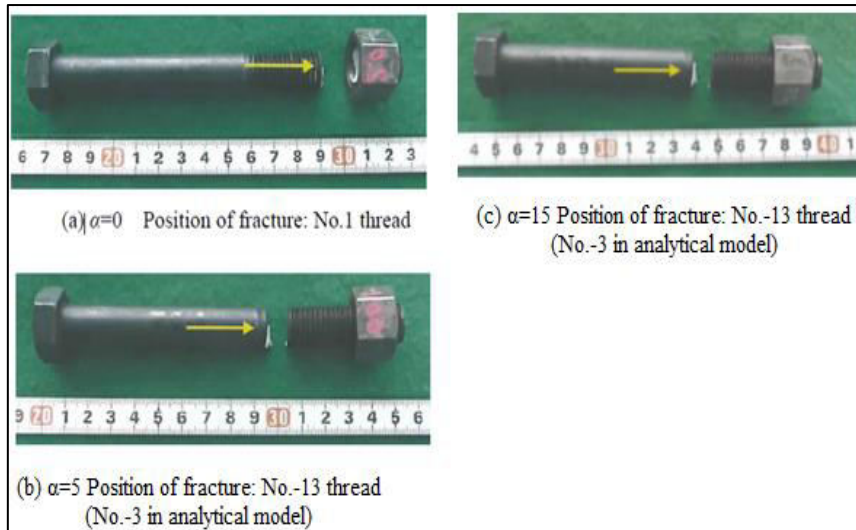


Figure 3: Fractured Specimen

Fatigue testing of bolts is a critical process to ensure the structural integrity and safety of various applications, from aerospace to automotive and construction industries. This method involves subjecting bolts to repeated loading and unloading cycles to simulate real-world conditions and assess their resistance to fatigue failure over time. The testing procedure typically begins with selecting representative samples and applying a controlled amount of load to the bolt. Through cyclic loading, engineers monitor the bolt's response, including stress levels, deformation, and any signs of cracking or failure. Advanced testing equipment such as servo-hydraulic machines or electromagnetic actuators may be employed to accurately replicate dynamic loading conditions. Additionally, factors such as material composition, surface finish, and environmental conditions are taken into account during testing to ensure comprehensive evaluation. The data gathered from fatigue testing allows engineers to determine the bolt's endurance limit, fatigue life, and performance under different operating conditions. By identifying potential weaknesses and optimizing design parameters, manufacturers can develop bolts that meet stringent quality standards and enhance the reliability and longevity of mechanical assemblies. Ultimately, fatigue testing plays a crucial role in guaranteeing the safety and durability of bolts in diverse industrial applications.

Finite Element Analysis

The stress at the bolt threads resulting from variations in pitch was investigated by conducting elastic and plastic finite element analyses using ANSYS Workbench. The analyses were carried out for pitch differences of $\alpha = 0$ micron, $\alpha = 5$ micron, and $\alpha = 15$ micron, with a model including standard M20 bolt and nut bodies in contact.

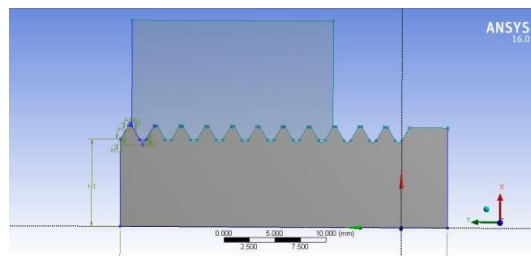


Figure 4: Development of 2D Drawing and Addition of Material

Initially, create a geometric outline of the typical M20 × 2.5 mm bolt based on the measurements provided in figure within the design modeler of ANSYS Workbench, depicted in figure. As an axisymmetric model is utilized for the two-dimensional analysis, transform the sketches into 2D surfaces, representing both the nut and bolt. This conversion is carried out to facilitate meshing the model using 2D elements.

To achieve precise outcomes at a specific point, a mesh is generated starting from the base of the bolt thread, with dimensions of 0.01 mm × 0.01 mm. Four-noded linear quad elements are then applied on the surface, utilizing an axisymmetric solid element.

Result and Discussion

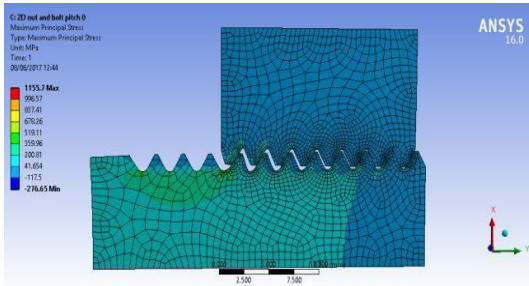


Figure 5: For Model when $\alpha=0\mu\text{m}$

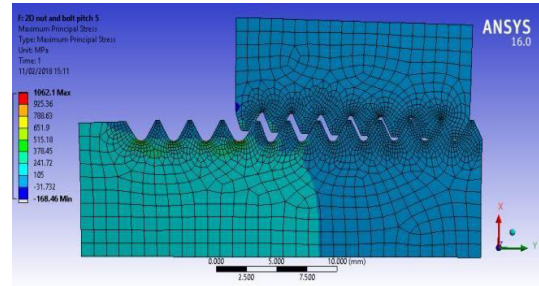


Figure 6: For Model when $\alpha=5\mu\text{m}$

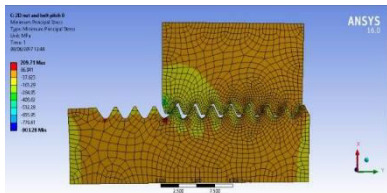


Figure 7: For model when $\alpha=0\mu\text{m}$

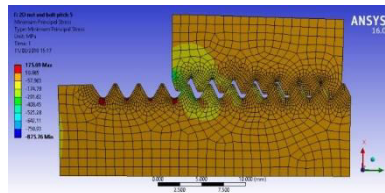


Figure 8: For model when $\alpha=5\mu\text{m}$

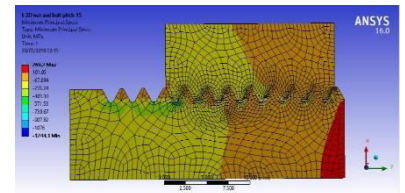


Figure 9: For model when $\alpha=15\mu\text{m}$

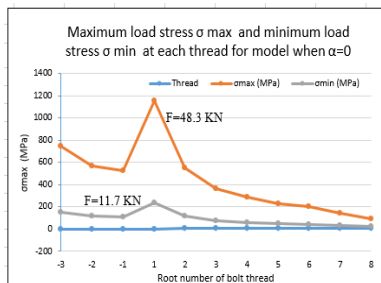


Figure 10: Location of maximum and minimum load stress at each thread for model when $\alpha=0\mu\text{m}$

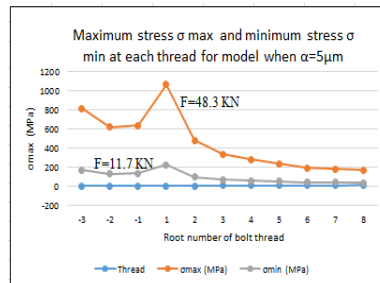


Figure 11: Location of maximum and minimum load stress at each thread for model when $\alpha=5\mu\text{m}$

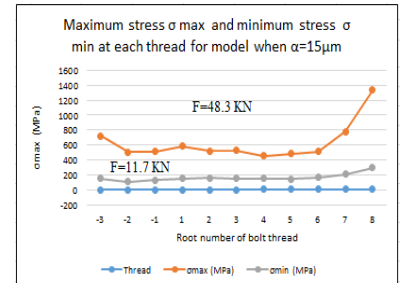


Figure 12: Location of maximum and minimum load stress at each thread for model when $\alpha=15\mu\text{m}$

The highest stress in each thread, designated as σ_{max} , occurs when the load is at its maximum, $F=30+18.3$ kN, while the lowest stress, denoted as σ_{min} , happens under the minimum load, $F=30-18.3$ kN. In the bolt-nut connection scenario with $\alpha=0$, it's evident that thread No. 1 experiences the greatest stress. However, with $\alpha=5 \mu\text{m}$, both the stress amplitude and mean stress for thread No. 1 decrease significantly. This decrease indicates an enhancement in load distribution among the bolt threads compared to the $\alpha=0 \mu\text{m}$ condition, reducing the difference in stress among threads. Transitioning to $\alpha=15 \mu\text{m}$, threads No. 7 and No. 8 display notable stress concentrations instead of thread No. 1. As shown in Figure 10, when there is a considerable pitch difference, threads No. 7 and No. 8 present a greater risk than thread No. 1, though fractures on threads No. 7 and No. 8 don't necessarily result in the bolt's ultimate failure. This suggests that other threads may carry and distribute the load, thereby mitigating the risk associated with individual thread failures.

IV. CONCLUSION

This research employed Finite Element Method (FEM) analysis to investigate bolt-nut connections, examining slight variations in pitch. Three specimens underwent analysis, revealing stress distributions along the bolt's root threads. The findings suggest the following: In a standard connection (with $\alpha=0 \mu\text{m}$), fatigue fracture occurs at the initial thread. However, when the pitch differs by $\alpha=5 \mu\text{m}$, stress at the first thread decreases compared to $\alpha=0 \mu\text{m}$. Furthermore, with $\alpha=15 \mu\text{m}$, the maximum stress relocates to the eighth thread. Notably, at this pitch difference, stress concentrates at the seventh and eighth threads, although this doesn't necessarily result in bolt failure. These findings imply that adjusting the pitch difference can diminish stress amplitude and average stress at the first root thread of the bolt.

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