EXPERIMENTAL AND FEA INVESTIGATION OF BOLT LOOSENING IN A BOLTED JOINT STRUCTURE

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ABSTRACT

By considering the tightening process, the experimental testing will be conducted to explore the mechanism of bolt self-loosening under biaxial loading. The most common mode of failure is overloading. Operating forces of the application produce loads that exceed the clamp load, causing the joint to loosen over time or fail catastrophically. Over torque might cause failure by damaging the threads and deforming the fastener, though this can happen over a very long time. Also, the bolts may fail under fatigue. The components used in the system are bolts, pneumatic cylinder and flow control valve. The pneumatic cylinder is actuated with the help of compressor. The flow of air in the cylinder will be controlled with the help of pneumatic cylinder which will be acted on the bolts in two directions that is from downward & upward direction. This means the load will be tensile and shearing load. The bolts are attached to the plates. Because of actuation of the pneumatic cylinder the bolts will become loose. Design of experimental setup in CATIA software while analysis in ANSYS software to determine failure or yield strength variation in bolt due to applied force by pneumatic cylinders. These bolts will be tested by using biaxial loading. The result & conclusion was drawn after the experimental testing.

Keyword - Bolted joints, Bolt loosening, FEA, FFT analyzer

I. INTRODUCTION

Bolted joints are one among the first regular components in development and machine structure. They comprise of fasteners that catch and join different parts, and are made sure about with the mating of strings. There are two principle sorts of darted joint structures: pressure joints and shear joints. In the pressure joint, the jolt and fasteners segments of the joint are intended to move an applied strain load through the joint by method of the braced segments by the arranging of a right parity of joint and jolt firmness. The joint ought to be structured such the brace load isn't overwhelmed by the outer pressure powers acting to isolate the joint. at the point when outside pressure powers conquer the brace load the cinched joint parts will isolate, permitting relative movement of the segments. The second kind of shot joint exchanges the applied burden in shear of the jolt shank and depends on the shear quality of the jolt. once in a while strain stacks on such a joint are just accidental. A preload stays applied yet thought of joint adaptability isn't as basic as inside the situation where burdens are transmitted through the joint in strain. Other such shear joints don't utilize a preload on the jolt as they're intended to allow pivot of the joint about the jolt, yet utilize different techniques for looking after jolt/joint trustworthiness. Joints that permit revolution incorporate clevis linkages, and accept a locking instrument (like lock washers, string glues, and lock nuts).
I.1 OBJECTIVES

- Design and modelling of bolt loosening setup in CATIA V5R20 software.
- To perform static analysis in ANSYS software to determine failure or yield strength variation in bolt due to applied force by pneumatic cylinders.
- To identify their relative importance and degree of contribution to bolt loosening.
- Experimental manufacturing of setup with defined parameters to study the effect of bolt loosening by varying defined parameters.

I.2 METHODOLOGY

II. LITERATURE REVIEW

Yuejie Cao et al. [1] in this paper it presented a dynamic damage model was created for researching the impacts of scope and impedance measures on the damage and failure of CFRP/Ti twofold lap, single-bolt joints under semi static loads. Numerical outcomes indicated that the grid stress failure ruled the joint failure mode. To explore the impacts of freedom and obstruction measures on the damage and failure of CFRP/Ti twofold lap, single-bolt composite joints, a dynamic damage model with the ABAQUS software is used. It is concluded that the grid stress failure was seen to be the principle failure mode in the joints under semi static ductile burden, also, the fiber stress come up short use was for the most part happened in 0-degreely. Fitting resistances had a conspicuous effect on the damage of the joints, and the 0.5% obstruction fit condition displayed the insignificant damage under the load of 17.8KN. The qualities of the joints were touchy to fitting resistances, and showed four principle stages in stage I, the qualities in-wrinkled fundamentally with the expansion of fitting resilience at that point in stageII, the qualities arrived at an immersion and were not delicate to the expansion of fitting resilience; in this way, the qualities of the joints expanded with the expanding of fitting resilience again and arrived at greatest qualities at the interference size of 0.5% in stageIII at last, the qualities started to decrease with the increment of fitting resilience.

Zhen Zhang et al. [2] in this article it represents a research on distinguishing proof of bolt extricating and quantitative gauge of the remaining torque for three sorts of joints was endeavored, hypothetically and tentatively, utilizing two methodologies in a near way a wave vitality dissemination (Marry)- based direct acoustic methodology and a contact acoustic nonlinearity (CAN)- based vibro-acoustic balance (VM) technique. The examination between two approaches uncovers that the nonlinear VM-based strategy offers improved exactness and affectability to bolt slackening than a direct In the nonlinear methodology, sidebands in signal spectra initiated because of contact acoustic nonlinearity (CAN), when the joint is exposed to the blended excitation, are found quantitatively identified with the level of bolt releasing. The nonlinear VM-based strategy demonstrates improved affectability to bolt relaxing than a direct WED-based approach, with extra legitimacy to identify multi-type joints and beginning time of bolt slackening. Also, with a capacity of implicit detecting utilizing scaled down sensors (PZT in this examination), the methodology can be actualized in an ongoing, programmed, and brief way, along these lines rendering a possibility to be reached out to online wellbeing checking (SHM) for bolted structures.

Yan Chenet al. [3] In this paper it presents a hexahedral fitting actualized by altering the hub facilitates dependent on chamber networks and an ABAQUS module is made for parametric modelling. With joining the fixing and self-releasing procedures, this paper uses the relative pivot edges and speeds to research the slip states on contact surfaces rather than the Coulomb rubbing coefficient strategy, which is utilized in many pasts looks into. Finally, we use the relative movement of hubs to portray the contact states, and the ordinary. Through contrasting and an improved pretightening calculation, it is exhibited that...
the fixing process can’t be supplanted, on the grounds that the disentangled way may cause a littler resultant torque due to the inverse course of the two torque segments on the string interface. By differentiate, the relative movement between hubs is found in a more prominent detail to depict the slip state at contact surfaces than Coulomb's law of erosion. As indicated by the recreation after-effects of bolt self-loosening, it uncovers that there exists a drag slip wonder on the bolt head bearing surface, which makes the bolt self-releasing happen in any event, when some contact aspects are trapped.

Jae Choet al. [4] In this paper, failure load forecast for composite joints with grasping force was led utilizing a trademark length strategy joined with Tsai-Wu failure standards. This is on the grounds that clipping causes grinding between the plate and clamping force, which re-convays the elastic and compressive worries of the composite overlay. In a composite overlay with a ±45° lay-up, the elastic and bearing failure loads expanded with expanding grasping torque. The ductile trademark length for an E-glass/epoxy composite with 50 Nm of grasping torque was longer than the trademark length for a composite exposed to 30 Nm of torque. For single lap-shear bolt joints, the ductile failure load expanded when the applied clipping torque expanded, inferable from the erosion force brought about by the clipping. The failure load expanded by around 9.33% when the bracing force changed from 30 Nm to 50 Nm.

Jianhua Liu et al. [5] In this journal it presents bolted joints under different preloads and excitation amplitudes. Three coatings are used to treat bolts, and their consequences for the counter slackening exhibition are considered. For the MoS₂ covered bolt, a sensible preload is determined, and its opponent of releasing execution is additionally analysed. Self-extricating conduct of bolted joints energized by forceful hub load is examined, and string damage is breaking down by OM, SEM and EDS. In the primary phase of extricating process, for the PTFE/MoS₂ covered bolts, countless severities on the contact surfaces distort plastically, decrease in size, or are even expelled during the fixing procedure because of the low hardness of the covering, the genuine contact region is huge, and the plastic distortion/expulsion of the ill tempers on the contact surfaces brought about by hub excitation is slight, at that point the change in cinching force is little. Conversely, the change in clipping force of the bolt covered with TiN is enormous in this stage. In the second phase of releasing procedure (from the 10th cycle to the 10th cycle), because of the poor attachment property of PTFE covering, the damage of the covering on strings is not unserious, and the change in grasping force of the PTFE covered bolts is huge in this stage. For the MoS₂ covered bolts, as a result of their great self-greasing up property and high holding quality, the string surface damage is slight and the change in grasping force is little in this stage. For the bolt covered with TiN, the damage of the covering on strings is slight because of its fantastic wear opposition, and the change in bracing force is too little in this stage. For the bolt covered with MoS₂, the fixing torque is little in light of the fact that of the low grating coefficient. It turns out to be little for the MoS₂ covered bolt under a reasonable level of preload advancement.

Song Zhou et al. [6] In this paper, the impact of geometric parameters on failure modes and failure load of bolt joints are examined by numerical and exploratory techniques. The impact of geometric parameters on failure modes and failure load of T700 carbon/epoxy twofold lap of composite bolted joints are researched. It is discovered that the expansion of the W (width) of composite bolt joints can fundamentally expand the failure load of the two sorts of composite bolted joints furthermore, the second stacking arrangement’s ([45/0/ - 45/90]) composite bolt joints has higher failure load than the first stacking group’s ([45/90/ - 45/0]) composite bolt joints from test results. Failure methods of the second stacking arrangement’s ([45/0/ - 45/90]) composite bolted joints are for the most part net-stress failure and bearing failure. At the point when W/D=4 and E/D is under 3, the expansion of E esteem has a critical impact on the improvement of the failure load. When the E/D is more prominent than 3, the expansion of E/D has no improvement impact on failure load. The second stacking succession’s ([45/0/ - 45/90]) composite bolt joints has higher failure load than the first stacking grouping’s ([45/90/ - 45/0]) s composite bolted joints on the grounds that the dehulling diminishes the load bearing limit of joints.

III. DESCRIPTION OF THE PROBLEM

Bolts are used in most of the places where connection between two structures is critical and there is a high need of maintenance, so that it can be removed from the main system easily. But due to the fluctuating force application. In order to predict bolt loosening, it is important to first identify the parameters that contribute to bolt loosening so they can be quantified. Here we need to identify the primary parameters that contribute to bolt loosening was the impetus for this study.

Studying on the loosening mechanism of screwed fasteners revealed that the relative sliding rotation between nut, bolt and components joined is the main reason for loosening:

i) The cause for the sliding and consequent loosening is explained by the fact that the lateral displacement of fastened element makes the bolt inclined, and hence increases the tensile stress coming on to the bolt.

ii) Increase of this tensile stress over a limit initiates slip at the engaged flank surface of the screw thread.
iii) The slip takes place not only in the direction of the flank but also in the direction of the axis of the screw thread due to the presence of lead angle.

iv) Differential thermal effects of clamped materials and fasteners may also induce loosening effect.

The sinusoidal excitation used in this test was as follows:

\[ d(t) = d_{\text{max}} \sin(2\pi ft) \]

Where \( d_{\text{max}} \) is the displacement amplitude (mm) and \( f \) is the vibration frequency (Hz).

The displacement amplitude \( d_{\text{max}} \) was kept constant. The maximum velocity excitation \( 2\pi f d_{\text{max}} \) and maximum acceleration excitation \( -(2\pi f)^2 d_{\text{max}} \) would be changed through changing the frequency \( f \). The time life was changed into life of the cyclic time. And the factors affecting the bolt loosening life could be found by comparing loosen cyclic times under different frequencies \( f \) and different maximum displacement excitations \( d_{\text{max}} \).

### IV. DESIGN & CALCULATIONS

**Pneumatic Cylinder**

Given data:

- Selecting Cylinder: 25*25
- Volume of air exhaust = stroke * area of piston
  \[ = 25\pi/4*25^2 \]
  \[ = 12271.83 \text{ mm}^3 \]
- Area of piston = \( \pi/4*25^2 = 490.873 \text{ mm}^2 \)
- Outstroke force (F) = pressure * area of cylinder
  \[ = 0.4*490.873 \]
  \[ = 196.349 \text{ N} \]
- Piston rod area \( A_1 = \pi/4*d^2 \)
  \[ = \pi/4*8^2 \]
  \[ = 50.20 \text{ mm}^2 \]
- Effective area = piston area - piston rod area
  \[ = 490.873 - 50.20 \]
  \[ = 440.673 \text{ mm}^2 \]
- In-stroke force = \( P*A \)
  \[ = 0.4*440.673 \]
  \[ = 176.2692 \text{ N} \]

**Solenoid Valve**

Pneumatic valves, also called directional control valves, are activated in a variety of ways including manually, solenoid operated and air piloted. Solenoid operated valves use an electrical coil to control the position of a poppet, plunger or spool to open or close a valve. Typical solenoid control voltages are 12VDC.
Arduino Mega
The reason for choosing an Arduino mega over an arduino UNO is as following 1) Having a Wi-Fi module increase the number of lines in the code dramatically and needs a more powerful processor to avoid possible chance of crashing while running the code. 2) having higher number of pins in case of being interested to expand the design and add some more features.

1-CHANNEL 5V RELAY MODULE
5 Volts 1-Channel relay module is an interface board that is compatible with Arduino, AVR, PIC, ARM, etc. This module can work in a high current like AC250V 10A or DC30V 10A. It controls larger loads and devices like DC motors, AC motors, and other AC and DC devices with the digital outputs from controllers and processors. It is a 1-channel relay module, so it can control any 1 device. Each relay or channel of 1 channel relay module needs 15-20mA driver current and 5 Volts supply.

V. FINITE ELEMENT MODELING AND ANALYSIS
In mathematics, the finite element analysis (FEA) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and variational methods from the calculus of variations to solve the problem by minimizing an associated error function.

Geometry

Table 1: Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1590</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>206 GPa</td>
<td>Pa</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Bulk Modulus</td>
<td>1.697E+11</td>
<td>Pa</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>7.572E+10</td>
<td>Pa</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>2.35E+06</td>
<td>Pa</td>
</tr>
<tr>
<td>Tangent Modulus</td>
<td>5.42E+09</td>
<td>Pa</td>
</tr>
</tbody>
</table>
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efficient Multiphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it.

After meshing of bolt loosening set-up nodes are 15090 and elements 6375.

Boundary Condition

LONGITUDINAL LOADING

In present force of approximately 200 N is applied as per calculation around 176 N along with fixed support at one end and frictional support in applied direction. A boundary condition for the model is that the setting of a well-known value for a displacement or an associated load. For a specific node you'll be able to set either the load or the displacement but not each. The main kinds of loading obtainable in FEA include force, stress and temperature. These may be applied to points, surfaces, edges, nodes and components or remotely offset from a feature.

Results

TOTAL DEFORMATION

Figure 11: Deformation results of longitudinal loading

EQUIVALENT STRESS

Figure 12: Equivalent stress result of longitudinal loading

TRANSVERSE LOADING

Figure 9: Meshing of bolt losing set-up

Figure 10: Boundary condition of longitudinal loading

In finite element method the total deformation and directional deformation are general terms irrespective of software being used? Directional deformation may be place because the displacement of the system in a very particular axis or user defined direction. Total deformation is that the vector sum of all directional displacements of the systems.
Similarly, transverse loading of 200 N is applied in transverse direction to study the effect on bolt loosening.

Similarly, in combined loading force is applied both longitudinally and transversally to study the effect on bolt loosening.
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It is observed that stress on bolt is around 220 MPa near to yield so material deforms elastically and moves around for loosening of bolt phenomenon.

VI. EXPERIMENTAL WORK

Experimental testing procedure

- Initially fixture of bolt loosening is designed in CATIA software and with proper dimension material are cut to form separate parts.
- All single parts are assembled are required parts are welded and in two plates bolt is inserted with pneumatic excitation at each section of plate.
- Compressed air is transferred through solenoid valve with respective boundary condition that is longitudinal, transverse and combined loading.
- Initially reference line is drawn and after excitation time is recorded along with degree of rotation for specified boundary condition.

![Figure 19: Experimentation Setup (1)](image1)

![Figure 19: Experimentation Setup (2)](image2)

![Figure 19: Experimentation Setup (3)](image3)

VII. RESULTS

Table 2: Comparison of experimental result

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Component</th>
<th>Time (Sec)</th>
<th>Angle shift (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Longitudinal loading</td>
<td>21.74</td>
<td>70 to 95</td>
</tr>
<tr>
<td>2</td>
<td>Transverse loading</td>
<td>8.03</td>
<td>80 to 156</td>
</tr>
<tr>
<td>3</td>
<td>Combined loading</td>
<td>17.74</td>
<td>80 to 110</td>
</tr>
</tbody>
</table>

VIII. CONCLUSION

- In this study, a novel analytical model has been proposed for single bolt flange joints, which accurately simulates their dynamic behavior.
- From FEA analysis it is observed that bolt has reached near to yield so it will have tendency to rotate about its axis to applied loading.
The time required for the cylinder which is acting in single direction is more but when the both cylinders are acting together then the time required is less.

It is observed from experimental testing that transverse loading has greater impact on vibration for bolt loosening as it has more degree of rotation with less time compared to longitudinal and combined loading.

In present research bolt loosening setup is successfully designed to understand the effect of longitudinal, transverse and combined loading on vibration through pneumatic excitation.

REFERENCES


